The Potential for Grass-Fed Livestock: Resource Constraints

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Summary. Using pasture and grazed forest-range for a system of producing livestock by feeding grass alone reduces the inputs of energy about 60 percent and land resources about 8 percent, but also reduces by about half the production of animal protein in the United States. Under a system in which only grass was fed, livestock would be restricted to beef, milk, and lamb production. The amount of grain fed to U.S. livestock is about 135 million tons (metric) or about ten times the amount consumed by the U.S. population.

More than 3 billion livestock are maintained to supply the animal protein consumed annually in the United States (*1*). In addition to the large amount of forage, this livestock population consumes about ten times as much grain as is consumed by the total U.S. human population (*2, 3*).

From our livestock, a total of 5.4 million tons (metric) of protein is produced annually. This then supplies 70 grams of animal protein daily per capita in the United States. With the addition of 32 g of available plant protein, a total of 102 g is available per capita (*3*). The United Nations Food and Agriculture Organization (FAO) (*4*) has recommended a protein intake of animal and plant material of 41 g per day per capita. Clearly, the consumption of protein, especially that from animals, is high in the United States.

In addition to animal protein from milk and eggs, about 100 kilograms (220 pounds) of meat is eaten per person per year. Of meat eaten, beef consumption amounts to 43 kg per capita; pork, 25 kg; chicken and turkey, 24 kg; fish, 6 kg; and veal and lamb, 2 kg (*2*).

Providing plant food for these animals uses land. In fact more than 420 million hectares of land are used to feed the U.S. livestock population forage and grain. Of this, some 380 million hectares are in improved pasture and extensively managed forest-range, and the remainder is in crop production. In addition to the large amount of forage and grasses unsuitable for human consumption but fed to animals, about 135 million tons of grain or about 620 kg per person in the United States are fed to animals to provide meat.

The proposals that have been made for moving from a system under which livestock are fed both grain and grass to one under which they are fed grass alone (*5, 6*) include energy and land conservation (*7*) as well as making more grain available for export (*8, 9*). In view of the growing pressures on the uses of arable land, dwindling fossil fuel supplies, and problems with our balance of payment, an evaluation of livestock production strategies seems timely. We have therefore assessed the potential of a "grass-only" livestock system for conserving energy, land, and labor resources in animal protein production. This investigation included an analysis of (i) energy, land, and labor resource inputs; (ii) quantity of animal protein produced; (iii) types of livestock; and (iv) quantity of grain released for other purposes.

Grain and Forage Production

Energy, land, and labor inputs are known to vary significantly according to the kind of crop being cultivated. Thus, when these inputs are considered along with food energy and protein produced, grains and some legumes like soybeans are produced more efficiently than fruits, vegetables, and animal products (*10*). In the United States, the average protein yield of the five major grains (plus soybeans) fed to livestock is about 460 kg/ha (Table 1). The energy input per kilogram of plant protein produced is 11.4 megacalories, and the yield of protein per man-hour of labor is about 53 kg (Table 1).

Forage produced on pastures and forest-range is fed to ruminant animals because they can convert forage cellulose into utilizable nutrients through microbial fermentation. The total plant protein produced on pasture and forest-range in the United States is 1.4 times that of grain protein production (Tables 1 and 2). Current yield from pasture and rangeland is 53.4 kg/ha, while the energy input per kilogram of protein is 2.6 Mcal. This is nearly one-quarter of the fossil energy input expended in producing grain protein (Tables 1 and 2).

At present the total digestible nutrients (TDN) obtained annually from pasture and grazed forest-range is calculated to be about 129 million tons (Table 2). Current improved pasture (*11*) accounts for 81.5 million tons, while grazed forest-range (*11*), which contains eight times as much land as improved pasture, furnishes only 47.3 million tons. The low productivity of currently grazed forest-range reflects present extensive management of this land and the fact that 60 percent of grazed forest-range is located on dry, relatively unproductive land in the western states. In addition, the condition of 55 million hectares of forest-range in the western states is poor.

The U.S. Forest Service analyzed the nation's forest-range and concluded that TDN could be increased from 47.3 million to 68 million tons (*11*). This analysis assumed a multiuse intensive management strategy for livestock, timber, watershed protection, and wildlife. Most of the increased grazing of forest-range would occur in the eastern states. Thus, through intensive management inputs on grazed forest-range and the present use of improved pasture, TDN would increase by 16 percent.

The intensive management inputs to increase TDN on extensively managed grazed forest-range would require an increase above current extensive inputs in labor and energy by 6 and 200 times, respectively. Including improved pasture with improved grazed forest-range (*11*), labor and energy inputs would increase

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to about two and five times current levels, respectively (Table 2). Different resources in different regions of the United States have required different levels of inputs for economically sound increases in the TDN (*12*). Yields from grazed forest-range in the regions of high rainfall in the Southeast could be improved with the additions of 180 kg of lime, 57 kg of nitrogen, and 22 kg each of potassium and phosphorus, whereas in the regions of low rainfall in the Southwest, only 13 kg of nitrogen and phosphorus and 9 kg of potassium would be economically feasible (*13*). High yields of forage are possible only on the more productive U.S. improved pasture and grazed forest-range ecosystems.

The data suggest two important considerations. (i) Pasture and forest-range lands differ in inherent productivity, extending from the productive, wet, coastal forest-range ecosystems of the Southeast to the desert grasslands of the Far West. The productivity of these natural environments places constraints on management inputs. For example, the yield of crested wheat grass increased an average 585 kg/ha with 45 kg of nitrogen added per hectare on foothill range in Utah (*14*). However, in the Southeast, 84 kg of nitrogen per hectare increased yields of Pensacola bahiagrass an average of 2900 kg/ha above the control (*15*). (ii) The marginal quality of much of the available grazed forest-range land would require large resource inputs for a relatively small increment in total forage yield. Grazing forest-range land managed by various government and private agencies is either restricted by law or managed to produce other resources, such as timber and wildlife, in addition to livestock. Approximately one-half of the increased yields of forage obtained from various inputs should remain on the land to protect the sustained productivity of pasture and forest-range (*16*). This reduces the practicality but does not preclude the commitment of investments of energy and manpower for small increases in pasture and forest-range forage yields for livestock grazing.

Livestock Production

In the United States, an estimated 37 million tons of plant protein is fed to livestock annually to produce an estimated 5.4 million tons of animal protein for human consumption. The plant protein source is 14.8 million tons from grains, 20.2 million tons from forage, and about 2 million tons from miscellaneous plant and animal by-products (Tables 1 and 2). Thus, for every kilogram of high-quality animal protein produced, livestock are fed about 7 kg of plant protein. In the conversion of plant protein into animal protein, there are two principal "costs," (i) the direct costs of production and (ii) the indirect costs for maintaining the breeding herds.

Some of the energy values calculated in our investigations were higher and others lower than the earlier values calculated by Pimentel *et al.* (*6*). The difference between the results of the two studies is that the first study used data for specific livestock systems from one particular region of the United States, whereas this study averaged data from all U.S. regions (*12*).

Of all the livestock systems evaluated, broiler production is the most efficient, with 39 Mcal of energy required to produce 1 kg of protein (Table 3). Milk production is the next most efficient, with 47 Mcal expended per kilogram of milk protein produced (Table 3). Of the feed protein consumed in the broiler and dairy systems, about 70 percent and 20 percent are grain protein, respectively; the remainder is protein from other sources, such as forages and by-products. Egg production requires an expenditure of 71 Mcal/kg. Again, about 70 percent of the protein fed to chickens is from grains.

Beef production—including cow-calf, feedlot, farm finishing, dairy culls, and veal production—requires energy inputs of 87 Mcal/kg (Table 3). The two major component systems, feedlot beef production and cow-calf (pasture) systems, require 101 and 120 Mcal/kg, respectively. For lean beef production, Lockeretz (*7*) calculated a range of 27 to 153 Mcal per kilogram of protein, and Hannon *et al.* (*17*) calculated 141 Mcal/kg.

Pork production required an input of 171 Mcal of energy per kilogram of protein produced, and the production of range sheep, an average of 392 Mcal/kg (Table 3). This relatively poor yield reflects the marginal land that range sheep generally graze and emphasizes the low return on capital investment under present management strategies. In addition, the energy ratio does not reflect the valuable production of wool by sheep.

The fossil energy input for all animal protein production averaged 76 Mcal/kg (Table 3). This is about seven times that of the average input : output ratio for grain protein production (Table 1). To humans, however, animal protein has about 1.4 times the biological value of grain protein (*18*).

The labor input per weight of animal protein produced was even more costly and amounted to 16 times that of plant protein production (Tables 1 and 3). On-

Table 1. The amount of grain fed to livestock annually, and the inputs of land, labor, and energy to produce the grain (*12*). Corn and sorghum silage for beef and dairy cattle is grown on an additional 4 million hectares.

Crop	Grain produced (kg × 10^6)	Grains fed to livestock: Quantity (kg × 10^9)	Grains fed to livestock: Protein (kg × 10^6)	Inputs: Land (ha × 10^3)	Inputs: Labor (hour × 10^6)	Inputs: Energy (kcal × 10^9)
Corn	146,297	102.0	9,078	17,100	159	109,851
Sorghum	19,241	11.5	1,265	3,313	35	24,820
Oats	9,552	4.3	503	2,356	15	4,876
Barley	8,328	4.8	427	2,273	14	6,647
Soybeans	41,351	10.8	3,283	5,838	55	18,687
Wheat	57,997	2.1	258	1,036	3	3,661
Total	282,766	135.5	14,814	31,916	281	168,542

Table 2. Current and potential yield of total digestible nutrients (TDN) per year from current improved pasture and grazed forest-range and potential improved grazed forest-ranges and the required inputs of land, labor, and energy (*12*).

System	Protein (kg × 10^6)	TDN (kg × 10^6)	Land (ha × 10^3)	Labor (hour × 10^6)	Energy (kcal × 10^{12})
Current	20,232	128,759	378,969	193.4	53.05
Improved pasture	12,588	81,488	40,917	151.6	52.05
Grazed forest-range	7,643	47,271	338,052	48.8	1.00
Improved	23,591	149,530	378,969	427.7	272.10
Pasture	12,588	81,488	40,917	151.6	52.05
Grazed forest-range	11,003	68,042	338,052	276.1	220.05

ly 3.2 kg of animal protein was produced per man-hour of labor, compared with 53 kg per man-hour for plant protein. Broiler production was the most efficient (25 kg per man-hour), and milk production the least (2 kg per man-hour) (Table 3).

Feed, the single greatest expense in beef feedlot cattle production, accounts for two-thirds of the total direct costs. Likewise in dairy cattle production half of the production costs can be directly attributed to total feed costs (*19*). Thus, the price of grain determines the amount fed in cattle and dairy operations (Fig. 1). The trend in cattle production during the last two decades has been for the utilization of forage to decrease as the use of feed grain increased because of the relatively low price of grain. For example, from 1960 to 1973, the use of hay as feed for cattle declined by more than 24 percent and pasturage by more than 32 percent (*19*). In 1974 and 1975, however, a sudden increase in grain exports and the disappearance of grain surpluses sent grain prices soaring to a high of between $100 and $145 per ton, and the amount of grain fed to livestock during this period declined by 28 percent (Fig. 1). In 1976 and 1977, grain prices declined to $64 and $100 a ton but were still higher than they were in the previous decade.

Currently, beef and milk protein constitute more than two-thirds of the total animal protein (5.4 million tons) annually produced in the United States (Table 3). The other third consists of protein from pork, broilers, eggs, turkeys, and sheep.

Systems for Producing Grass-Fed Livestock

If grain were no longer fed to livestock and only grass (*20*) on current pastures and grazed forest-ranges were available, animal production systems would be modified to include primarily dairy, beef, and sheep. The total amount of animal protein produced under this system would be about 2.9 million tons, or slightly more than half the animal protein currently produced (Tables 3 and 4). The inputs for this system of grass-fed livestock would be reduced as follows: land, 8 percent; labor, 34 percent; and fossil energy, 59 percent. However, this 59 percent energy saving (241×10^9 Mcal) represents only about 1 percent of the total energy (19×10^{12} Mcal) consumed annually in the United States. In addition, the increase in available land would probably not be as large as 8 percent, because some of it might be used to grow the plant foods needed to compensate for the reduced animal products in the human diet.

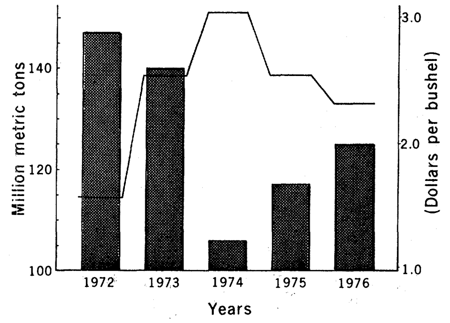

Fig. 1. Histogram showing the amounts of cereal grains fed to livestock from 1972 to 1976 (*1*). Average price of corn as an index of change in the price of grain is shown as a line graph.

The reduction in animal protein production in a grass-only system without grains is attributable to the loss of poultry and hogs plus the reduction from beef and dairy systems (Tables 3 and 4). Milk production, for instance, would be reduced by 28 percent from current production levels, but would be 38 percent more efficient relative to energy inputs per kilogram of milk produced.

A grass-only system would release for possible export most of the grain currently fed to livestock (*8*)—135 million tons of grain with a potential value of about $14 billion (*1*). This would not pay for current oil imports, valued at about $50 billion, but increased grain exports would certainly help reduce the balance of payments deficit.

If the forest-range currently grazed by dairy and beef cattle and sheep were "improved" (*11*) through better management inputs, the total TDN might be increased 16 percent (Table 2); the yield of animal protein would increase 0.2 million ton or about 7 percent. Thus, the total protein from grass-fed animals would rise to 3.1 million tons, still significantly less than the current production of 5.4 million tons (Tables 3 and 5). Compared with the current grain-grass system, the total resource inputs for the "improved grass-only" system would be reduced as follows: land, 8 percent; labor, 28 percent; and energy, 7 percent.

Improving grazed forest-range in a grass-only system would raise the yield of beef but not affect that of milk, because the dairy systems already use improved pastures (Tables 3, 4, and 5). Under a grass-only system with improved grazed forest-range, beef production would increase about 9 percent above

Table 3. Current production of animal protein systems and the required resource inputs of land, labor, and energy (*12*).

Animal production system	Output per year			Input per year		
	Unit ($\times 10^3$)	Product (kg $\times 10^9$)	Protein (kg $\times 10^6$)	Land (ha $\times 10^6$)	Labor (hour $\times 10^6$)	Energy (kcal $\times 10^{12}$)
Broilers	2,932,711	5.02	465	2.5	18	18.24
Turkeys	124,255	1.04	118	0.9	14	6.40
Eggs	64,362,000	3.82	438	4.2	78	31.14
Sheep	7,521	0.74	18	94.5	23	7.05
Dairy	11,151	53.26	1,864	16.3	825	87.22
Pork	68,687	7.49	535	15.3	168	91.51
Beef						
Cattle	41,464	20.07	1,957	288.7	592	171.07
Calves	5,406					
Total			5,395	422.4	1,718	412.63

Table 4. Potential production of animal protein systems without current grain inputs and with current forage and the required resource inputs of land, labor, and energy (*12*).

Animal production system	Output per year			Input per year		
	Unit ($\times 10^3$)	Product (kg $\times 10^9$)	Protein (kg $\times 10^6$)	Land (ha $\times 10^6$)	Labor (hour $\times 10^6$)	Energy (kcal $\times 10^{12}$)
Dairy	8,015	38.47	1,346	11.8	590	38.47
Beef						
Cattle	35,616	15.30	1,486	283.2	514	127.77
Calves	4,494					
Sheep	7,521	0.74	18	94.5	23	4.58
Total			2,850	389.5	1,127	170.82

the grass-only system without improvements.

In addition to improving the forest-range for forage, we could increase the production of animal protein by planting 10 million more hectares of land in corn and sorghum silage. Total milk, beef, and sheep protein production under these conditions is calculated to be 4.4 million tons compared with current total production of 5.4 million tons (Tables 3 and 6). Compared with the current system, the resource inputs for the "improved grass and silage system" decline by 5 percent for land and 8 percent for labor. Energy use, however, rises about 13 percent above the current level. The increased energy input, in a time of scarce energy and high prices, may make this system inefficient and therefore inappropriate.

If the grain acreage used to feed dairy cattle were converted to corn and sorghum silage production for a "grass-only system with improved grazed forest-range," milk protein production would be expected to rise by nearly 25 percent (Tables 3 and 6) because improving pastures and including silage instead of grain would increase the TDN available per animal. Consideration in the analysis was given to the capacity of the dairy cattle to use the added silage bulk. The energy input per kilogram of milk produced from grass was only 37 Mcal, considerably less than the current inputs of 47 Mcal (Tables 3 and 6).

With improved grazed forest-range plus silage, total beef protein production would remain approximately the same as under the current system (Tables 3 and 6). Land use in this system would remain the same, and labor would increase about 10 percent. The fossil energy input would be double that of the current beef system, primarily because large energy inputs would have to be expended to improve forest-range production and to increase the yield of nutrients (Table 2).

Although about 10 million hectares would be used to produce silage for beef and dairy cattle to increase protein production, about 40 million hectares would still be available to produce grain for export or other purposes. The amount of grain available for export produced from this land would be about 82 million tons.

If there were a change toward a grass-only system, we believe that some grain resources as well as by-products (*20*) would continue to be devoted to egg, broiler, and pork production. Not only are eggs valuable as ingredients in many processed foods, but the quality of egg protein is better nutritionally than any other protein available (*21*).

Egg production is relatively efficient. Currently the total land input for egg production is less than 1 percent that for all protein sources, and the energy input is only about 1 percent of that in the total livestock production system (Table 3).

Broiler production is also an efficient animal system; broilers convert about 2 kg of feed into 1 kg of liveweight (*22*). If the 10 million hectares of grainland now used in dairy and beef production were planted in corn, approximately 5.9×10^{10} kg of corn grain could be used for broiler production. If a broiler diet consisted of 70 percent corn and 30 percent by-products (*23*), then approximately 4.2×10^{10} kg of liveweight broilers could be produced. This amounts to about 3.7 million tons of protein, or more than twice the protein that could be produced by using this land to grow silage and feeding it to dairy and beef cows (Tables 5 and 6). Some pork production would also be continued for variety because hogs can utilize some by-products and wastes such as garbage.

Table 5. Potential production of animal protein systems without grain inputs and with the use of improved pasture, improved grazed forest-range, and the required resource inputs of land, labor, and energy (*12*).

Animal production system	Output per year			Input per year		
	Unit ($\times 10^3$)	Product (kg $\times 10^9$)	Protein (kg $\times 10^6$)	Land (ha $\times 10^6$)	Labor (hour $\times 10^6$)	Energy (kcal $\times 10^{12}$)
Dairy	8,015	38.47	1,346	11.8	590	38.47
Beef						
Cattle	39,032	16.63	1,613	283.3	551	311.54
Calves	4,494					
Sheep	39,276	3.86	94	94.5	94	35.15
Total			3,053	389.6	1,235	385.16

Table 6. Potential production of animal protein systems with silage substituted for grain and the use of improved pasture and improved grazed forest-range, and the required resource inputs of land, labor, and energy (*12*)

Animal production system	Output per year			Input per year		
	Unit ($\times 10^3$)	Product (kg $\times 10^9$)	Protein (kg $\times 10^6$)	Land (ha $\times 10^6$)	Labor (hour $\times 10^6$)	Energy (kcal $\times 10^{12}$)
Dairy	11,151	66.26	2,319	16.3	825	86.12
Beef						
Cattle	44,684	20.76	2,023	288.6	654	346.48
Calves	5,406					
Sheep	39,276	3.86	94	94.5	94	35.15
Total			4,436	399.4	1,573	467.75

Effect on Human Nutrition

If current livestock systems in which both grain and grass are fed were changed to a grass-only system, considerable changes would occur in dietary patterns of the U.S. population. Currently, animal products supply about 69 percent of the daily protein available for consumption in the United States, 33 percent of the energy, and substantial amounts of other nutrients, notably calcium, available iron, riboflavin, niacin, vitamin B_6, and vitamin B_{12} (*3*). Reducing animal protein intake from 70 to about 40 g, as would be required under the grass-only systems described here (Table 4), would substantially alter sources of various nutrients in the U.S. diet.

The decline in energy available from animal products would probably necessitate an increase in consumption of grains, vegetables, and high-protein plant foods such as legumes or processed vegetable proteins. Under a grass-only system, such a direct increase in consumption of plant energy sources by the human population of the United States would increase protein intake to more than the calculated 71 g available from animal and plant sources. The protein available would be sufficient on the average for the U.S. population, although distribution among all socioeconomic levels might be a serious problem if the economic forces at play make the limited available meat and milk products expensive protein sources. This could result in some protein malnutrition in some groups.

Currently, calcium and iron represent two nutrients whose consumption frequently falls below the recommended daily allowance (RDA) when food consumption data are analyzed. Dairy products represent the major source of calcium in the U.S. diet (75 percent) (*3*). Reduced consumption of dairy products could have deleterious effects on the calcium status of the population. Similarly, animal products account for 37 percent of the iron available for consumption (*3*). Animal sources of iron are generally at least twice as available as plant sources, and, in reality, the animal products probably provide more than 70 percent of the available iron in the U.S. diet. Since iron deficiency anemia among women of childbearing age is the most frequently encountered nutritional deficiency disease in most recent nutrition surveys (*24*), this shift in pattern of nutrient availability would need to be examined carefully.

A shift in the pattern of nutrient intake could have other effects on the U.S. population. A reduction in meat consumption would also be expected to decrease fat consumption and thus provide some health benefits. Grass-fed beef and lamb produced would have less fat and be at lower average grades than current meat grades. The shift to plant protein and energy sources would increase complex carbohydrate sources and perhaps provide a greater proportion of unsaturated fatty acids in the dietary pattern. These shifts in consumption patterns may have some positive health consequences to the human population.

One of the greatest concerns about the nutritional effects of the dietary shifts envisioned by the production patterns described involves the socioeconomic questions of accessibility to all population groups. Since meat and other foods high in protein are the most highly valued by human populations in terms of the commitment of economic resources to purchase them, a society with the economic resources of the United States is likely to bid the price of animal products to high levels. This could seriously affect nutrient availability to certain socioeconomic groups in the population, and nutrient deficiency could occur as a result of socioeconomic forces. The consequences of such shifts in patterns of food availability would have to be carefully dealt with to ensure some form of fair allocation.

World Food Needs and Grain Supplies

Worldwide, the need for food is projected to rise along with the rapidly growing world population (*25, 26*). The world population is already more than 4 billion and is expected to reach about 6 billion by the turn of the century (*25*). These people should receive a nutritionally adequate food supply, one that can be produced from the given resources of the earth. Because half of the world protein and calories is provided by cereal grains (*6, 27*), demand for grains, as for all food, will rise. An increase in demand will probably result in price rises for grain on the world market. During 1973–1974, the increased demand for wheat raised prices paid to the farmer in the United States in 1 year from \$1.97 to \$5.52 per bushel (*28*). This price increase for wheat plus price increases in other grains resulted in significantly less grain being fed to livestock in the United States (*8*) (Fig. 1). The quantity of grain that was fed to livestock declined 28 percent from 147 million tons in 1972 to 106 million tons in 1974. Thus, elevated grain prices provide an incentive to reduce the grain fed to livestock, in particular beef and dairy cattle.

Likewise, high meat prices influence the quantity of meat consumed; in 1972 and 1973, beef prices increased significantly and the public reduced its beef consumption by 6 percent (*29*). Although this is not a major change, it does indicate that meat consumption is also sensitive to price change.

At present the United States is the largest food exporter in the world (*30*). About 25 percent of our food is exported, but we import about half that amount in other food items, resulting in a net food export of about 12 percent. Some of the grain and soy exported is, in fact, fed to livestock in the recipient country.

One of the United States' valuable export resources is grain. When world food demand increases and the price rises, grain exports will probably increase. All but about 10 of the other 81 nations in the world are net cereal importers (*30*).

Although food production is expected to rise throughout the world, the availability of land, water, and energy resources are already known constraints (*25, 31*). Most of the arable cropland in the world today is already in crop production (*25*). Many millions of hectares that are in production should not be because of steep slopes and serious erosion problems (*25, 31, 32*).

Throughout the world, arable land is estimated to be 1.5 billion hectares, most of which is in production (*25, 31*). With more than 4 billion humans, this amounts to less than 0.4 ha per person. In the United States, excluding exports, more than 0.6 ha is used to feed each person. Of course, we also use significantly more energy in the form of fertilizer and pesticides per hectare than the world average (*33*). Even now, arable land in the world is insufficient (even if energy resources and technology were available) to feed the current world population a diet similar to that in the United States (*6, 34*). Future food needs will probably stress most resources vital to food production.

The estimates of land availability for food production have assumed no loss of land, but, of course, serious degradation of agricultural land is taking place (*31*). In the United States, for example, between 1945 and 1975 about 18 million hectares (about the size of Nebraska) of arable land have been lost through urbanization and highway construction (*34*). In addition, about one-third of the topsoil has been lost from U.S. cropland, reducing its productivity and thus requiring additional inputs of fertilizers to offset the degradation (*34, 35*).

The pattern is similar throughout the world. With growing urbanization and poor strategies of land use, land degradation is taking place as rapidly or even more rapidly than in the United States (*25*). In addition, deforestation occurring in parts of the world intensifies environmental degradation (*36*). The cutting of forests for firewood is leaving barren slopes exposed to soil erosion and rapid water runoff. This runoff contributes to the flooding of valleys and the subsequent loss of agricultural production.

Further, the burning of crop remains for fuel contributes to the degradation of the soil in many developing countries (*37*). Proposals to use crop remains in the United States for biomass energy conversion would have a similar impact. A recent study strongly recommended against using crop remains for biomass energy conversion (*38*).

Energy shortages, in addition to shortages of arable land, will surely influence food supplies. The expenditure of energy in food production can best be illustrated by analyzing the use of fossil fuel in food production. If petroleum were the only source of energy for food production, and if we used all petroleum reserves solely to feed the world population a diet similar to that of the United States, the petroleum reserves would last a mere 13 years (*6*). The reserves would last a little longer if a diet low in animal protein were consumed.

Limitations in both energy and land resources, therefore, appear to make it impossible to feed the world a high-protein, high-calorie diet. In future decades, world diets will remain primarily vegetarian and U.S. diets will probably be modified to substitute some plant foods for the current animal foods consumed. Not only energy shortages and world demand for food, but also the projected growth in the U.S. population of 24 percent in the next 25 years (*39*), will cause this shift.

With an increased demand for grain by a growing world population, we project higher grain prices in general and increased food exports by the United States. This would increase our cost of producing grain-fed livestock and result in a greater dependence on grass-fed livestock. Although the U.S. population would not need to become vegetarians, more plant foods would be substituted for some of the currently used animal foods now consumed in large amounts.

If all the grain currently fed to livestock in the United States were consumed directly by people, the number that could be fed would be about 400 million, or less than 10 percent of the world population today. Exporting all this grain would provide the United States with an added $15 billion annually.

Conclusion

On the basis of these analyses, some changes in crop and livestock production systems and consumption patterns are projected for the year 2000, as the world population grows and food demand rises. Wheat, corn, barley, sorghum, and other grains plus soy exports from the United States are expected to increase as both world food needs and grain prices rise. Expensive grain would tend to reduce the quantity of grain for feeding livestock.

Although the number of grain-fed livestock might decline and grass-fed livestock might increase in the future, the production of eggs, broilers, and hogs will probably continue to depend on grain. Each of these livestock systems produces animal products having distinct advantages in the U.S. food system and offering benefits in efficiency of energy, land, and labor resources. They also contribute to the high nutritional quality of U.S. diets.

Increasing the use of pasture and forest-range for livestock production would not only reduce energy, land, and labor inputs in livestock production, but would also reduce by about half the production of animal protein. The savings in energy, land, and labor in moving toward a grass-fed system, however, would not be as large as suggested by the analysis, because some grain and other food resources would be consumed directly by the U.S. population as a substitute for reduced intake of animal products.

Higher grain prices and increased exporting of grain by the United States would be expected to improve the U.S. balance of payments in the world economy, but even this could not be expected to balance our payment for oil imports.

The agricultural system in this country has proven capable of modifying both crop and livestock production to provide a nutritious diet for the U.S. consumer. As we look to the future, we will need to judiciously modify present techniques to better meet the food needs of the United States and the growing needs of the world.

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