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ENERGY AND AGRICULTURAL DEVELOPMENT

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APPENDIX A

ENERGY AND AGRICULTURE: DEFINITIONS AND CONVERSION FACTORS

In this Appendix, we have presented the definitions and conversion factors for the energy units used in this paper. Two major units have been used in the text and all other units have been converted into one of these two units. For heat units, available data from original sources have been converted into 'Oil Equivalents' using the conversion factors given in this Appendix. For example, kilocalories have been converted into kilograms or Tons of Oil Equivalent (TOE), Trillion Kilocalories (10^{12} kcal) have been converted into Million Tons of Oil Equivalent (MTOE) while other units (Btus, Joules, coal equivalents, Kwh) have been expressed in terms of corresponding oil equivalent units. The units of work have been kept in terms of Horsepower Hours and have not been converted into 'oil equivalent' units.

DEFINITIONS OF UNITS*

Calorie (cal): A calorie is perhaps the most familiar of energy units, whose popularity owes much to its use in dietetics. It is technically defined as the heat required to raise the temperature of 1 gram of water from 14.5° to 15.5°C at a constant pressure of 1 atmosphere. Nutritionists use the Calorie, which is equal to 1000 calories (1 Kcal), as their unit.

Joule: (J): The joule is the metric unit of energy. Its technical definition is complicated: a joule is the work done by a force of one newton when it displaces the point where it is applied by 1 meter, while a newton is a force which will accelerate a mass of 1 kilogram at the rate of 1 meter per second per second. A joule is a very small unit of energy for aggregative purposes: A cal is 4.1868J.

Watt-hour (Wh): Watt-hours are also used as a unit of energy, whose form is distinquished by a suffix (for instance, thermal energy is measured in Wh_{th}. electrical energy in Wh_e). This measure is a variant of the joule. A joule is a watt-second, and a watt-hour is 3600 joules.

British thermal unit (Btu): The British thermal unit is the unit of heat in the imperial system. It is equal to the heat required to raise the temperature of 1 pound of air-free water from 60° to 61°F. A therm is equal to 100,000 Btus.

Foot-pound (ft-lb): This is the unit of work in the British system, defined as the work done by 1 lb of force applied at a point when the point is displaced 1 foot.

Horsepower-hour (hph): Horsepower is a force of 550 foot-pounds per second; a horsepower-hour is equal to the same force applied over an hour, or 1.98 million ft-lb.

* These definitions are adopted from Desai (1980) and Report of the Fuel Policy Committee (1974), Government of India.

Ton coal-equivalent (tce): This was the unit in early energy studies and is still used in the United Nations studies (e.g., United Nations: World Energy Statistics). Since coal varies in heat content, two types of coal have been used for giving conversion factors. The UN tce is equivalent to 7 million kcal. The Indian tce is currently defined at 5 million kcal for non-co king coal.

Ton oil-equivalent: This is the unit adopted in OECD statistics. It is defined as 10.29 million kcal, roughly the heat content of a metric ton of crude oil.

Ton coal-replacement: (tcr): This is not a distinct unit of energy, but a hybrid concept denoting useful as against final energy. Final energy measures the work or heat capacity of energy forms whilst useful energy measures the energy actually used. Indian energy statistics are in terms of final energy. As it happens, however, the efficiency of use of oil is much higher than that of coal in comparable uses; the difference is greater than the heat content per ton of either fuel would imply. Hence, Indian energy statistics have also been compiled in terms of a set of equivalents in which certain hydrocarbons like gas, gasoline, kerosene, diesel oil and jet fuel are given higher weight than their heat content would imply. This alternative set of statistics is said to be in terms of tons coal-replacement. For example, one ton of diesel = 9 tcr, one billion kwh of electricity = 1 tcr, etc.

Quad: This is a new, mammoth American measure equal to quadrillion (10^{15}) Btu, or 1,055055 MTJ (megaterajoule).

Table A.1

CONVERSION FACTORS

1 Kilogram of Oil Equivalent (KGOE)	=	43.08×10^3 KJ (10^3J)
	=	10.29×10^3 K cal (10^3 cal)
	=	40.83×10^3 Btu
	=	12.00 Kwh
	=	1.47 Kgs of UN coal
	=	2.00 kgs of Indian coal
1 Ton of Oil Equivalent (TOE)	=	43.08×10^6 KJ = 43.08 Giga Joules or GJ (10^9J)
	=	10.29×10^6 K cal
	=	40.83×10^6 Btu
	=	12.00×10^3 Kwh
	=	1.47 Tons of UN coal equivalent
	=	2.00 Tons of Indian coal equivalent
1 Million Tons of Oil Equivalent	=	43.08×10^{12} KJ = 43.08×10^6 GJ (10^9J)
	=	10.29×10^{12} K cal
	=	40.83×10^{12} Btu
	=	12.00×10^9 Kwh
1 Kilogram of Diesel Fuel	=	1.1494 liters
1,650 liters = 570 kg		
1 Horsepower-Hour	=	641 Kcal
	=	2.68×10^6J
1 Kilowatt-Hour (Kwh)	=	860 Kcal
	=	6.3×10^6J
1 British Thermal Unit (BTU)	=	0.24 Kcal
	=	1.06×10^3J

APPENDIX B

ENERGY USE AT THE FARM LEVEL

The studies of energy-use at the farm level can be grouped into three broad categories: (i) studies which compare energy inputs in developing countries with the corresponding inputs in developed countries and try to derive conclusions regarding energy-intensity (or energy productivity) of output in these countries (ii) studies which give estimates of energy inputs in various forms for selected crops at different levels of mechanization in a given country, and (iii) studies on energy inputs and yield under no-tillage agriculture. The main studies in the first category are those by Pimentel and Pimentel (1979), Makhijani and Poole (1975), Stout (1979), F.A.O. (1976, 1977) and Ward, Sutherland and Sutherland (1980). The papers in the second category include those by Austin, et al (1978), Kuether and Duff (1979), G. Singh and W. Chancellor (1975), L.R. Singh and B. Singh (1976), A.J. Singh and S.S. Miglani (1976) as well as various Reports of studies on Energy Requirements in Intensive Agricultural Production conducted by agricultural universities in different parts of India and sponsored by Indian Council of Agricultural Research of the Government of India. The main papers on no-tillage agriculture are by Phillips, et al (1980), Wijewardene (1978) and Greenland (1975). This appendix presents an analysis of the three types of studies followed by a section on energy costs for various agricultural operations.

It may be mentioned that in all the farm level or crop level studies, agriculture is mainly treated as a user of energy and the analysis of energy-use efficiencies or the contribution of animals is done in this partial setting. The contribution of the agricultural sector as a producer or as a source of energy is invariably not considered and, hence, the results are biased against developing countries where agriculture plays a major role as a source of energy for agricultural activities, as well as for other household activities such as cooking, space heating, pottery and brickmaking and metal work in the rural areas. It

is argued in the next sections that if a systems view is taken in which agriculture's role as a user and source of energy is properly quantified, the results of some of the earlier analyses would be changed.

In most of these studies, the approach is oriented towards using engineering or biological concepts of energy use. It is very rarely that economic concepts of opportunity costs or value in alternative uses, resource costs of production and economic equivalence in terms of work capacity of animals and machines are used. As a consequence, the results are biased against developing countries where animals, who perform most of the agricultural work, use resources which have no alternative uses. This kind of bias is clear from the example given by Pimentel and Pimentel (1979) where they show how the negative energy output/input ratio of 0.96 in wheat in Uttar Pradesh, India, becomes 5.0 when allowance is taken of the fact that bullocks convert the grass energy (which has no alternative use) into wheat energy through their labor in wheat fields. Although, as discussed later, this analysis is also not complete but it does show the significance of the kind of analysis that is required.

Another shortcoming of these studies lies in using "engineering equivalence" of draft animals which results in underestimation of the efficiency of bullocks. In many studies, mostly of the second type, it is assumed that a draft animal develops between 0.5 to 0.7 horsepower (hp) and his useful energy is estimated in terms of horsepower-hours (or equivalent KJ or Kcal) by multiplying this estimate of horsepower with the number of hours of farm work done by a draft animal during the year. As has been shown in a detailed analysis of the assumptions used by Makhijani and Poole (1975), a comparison of horsepower of draft animals and tractors is misleading since it is based on "engineering equivalence" and not "economic equivalence" in terms of work capacity or replacement ratios. For example, "engineering equivalence" would imply that a tractor of 35 hp would

be equivalent to 35 pairs of bullocks while in terms of the work done during the peak period or the number of bullock pairs replaced by a tractor in actual farm situation, a tractor may be equal to only 5 to 6 pairs of bullocks. If this correction is incorporated, a draft animal would provide 6 times the useful energy estimated under "engineering equivalence" assumptions and may 'improve' the energy efficiency of draft animals from 5% to 30%. If further correction is incorporated for the fact that about 80% of animal feed comes from pasture lands and crop residues which have no alternative uses, the "economic efficiency" of a draft animal would be of the order of 150%. If energy contribution of dung (which is about 50% of the caloric value of food intake) is also included in a systems view, the draft animal would become a super efficient energy producing machine giving an output/input ratio of four to one*.

* These calculations are done as follows: Assume that the total energy in food intake is 100 Kcal of which only 20% is coming from items which have alternative uses. This 100 Kcal used by animals produces 30 Kcal of useful energy in terms of work (taking "economic equivalence" of work capacity) and 50 Kcal in terms of energy in dung cakes. This gives an output of 80 Kcal from an input of 20 Kcal of usable energy input. However, the ratio would be much lower if useful energy from dungcakes in burning (10% fuel efficiency in open 'chulahs') is taken into account. But, it may be noted that the lower efficiency of dung-use can be significantly improved if biogas plants are used.

B.1 ENERGY USE AT FARM LEVEL: FIRST GROUP OF STUDIES

The energy-use in different farming systems is analyzed (a) in terms of traditional, transitional and modern and/or (b) in terms of level of mechanization: hand-tool technology, animal draught power and mechanical power technology. In many countries, all three levels exist side by side. An analysis of data available for different farm systems, levels of mechanization and cropping patterns is presented below.

Energy Inputs in Rice Production

Table B.1 provides estimates of energy input into rice production for four countries. It may be seen that rice production by the Iban tribe of Borneo, using only manpower consumes only 1.034 million Kcal per hectare. About two-thirds of this (equivalent to 1186 man-hours per hectare) is expended for manpower and the other third for seeds. The crop yield is 2016 Kgs or equivalent of 7.318 million Kcal. Thus, the output/input ratio as estimated by Pimentel and Pimentel (1974) is given as 7:1, denoting a relatively high return for investment. In the Philippines, both man and animal power are used in rice production. Total energy inputs are 1.8 million Kcal to produce about 1650 Kg or rice which has the equivalent of 6 million Kcal food energy. The resulting output/input ratio is 3:1, about half that of the Iban tribe in Borneo. It may be noted that in the Philippines, about half the energy input is provided by animal (carabao) draft power. When compared with Borneo, rice production in Philippines used about half the human energy, but this reduction in human energy is compensated by the addition of animal power which is about three times the reduction in manpower. Although there is increase in energy input in the case of Philippines, the rice yield is lower which shows that the conditions of cultivation are significantly differnet in the two countries.

As a contrast to developing countries,* energy input in U.S. (California) is about 7.8 times and in Japan about 4 times that in Philippines. In U.S.A., the

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* It may be mentioned that, as discussed above, this analysis is only partial in the sense that it does not incorporate the energy output in terms of crop residues and animal residues which would make energy-use even more efficient in developing countries.

TABLE B.1

ENERGY INPUTS AND OUTPUT IN RICE PRODUCTION
(000 Kcal/ha)

INPUT	Borneo	Philippines	U.S. (California)	Japan
Labor	626	304	8	804
Axe and hoe	17			
Irrigation			1299	910
Field work - equipment		41		
Carabao (draft)		952		
Machinery			360	180
Diesel			3264	
Gasoline			657	910
Liquid petroleum			354	
Nitrogen		85	4116	2087
Phosphorous			201	225
Potassium				141
Limestone			11	
Seed	392	400	1140	813
Insecticides			191	348
Herbicides		44	1119	699
Drying			1217	
Electricity			380	7
Transport			121	51
TOTAL	1034	1825	14440	7176
OUTPUT				
Yield (000 Kcal/ha)	7318	6004	22361	17598
Kcal output/Kcal input	7.08	3.29	1.55	2.45
Rice yield (Kg/ha)	2016	1654	6160	4848
Protein (Kg/ha)	141Kg/ha	116Kg/ha	462Kg/ha	364Kg/ha

Source: David Pimentel and Marcia Pimentel, Food, Energy and Society, John Wiley & Sons, New York, 1979, pp. 75-78

TABLE B.1 a

ENERGY INPUTS AND OUTPUT IN RICE PRODUCTION

KGOE
(Kilograms of Oil Equivalent/ha)*

INPUT	Borneo	Philippines	U.S.(California)	Japan
Labor	61	30	1	76
Axe and hoe	2			
Irrigation			126	88
Field work - equipment		4		
Carabao (draft)		93		
Machinery			35	17
Diesel			317	
Gasoline			64	88
Liquid petroleum			34	
Nitrogen		8	400	203
Phosphorous			20	22
Potassium				14
Limestone			1	
Seed	38	39	111	79
Insecticides			19	34
Herbicides		4	109	68
Drying			118	
Electricity			37	1
Transport			12	5
TOTAL	100	177	1403	697
OUTPUT				
Yield (KGOE/ha)	711	583	2173	1710
Kcal output/Kcal input	7.08	3.29	1.55	2.45
Rice yield(Kg/ha)	2016	1654	6160	4848
Protein(Kg/ha)	141Kg/ha	116Kg/ha	462Kg/ha	364Kg/ha

Source: David Pimentel and Marcia Pimentel, Food, Energy and Society, John Wiley & Sons, New York, 1979, pp. 75-78.

* 1 KGOE (kilogram of oil equivalent) = 10.29×10^3 kcal.

the major energy input is in terms of diesel oil, electricity, gasoline and fossil fuels used for fertilizers, machinery and herbicides. Although the yield of rice is quite high (6160 Kgs/ha), high energy input of 1403 [illegible] results in a low 1.6:1 output/input ratio. In Japan, the rice yield (4848 Kgs/ha) is lower than in U.S.A., the energy inputs are also lower (about 50% lower) which gives an output/input ratio of 2.5:1. Another interesting feature of Japanese agriculture is that it is as labor intensive as in developing countries and uses about 1730 hours of manpower per hectare as compared with only 17 hours in the U.S.

Another set of similar data on fossil fuel energy required for rice production by modern, transitional and traditional methods is given in Table B.2 based on FAO Report (1976). In this example, traditional method uses very little energy in the form of some equipment which is assumed to weigh 10 Kgs/ha and to last five years. The transitional method uses higher amount of fossile fuels in the form of machinery and some fuel is used on the farm for primary tillage. Some fossil fuel energy is also used in the form of commercial fertilizers, pesticides, high-yielding variety seeds, etc. However, the quantities involved are relatively low and, hence, fossil fuel input is only around one-tenth of that in modern farming as practiced in U.S.A. If fossil fuels required for supplementary irrigation with mechanically-powered pumps are considered in transitional agriculture, energy inputs would go up significantly, resulting in higher yields. In the modern rice production methods, energy input is higher by ten times while crop yield is higher only by 2.15 times. Of the total fossil fuel input, irrigation accounts for the major share 41%, followed by fertilizers (17%), fuel for machinery operation (14%) and drying and machinery manufacture (7% each).

TABLE B.2

FOSSIL FUEL ENERGY REQUIRED FOR RICE PRODUCTION
BY MODERN, TRANSITIONAL AND TRADITIONAL METHODS

Input	Modern (United States)		Transitional (Philippines)		Traditional (Philippines)	
	Qty/ha	KGOE/ha*	Qty/ha	KGOE/ha	Qty/ha	KGOE/ha
Machinery	1.0 x 10^6Kcal (1)	97	80,000 Kcal (1)	8	41,400 Kcal (2)	4
Fuel	224.7 litre	209	40 lit	37	–	–
Nitrogen fertilizer	134.4 Kg	242	31.5 Kg	57	–	–
Phosphorous fertilizer	–		–		–	–
Potassium fertilizer	67.2 Kg	15	–		–	–
Seeds	112.0 Kg	79	110.0 Kg	40	107.5 Kg	
Irrigation	683.4 litre	635	–		–	–
Insecticides	5.6 Kg	13	1.5 Kg	1	–	–
Herbicides	5.6 Kg	13	1.0 Kg	2	–	–
Drying	1.1 X 10^6Kcal	107	–		–	–
Electricity	765 700 Kcal	74	–		–	–
Transportation	172 900 Kcal	17	7,400 Kcal		–	–
Total		1502		146		4
Yield Kg/ha	5,800		2,700		1,250	

[1]Energy input to produce 1 Kg of equipment is assumed to be 20712 Kcal - Equipment is assumed to weigh 10 Kg/ha and to last five years - [3]1 ml of fuel is assumed to contain 9.57 Kcal of energy - [4]Production of 1 gram of nitrogen fertilizer is assumed to require 17.6 Kcal of energy - [5]Production of 1 gram of potassium is assumed to require 1 Kcal of energy - [6]Production of high grade seed is assumed to require 7.3 Kcal/gram of energy - [7] Production of seed is assumed to require 3.6 Kcal/gram of energy - [8]Production of 1 gram of insecticide, herbicide or fungicide is assumed to require 24.2 Kcal of energy - [9]Assumed to be similar to maize (1). Pimentel et al, Science, 182, November (1973) - [10]Transport input is assumed to be 7410 Kcal.

Source: Energy for Agriculture in the Developing Countries, F.A.O. Rome, February 1976.

* 1 KGOE = 10.29 X 10^3 kcal.

A comparison of energy requirements for alternative rice production systems in the tropics is presented by Kuether and Duff (1979). It is claimed that the traditional, mechanical and transitional systems considered in the study (and their minor variations) are used by the vast majority of Asian farmers to produce most of the world's rice.* Basically, the traditional system uses draft power for land preparation (primary and secondary tillage) and human labor for transplanting, crop care, harvesting and threshing. In the mechanical system, a 5-7 hp power tiller is used for land preparation, a power thresher is used for threshing, a mechanical dryer for crop drying, while human labor is used for transplanting, crop care and harvesting. In the transitional system, however, a tractor (50 hp) is used for primary tillage, a draft animal for secondary tillage and human labor for rest of the activities. It may be mentioned that the production systems analyzed here are flooded lowland systems** which receive all moisture from accumulated rainfall. Since, even these areas need irrigation during drought periods and irrigation can be used to increase yields, energy requirements for a small, low-lift pump to draw water from shallow wells or low-lying water sources have also been studied.

The following points from Table B.3 may be noted: Energy inputs under traditional and transitional systems are more or less equal, although animal power in traditional system is replaced by higher input of fuels and oil in transitional system. The oil consumption increases by an equivalent of about 26 Kgs of diesel fuel per hectare. Under the mechanical system, animal power is completely replaced and fuel and oil increase is equivalent of 68.1 Kgs of diesel fuel as compared with traditional system. Under the mechanical system, the overall

* It is recognized that a small amount of Asian rice land is still tilled completely by human power, while there are few large highly mechanized farms that employ the same machinery and cultural techniques that are used in the developed countries.

** It is estimated that 50% of all rice in Asia is this type. About 25% is upland rice and about 25% is irrigated.

TABLE B.3

ENERGY INPUTS FOR RICE PRODUCTION
IN THREE PRODUCTION SYSTEMS

(Kilograms of Diesel Fuel per Hectare)

	Traditional	Transition	Mechanical
Human	19.4	17.8	14.6
Animal	25.0	9.2	0
Machine	7.5	6.9	12.6
Fuel and oil	1.2	27.2	69.3
Seed	14.0	14.0	14.0
Fertilizer	73.5	73.5	73.5
Insecticide	6.9	6.9	6.9
Herbicide	1.7	1.7	1.9
Sub-Total	149.1	156.3	197.6
Irrigation*	67.4	62.4	67.4
Total	216.5	223.7	265.0
Total** (Mn 1kcal)	2.3	2.4	2.8
Total** (HP-hrs.)	3557	3674	4353

Source: Kuether and Duff (1979).

* Low lift system for irrigation during dry season.

** Conversion factors:

1 HPhr = 2.68452×10^6 J

1 Kcal = 4.1868×10^3 J

Diesel fuel: 38.36×10^6 J per litre

1 kilogram of diesel = 1.494 litres

energy increase is of the order of 30% only, although there is a significant change in the composition of energy input, fuel and oil now accounting for about 35% of the total. Crop drying accounts for about 60% of fuel consumed. If irrigation is added, energy input, mainly in the form of fuel, increases by 34% in mechanical system. It must be emphasized that energy input for fertilizer accounts for almost half of the total input even under the traditional and transitional systems. Energy input in fertilizers is higher than fuel and oil inputs under the mechanical system and accounts for about 37% of total energy input (excluding irrigation). This shows that as rice production is modernized, the proportion of commercial forms of energy increases and inputs in the form of fuels go up which makes it relatively more sensitive to energy price increases. Human effort contributes a relatively small proportion of the total energy consumed in each production system, never exceeding 13% of the total, though 735 man-hours are required to produce that share.*

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* It may be noted that the method of estimating human energy input in these calculations is different from other studies, especially those sponsored by the Indian Council of Agricultural Research. The human energy expenditures used in this paper for the rice growing tasks were obtained experimentally with protable cardiac monitoring instruments. These varied from 1.05×10^6 J per hour for fertilizer application to 0.79×10^6 J per hour for transplanting. Animal energy expenditure was estimated as 10.47×10^6 J per hour for tillage with buffalo. The ICAR (Indian Council of Agricultural Research) studies covered in the later section assume that an adult develops 0.1 hp giving equivalent figures of 0.268×10^6 J per hour for animals. The latter figures are lower by a factor of 4.

Since the data used by Makhijani and Poole (1975) have been quoted in other studies, it would be useful to review the main concepts, data assumptions and results of this study. Table B.4 presents the estimates for five countries, of (a) installed horsepower (hp) per hectare of farm machines and draft animals (b) energy for farm operations, irrigation and nitrogen manufacture (c) rice yield per hectare and (d) energy intensity (amount of energy, including the indirect energy inputs in the form of fertilizers, that it takes to produce one ton of food. Using the data given in the table, the following conclusions have been drawn (i) the installed horsepower per hectare is highest in Japan and the U.S., but the energy required for farm operations (plowing, sowing, harvesting, etc.) is smaller in the U.S. than any other country. (ii) much of the horsepower in the Third World farms is in the form of animals. For every hectare of cultivated land in India, there is one draft animal, usually a bullock. (iii) draft animals are relatively inefficient sources of mechanical power (though they are not as inefficient when the dung is used effectively.) (iv) the energy required per hectare is about the same in all countries when the requirements of irrigation and fertilizers are taken into account. (v) since the yield of rice is higher in Japan and the U.S., the energy requirements per ton of rice are much smaller than in India or China. (vi) thus, energy use per ton of food (rice) in the under-developed countries is much higher in comparison with mechanized farming even when the heavy energy investments in irrigation and fertilizers are taken into account.

It may be argued that the above conclusions are rather specific to the methodology and data used by Makhijani and Poole. A comparison of horsepower of draft animals and tractors (and other machinery) is misleading if it is based on their "engineering equivalent" figures. The authors use a figue of 0.5 horse-power (hp) per animal or 1.0 hp per pair of bullocks. According to this method of "engineering equivalence", a tractor of 35 hp would be equivalent to 35 pairs

Table B.4

ENERGY USE PER HECTARE IN RICE PRODUCTION IN VARIOUS COUNTRIES[a,b]

Country	Installed horsepower hp per ha[c] farm machines and draft animals only	Energy for farm operations million Btu per ha[e]	Energy for irrigation and nitrogen fertilizers manufacture million Btu per ha	Total energy input per ha million Btu	Rice yield kg/ha	Energy intensity ---------- million Btu per ton of Rice
India	0.7	20	6.5	26.5	1,400	19
China	0.7	20	12	32	3,000	10.7
Taiwan	0.5	10	22	32	4,000	8
Japan	1.6	10	25	35	5,600	6.2
U.S.A.	1.5	7	25	32	5,100	6.3

[a] We have chosen to compare a simgle grain (rice) since total grain production not only depends on seed variety, soil quality, etc., but also on the mix of grains grown. Comparing a single grain, therefore, gives a better comparison of the energy intensity of various farming methods.

[b] Installed horsepower and energy use are based on national average energy use in agriculture. The numbers in this table are very approximate.

[c] For India and China about 20 percent of the installed horsepower is in tractors; for Taiwan 50 percent; for Japan 90 percent; for the U.S. 100 percent.

[d] We assume that one draft animal (ox, horse, mule) is approximately equal to 1/2 horsepower. This implies a draft animal of about 250 kg[3]. For lack of data, it is assumed that draft animal weight is about the same in all poor countries. Since a bullock or horse weighing 250 kg. is a rather small animal, this assumption may give rise to an underestimate of installed horsepower for some countries (e.g. Taiwan). It is assumed that 75 percent of the energy output of the draft animals is used on farms, the other 25 percent being used for transportation, pumping domestic water, and similar nonfarm activities (which are excluded from the calculations). Installed horsepower numbers include tractors, but exclude irrigation equipment, trucks, and autos on farms. Annual energy input per draft animal is assumed to be 25 million Btu. Tractor fuel input 7 million Btu/ha/yr for fully mechanized farms (U.S. data).

[e] The energy for irrigation varies according to the irrigation method, terrain, rainfall, water table depth, etc. For the purposes of comparison we have used 15 million Btu of energy input (3 million Btu of useful work) per irrigated hectare per crop. Thus in India, about 40 percent of the rice-producing land is irrigated, so that the irrigation energy input per hectare of rice-producing land is taken os $0.4 \times 15 \times 10^6$ Btu or 6 million Btu. The energy input for chemical nitrogen fertilizer manufacture is about 75 million Btu per metric ton of nitrogen. No energy cost is assigned to the preparation of organic fertilizer. The energy requirements for potassium and phosphorous are small compared to those for nitrogen fertilizers.

Source: Ajun Makhijani and Poole (1975), p. 17.

Table B.4a.

ENERGY USE PER HECTARE IN RICE PRODUCTION IN VARIOUS COUNTRIES[a,b]
IN KGOEs

Country	Installed horsepower hp per ha[c] farm machines and draft animals only	Energy for farm operations KGOE per ha[e]	Energy for irrigation and nitrogen fertilizers manufacture KGOE per ha	Total energy input per ha KGOE	Rice yield kg/ha	Energy intensity KGOE per ton of Rice
India	0.7	490	149	649	1,400	465
China	0.7	490	294	784	3,000	262
Taiwan	0.5	245	539	784	4,000	196
Japan	1.6	245	612	857	5,600	152
U.S.A.	1.5	171	612	784	5,100	154

[a]We have chosen to compare a simgle grain (rice) since total grain production not only depends on seed variety, soil quality, etc., but also on the mix of grains grown. Comparing a single grain, therefore, gives a better comparison of the energy intensity of various farming methods.

[b]Installed horsepower and energy use are based on national average energy use in agriculture. The numbers in this table are very approximate.

[c]For India and China about 20 percent of the installed horsepower is in tractors; for Taiwan 50 percent; for Japan 90 percent; for the U.S. 100 percent.

[d]We assume that one draft animal (ox, horse, mule) is approximately equal to 1/2 horsepower. This implies a draft animal of about 250 kg[3]. For lack of data, it is assumed that draft animal weight is about the same in all poor countries. Since a bullock or horse weighing 250 kg. is a rather small animal, this assumption may give rise to an underestimate of installed horsepower for some countries (e.g. Taiwan). It is assumed that 75 percent of the energy output of the draft animals is used on farms, the other 25 percent being used for transportation, pumping domestic water, and similar nonfarm activities (which are excluded from the calculations). Installed horsepower numbers include tractors, but exclude irrigation equipment, trucks, and autos on farms. Annual energy input per draft animal is assumed to be 25 million Btu. Tractor fuel input 7 million Btu/ha/yr for fully mechanized farms (U.S. data).

[e]The energy for irrigation varies according to the irrigation method, terrain, rainfall, water table depth, etc. For the purposes of comparison we have used 15 million Btu of energy input (3 million Btu of useful work) per irrigated hectare per crop. Thus in India, about 40 percent of the rice-producing land is irrigated, so that the irrigation energy input per hectare of rice-producing land is taken as $0.4 \times 15 \times 10^6$ Btu or 6 million Btu. The energy input for chemical nitrogen fertilizer manufacture is about 75 million Btu per metric ton of nitrogen. No energy cost is assigned to the preparation of organic fertilizer. The energy requirements for potassium and phosphorous are small compared to those for nitrogen fertilizers.

Source: Ajun Makhijani and Poole (1975), p. 17.

of bullocks. However, if we consider "economic equivlence" in terms of work performance or replacement ratios, the equivalent number of bullocks would be much less. Although the precise estimate of the bullock pair equivalent of tractor in terms of acreage farmed would depend on the type of implements used by the bullock, the type of soil and cropping pattern, it may be reasonable to assume that the peak demand for draft power of a 30-acre farm can be met either by a 35 hp tractor or by 5 to 6 pairs of bullocks*. This would imply that a pair is equivalent to 6 hp and one bullock develops 3 hp on farm. If this correction is made, the level of horsepower capacity on Indian farms would be much higher than that estimated in the table.

A more serious consequence of this underestimation of the "economic equivalence" of draft power has been the resulting underestimation of useful energy of animals. Makhijani and Poole use a figure of 0.5 horsepower per animal and combine it with an estimate of an annual working time of 1000 hours and derive the estimate of useful energy output of about 500 horsepower-hours per draft animal. This is converted into an equivalent energy input of 1.2 million Btu (or 0.3 million Kcal). Using an estimate of food intake of 25 million Btu per year per animal, an efficiency figure of 5% (1.2/25) is derived. This figure would dramatically change if (a) the "economic equivalence" method of horsepower of draft animals is used giving an estimate of 3 hp per bullock (b) credit is given for the dung output of cattle, estimated by Makhijani and Poole at 10 to 15 million Btu and (iii) it is recognized, as emphasized by Pimentel in his papers, that a large portion of animal feeds consists of by-products and grazing at pasturelands. Taking some rough approximate values for the above three factors would indicate that energy output per bullock is 17.2 million Btu (7.2 from farm

* If the number of pairs of bullocks actually replaced by a tractor is considered, the number of bullock pairs would not be more than 3 or 4. For a detailed discussion on these points and some estimates, see Bhatia (1976, 1977a) and Sharma (1972).

work plus 10 from dung) while the energy input* would be only around 5 million Btu. If this figure of energy input is considered, the energy output to input ratio would be 3.44. This correction would suggest that draft animals are not inefficient sources of mechanical power if appropriate concepts and data are used.

Once it is recognized that not only draft animals do not use energy inefficiently on the farm, but, in fact, contribute to the energy supplies available for other household uses (by converting crop residues into dung), the entire calculations regarding energy intensity of rice production would have to be revised. For example, if the figures for energy input for India are used, it would seem that the 'real' energy input (which competes with human uses) in cattle feed would be 5 million Btu/year (20% of the total of 25 mn Btu) and energy for irrigation and fertilizer manufacture estimated at 6.5 million Btu per ha, the total input would be 11.5 million Btu/year as against an energy output of 17.2 million Btu per year per hectare. This would give a net contribution of energy into the system which would make rice cultivation in India more energy efficient as compared with U.S. or Japan.

* Assuming that one-fifth of animal feed consists of grains and pulses which could be used by human beings and the rest comes from pastures and by-products.

Energy Inputs in Corn Production:

Table B.5 presents a comparison of energy inputs and output in corn production for various countries at different levels of mechanization. When only manpower is used in raising corn in countries such as Mexico, Guatemala and Nigeria, the energy input ranges between 0.556 Mn.Kcal to 0.782 Mn. Kcal per hectare*. When energy content of output is taken into account, the output to input ratio ranges between 4.84 for Guatemala to 6.41 for Nigeria and to 10.74 for Mexico.

In the case of Mexico and Guatemala, energy input is 0.77 Mn. Kcal and 1.216 Mn. Kcal per hectare when animal power is used. In Mexico, about 200 hours of ox power are needed to produce one hectare of corn. Concurrently, the man-hours needed are reduced from 1140 hours to 380, thus indicating that one hour of oxpower replaces nearly four hours of man-power. If an ox consumes about 20,000 Kcal per day in feed (most of it forage unsuitable for humans) and a man consumes 4120 Kcal per day, the energy input for man/ox combination is 0.77 Mn. Kcal, for an output/input ratio of 4.34. In Guatemala, the use of about 310 hours of oxpower reduces the man-power input almost in half. Because the food-energy input for the man/ox combination is greater (1.2 Mn. Kcal/ha) than that for manpower alone while the corn yields are assumed the same, the output/input ratio at 3.11 is relatively lower. In the case of Philippines where carabao draft animals are used, the energy output/input ratio is 5.06, similar to the case in Mexico.

However, when agriculture is mechanized, as in U.S.A., the total manpower is dramatically reduced and there is heavy reliance on machines for power. The labor input is reduced from around 383 hours in Mexico to 12 hours in U.S.A., representing an energy input of 5580 Kcal/ha. Balanced against this low manpower input is the

* For example, in Mexico, producing corn by hand, using swidden or cut/burn agricultural technology requires only a man with an axe and a hoe. Corn requires about 1140 hours (143 days). The total energy input for the man-power is 4120 Kcal per day (8 hours work @ 350 Kcal/hr; 6 hours of other activities @ 145 Kcal/ha and 10 hours of rest @ 45 Kcal/hr). When the energy for making axe and hoe and producing seed is added, the total energy input is 0.642 million Kcal.

TABLE B.5

ENERGY INPUTS AND OUTPUTS IN CORN PRODUCTION

(000 Kcal/ha)

	Mexico		Guatemala		Nigeria	Philippines	U.S.
INPUTS	only manpower	using ox	only man	using ox	only man		
Labor	589	197	729	361	319	152	6
Axe and hoe	17		17		17		
Seeds	37	37	37	37	37	37	525
Ox		495		778			
Nitrogen					162	59	1182
Phosphorous					12	3	216
Potassium					10	.4	128
Machinery		41		41		41	558
Carabao						364	
Transportation						3	35
Diesel							1279
Limestone							32
Irrigation							780
Insecticides							87
Herbicides							200
Drying							426
Electricity							380
TOTAL	642	770	782	1216	556	660	6532
OUTPUT							
Yield (Kg /ha)	1944	941	1066	1066	1004	941	5394
Yield (000 Kcal/ha)	6901	3341	3784	3784	3564	3341	19149
Kcal output/ Kcal input	10.74	4.34	4.84	3.11	6.41	5.06	2.93
Protein Yield	175Kg/ha	85Kg/ha	96Kg/ha	96Kg/ha	90Kg/ha	85Kg/ha	485Kg/

Source: From Pimentel and Pimentel, Food, Energy and Society, John Wiley & Sons, 1979, P. 63-72

TABLE B.5a

ENERGY INPUTS AND OUTPUTS IN CORN PRODUCTION

Kilograms of Oil Equivalent*

	Mexico		Guatemala		Nigeria	Philippines	U.S.
INPUTS	only manpower	using ox	only man	using ox	only man		
Labor	57.24	19.14	70.85	35.0	31.0	14.77	.55
Axe and hoe	1.65		1.65		1.65		
Seeds	3.6	3.6	3.6	3.6	3.6	3.6	51.2
Ox		48.1		75.61			
Nitrogen					15.74	5.73	114.87
Phosphorous					1.17	.29	20.99
Potassium					.97	.4	12.44
Machinery		3.98		3.98		3.98	54.23
Carabao						35.37	
Transportation						.29	3.4
Diesel							
Limestone							124.3
Irrigation							3.11
Insecticides							8.95
Herbicides							19.44
Drying							41.4
Electricity							36.93
TOTAL	62.39	74.83	76.0	118.17	54.03	64.14	634.79
OUTPUT							
Yield (kg/ha)	1944	941	1066	1066	1004	941	5394
Yield (000 Kcal/ha	670.65	324.68	367.74	367.74	346.36	324.68	1860.93
Kcal output/ Kcal input	10.74	4.34	4.84	3.11	6.41	5.06	2.93
Protein Yield	175Kg/ha	85Kg/ha	96Kg/ha	93Kg/ha	90Kg/ha	85/Kg/ha	485Kg/ha

Source: From Pimentel and Pimentel, Food, Energy and Society, John Wiley & Sons, 1979, P. 63-72

* 1 Kilogram of oil equivalent = 10.29×10^3 kcal.

significant increase in fossil energy input needed to run the machines that replace man. Thus, in U.S., fossil fuel energy inputs at 6.532 million Kcal/ha are about 10 times those in Mexico or the equivalent of about 700 litres of gasoline. Although the corn yield is high at 5.394 tons/ha, the output/input ratio is the lowest - 2.93. The fossil energy inputs in U.S. corn production are primarily from petroleum and natural gas, the latter used for fertilizer production and accounting for more than a quarter of the energy input. Machinery input and fuel together total about 28% of the fossil energy input. From this, Pimentel and Pimentel (1979) conclude that taken as a whole, about half the energy inputs in U.S. corn production reduce man and animal labor inputs, and about half increase corn productivity. Energy inputs in corn production in U.K. are considered similar to those in U.S.A. although the output/input ratio of 2.34 in U.K. is lower than in U.S.A.

Energy Input in Wheat:

The energy-input in wheat is discussed for U.S.A., U.K. and India (Table B.6). The output-input ratios are 2.41 for U.S., 3.51 for U.K. and 0.96 for India. It has been pointed out by Pimentel and Pimentel (1979, p. 70) that a ratio of o.96 for India, (indicating that less wheat energy is produed than energy expended) may be somewhat misleading. This is because out of the total energy input of 2.8 million Kcal, 2.25 is for two bullocks and bullocks consume primarily grasses and crop residues and little grain. Thus, the bullocks convert grass energy into wheat energy through working on the fields. If only 20% of the feed of bullocks is assumed to compete with human uses, the output/input ratio would be 2.7. This indicates that it is very important to determine which inputs have economic value in alternative uses before the contribution of animal power is estimated and energy output/input ratios are calculated.

TABLE B.6

ENERGY INPUTS AND OUTPUT IN WHEAT PRODUCTION
(000 Kcal/ha)

INPUTS	U.S.	U.K. (winter wheat)	India (U.P.)
Labor	3		324
Bullock			2248
Machinery	360	Tractors 774 Equipment 308 Total 1082	41
Diesel	605		
Nitrogen	715		
Phosphorous	78	All Fertilizers 2119	
Potassium	48		
Limestone	11		
Manure			
Irrigation			
Seeds	700		215
Herbicides	50		
Sprays		95	
Electricity	200		
Transportation	45		
Drying - Fuels		399	
Drying - Machinery		134	
TOTAL	2815	3829	2828
OUTPUT			
Yield (kgs/ha)	2060	3780	821
Yield (000 Kcal/ha)	6798	13426	2709
Kcal Output/Kcal Input	2.41	3.51	.96*
Protein Kg/ha	247 Kg/ha	452 Kg/ha	99 Kg/ha

Notes: 1. Source: Pimentel & Pimentel, Food, Energy and Society, John Wiley & Sons, 1979 p. 72-73

2. *Bullocks consume mainly waste crop residues and grasses on pasture land which could be used for little else. Without bullocks, energy ratio is 5 Kcal out/Kcal input. For a detailed discussion, see Pimentel & Pimentel (1979), p. 70

TABLE B.6a

ENERGY INPUTS AND OUTPUT IN WHEAT PRODUCTION

(Kilograms of Oil Equivalent/ha)*

INPUTS	U.S.	U.K. (winter wheat)	India (U.P.)
Labor	.3		31
Bullock			218
Machinery	35	Tractors 75 Equipment 30 Total 105	4
Diesel	59		
Nitrogen	69		
Phosphorous	7.6	All Fertilizers 206	
Potassium	5		
Limestone	1		
Manure			
Irrigation			
Seeds	68		21
Herbicides	5		
Sprays		9	
Electricity	19		
Transportation	4		
Drying - Fuels		39	
Drying - Machinery		13	
TOTAL	274	372	275
OUTPUT			
Yield (kgs/ha)	2060	3780	821
Yield (KGOE /ha)	661	1305	263
Kcal Output/Kcal Input	2.41	3.51	.96*
Protein Kg/ha	247 Kg/ha	452 Kg/ha	99 Kg/ha

Notes: 1. Source: Pimentel & Pimentel, Food, Energy and Society, John Wiley & Sons, 1979 p. 72-73

2. *Bullocks consume mainly waste crop residues and grasses on pasture land which could be used for little else. Without bullocks, energy ratio is 5 Kcal out/Kcal input. For a detailed discussion, see Pimentel & Pimentel (1979), p. 70.

3. *1 KGOE (kilograms of oil equivalent) = 10.29×10^3 kcal.

Energy Yields and Support Energy Requirements for Sugar Beet and Sugarcane:

Austin, et al (1978) present estimates of gross energy yields and support energy requirements for production of sugar from sugarbeet crops in U.K. and California and sugarcane in Queensland (Australia) and Transvaal (South Africa). The following points may be noted from Table B.7: (a) gross energy yields are around 4.7-5.6 TOE/ha/year for beet crops as compared with 15.4-16.2 TOE/ha/yr for cane crops (b) recoverable sucrose constituted about 45% of the gross energy yield in the sugarbeet crop but only about 29 percent in cane crops, largely due to bagasse energy in the latter (c) since sugarcane bagasse was used as fuel, it provided nearly all the energy for the production of sugar from sugarcane crops, but sugarbeet byproducts supplied no energy for the production of sugar from sugarbeet (d) due to this difference, the total support energy requirements were almost equal in U.K., Queensland and Transvaal, although on-farm energy input in cane crop was relatively higher (e) on account of use of energy from bagasse for sugar production from cane, output/input ratio for refined sucrose was between 0.49 and 0.71 for sugarbeet while it was between 1.57 and 1.63 for sugarcane (f) the overall output/input ratio based on gross energy in sucrose and available by-products (excluding bagasse in the case of production from cane) range between 4.05 to 4.4 for cane crop. This is a good example of treating an agricultural crop both as a user of energy and a source of energy. There is need to do a similar comprehensive analysis for other crops in various regions and different farm systems in developing countries.

TABLE B.7

GROSS ENERGY YIELDS and SUPPORT ENERGY REQUIREMENTS
FOR SUGARBEET and SUGARCANE

	Sugarbeet		Sugarcane	
	U.K.	California	Queensland	Transvaal
1. Mean Crop Duration (days)	230	202	412	420
2. Yield (tons/ha/yr)	5.2	6.8	12.8	10.8
3. Gross Energy Yields (TOE/ha/yr)				
. Sucrose	2.03	2.65	4.99	4.21
. Leaves	1.31	1.18	6.46	6.55
. Bogasse or pulp	.77	1.13	3.04	4.45
. Filter Mud			.25	.32
. Molasses*	.58	.66	.71	.70
. Total	4.69	5.62	15.45	16.2
4. Support Energy Requirements (TOE/ha/yr)				
. Fuel used in Cultivation	.16	.21	.16	.12
. Energy equivalent of Farm machinery	.12	.20	.22	.22
. Irrigation (Pumping)	0	.24	.21	.36
. Fertilizers	.36	.33	.24	.26
. Fuel used in factory and for refining, etc.**	2.17	4.39	2.23	1.69
. Total	2.34	5.40	3.07	2.65
5. Output/Input Ratio	1.65	1.04	4.05	4.40

Notes: 1. 1GJ = Gigajoules = 10^9 J = 0.25 X 10^6 1 TOE (ton of oil equiv.) $10.29 X 10^6$ kca

2. Source: Austin et al (1978)

3. * energy equivalent of Sucrose in Molasses.

** includes energy required for transport to factory and energy equivalent of factory machinery.

B.2 ENERGY-USE AT FARM LEVEL: SECOND GROUP OF STUDIES

The energy-use data available in these studies has the following characteristics: (i) energy input is measured in terms of horsepower of mechanical equipment and not in terms of the energy content of the fuels used as in the case of some other studies. Typically, the rated horsepower of a tractor/ electric motor/diesel engine/thresher is multiplied by the number of hours of operation of that machine and the resulting horsepower-hours are the estimates of energy input of a relevant machine/equipment. (ii) animal power and human energy are also considered in terms of horsepower-hours using the method of "enginereering equivalence" in which it is assumed that one adult man develops 0.10 horsepower and one pair of bullocks develops 1.0 horsepower. Thus, the contribution of bullocks is estimated in terms of horsepower-hours (a product of horsepower and number of hours of operation) and not in terms of energy content of the animal feed consumed for work. (iii) energy contribution of differential crop residues, animal residues and their pattern of use is entirely ignored. The implications of all these assumptions will be discussed after the data are presented.

Energy Use and Farm Size:

Energy-use for different farm-sizes for paddy in Uttar Pradesh, India, is given in Table B.8. It may be noted that when irrigation is provided through canals, level and pattern of energy use in small, medium and large farms is not significantly different. However, once the tubewell with a pumpset is introduced on a large farm. energy input goes up by 45%, irrigation and threshing accounting for the major share of the increase. In another study in the Punjab, India, it may be noted that energy input per hectare in terms of horsepower-hours increases with farm size (Table B.9) In these sample farms, as farm size increases, share of bullock energy decreases while that of tractor energy rises. The result is that on larger farms, tractor energy accounts for roughly two-thirds of total energy. However, it should be kept

TABLE B.8

ENERGY-USE FOR DIFFERENT FARM SIZES: PADDY(HIGH YIELDING VARIETY-IRRIGATED) In U.P. (India)

(Horsepower-hours per hectare)

Farm size	Small Farms		Medium Farms		Large Farms			
Source of Irrigation	Canal		Canal		Canal		Canal and tubewell with pumpset	
		%		%		%		%
Field preparation[a]	280	42	248	40	198	32	315	33
Irrigation	210	32	273	44	311	50	413	43
Fertilization	2	*	2	*	2	*	2	*
Intracrop care[b]	25	4	32	5	25	4	24	3
Harvesting	24	4	35	6	32	5	28	3
Transportation	34	5	13	2	2		2	*
Threshing and Winnowing	87	13	20	3	53	9	173	18
TOTAL (Index)	662 (100)	100	613 (93)	100	623 (94)	100	957 (145)	100
Yield Qtl/ha	40		48		48		52	

* Less than 1%

Notes: 1. Source: Indian Council of Agricultural Research, Government of India Report on Energy Requirements of Intensive Agricultural Production, 1977-78 (Pant Nagar, U.P.)

2. a) Field preparation includes land preparation and sowing

b) Intracrop care includes plant protection, interculture and other pre-harvest operations

TABLE B.9

ENERGY USE PER HECTARE FROM DIFFERENT SOURCES IN THE STUDY AREA
FEROZEPUR DISTRICT, PUNJAB: 1973-74

(horse power hours)

Source of energy	Farm Size-group I (below 6 ha)	II (6-9 ha)	III (9-14 ha)	IV (14-24 ha)	Pooled
Irrigational energy	5.94 (1.31)	5.37 (1.05)	4.48 (0.63)	3.76 (0.48)	4.41 (0.65)
Human energy	62.47 (13.76)	51.17 (10.09)	42.06 (10.30)	36.73 (4.68)	42.76 (6.33)
Bullock energy	107.75 (37.62)	137.18 (27.08)	73.25 (10.30)	51.27 (6.53)	82.28 (12.19)
Tractor energy	100.16 (22.06)	224.06 (44.20)	471.21 (66.28)	533.44 (67.90)	425.31 (62.99)
Stationary machinery energy	114.59 (25.25)	89.14 (17.58)	120.17 (16.90)	160.41 (20.41)	120.43 (17.84)
Total	453.91 (100.00)	506.92 (100.00)	711.17 (100.00)	785.61 (100.00)	675.19 (100.00)

Notes: 1. Source: A.J. Singh and S.S. Miglani (1976), p. 166.

2. Figures in brackets are percentages to column totals.

in mind that this data is for the entire farm operations (and not for individual crop) and the increase in energy input reflects the effect of tractorization rather than the effect of farm size.

Energy Inputs and Level of Mechanization:

Energy inputs in bullock and tractor operated farms are presented in Tables B.10-11 for two agriculturally advanced areas in the Punjab and Uttar Pradesh (U.P.) states of India. For HYV paddy in U.P. (Nainital district), tractor farms use about 20% higher energy per hectare, most of the increase being accounted for by land preparation. Since irrigation is provided through mechanical sources in both type of farms, mechanical power accounts for roughly 73% of the total energy input on bullock farms. Data for wheat show that tractor operated farms use about twice as much energy per hectare as bullock operated farms, the difference being acccounted for by land preparation and threshing. Since irrigation and threshing is done by mechanical sources even on bullock operated farms, share of mechanical power on bullock farms is more than 75%.

Another set of data pertaining to the western part of U.P., India, also shows that energy input increases by about 45% if only irrigation is mechanized and by about 70% if electric motor/diesel engine is used for irrigation and tractor is used for land preparation/threshing.(Table B.12). The energy input is substantially higher (about 50%) if tractor is used instead of electric motor/diesel engine for irrigation and other tasks.

Energy requirements per cropped hectare for bullock and tractor operated farms in the study area of Ferozepur district of Punjab, India, are given in Table B.13. The data show that human energy dominates (more than half) energy use in the case of bullock operated farms where irrigation is provided through canal. Human energy is used for all operations, harvesting accounting for 50% of the total. Bullocks are

TABLE B.10

ENERGY INPUTS PER HECTARE FOR HYV PADDY (Irrigated) IN BULLOCK AND TRACTOR OPERATED FARMS IN U.P., INDIA

(Horsepower hours)

Operations	Manual power	Bullock power	Mechanical power	Total	Fertilizer cost (Rs.)	Yield (quintals)
Bullock operated farms						
Land preparation	18.78	744.08	105.40	268.26	472.46	46.11
Sowing	25.33	- -	- -	25.33		
Fertilization and manuring	1.78	3.04	- -	4.82		
Irrigation	8.08	- -	597.86	605.94		
Plant protection measures	0.62	- -	- -	0.62		
Inter-culture	22.17	- -	- -	22.17		
Other pre-harvesting operations	1.12	- -	- -	1.12		
Harvesting	24.60	- -	- -	24.60		
Transportation	4.08	- -	- -	4.08		
Threshing and Winnowing	9.19	7.36	13.07	29.62		
Total	115.75	154.48	716.33	986.56		
Tractor operated farms						
Land preparation	4.42	16.32	576.16	596.90	870.71	55.13
Sowing	37.31	- -	- -	37.31		
Fertilization and manuring	1.63	- -	- -	1.63		
Irrigation	6.37	- -	457.56	463.93		
Plant protection measures	0.45	- -	0.66	1.11		
Inter-culture	36.80	- -	- -	36.80		
Other pre-harvesting operations	4.02	- -	- -	4.02		
Harvesting	25.90	- -	- -	25.90		
Transportation	4.31	- -	- -	4.31		
Threshing and winnowing	10.06	- -	1.38	11.44		
Total	131.27	16.32	1,035.76	1,183.35		

Source: L.R. Singh and B. Singh (1976) p. 160.

TABLE B.11

ENERGY INPUT PER HECTARE FOR HYV WHEAT (Irrigated) IN BULLOCK AND TRACTOR OPERATED FARMS IN U.P., INDIA

(Horsepower-hours)

Operations	Manual Power	Bullock Power	Mechanical Power	Total	Fertilizer cost (Rs.)	Yield (quintals)
Bullock Operated Farms						
Land preparation	7.21	72.16	297.51	376.88	609	28.61
Sowing	1.36	9.36	60.25	70.97		
Fertilizer and manuring	0.98	- -	- -	0.98		
Irrigation	4.29	- -	237.37	236.66		
Plant protection measures	0.24	- -	- -	0.24		
Inter-culture	8.38	- -	- -	8.38		
Other pre-harvesting operations	- -	- -	- -	- -		
Harvesting	17.64	- -	- -	17.64		
Transportation	4.60	3.92		8.52		
Threshing and Winnowing	5.77	12.72	214.72	233.21		
Total	50.47	98.16	804.85	953.48		
Tractor Operated Farms						
Land preparation	2.78	1.28	1,069.11	1,073.17	881	36.90
Sowing	0.56	1.36	83.43	85.35		
Fertilization and manuring	1.44	- -	- -	1.44		
Irrigation	4.25	- -	216.78	221.03		
Plant protection measures	- -	- -	- -	- -		
Inter-culture	22.49	- -	- -	22.49		
Other pre-harvesting operations	- -	- -	- -	- -		
Harvesting	21.13	- -	- -	21.13		
Transportation	5.25	5.68	- -	10.93		
Threshing and Winnowing	5.37	- -	550.25	555.62		
Total	63.27	8.32	1,919.57	1,991.16		

Source: L.R. Singh and B. Singh (1976), p.161.

TABLE B.12

ENERGY INPUTS FOR WHEAT UNDER DIFFERENT LEVELS OF MECHANIZATION

(Horsepower-hours per hectare)

	Persian Wheel	Electric or Diesel for Irrigation only	Electric/Diesel for Pump and other Machines	Tractor used for Everything	Tractor & Electric or Diesel Engine for Irrigatio
HIGH YIELDING VARIETY					
Human labor	115	100	59	43	46
Bullock labor	650	492	170	35	49
Electric/Diesel	158	719	971	0	937
Tractor	37	15	82	2135	504
TOTAL	960	1326	1282	2213	1582
LOCAL VARIETY					
Human labor	120		58		
Bullock labor	556		188		
Electric/Diesel	37		840		
Tractor	30		0		
TOTAL	743		1086		

Source: Singh and Chancellor, Energy Inputs and Agricultural Production under Various Regimes of Mechanization in Northern India, published by the American Society of Agricultural Engineers - St Joseph - MI reprinted from the transactions of the ASAE, vol. 18, No. 2, pp. 252-59, 1975

TABLE B.13

ENERGY REQUIREMENTS PER CROPPED HECTARE FOR DIFFERENT AGRICULTURAL OPERATIONS FOR BULLOCK AND TRACTOR OPERATED FARMS IN THE STUDY AREA, FEROZEPUR DISTRICT, PUNJAB: 1973-74

(horsepower-hours)

Operations	Bullock Operated Canal Irrigated			Bullock Operated Tubewell Irrigated			Tractor Operated Canal Irrigated			Tractor Operated Tubewell Irrigated		
	H.E.	B.E.	M.E.	H.E.	B.E.	M.E.	H.E.	B.E.	M.E.	H.E.	B.E.	M.E.
Preparatory Tillage	4 (2)	38 (66)	12 (22)	10 (16)	87 (75)	54 (9)	.7 (0.6)	6 (35)	147 (52)	2 (5)	0.8 (14)	379 (33)
Sowing	1 (0.8)	7 (12)		6 (10)	14 (12)	5 (0.7)	1 (0.8)	4 (27)	24 (8)	4 (9)	3 (48)	46 (4)
Fertilization & Manuring	1 (0.7)	3 (5)	3 (6)	2 (4)	6 (5)	5 (0.7)	0.8 (0.7)	0.1 (0.6)	41 (15)	2 (3)	0.1 (2)	47 (4)
Irrigation	19 (11)		9 (16)	9 (15)		467 (76)	15 (12)		10 (3)	9 (19)		490 (43)
Inter-culture	34 (20)	5 (8)	0.7 (1)	7 (11)	2 (1.5)		0.3 (0.3)	4 (27)	4 (2)	10 (21)	2 (26)	0.5 (0.04)
Plant Protection	3 (2)		3 (5)	0.2 (0.3)			5 (4)		5 (2)	0.1 (0.2)		
Harvesting	75 (44)			18 (30)			70 (58)			13 (28)		
Threshing	28 (17)	3 (5)	27 (49)	7 (12)	2 (2)	81 (13)	25 (21)	1 (8)	29 (10)	7 (14)	0.2 (3)	125 (11)
Transportation	4 (3)	2 (3)		1 (2)	5 (5)		3 (2)	0.2 (2)	23 (8)	0.1 (0.3)	0.5 (22)	57 (5)
Total	169 (100)	58 (100)	54 (100)	60 (100)	116 (100)	611 (100)	120 (100)	16 (100)	282 (100)	48 (100)	6 (100)	1144 (100)

Note: Figures in parentheses are percentages. H.E. = Human Energy, B.E. = Bullock Energy, M.E. = Mechanical Energy

Source: Singh and Miglani (1976), p. 168.

used for preparatory tillage and sowing while mechanical energy is mainly used for threshing. On tractor operated farms where canal irrigation is used, preparatory tillage and sowing account for the major share of increased mechanical energy on the farm. Although mechanical energy increase five fold on such a farm, the total energy input increases only by 50%. This shows that if only ploughing is mechanized, there would be a reduction in bullock and human energy inputs on the farm and, hence, the total energy-use would not be substantially higher. However, if irrigation is mechanized and tubewell is used for irrigation, there is no corresponding reduction in bullock energy and hence, total energy input is substantially higher as compared with that on a bullock-operated farm. If both preparatory tillage (including sowing) and irrigation are mechanized, there is substantial reduction in bullock and human energy but a sharp increase in total energy input. For example, as given in Table B.13, total energy input under this category of farms is around 1200 horsepower-hours (hp-hrs) per hectare compared with 720 hp-hrs on a farm where irrigation alone is mechanized, 412 hp-hrs where land preparation alone is mechanized and 281 hp-hrs on bullock operated farms.

Energy-Use in Various Agricultural Operations:

Energy-use per hectare of cropped area in Nainital district of U.P., India, (Table B.14) show that on bullock farms, land preparation, irrigation and threshing are the major operations involving energy-use. Land preparation and irrigation use about equal energy input (500 hp-hrs each) while threshing uses about one-third of the energy-input of land preparation. In tractor farms, the share of land preparation is high (about 50% as compared with 40% on bullock farms) followed by irrigation and threshing*. Typically, harvesting accounts for a small share in energy input since it is done by manual power.

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* As has been explained elsewhere, this method of "engineering equivalence" gives a misleading picture of the share of animal power. If "economic equivalence" is used and a pair of bullocks is considered to be of 10 hp, the share of land preparation would be much higher on bullock farms.

TABLE B.14

ENERGY INPUT PER HECTARE OF OPERATED AREA
IN NAINITAL, U.P., INDIA

(horsepower-hours)

Operations	Manual Power	Bullock Power	Mechanical Power	Total Energy Input	Gross Income(Rs.)	Cropping Intensity (%)
Bullock operated farms						
Land preparation	17.01	153.10	354.86	524.97	5,774.70	165
Sowing	15.06	16.47	60.62	92.15		
Fertilization and Manuring	1.87	3.16	- -	5.03		
Irrigation	5.77	- -	498.52	504.29		
Plant protection measures	0.43	- -	- -	0.43		
Inter-culture	19.38	2.71		22.09		
Other pre-harvesting operations	7.32	- -	- -	7.32		
Harvesting	35.23	- -	- -	35.23		
Transportation	9.14	18.96	- -	28.10		
Threshing and Winnowing	13.53	22.93	134.66	171.12		
Total	124.74	217.33	1,048.66	1,390.73		
Tractor operated farms						
Land preparation	6.42	26.36	1,642.02	1,674.80	8,257.29	186
Sowing	24.88	4.55	104.11	133.54		
Fertilization and manuring	2.29	- -	- -	2.29		
Irrigation	8.06	- -	733.42	741.48		
Plant protection measures	0.28	- -	- -	0.28		
Inter-culture	40.45	0.26	- -	40.71		
Other pre-harvesting operations	9.58	- -	- -	9.58		
Harvesting	56.75	- -	- -	56.75		
Transportation	7.17	34.98	- -	42.15		
Threshing and winnowing	9.34	1.04	521.39	531.77		
Total	165.22	67.19	3,000.94	3,233.35		

Source: Singh and Singh (1976), p. 163.

The share of energy input for various operations is not the same for different crops. In paddy, irrigation alone accounts for 60% of energy input on bullock farms while the corresponding figures for wheat and sugarcane (planted) are 25% and 29%, respectively. For tractor farms, however, share of irrigation is 40% for paddy, 11% for wheat and 16% for sugarcane. Land preparation accounts for 25, 27 and 40 percent of total energy inputs on bullock farms in the case of paddy, wheat and sugarcane respectively. Threshing and winnowing is important for wheat crop accounting for about a quarter of the total energy input. Share of transportation in the total is important only in the case of sugarcane crop where it is done by using bullocks.

In the case of bullock-operated canal irrigated farms in the Punjab, preparatory tillage accounts for bulk of bullock energy and harvesting, threshing and interculture account for the bulk of human energy input. On tractor operated canal irrigated farms, preparatory tillage and sowing account for about 60% while threshing accounts for 10% of the total mechanical energy. When land preparation and irrigation are mechanized, the share of different operations in total mechanical energy use is as follows: land preparation and sowing 37%, irrigation 43%, threshing 11% and transport 5%. Transportation accounts for 3-5 percent of bullock energy on bullock farms and 5-8 percent of mechanical energy on tractor farms. (Table B.13).

Energy Inputs for Different Crops:

It is interesting to note from Table B.15 that total energy inputs on bullock farms are not significantly different in paddy, wheat and sugarcane crops. The range of energy input is 910 horsepower-hours (hp-hrs) for sugarcane to 987 hp-hrs for paddy, wheat lying in the middle with 954. However, share of energy use for various operations is not the same: irrigation accounts for 60% of the total input in paddy, 25% in wheat and 25% in sugarcane; land preparation accounts for 25, 27 and 40 percent of total input in paddy, wheat and sugarcane; threshing and winnowing

TABLE B.15

Total Energy Input in Different Crops for Bullock and Tractor Farms in Nainital, (Uttar Pradesh) India.

(Horsepower-hours per hectare)

	Paddy (Hyv, Irrig.)		Wheat (Hyv, Irrig.)		Sugarcane (Planted, Irrigat	
	Bullock Farms	Tractor Farms	Bullock Farms	Tractor Farms	Bullock Farms	Tracto Farms
1. Land Preparation	268	597	377	1,073	365	752
2. Sowing	25	37	71	85	38	33
3. Fertilization & Manuring	5	2	1	1	1	1
4. Irrigation	606	464	237	221	262	192
5. Plant Protection	1	1	1	-	-	-
6. Inter Culture	22	37	8	23	25	23
7. Other Pre-harvesting Operations	1	4	-	-	13	3
8. Harvesting	25	26	18	21	87	97
9. Transportation	4	4	9	11	119	119
10. Threshing and Winnowing	30	11	233	556	-	-
11. Total	987	1,183	954	1,991	910	1,220
12. Crop Yield (Q/Ha.)	46.1	55.1	28.6	36.9	570	609

Source: L.R. Singh and B. Singh (1976)

are important for wheat crop only and account for about a quarter of the total energy input; harvesting's share is about 2-3% in paddy and wheat, while it is around 10% in paddy, transportation is important only for sugarcane and is done by bullocks even on tractor farms.

On tractor farms, however, energy input is approximately equal for paddy and sugarcane, while it is around 55% higher in the case of wheat. Bulk of this increase for wheat is for land preparation and about a quarter for threshing and winnowing. As compared with bullock farms, tractor farms use 20-30% higher energy in paddy and sugarcane and about 100% higher in the case of wheat.

For another advanced district (Meerut) of Uttar Pradesh (U.P.), India, Singh and Chancellor have presented results of their survey of 26 farmers and 500 crop plots. (Table B.16). For the most mechanized farms having a tractor for tillage and transportation and having an electric motor and diesel engine to power irrigation pump and other machines, total energy input, in horsepower-hours per hectare, for different crops was as follows: wheat (HYV) 1536, rice 1510, maize 476, cotton 687, sugarcane (planted) 2944, sugarcane (ratoon) 2860 and fodder crops (winter) 2045. It can be seen from Table B.16 that tractor energy has major share in wheat (HYV), sugarcane (planted) and maize crops, while electric/diesel energy has significant shares in rice, cotton, fodder (winter) and wheat. Energy used to produce 100 Kg of crop varies from 4.6-5-9 hp-hrs for sugarcane to 30 hp-hrs for maize, 46 hp-hrs for wheat, 57.8 hp-hrs for rice and 69.3 hp-hrs for cotton. Energy input for high yielding variety of wheat is about 20% higher than that for local variety.

Tables B.17-18 provide data for energy inputs into paddy and wheat at different levels of mechanization for the eastern Gangetic plain of India, in the State of West Bengal. For paddy, the total energy input on bullock farms is 745 hp-hrs as compared with 910 hp-hrs in Nainital district of U.P. Irrigation accounts for

TABLE B.16

ENERGY USE IN MECHANIZED AGRICULTURE:
A COMPARISON FOR DIFFERENT CROPS
IN UTTAR PRADESH(WEST), INDIA (Horsepower-Hours per hectare)

	Wheat HYV*	Wheat local**	Paddy	Sugarcane (Planted)	Sugarcane (Ratoon)	Maize	Cotton
Human labor	46	58	75	175	123	56	106
Bullock labor	49	188	5	12	114	10	15
Electric/diesel	937	840	1109	1324	1720	126	282
Tractor energy	504	0	321	1349	351	284	284
Total energy	1536	1086	1510	2860	2308	476	687
(Index)	100	70	96	181	146	30	43
Yield (kg/ha)	3342	--	2529	--	--	1568	--
Yield (Mn Kcal/ha)	11.0	--	9.2	--	--	5.6	--
Total energy per 100 Kg of output (HP-Hrs)	45.9	--	57.8	--	--	30.3	69.3

Notes: 1. Data is based on a year long survey in 1971-72 with 500 crop plots of 26 farmers in seven villages of Meerut district in North Central India. For details see Singh and Chancellor (1975).

2. Data for all crops (except local wheat) is for farms having a tractor and using it mainly for tillage and transportation activities, and having an electric motor or diesel engine to power an irrigation pump and other stationary machines such as wheat thresher, cane crusher or maize shellers. Farms growing local wheat do not have tractors.

3. Totals do not add because of rounding error.

4. The following conversion factors have been used for the energy content of different agricultural crops; Kcal/kg., Maize 3550; wheat 3300; rice 3630.

Source: Pimental and Pimentel (1979).

TABLE B.17

ENERGY REQUIREMENTS FOR GROWING PADDY CROP
UNDER DIFFERENT LEVELS OF MECHANIZATION
IN WEST BENGAL, INDIA

(Horsepower-hours per hectare)

Farm Operation	Bullock Operated				Power Tiller (8 HP)			Tractor (35 HP)		
	Human	Bullock	Machine	Diesel liters/ha	Human	Machine	Diesel liters/ha	Human	Machine	Diesel liters/ha
Field Preparation (Nursery and Transplanting)	67	55	16[c]	4	55	204	54	62	454	50
Intercrop care	46		*		47	*			*	
Fertilizer	8				8			8		
Irrigation (5 hp)	19		472	118	18	440	110	16	394	98.5
Harvesting	25				23			32		
Threshing	13				9	49	11 Kwh/hr	9	51	11 Kwh/hr
Transport	17				14	13[a]	3	13	12[b]	3
Miscellaneous	6				6			6		
Total	202	55	488	122	180	706	168	203	911	151
Yield	24 quintal/Ha				26 quintal/Ha			27 quintal/Ha		

Notes 1. Source: Department of Agricultural Engineering, Indian Institute of Technology, Annual Report (From April 1975 to March 1976) The Coordinated Research Scheme on Energy Requirements in Intensive Agriculture Production. (Sponsered by ICAR) Kharagpur, West Bengal, India.

2. Field preparation includes nursery raising which includes ploughing, disc harrowing, planing, seeding, fertilizer, and irrigation, and puddling, and transplanting. Transplanting is the largest user of human energy. Intercrop care includes weeding and plant protection.

3. a, based on 3 hp engine.
b, based on 13 hp engine.
c, based on 5 hp engine.

TABLE B.18

ENERGY REQUIREMENTS FOR WHEAT UNDER DIFFERENT LEVELS OF MECHANIZATION IN WEST BENGAL, INDIA

(Horesepower-hours per hectare)

Farm Operation	Bullock operated				Power Tiller(8hp)			Tractor(35hp)		
	Human	Bullock	Machine	Diesel litres/ha	Human Human	Machine	Diesel Litres/ha	Human	Machine	Diesel
Field Preparation[a]	8	68			5	95	50	1	347	44
Interculture[b]	9				9					
Fertilizer	2				2			2		
Irrigation	9		213	53	8	189	47	9	234	58
Harvesting	10				12			10		
Threshing	14	64			9	115	24*	3	258	30
Transport	5				2	5	2	1	1	1
Miscellaneous	3				3			3		
Total	60	132	213	53	49	404	99	40	840	133
Yield (Quintals/ha)	16.8				18.8			17.8		

1. Source: Department of Agricultural Engineering, Indian Institute of Technology, Annual Report (from April 1975 to March 1976) for The Coordinated Research Scheme on Energy Requirements in Intensive Agricultural Production (sponsored by ICAR) Kharapur, West Bengal, India

a. Field preperation includes sowing

b. Interculture includes plant protection

* Kwh/ha

almost the entire mechanical power used on the farms which is about 65% of the total. When a 8 horsepower power tiller is used for field preparation (which is defined to include nursery raising and transplantation) the machine power on these operations increases about 4 times to 204 hp-hrs. The total energy input under power tiller conditions is 1054 hp-hrs, about 40% higher as compared with bullock farms. In the case of tractor farms, energy input increases to 1265 hp-hrs, most of the increase being for machine power used in transplantation. One useful data that is available for these farms is regarding fuel consumption. Bullock farms use about 118 litres of diesel per hectare per year for irrigation pump of 5 hp capacity. When power tiller/tractor is added, the diesel consumption increases by about 50 litres per hectare, i.e., a total of diesel consumption of 150-160 litres per hectare. Thus, use of power tiller or tractor increases diesel consumption by about 40-50 percent only.

The data on wheat (HYV) show that energy input on bullock operated farms is 405 hp-hrs, on power tiller operated farms is 453 hp-hrs and on tractor farms is 880 hp-hrs. Mechanical power is used for irrigation on all farms, while power tiller and tractor are used for field preparation and threshing. In terms of diesel consumption, the figures are as follows: 18 litres/ha on bullock farms for irrigation to 99 litres/ha on farms using power tillers and 133 litres/ha on farms using tractors.

As was discussed earlier, conversion of animal power on the basis of "engineering equivalence" of 1.0 hp per pair of bullocks leads to an underestimation of the contribution of animal power. Hence, it may be useful to present data in terms of utilization time (hours per hectare) for various operations under different levels of mechanization. This data is given for wheat and maize for Punjab farms in Tables B.19-20. It may be noted that on bullock operated farms, 745

TABLE B.19

UTILIZATION TIME (hr/ha) OF DIFFERENT POWER SOURCES IN DIFFERENT OPERATIONS FOR RAISING WHEAT UNDER MAIZE-WHEAT ROTATION

Operation	Bullocks with improved implements				Tractor with matching implements			Tractor with implements of future		
	Man	Bullock	Tractor	Diesel Engine	Man	Tractor	Diesel Engine	Man	Tractor	Diesel Engine
1. Seedbed preparation	53	47	–	–	14	9	–	10	10	–
2. Sowing	20	30	–	–	7	2	–	4	4	–
3. Fertilizer application	7	–	–	–	–	–	–	–	–	–
4. Interculture	109	–	–	–	223	–	–	–	–	–
5. Irrigation	46	–	–	46	46	–	46	16	–	16
6. Chemical weed control	–	–	–	–	–	–	–	2	–	–
7. Harvesting	320	–	–	–	320	–	–	32	2	–
8. Threshing	100	–	7	–	234	10	–	–	–	–
9. Total	745	67	7	46	854	21	46	95	16	46

Source: "Energy Requirements of Intensive Agriculture", Report prepared for Indian Council of Agricultural Research, Government of India, by Punjab Agricultural University, Ludhiana, 1974-75

TABLE B. 20

UTILIZATION OF TIME(hr/ha) IN DIFFERENT POWER SOURCES IN DIFFERENT OPERATIONS FOR RAISING MAIZE UNDER MAIZE-WHEAT ROTATION

Operation	Bullocks with improved implements				Tractor with matching implements		
	Man	Bullock Pair	Tractor	Diesel Engine	Man	Tractor	Diesel Engine
1. Seedbed preparation	31	27	-	-	15	12	-
2. Planting	247	-	-	-	8	2	-
3. Fertilizer application	7	-	-	-	7	-	-
		-			741	-	-
4. Interculture	741	-	-	-	89	-	45
5. Irrigation	89	-	-	44			
6. Chemical weed control*							
7. Harvesting*							
8. Picking and threshing*							
9. TOTAL	1115	27	-	44	860	14	45

* Data for these operations could not be recorded due to the crop failure

Source: Energy Requirements of Intensive Agriculture, Report prepared for Indian Council of Agricultural Research, Government of India, by Punjab Agricultural University, Ludhiana, (1974-75)

man-hours are used per hectare for wheat as compared with 854 hours on tractor farms with matching (present) implements. As a considerable amount of labor input is still used for interculture, harvesting and threshing, a tractor with future (advanced) implements can eliminate the use of human labor for all these operations. However, in the transitional period, a tractor only replaces bullock labor and about 14 tractor-hours replace 67 bullock-pair-hours, giving a replacement ratio of 4.78. This is quite crucial since it shows that in the initial phase of tractorization, there is no net reduction in human labor (in fact, there is a marginal increase) since reduction in seedbed preparation and sowing is more than compensated by an increase in interculture and threshing. However, it must be emphasized that tractorization has the potential of reducing labor inputs to almost 10% of the present levels and hence can have significant implications for agricultural employment.

As has been discussed earlier, the method of "engineering equivalence" of animal power does not convey a correct picture of the level and pattern of energy-use at different levels of mechanization. For example, in the results presented by L.R. Singh and B. Singh (1979) for Nainital farmers (Table B.14) it is found that per hectare of operated area bullock farms use 1391 hp-hrs as compared with the tractor farms which use 3233 hp-hrs. On the basis of this data, it is concluded that energy use per hectare on tractor farms is more than double of that used on the bullock farms. However, it may be noted that this high level of energy use for land preparation on tractor farms (three times that on bullock farms) is mainly due to the method of comparison of bullock labor with tractor power. In bullock farms, 153 bullock pair-hours of work has been converted into 153 hp-hrs, while about 48 hours of work with a tractor (35 hp) is converted into 1642 hp-hrs. If "economic equivalence" in terms of work capacity or replacement ratio is taken,

This data indicates that a tractor should be considered as "equivalent" to 3.2 (153/48) pairs of bullocks and the work capacity of a pair of bullocks should not be treated as less than 10 horsepower. If such adjustments (or corrections) are made to the above data, the results with regard to share of bullock energy in total energy would be considerably affected. It should be recognized that the "economic equivalence" would depend on the quantity and quality of work that can be performed by mechanical or animal power in a given time frame. If ploughing of a hectare requires 60 to 75 hours (6 to 8 man/bullock days) and during this 6-day period a 35 HP tractor could plough 10 hectares (but actually ploughs 5 hectares due to smaller farm size), 5 pairs of bullocks would be required to do the equivalent work in the same time frame.*

* For details on this and other related issues, see Bhatia (1976).

(continued on next page)

B.3 ENERGY INPUTS and YIELDS UNDER NO-TILLAGE AGRICULTURE

Recently there has been considerable interest in the energy efficiency and economics of no-tillage agriculture. Since land preparation requires a substantial energy input in the form of animal power and/or fossil fuels for operating the machinery, higher energy costs have given a filip to such studies. We are presenting here, results of four papers by Ronald Phillips (1980), Ray Wijewardene (1978), D.J. Greenland (1975) and David Cole and David Vail (1980). The International Institute of Tropical Agriculture in Ibadan, Nigeria has been conducting studies on the applicability of no-tillage techniques for a range of soils and crops in West Africa. Results from South America and the Philippines and other parts of Asia also indicate that the no-tillage system may soon become more widely used in many parts of the world. In 1974, in the United States, the amount of cropland under no-tillage cultivation was 2.23 million hectares and it is estimated that 62 million hectares or 45 percent of total U.S. cropland will be under the no-tillage system by 2,000.

Based on the article by Phillips et al, conventional tillage is defined as moldboard plowing followed by disking one or more times while no-tillage system is defined as one in which the crop is planted either entirely without tillage or with just sufficient tillage to allow placement and coverage of the seed with soil to allow it to germinate and emerge. Usually, no further cultivation is done before harvesting. Weed and other competing vegetation are controlled by chemical herbicides. There are several advantages and disadvantages of no-tillage system with regard to soil erosion, efficient use of water and fertilizers, lower soil temperature, pollution from pesticides etc., we would here be concerned with mainly the energy requirements of the alternative systems. Table B.21 gives a comparison of energy consumption of two systems. Since plowing, disking and some trips over the field with machinery are eliminated with no tillage system, a

TABLE B.21

COMPARISON OF ENERGY CONSUMPTION FOR THE PRODUCTION OF CORN BY CONVENTIONAL TILLAGE AND NO-TILLAGE SYSTEM

(10^3 Kcal per hectare)

Input or Operation	Conventional Tillage	No-Tillage
1. Machinery	237	195
2. Fertilizers	2,149	2,149
3. Seed	64	73
4. Herbicides and Insecticides	56	82
5. Plow & Disk	317	-
6. Plant	83	83
7. Apply herbicides	17	17
8. Broadcast fertilizer	18	18
9. Harvesting, drying & transporting grain	1,776	1,776
TOTAL	4,716	4,392

For details on assumptions, see

Source: Ronald Phillips et al, No-Tillage Agriculture, Science, 208, June 6, 1980

TABLE B.21a

COMPARISON OF ENERGY CONSUMPTION FOR THE PRODUCTION OF CORN BY CONVENTIONAL TILLAGE AND NO-TILLAGE SYSTEM

Input or Operation	Kilograms of Oil Equivalent per Hectare* (KGOE/Ha) Conventional Tillage	No-Tillage
1. Machinery	23.0	19.0
2. Fertilizers	208.8	208.8
3. Seed	6.2	7.1
4. Herbicides and Insecticides	5.4	8.0
5. Plow & Disk	30.8	-
6. Plant	8.1	8.1
7. Apply herbicides	1.7	1.7
8. Broadcast fertilizer	1.7	1.7
9. Harvesting, drying & transporting grain	172.6	172.6
TOTAL	458.3	426.8

For details on assumptions, see

Source: Ronald Phillips et al, No-Tillage Agriculture, Science, 208, June 6, 1980

* 1 KGOE = 10.29×10^3 kcal.

considerable quantity of fuel is saved with this method. However, the requirements for additional herbicides in no-tillage system offset some of these gains. The elimination of plowing and disking and reduction in machinery manufacture results in an annual energy saving equivalent to about 36.6 litres of diesel fuel per hectare. The extra pesticides needed for the no-tillage system offset 2.65 litres of this saving. Additional seed, which is usually recommended for no-tillage agriculture, offsets another 1 litre per hectare. Thus, the energy saving for the no-tillage production of a hectare of corn is equivalent to about 33 litres of diesel fuel annually, compared to conventional tillage. This is about 7 percent less per year or in terms of total kilocalories, 4.392 million Kcal under no-tillage system as compared with 4.716 million Kcal under conventional tillage. It is estimated that for soyabean production there is a saving of 18 percent of energy in favour of no-tillage. Another result which is useful to note is that when no nitrogen fertilizer was applied, corn grain yields were higher (by about 15%) with conventional tillage than with the no-tillage system. However, yields were equal when nitrogen was applied at the rate of 84 Kgs/ha and application of 168 kg of N per hectare resulted in higher yields of corn with the no-tillage system than with conventional system. This is an important finding since in developing countries, lower dosages of nitrogenous fertilizers coupled with non-availability of herbicides in rural areas may offset the advantages of no-tillage system.

Ray Wijewardene (1978) reports results of research at International Institute of Tropical Agriculture, Nigeria, where he shows that maize yields are relatively higher under zero-tillage system and energy input is reduced from 235 X 10^6 J/ha in conventional tillage to 52 X 10^6 J/ha under zero-tillage. He has also discussed the need for developing appropriate tools (planters, sprayers etc.) which could be used by small farmers in the tropics.

David Cole and David Vail (1980) have presented a comparative analysis of no-tillage system and tractor tillage in the context of the Abyei project in Sudan. They have considered the system developed by IITA consisting of a rotary job planter and a controlled droplet, ultra low volume herbicide sprayer. Assuming that the technical problems relating to the performance of job planter in heavy clay soils and light weight spray equipment will not arise, they have simulated life time gorss margin from the no-tillage system. The results show that tractors generate a 20% higher gross margin than no-tillage system. However, no-till system requires about 40% of labor-days required under tractor tillage and hence gross margin per workday is about 100% higher in the no-till system. They have also referred to the problems of implementation involved in distribution, maintenance and storage of sprayers, batteries and herbicides. They recognize that a well organized extension education program for proper timing and applications procedures would be a key ingredient of the no-tillage technology.

Greenland (1975) has suggested potential farming systems for the small farmer in the lowland tropics which will be based on (i) zero tillage, and plant residue mulches (ii) mixed crops of high yielding varieties that are disease and pest resistant (iii) legumes with active nitrogen-fixing rhizobia to supply nitrogen and (iv) control of acidity by means of ash or mulches of deep-rooted species.

Thus, though the potential of no-tillage or minimum tillage is recognized, the realization of energy reduction would require effective weed control through improved herbicides and more efficient methods of application.

B.4 ENERGY AND BASIC FARMING SYSTEMS FOR A SMALL FARMER: A SYSTEMS VIEW

Ajay Sanghi and Melvin Blase (1976) has presented an interesting discussion of elementary farming systems for a small farmer in India. They have distinguished three Basic Systems, one with wheat-rice rotation, the second with wheat-rice rotation with lower rice yield and the third with wheat-maize rotation. (Table B.22). The elementary system has eight farm workers, two bullocks and four cows or buffalos on a 2-hectare farm. Their conclusions are: (i) An analysis of alternative farming systems for a small farm reveals that the energy requirements for field operations and irrigation, atleast for the crops not having heavy water requirements, can be met by the Basic System. The Basic System is able to supply the input requirements with the exception of chemical fertilizer and seed for a higher level of food production. The Basic System maximizes the use of the farm's biological energy resources and assures a small farmer a relatively high level of income with a minimum of risk and capital requirements; (ii) If a farmer can invest and add a tubewell to the Basic System, the rice yield can be increased by 30%, the net return would not be higher than in the Basic System. The tubewell irrigation is vulnerable from energy price fluctuations and particularly from power failure in India. Also, on social grounds, there does not seem to be any case to encourage a small farmer to own a tubewell. In the Basic System I, 7200 Kg of grain is produced using commercial energy of 0.996×10^6 Kcal, i.e., on an average 138.3 Kcal/kg of grain. The Basic System plus a tubewell can produce an additional 2400 Kg of grain by expending 1.179×10^6 Kcal of commercial energy with a high opportunity cost, i.e., on an average the additional 2400 Kg of rice is obtained at an energy cost of 491.2 Kcal/kg which is more than three-and-a-half times the calories required to produce 1 Kg of grain in Basic System I; (iii) Similar calculations can be done for introduction of a tractor but one thing which is sure is that the replacement of two bullocks by a tractor makes the small farmer vulnerable to fluctuations in the price of fossil fuels and tractor breakdowns as well as the mismanagement in the centralized distribution system of fossil fuels; (iv) Addition of a biogas (gobar gas) plant

TABLE B.22

COSTS AND RETURNS FROM ALTERNATIVE FARMING SYSTEMS

Farming system	Capital cost (Rs.)	Annual carrying cost (Rs.)	Gross income (Rs.)	Net income (Rs.)	Cost of Variable inputs dependent on commercial energy (Rs.)	Vulnerability Index (8)	Variable cost (8) Kcal X 10^6
Basic (wheat-rice rotation)	7,500	8,707 (1)	18,907 (2)	10,200	823	9.45%	0.996
Basic I (30 percent less rice yield) (3)	7,500	8,707 (1)	17,107 (2)	8,400	823	9.45%	0.996
Basic II (wheat-maize rotation)	7,500	8,707 (1)	19,906 (2)	11,199	823	9.45%	0.996
Gobar gas* (60 cu.ft. plant)	2,300	397 (4) (530)**	644 (5) (2,898)**	247 (2,368)**	0	0 %	0
Tube-well*	10,000	2,618 (6) (3,906)**	0	0	368	14%	1.179 (9)
Tractor*	15,000	6,032 (7)	0	0	1,820	30%	4.547 (10)

*Gobar gas plant, tube-well and tractor are not farming systems. However, they can be added to any one of the farming systems described above.

**Figures in parentheses give economic costs or benefits.

(1) Includes fertilizer requirement not met by dung.

(2) Includes inputed value of 400 miles of transportation assuming alternatively it can be satisfied by tractor at Rs. 4.55 per 5 miles.

(3) Assumes insufficient water delivered by the Persian wheel for summer rice which results in 30 percent decline in rice yield.

(4) 25 percent subsidy for a gobar gas plant is provided by the government. Therefore, to estimate the cost to the farmer, interest and depreciation costs are calculated on Rs. 1,725 of capital cost. This works out to Rs. 397.

(5) Dung from six cattle when digested in gobar gas plants yields 2.63 X 10^6 k.cal. of useful cooking heat. Assuming 95 percent efficiency of an electric stove 2.63 X 10^6 k.cal. of useful cooking heat is provided by 3,220 kwh of electricity. Assuming that the farmer has to pay Re. 0.20/kwh, the imputed value of bio-gas to the farmer is Rs. 644. As we have mentioned earlier, the economic cost of electricity is Re. 0.90/kwh. Therefore, the imputed economic value of bio-gas is equal to Rs. 2,898.

(6) Assumes maximum water requirement for crop, i.e., .86 m/ha for rice and .39 m/ha for wheat is met by tube-well irrigation. This implies 368 hours of tube-well operation in a year.

(7) Assumes tractor is used for 400 hours a year for field operations, threshing and 500 miles of transportation.

(8) Variable cost dependent on commercial energy divided by annual carrying cost.

(9) The energy consumption for irrigation from tube-well is estimated as 1840 hp-hrs which is equal to 1.179 X 10^6 Kcal.

(10) 400 litres of diesel is used in tractor, the energy value being 4.595 X 10^6 Kcal.

Source: Ajay Sanghi and Melvin G. Blase (1976), p.186-87

reduces the vulnerability of the small farmer by providing gas for irrigation, lighting and cooking based on farm resources. This also increases his net income by Rs. 247.

It may be noted, as in Bhatia (1976), that the conclusions of Sanghi and Blase paper crucially depend on the assumptions regarding additional yield from tubewell, social costs of electricity and the method of comparisons of net returns with and without tubewell. However, they have presented a very useful conceptual framework which takes a systems view and recognizes the role of agriculture both as a user of energy as well as source of energy.

B.5 ENERGY COSTS FOR VARIOUS AGRICULTURAL OPERATIONS:

Data on energy costs for various operations is available in two types of studies: (1) Energy input studies in which different forms of energy are valued at some designated prices (usually prevailing market prices) and energy costs for different operations are calculated. (ii) Fixed and variable costs of using bullocks, tractors, electric motors and diesel engines are estimated for some sample farms. Data from these two types of studies is presented below.

Table B.23 gives the data for various items based on input price averages prevailing in rural areas of Philippines. It may be noted that cost of inputs per hectare at market prices are highest under traditional system and decline as production is modernized. This is on account of relatively higher rates, (e.g., based on rental rate for animal power) used for human and animal power while fossil fuels are priced relatively low. If it is assumed that both human labor and animal power are available on the farm (either owned or used jointly) and the costs are excluded from the calculations, the remaining costs would show a steady increase from traditional to transitional and mechanical system.

TABLE B.23

COSTS OF INPUTS AT MARKET PRICES
FOR ALTERNATIVE RICE PRODUCTION SYSTEMS

($ per hectare)

ITEM	Unit Cost $	Traditional	Transitional	Mechanical
Seed	0.16/kg	8.00	8.00	8.00
Fertilizer	0.58/kgN	23.20	23.20	23.20
Insecticide	36/kg a.i.*	27.00	27.00	27.00
Herbicides	38/kg a.i.	26.60	26.60	26.60
Fuel	0.193/litre	0.38	6.04	15.42
Machinery (Fixed Component)		10.00	24.00	29.34
Animal Power	0.65.hour	68.25	25.35	0
Human Labor	0.17/hour	125.00	114.46	92.68
Total		288.43	254.65	222.24
Total (excluding human labor & animal power)		95.00	114.84	129.56

* a.i. - active ingredients

Notes: 1. Input prices are averages prevailing in rural areas of Philippines - U.S. $ = ₱ 7.35
2. Source: Kuether and Duff (1979) Table 9.

Another thing worth emphasizing here is that under transitional and mechanical systems, fuel costs account for only 3 to 7 percent of the total costs. Even when the cost of fertilizers is included, the share of these costs ranges between 12 to 17 percent. However, when the costs of human and animal labor are excluded from the total costs, the share of fuel and fertilizer costs ranges between 25 percent for traditional, 25.5 percent for transitional, and 30 percent for mechanical systems.

Table B.24 presents data on energy cost per hectare of operated area of sample farms in Nainital district of U.P., India. The following points seem important: On bullock farms, human energy accounts for about half the total costs while the shares of cost of bullock power and mechanical power are 15% and 29% respectively. In these farms, land preparation including sowing accounted for about one-third of total cost, the other major items being harvesting, threshing and irrigation, in that order. In tractor farms, the per-hectare costs are 24% higher than those in bullock farms. Even on tractor farms, human energy costs were 59 percent of the total, the share of mechanical power being 37 percent.

Table B.25 gives a comparative picture of the energy costs for three crops in U.P. The costs for sugarcane are about 50% higher, on average. The costs on tractor farms are about 5 to 8 percent higher than those on bullock farms. Costs of manual power are around 65 to 70 percent in the case of paddy and sugarcane while these are only 35-40 percent in the case of wheat. Mechanical power costs are relatively higher on wheat, on account of threshing and winnowing.

An idea of the relative costs of energy inputs to other costs and estimated value of output can be obtained from the second part of the table mentioned above.

TABLE B.24

ENERGY COST PER HECTARE OF OPERATED AREA
IN NAINITAL, U.P., INDIA

(Rupees per hectare)

Operations	Manual Power	Bullock Power	Mechanical Power	Total Cost	Gross Income (Rs.)	Cropping Intensity (%)
Bullock operated farms						
Land preparation	107.63	153.10	177.91	438.64	5,744.70	165
Sowing	94.09	16.47	31.74	142.30		
Fertilization and manuring	11.78	3.16	- -	14.94		
Irrigation	34.48	- -	133.66	168.14		
Plant protection measures	2.77	- -	- -	2.77		
Inter-culture	121.18	2.71	- -	123.89		
Other pre-harvesting operations	45.76	- -	- -	45.76		
Harvesting	220.21	- -	- -	220.21		
Transportation	57.16	18.96	- -	76.12		
Threshing and winnowing	84.56	22.93	69.61	177.10		
Total	799.62	217.33	412.92	1,409.87		
Tractor operated farms						
Land preparation	40.21	20.36	333.45	400.02	8,257.29	186
Sowing	155.57	4.55	23.62	183.74		
Fertilization and manuring	14.38	- -	- -	14.38		
Irrigation	50.38	- -	149.22	199.60		
Plant protection measures	1.77	- -	- -	1.77		
Inter-culture	252.93	0.26	- -	253.19		
Other pre-harvesting operations	59.93	- -	- -	59.93		
Harvesting	353.39	- -	- -	353.39		
Transportation	44.89	34.98	- -	79.87		
Threshing and winnowing	58.37	1.04	140.72	200.13		
Total	1,031.82	67.19	647.01	1,746.02		

Source: Singh and Singh (1976), p. 163.

TABLE B.25

Energy Costs Per Hectare for Different Crops (Irrigated) in Uttar Pradesh (India)
(Rs per hectare)*

	Paddy (HYV)		Wheat (HYV)		Sugarcane (Planted)	
	Bullock Farms	Tractor Farms	Bullock Farms	Tractor Farms	Bullock Farms	Tractor Farms
1. Manual Power	724	820	316	396	1122	1106
2. Bullock Power	155	16	98	8	210	204
3. Mechanical Power	243	148	494	573	242	398
4. TOTAL	1122	1184	908	977	1574	1708
5. Fertilizer Costs	472	871	609	881	414	575
6. Crop Yield (Quintals)	46.1	55.1	28.6	36.9	570	609
7. Value of Crop	3456	4133	3575	4613	5700	6090
8. Energy Costs as Percent of Value of Output	32.5	28.6	25.4	21.2	27.6	28.0

* 1 U.S. $ = Rs. 8

1. Source: L.R. Singh and B. Singh (1976) p. 160 - 169

2. Energy costs have been calculated on the following assumptions:

   One adult develops 0.1 horsepower (hp) and one pair of bullocks develops 1.0 hp. For mechanical power sources, their rated horsepower has been used. The cost of hired and family inputs has been calculated using prevailing rates, which on average, are Rs 5 per 8-hour day per adult; Rs 8 per bullock pair per 8-hour day.

3. Value of crop is estimated as follows: Rs 125/Q for Wheat, Rs 75/Q for Paddy, Rs 10/Q.

Energy costs are consistently higher than fertilizer costs in each crop, the difference being wider in the case of bullock operated farms, especially for sugarcane. Energy costs as percent of value of output range between 21.2 percent to 32.5 percent. Since mechanical power costs in paddy and sugarcane lie between 12 to 24 percent, this would indicate that costs of mechanical power, which are associated with out-of-pocket expenses, are not more than 6-7 percent of the value of output. Even in the case of wheat, mechanical power costs do not exceed 12-14 percent of the gross value of crop output. These figures are important when analyzing the impact of higher energy prices on energy costs, cropping pattern and yields.

The second type of data on costs of bullocks, tractors, electric motors and diesel engines is given in Tables B.26 to B.29. The following points are important: (a) In the case of bullock costs, feed and fodder costs are about 47 percent of the total costs of Rs. 1430 per pair on U.P. farms. Since a major share of fodder may be from crop residues, and livestock maintenance is by unskilled family labor the economic costs of raising and maintaining bullocks on the farm is very low. If it is assumed that all farmers raise their bullocks on the farm, the out-of-pocket expenses are only Rs. 152 (about 10% of the total) which is equivalent of Rs. 1.58 as compared with the market prices ranging between Rs 6-8 per day. (b) The average costs per tractor per annum is estimated (1975 prices) at Rs. 11373 which is about 10 times the cost of a pair of bullocks (after accounting for dung benefit). In terms of out-of-pocket expenses, tractor costs are about 75 times as compared with bullock costs. (c) Fuel and lubricant costs in tractors account for about 18.98 percent of the total costs and 36.6 percent of variable costs. This gives an average fuel cost of Rs. 5 per hour of

TABLE B.26

THE AVERAGE COST INCURRED PER PAIR
OF BULLOCKS ON THE SAMPLE FARMS

	Cost items	Rs. per annum	Rs. per working day*
1.	Depreciation on bullocks (12%)	133.82 (9.36)	1.40
2.	Interest on investment in bullocks (a) (11%)	122.66 (8.57)	1.28
3.	Depreciation on sheds, equipment and machinery	95.57 (6.69)	1.00
4.	Interest on investment in shed, equipment and machinery (11%)	35.50 (2.49)	0.37
5.	Miscellaneous expenditure	20.47 (1.43)	0.21
6.	Labour costs	348.39 (24.36)	3.64
7.	Feed and fodder costs	673.61 (47.10)	7.06
8.	Total costs	1,430.04 (100.00)	14.96
9.	Value of dung	69.39	0.73
10.	Net costs (8-9)	1,360.65	14.23
	'Out of pocket' expenses (i) Assuming all farmers purchase their bullocks (1+2+3+4+5)	408.02	4.27
	(ii) Assuming all farmers raise their bullocks on the farm itself (3+4+5)	151.54	1.58

Note: - Figures in parantheses indicate the percentages of the total cost.

*The average number of working days for bullock power was 95.58.

Source: D.K. Mishra, R.N. Pandey and V.K. Pandey: Economic Costs of Bullock and Tractor Power Use in Uttar Pradesh Agriculture; Indian Journal of Agricultural Economics, July - Sept. 1976, p.194

TABLE B.27

THE AVERAGE COST INCURRED PER TRACTOR PER ANNUM AND PER HOUR ON THE SAMPLE FARMS*

(Rupees)

Particulars	Total cost	%	Cost Rs/hr.
I. Fixed costs			
1. Depreciation on tractors (10%)	2,639.99	18.37	4.79
2. Depreciation on implements (10%)	259.15	1.80	0.47
3. Interest on investment (12%)	3,688.85	25.66	6.69
4. Depreciation on sheds	56.05	0.32	0.10
5. Insurance and taxes	279.33	1.94	0.50
6. Total fixed costs	6,923.37	48.17	12.56
II. Variable costs			
1. Fuel oil and lubricant charges	2,728.94	18.98	4.95
2. Repairs and maintenance costs	1,720.81	11.97	3.12
3. Driver's wages (Rs. 250/mo.	3,000.00	20.87	5.44
Total variable costs	7,449.75	51.83	13.51
III. Total costs	14,373.12	100.00	26.07
IV. Out of pocket expenses	11,373.12		20.63

*At the existing use pattern based on the sample farmers the average working hours per tractor per year was 551.27.

Source: D.K. Mishra, R.N. Pandey and V.K. Pandey: Economic Costs of Bullock and Tractor Power Use in Uttar Pradesh Agriculture, Indian Journal of Agricultural Economics, July - Sept. 1976, p.195

TABLE B.28

COST OF WATER FROM TUBE-WELLS

(Rupees/tube-well)

	Particulars	5 H.P. diesel	6.5 H.P. diesel	5 H.P. electric	7.5 H.P. electric
1.	Equipment	3,622	3,842	2,142	2,054
2.	Civil works				
	(a) Boring	1,522	1,234	1,725	1,767
	(b) Pump house	-	-	2,800	3,088
	(c) Security	-	-	432	500
	(d) Total	1,522	1,234	4,957	5,375
3.	Depreciation on (1) and (2) @ 10%	514	508	710	743
4.	Interest charges on (1) and (2) @ 10%	514	508	710	743
5.	Fixed energy charges @ Rs. 15/H.P. per month	-	-	900	1,350
6.	Total fixed costs	1,028	1,016	2,320	2,836
7.	Repairs and maintenance	19	-	-	-
8.	Energy Charges				
	(a) Diesel/electric	189	217	-	-
	(b) Mobil oil	87	93	-	-
9.	Total variable costs (7) + (8)	295	310	-	-
10.	Total cost (6) + (9)	1,323	1,326	2,320	2,836
13.	Number of running hours in the year (hours)	145	154	301	338
14.	Delivery capacity (cusecs)	0.71	0.72	0.71	0.75
15.	Total water delivered (cusecs)	102.95	110.88	213.71	253.50
16.	Cost of water (Rs. per cusec)	12.85	11.95	10.85	11.18

Source: T.V. Moorti and K.K. Verma (1976) p.209

TABLE B.29

OPERATING COSTS OF ELECTRIC AND DIESEL TUBE-WELLS

(Rs. / year)

Particulars	Electric Tube-well		Electrified Dug-cum-bore wells		Diesel dug-cum-bore wells	
	Per pump (37 HP)	%	Per pump (11 HP)	%	Per pump (9 HP)	%
A. Fixed cost:						
Depreciation	6,298		1,051		871	
Interest	12,391		1,750		1,290	
Others	854		340		-	
Total (A)	19,543	62.6	3,141	56.7	2,161	44.7
B. Variable cost:						
Power/fuel	8,062	25.8	1,548	27.9	1,170	24.2
Oil	-	-	-	-	525	10.9
Repairs	1,378	4.4	562		469	9.7
Labour	2,225	7.2	292		510	10.5
Total (B)	11,665	37.4	2,402	43.3	2,674	55.3
Total Operating cost (A+B)	31,210	100	5,543	100	4,835	100

Notes: 1. Figures in parentheses indicate the percentages to the total operating cost.

2. Source: M.R. Patel and S.B. Singh (1976)

tractor use. When farmers use tractors for more than 551 hours per year (as used by sample farmers) and the price of diesel etc. goes up, the fuel costs would increase. If a farmer owns and drives his own tractor and if interest and depreciation charges are ignored, fuel costs would form more than half of the out-of-pocket expenses and this share will go up with increase in fuel prices. (d) For electric motor used for irrigation, fixed energy charges account for 39 to 47 percent of total costs depending on the size of the motor. For diesel engines, energy costs of diesel and lubricating oils are about 22 percent of the total costs. In another set of data (for Gujarat) presented in Table B.29 , fuel costs account for 26-28 percent in electric tubewells and 35 percent in diesel dug-cum-bore wells. If these ratios are applied to the estimated annual cost of irrigation in Table B.30, the fuel costs would be 4 to 6 percent of net additional income from irrigation using electric motors. In the case of diesel engine the ratio is between 9 to 16 percent of the net additional income depending on the farm size. Even in the smallest case of a 2-acre farm, fuel costs do not exceed 16 percent of the additional net income obtained from irrigation provided by the diesel engine. This indicates the available margin in net additional income from irrigation in the context of increasing fuel prices. Another set of data for U.P. indicates that the net returns from a private tubewell are Rs. 1660 per hectare as compared with the irrigation costs of Rs. 123 per hectare. Even if fuel costs account for half the irrigation costs, there is enough margin to absorb higher energy costs.

TABLE B.30

ESTIMATED RETURNS TO IRRIGATION ON SMALL FARMS

	2-acre farm		5-acre farm	
	Oil Pump	Electric Pump	Oil Pump	Electric Pump
	rupees			
Additional net income from irrigation	2,134	2,134	3,639	3,639
Annual cost of irrigation	975	475	975	475
Interest on additional cash expense (Rs. 412 at maximum rate of 24%)	99	99	-	-
Interest on additional cash expense (Rs. 634 at maximum rate of 24%)	-	-	152	152
Net returns to oil pump irrigation (Rs. 9,000 investment)	1,060	-	2,513	-
Net returns to electric pump irrigation (Rs. 6,000 investment)	-	1,560	-	3,012
	percent			
Percentage return	12	26	27	50

Source: V.P. Shukla (1971), p.64

APPENDIX C

ENERGY AND AGRICULTURE: SOME ESTIMATES AT NATIONAL, REGIONAL AND VILLAGE LEVELS

In this Appendix, an attempt is made to

(i) present estimates of energy use in agriculture as well as contribution of agriculture to energy needs of other sectors at national, regional and village levels;

(ii) to discuss the conceptual and data problems of estimating energy inputs into agriculture, the alternative methods of aggregation of energy available in different forms and estimating energy contents of various crop and animal residues.

India has been selected for this Appendix as a case study, although data from other countries have also been utilized, because:

(i) India is a major developing country which accounts for around one-fourth of the total energy consumption of around 90 oil importing developing countries in the world*;

(ii) Agriculture in India still accounts for about one-half of the national income and over three quarters of the work force is engaged in agriculture. There have been significant increases in energy intensiveness of agriculture in some regions of the country in an attempt to raise agricultural productivity and hence, an analysis of this data can provide rough order of magnitude of energy use for increased agricultural output;

(iii) There are simultaneously available farming systems in the country which can represent traditional, transitional, mechanized, irrigated, semi-arid tropics and dry farming. Besides, being a large sub-continent, all the major crops are grown in the country.

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* As per the U.N. statistics on World Energy Supplies 1973-78, Series J, No. 22, 1979, India's total energy consumption was 114 million tons of coal equivalent (mtce) as compared with 586 mtce for 95 oil importing developing countries in Asia, Africa and Latin America. India was the largest single energy consumer in this group, followed by Brazil, Korea, Argentina and Thailand.

(iv) There are a number of studies done by individual scholars, academic and government institutions which present data at national/regional/farm levels. Such data is very difficult to get for any other country in published sources.

It is expected that the following discusion would throw considerable light on both conceptual and data problems to provide useful insights into the relevant issues and could be used for collecting similar information for other countries.

C.1 ENERGY AND AGRICULTURE IN INDIA

Table C.1 presents a comparison of different estimates of commercial energy use in Indian agriculture. Basically, the difference is estimates are due to coverage and the method of conversion of oil products into common unit of measurement. Pimentel and Beyer (1976) alone present a comprehensive picture of energy-use by taking into account both the 'direct' and 'indirect' energy inputs. The estimates by Bhatia (1977) also incorporate electricity, naphtha and fuel oil used for manufacturing fertilizers but ignore fossil fuels used in pesticides and machinery. All studies, except that by Bhatia, convert different forms of energy into kilocalories. In the paper by Bhatia, the contribution of electricity and oil products has been expressed in terms of million tons of coal replacement (mtcr) which reflects the fact that oil has much better efficiency of utilization than coal and about 8 to 9 tons of coal may be required to replace one ton of oil (see Appendix A).

Contribution of Animal Power: There are three ways in which energy contribution of draft power has been estimated. The first method used by Revelle (1976) and adopted by Pimentel and Beyer (1978) is to estimate energy input for draft animals. Revelle, first estimated the energy consumed annually in feed by the bullock itself, minus the energy in its dung, divided by the number of hours worked. This gave a figure of 5.3×10^3 kcal per hour. Assuming that a fully employed bullock, like a human being, utilizes about 43 percent of the energy it consumes in work, this gives an estimate of 2.3×10^3 kcal per hour. Further, he assumed that an average bullock worked for 1200 hours per year and 83 percent of work by 70.4 million bullocks was carried out in rural areas and about 82 to 85 percent of the work

TABLE C.1

COMMERCIAL ENERGY USE IN INDIAN AGRICULTURE:
A COMPARISON OF DIFFERENT ESTIMATES

	Bhatia (1977) for 1970-71				Revelle (1976) for 1970-71	Pimentel & Beyer (1976) for 1972	Desai (1980) for 1974, estimates for final energy	
	Original Units							
	Bn kwh	Mn Tons	MTCR*	10^{12} Kcal	10^{12} Kcal	10^{12} Kcal	KTJ (10^{15} J)	10^{12} Kcal
Direct								
Electricity for Irrigation	4.51		4.5	3.9	15.0	4.3	27.7	6.6
Diesel for Irrigation		0.42	3.8	4.5	**	8.9		
Diesel for Draft Power (tractors)		0.19	1.7	2.0			41.7	10.1
Sub-total				10.4	15.0	13.2		16.7
Indirect								
Electricity for Fertilizer	4.45		4.5	3.9	**			
Naphtha, natural gas, and fuel oils for fertilizers		0.89	3.7	9.6	43.0	32.1		
Fossil fuels in pesticides						0.8		
Fossil fuels in machinery						3.6		
Sub-total				13.5	43.0	36.5		
Direct and Indirect								
Electricity			9.0	7.8	15.0	4.3		
Fossil fuels			9.2	16.1	43.0	45.4		
Total			18.2	23.9	58.0	49.7		16.7

* MTCR: Million Tons of Coal Replacement.
** Included elsewhere in the table.

Notes:
1. Sources: Bhatia (1977), Desai (1980), Pimental & Beyer((1978).
2. Assuming 1 Bn kwh = 0.86 x 10^{12}Kcal; energy in diesel oil 10.81 x 10^{6} Kcal/ton and Kcal= 4.1868 kJ(10^{3}J).
3. Desai's estimates of useful energy have been converted into final energy for the sake of comparison, using the following utilization efficiencies from his Table XII.1. Oil for motive power in agriculture 0.15, oil for traction in agriculture 0.2, electricity for motive power in agriculture 0.65.
4. Estimated consumption of diesel oil for irrigation by Pimentel and Beyer is an overestimate since the total diesel consumption of agriculture was only 0.45mn tons as compared with a figure of 0.825 used by them. Similarly, the estimate of energy consumed in fertilizer manufacture is much higher than the actual energy inputs of naphtha, natural gas, fuel oil and electricity obtained directly from energy statistics. This figure alone is responsible for the discrepancy in estimates by Bhatia and Pimentel.

TABLE C.12

COMMERCIAL ENERGY USE IN INDIAN AGRICULTURE:
A COMPARISON OF DIFFERENT ESTIMATES

	Bhatia (1977) for 1970-71				Revelle (1976) for 1970-71	Pimentel & Beyer (1976) for 1972	Desai (1980) for 1974, estimates for final energy	
	Original Units							
	Bn kwh	Mn Tons	MTCR*	MTOE	MTOE	MTOE	KTJ (10^{15}J)	MTOE
Direct								
Electricity for Irrigation	4.51		4.5	.38	1.46	.42	27.7	.64
Diesel for Irrigation		0.42	3.8	.43	**	.86		
Diesel for Draft Power (tractors)		0.19	1.7	.19			41.7	.98
Sub-total				1.01	1.46	1.28		1.62
Indirect								
Electricity for Fertilizer	4.45		4.5	.38	**			
Naphtha, natural gas, and fuel oils for fertilizers		0.89	3.7	.93	4.18	3.12		
Fossil fuels in pesticides						.08		
Fossil fuels in machinery						.35		
Sub-total				1.31	4.18	3.55		
Direct and Indirect								
Electricity			9.0	.76	1.46	.42		
Fossil fuels			9.2	1.56	4.18	.44		
Total			18.2	2.32	5.64	4.83		1.62

* MTCR: Million Tons of Coal Replacement.
** Included elsewhere in the table.

Notes:
1. Sources: Bhatia (1977), Desai (1980), Pimental & Beyer (1978).
2. Assuming 1 Bn kwh = 0.86 x 10^{12}Kcal; energy in diesel oil 10.81 x 10^{6} Kcal/ton and Kcal= 4.1868 kJ(10^{3}J).
3. Desai's estimates of useful energy have been converted into final energy for the sake of comparison, using the following utilization efficiencies from his Table XII.1. Oil for motive power in agriculture 0.15, oil for traction in agriculture 0.2, electricity for motive power in agriculture 0.65.
4. Estimated consumption of diesel oil for irrigation by Pimentel and Beyer is an overestimate since the total diesel consumption of agriculture was only 0.45mn tons as compared with a figure of 0.825 used by them. Similarly, the estimate of energy consumed in fertilizer manufacture is much higher than the actual energy inputs of naphtha, natural gas, fuel oil and electricity obtained directly from energy statistics. This figure alone is responsible for the discrepancy in estimates by Bhatia and Pimentel.
5. 1 MTOE (million tons of oil equivalent) = 10.29 X 10^{6} kcal.

of bullocks was used directly in agriculture, the estimate of energy input in agriculture was 136 X 10^{12} kcal, (Table C.2). Pimentel and Beyer think that this approach is not appropriate because livestock must still be fed, and are a cost to the farmer, whether they are working or not. They suggest that since most of the feed comes from by-products and "free" pastures, most of the feed is "free" and hence total food energy utilized by draft animals should not be included. Hence, their estimates include only those feeds which could be used directly for human consumption, and those feeds grown as fodder on land which could have been use for other crops. This feed, whose use competes with human consumption is estimated to represent about 15% of the feed energy consumed. Using these

assumptions, the estimate of energy input in draft animals is given as follows: total food energy input into male bovines: 549X10^{12} kcal; total energy in food potentially useful to man (excludes by-products and grazing) but consumed by male bovines: 83.3X10^{12} kcal. To this should be the estimated 8.2X10^{12} kcal of human labor used for livestock maintenance. Of this total, it has been estimated that 73 percent of draft power was used in agriculture and the rest in transportation, i.e. 66.8X10^{12} kcal was used in agriculture. It may be noted that, though conceptually a better approach, this method can present considerable data difficulties in allocating feed which is of direct benefit to male or female bovines or other animals. Since potentially a major portion of these by-products from crops could be

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* It may be pointed out that the draft output was estimated as equivalent of 22.4X10^{12} kcal on the basis of an assumed work output of 300 kwh (400 hr-hrs) per year.

TABLE C.2

ANIMAL POWER INTO INDIAN AGRICULTURE:
A COMPARISON OF FOUR ESTIMATES

	Energy Input (10^{12} Kcal)	Final Energy (10^{12} kcal)	Useful Energy (10^{12} kcal)	Diesel Equivalent	
				10^{12} kcal	Million tons o Coal Replaceme
1. Revelle (1976) Study	136				
2. Pimental and Beyer (1978)					
- Total food Energy input	549				
- Total energy useable by humans (excludes by-Products and Grazing)	66.8				
3. Desai (1980)					
- Energy in food Consumed	1023.5				
- Final energy Assuming ratio of work capacity to food intake is 10 percent		102.4			
- Useful energy Output			39.5		
4. Bhatia (1977)				69.5	63.9

Source: See text

TABLE C.2 a

ANIMAL POWER INTO INDIAN AGRICULTURE:
A COMPARISON OF FOUR ESTIMATES

(Million Tons of Oil Equivalent)*

	Energy Input	Final Energy	Useful Energy	Useful Energy
1. Revelle (1976) Study	13.22			
2. Pimental and Beyer (1978)				
- Total food Energy input	53.35			
- Total energy Useable by humans (excludes by-Products and Grazing)	6.49			
3. Desai (1980)				
- Energy in food Consumed	99.47			
- Final energy Assuming ratio of work capacity to food intake is 10 percent		9.95		
- Useful energy Output			3.84	
4. Bhatia (1977)				6.75

Source: See text

*1 MTOE (million tons of oil equivalent) = 10.29×10^{12} kcal.

either burnt to provide heat or used for thatching of roofs or making other items or could be ploughed back into the fields, it would be difficult to assume these as "free". The minimum adjustment required would be to include the potential heat content of plant residues in the absence of which dungcakes may have to be burnt. Besides, if potential of pasture land for fuelwood plantations is considered, the estimate of energy input into agriculture in the form of work animals would have to be modified considerably.

The second method which is invariably used in the farm level energy use studies conducted by agricultural universities and has also been adopted by Desai (1980) is to estimate the work output of draft animals in terms of horsepower. Using this approach, Desai accepts a range of 0.5 to 0.7 hp (horsepower) draft power per bullock used in ploughing or in Persian wheels. Taking a National Sample Survey estimate that 43 percent of bullock's days or 157 days (8-hr day) a year are utilized in work, he estimates the range from 628 horsepower hours (hp-hrs) to 880 hp-hrs or an equivalent of 1687-2383 MJ (10^6 Joules) for the annual work done by animals. He adopts a round figure which, for 82.7 million working animals in 1972, gives an estimate of 165.4 KTJ (10^{15}J) as the useful energy* output by animals. This is to be compared with the estimate of 429 KTJ of final energy assuming that work capacity of animals is 10 percent of feed intake (equivalent of 4285 KTJ of final energy). These estimates when converted into kilocalories, give figures of $39.5X10^{12}$ kcal of useful energy and $1023.5X10^{12}$ kcal of primary energy. These estimates when contrasted with figures given by

* Desai has used the concepts of primary energy, final energy and useful energy as follows: Primary Fnergy is energy in natural forms extracted by producing industries and would exclude thermal electricity and oil products since coal, oil or crude oil used to produce them would have been included. Final energy is the sum of energy finally consumed in the economy and takes into account the transformation and distribution losses in producing energy. Primary and final energy are calculated in terms of the capacity of energy forms. The energy capacity of fossil fuels can be measured by burning them in a calorimeter and measuring the heat generated. There are difficulties in estimating work capacities of nuclear power, animal or human energy. Useful energy is the defined as heat or work actually used in consuming industries. The way to estimate it would be to estimate the efficiencies of utilization of each energy form in each use and weight the energy capacity of each form by its efficiency when aggregated. (See Appendix A).

Pimental and Beyer indicate that although Desai's estimates of food intake are about twice as high, the estimated useful energy provided by animals is only one-half. This comparison shows the significance of the method used for estimating energy equivalent of the work of animals. Desai (1976, 1980) feels that it is the "energy equivalent of the work done by them that mattered and not the energy required to support them". Pimentel and Beyer and Revelle, however, feel that "for a comparison with other power sources, an estimage of energy input is desirable". One thing, however, can be said: if the constribution of mechanical power is estimated in terms of horsepower-hours, the consistent procedure for work animals would be to estimate their contribution in horsepower-hours. However, if in the case of mechanical power, it is the energy equivalent of inputs (electricity, diesels, etc.) to operate these mechanical equipment is used, the consistent procedure would be to estimate the energy input into work animals, corrected for the energy input 'embodied' in the stock of bullocks.

The third method has been used by Bhatia (1977) in which the contribution of animal power has been estimated in terms of diesel equivalents, i.e., the quantities of high speed diesel and light diesel oil that would be required if all the bullocks were replaced by tractors and diesel engines for providing draft power and lift irrigation. It has been argued that the energy contribution of bullocks is not the same as energy input of feed utilized by them for work. Instead, their contribution to the energy budget should be estimated as the amount of fossil fuels (say, diesel) which would be required in the absence of animal power, i.e., the additional energy which would be required if tractors and diesel engines were employed to perform the same work that is currently being done by animals.

For estimating the contribution of bullocks in terms of diesel saved, it is necessary to estimate the number of pairs of bullocks which would be replaced by a tractor. Here, it is important not to use the "engineering equivalence" which assumes that a pair of bullocks develops one horsepower and hence, a tractor of 35 horsepower is "equivalent" to 35 pairs of bullocks. If "economic equivalence" in terms of work performance or replacement ratios is considered,

the equivalent number of bullocks would be much less. The equivalent work performance is difficult to estimate since it would depend on the type of implements used by the bullocks, the type of soil and the cropping pattern. On the basis of various estimates avialable in the literature, it has been to assume that, on the average, one tractor would replace 6 pairs of bullocks. Assuming an average consumption of 1464 litres of diesel oil (@ 3 litres per hour for 538 hours per year), the diesel oil equivalent of 35.2 million pairs of bullocks was estimated as 7.1 million tons. Taking a coal replacement figure of 9 tons of coal per ton of high speed diesel, the contribution of animal power was estimated as 63.94 million tons of coal replacement*. This would be an equivalent of 320×10^{12} kcal assuming that a ton of coal (Indian) is equivalent of 20.934 GJ(10^9 J) and one kcal is equal to 4.1868 KJ (10^3 J). If, however, 7.1 million tons of diesel is directly converted into kilocalories, the energy equivalent of animal power would be 69.5×10^{12} kcal assuming 41×10^9 J per ton of diesel oil. The various estimates of animal power into the agricultural sector are summarized in Table C.2.

* It is estimated that 9 tons of coal are required to replace one ton of diesel in railways since per engine-kilometer, steam engines consumed around 9 times the energy sonsumed by diesel locomotives. For a detailed discussion on coal replacement conversion factors, see Report of the Fuel Policy Committee, Government of India, 1974 and Appendix A.

Agriculture as a Source of Energy: The role of agriculture as a source of energy has not been recognized explicitly. As we have seen in the discussion earlier, agriculture contributes valuable by-products in the form of crop residues which are directly used as sources of energy for cooking, lighting or local industry or are used as animal feed. These animals, in turn, provide* draft power for crop production and animal residues which are used as manure or burnt as fuel. Apart from by-products, some varieties of fuelwood are specially grown by farmers, generally on field boundaries. Besides, low quality agricultural land is used as pasture land to provide animal feed and can be used to grow fuelwood. In this section, we attempt to provide some data on availability of crop residues. animal residues and their energy content for different crop systems. Most of the discussion here is based on the work of Desai (1980) Pimentel and Beyer (1976) and Tyers (1978) at aggregate level. It may be mentioned that these crop and animal residues have alternative uses and the pattern of present uses may be determined by a complex nutritional, economic, social, technological and historic factors. Similarly, the extent of useful energy available form these resources depends on availability of technology and socio-economic factors which will be discussed at length in later sections.

Crop Residues: Availability and Use: Table C.3 presents data on availability of by-products from different crops from various sources. It can be seen that there are wide differences between sources and between different crop varieties. Some of these differences are due to, (a) method of data collection, (b) variety of crop, (c) moisture content of crop residues/grain at the time of weighing and, (d) the coverage of data source (e.g., one village, number of villages, average for the country, etc.). It may be mentioned that there is need for obtaining better estimates of availability and use of crop residues at village, regional and national levels. The importance of this can be seen from the fact that for a given level of grain output of 120.6 million tons in 1973-74, in India, Desai (1980) estimated an average straw output of 218.4 million tons. In addition, he estimated that perhaps in 1973-74, Indian agriculture produced about 40 million

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* It must be emphasized that milch animals provide milk which is more valuable than its energy content. Milk contains valuable proteins, fat and amino acids especially lysine which is deficit in foodgrains and is an essential nutrient for vegetarians.

TABLE C.3

ESTIMATES OF STRAW-GRAIN RATIOS FROM DIFFERENT SOURCES

CROP	ICAR (1977) (India)	NCA (1972) (India)	BRISCOE (1979) (Bangladesh)		TYERS (1978) Bangladesh		SMIL (1978) Egypt
			Tradi- tional	Modern	Trad.	Modern	
Rice*	1.50	1.2	4.78***		4.5	1.0	1.2 (dry)
Wheat	1.48	1.2					1.2 (dry)
Jowar	2.26	1.97					
ajra	2.19	1.97					
arley	1.58	1.97					
Maize (corn)	2.08	1.97					1.2 (dry)
Ragi	1.85	1.97					
Millets	2.10	1.97					1.2 (dry)
Gram	1.98						
Groundnut	3.55	0.55					
otton	7.55						3.0 (dry)
Jute	1.37		2.4		2.0	-	
Tapioca**	2.0						
Sugarcane**	0.22 (dry)						
Pulses		0.50					

Notes: 1. *In the case of rice, about 30% of grain output is also available as husks.
**Estimates from outside, not from ICAR.

2. Sources, ICAR - Indian Council of Agricultural Research, All India Coordinated Agronomic Research Project, Annual Report 1974-75 as quoted in Desai (1980)
NCA - National Commission on Agriculture, Report, Part VII, p.392

3. Straw includes jute sticks, cotton sticks which are used as fuel in the estimates of ICAR.

4. ***Briscoe's estimates are: Amon Paddy 4.12 kg Nara per kg paddy, Amon Kher 0.66 kg per kg paddy. 80% Kher is used as fodder. Aus Kher 1.5 kg/kg.

tons of biomass consisting of 12 million tons of tapioca sticks for fuel, 15 million tons of sugarcae tops for fodder and 12 million tons of green fodder. Table C.4 gives one of the detailed available estimates by Desai (1980) regarding biomass yield and its utilization in India in 1973-74

Table C. 4 shows that besides food, milk and tobacco, etc., the agricultural sector (broadly defined to include forests and pastures) provided about 399 million tons of biomass in the form of concentrates, dry fodder and green fodder, 131 million tons of biomass as domestic fuel, 32 million tons as industrial fuel and raw materials and 15 million tons as timber. Even if farm and plantations alone are considered, agriculture provided 426 million tons of biomass which was 3 times the quantity of foodgrains and industrial raw materials produced in that year. Thus, alongwith food, milk and industrial raw materials, agriculture provided around 74 million tons of industiral fuel for non-agricultural uses.

Animal Residues: Availability and Use: The availability of dung depends on the size of the animal and quantity and quality of feed. Since dung is produced as a by-product of fodder intake by animals, it may be easier to express dung availability as a raio of fodder consumption. After a careful analysis of data from West Bengal, Punjab and U.P., India, Deasi (1980) has suggested a dry-weight ratio of 0.30, i.e. a ton of fodder (dry-weight) would produce 1.5 tons of dung (wet-weight) or 0.3 tons of dung (dry-weight). The data on Punjab and U.P. show that dung collected (dry-weight) ranges between 1.54 to 1.66 per kg per day, giving an annual estimate of around 600 kgs. These are average figures for cows, bullocks, buffalos and young cattle. Data from a village in U.P. reported in Bhatia and Niamir gives estimated dung outturn of kg for large animals and the estimates for large animals reported by Tyers (1978) for Bangladesh are 900 kg/head/year and for Nepal are 910 kg/head/year reported in Asian Society

TABLE C.4

BIOMASS YIELD AND UTILIZATION IN INDIA: 1973-74

	Forests and Waste land	Pastures & Fallow	Farms & Plantations	Total	Animal Residues
Reporting Area (Mn ha)	128	34	168	330	
Yields (t/ha)	1.67	1.67	2.6	2.14	
No. of Animals (Mn)					
- cattle					130.9
- youngstock					47.5
Output or Offtake (Mn tons)					
Food, drink, tobacco			112	112	
Concentrates			17	17	
Dry Fodder			207	207	
Green Fodder	100	55	20	175	
Domestic Fuel	93		38	131	
Industrial Fuel (Bagasse)			30	30	
Industrial Raw Material			2	2	
Timber	15			15	
TOTAL	208	55	426	689	
Utilization of Animal Residues (Mn tons)					
Manure					71.0
Domestic Fuel					36.0
Waste (not collected)					12.0
TOTAL					119.0

1. Source: Desai (1980)
2. Total fodder intake of grazed and stalled animals is 399 million tons, 30% of which is supply of dung, thus giving a figure of 119 million tons. The overall collection efficiency of dung is assumed as 90%. For details see Desai (1980) p.44-61
3. All estimates are on dry-weight basis.

(1976). The corresponding figures for medium animals (goats, sheep, young stock) are around 400-600 kgs/head/year.

Using Desai's (1980) estimates, Table C.4 presents a figure of 119 million tons to animal residues (30% of 399 mn tons of fodder) on dry-weight basis, out of which 71 million tons was used as manure and 36 million tons was burnt as domestic fuel.

Data availability on energy content of crop and animal residues is not very good. The available data, presented in Table C.5 has to be taken as showing only "order of magnitude" figures as discussed in detail in Bhatia (1977 b) and Harrington (1977).

Energy and Agriculture in India: A Systems View

The most comphrehensve treatment of agriculture as a user and a source of energy is available from the paper by Pimentel and Beyer (1976). As is shown in Figure 2 and Table C.6, agriculture produced 1017 X 10^{12} Kcal of energy in terms of food output and crop residues. Out of this, an equivalent of 150 X 10^{12} Kcal of food and 586 X 10^{12} Kcal of crop residue w used within agricu re as animal feed. In addition, animals also obtain feed equivalent of 228 X 10^{12} Kcal from pastures. These animals provided both milk and draft power. Although milk is more valuable to human beings as a valuable source of protein and micro-nutrients, its equivalent energy can be estimated at 19 X 10^{12} Kcal. The draft animals provide animal power for field preparation and irrigation, etc. which is estimated at equivalent of 67 X 10^{12} Kcal. Besides milk and draft power, animals also provide cattle dung which was used as fuel and as manure for fertilization. The energy equivalent figures for cooking fuel were 223 X 10^{12} Kcal and 201 X 10^{12} Kcal as manures. Thus, a part of the total energy produced by agriculture was consumed within agriculture, while a part was available for outside use as food,

TABLE C.5

Gross Energy and Useful Energy (at current use patterns) for crop residues, cattle dung and fuelwood

Crop Residues of:	Gross Energy (Kcal/kg)	Efficiency of Current Use (%)	Useful Energy Kcal/kg
RICE			
Straw	3000 - 3800	17%	510-646
Husks	3000	17%	
Wheat	3800	17%	646
Millets	3800	17%	646
Jute Sticks	3000	11%	330
Bajasse	1780	20%	356
Animal Residues			
Cattle Dung Cakes (dry)	2440 - 3300	11.2%	268- 363
Fuel Wood	4702	13.7%	644

Source: Bhatia and Niamir (1979), Tyers (1978) Harrington

TABLE C.6

ENERGY AND AGRICULTURE IN INDIA: 1972

(10^{12} Kcal per year)

	Total Availability	Used within Agriculture	Net Available from Agriculture	Sub-Totals	Totals
I. Agriculture as a Source of Energy					
A. Crop Production					
1. Food Production				351	1017
a. For people			201		
b. Animal Feed		150			
1) for milk animals	67				
2) for draft animals	83				
2. Crop Residues				666	
a. Household fuel			80		
b. Animal feed		586			
1) for milk animals	242				
2) for draft animals	344				
B. Animal Produced Energy					643
1. Milk			19		
2. Draft Power		67			
3. Residues				557	
a. Household fuel			223		
b. Fertilizers		201			
c. Other - including waste	133				
C. Total					1660
D. Total Produced by Agriculture (not reused within)			313		

TABLE C.6 (continued)

(10^{12} Kcal per year)

II. Agriculture as a User of Energy	Components	From within Agricultural Sector	Net into Agricultural Sector from Outside	Subtotals	Totals
A. Crop Production					378
1. Irrigation				28	
a. Electricity			11		
1) from fossil fuels	9				
2) from hydro	2				
3) nuclear	.1				
b. Fossil fuels			9		
c. Draft animals		7			
d. Human labor			1		
2. Fertilization				244	
a. Animal residues		201			
b. Chemical Fertilizer (fossil fuels)			43		
3. Field Preparation				105	
a. Draft animals		60			
b. Human labor			41		
c. Machine (fossil fuels)			4		
1) fuel	3.3				
2) manufacture	.7				
4. Pesticides (fossil fuels)			1	1	
a. Insecticides	.8				
b. Herbicides	.04				
c. Fungicides	.24				
5. Harvesting					
6. Agroprocessing					
B. Livestock Maintenance					981
1. Draft Animals				549	
a. Human labor			8		

TABLE C.6 (continued)

(10^{12} Kcal per year)

	Components	From within Agricultural Sector	Net Into Agricultural Sector from Outside	Subtotals	Totals
b. Feed		541			
1) food which could be eaten by humans	83				
2) crop residues	344				
3) Pastures	114				
2. Milk Animals				432	
a. Human labor			9		
b. Feed		423			
1) Food (which could be eaten by humans)	67				
2) Crop residues	242				
3) Pastures	114				
C. Total Used					1359
D. Total from Outside Agricultural Sector - includes labor but not pastures			127		
E. Total from within		1231			
F. Net into Agriculture from Outside - not including human labor			69		
III. Net Energy Available from Agriculture		ID - IID			+396
Net Energy Available (excluding food and milk)					

TABLE C.6a

ENERGY AND AGRICULTURE IN INDIA: 1972

(Million Tons of Oil Equivalent/yea

	Total Availability	Used within Agriculture	Net Available from Agriculture	Sub-Totals	Totals
I. Agriculture as a Source of Energy					
A. Crop Production					
1. Food Production				34.1	98.83
a. For people			19.53		
b. Animal Feed		14.58			
1) for milk animals	6.51				
2) for draft animals	8.07				
2. Crop Residues				64.72	
a. Household fuel			7.77		
b. Animal feed		56.95			
1) for milk animals	23.5				
2) for draft animals	33.43				
B. Animal Produced Energy					62.49
1. Milk			18.47		
2. Draft Power		6.51			
3. Residues				54.13	
a. Household fuel			21.67		
b. Fertilizers		19.53			
c. Other - including waste	12.93				
C. Total					161.32
D. Total Produced by Agriculture (not reused within)			50.83		

TABLE C.6$_A$ (continued)

(MTOE/year)

Components	From within Agricultural Sector	Net into Agricultural Sector from Outside	Subtotals	Totals
II. Agriculture as a User of Energy				
A. Crop Production				36.73
1. Irrigation			2.72	
a. Electricity		1.07		
1) from fossil fuels	.87			
2) from hydro	.19			
3) nuclear	.01			
b. Fossil fuels		.87		
c. Draft animals	.68			
d. Human labor		.1		
2. Fertilization			23.71	
a. Animal residues	19.53			
b. Chemical Fertilizer (fossil fuels)		4.18		
3. Field Preparation			10.20	
a. Draft animals	5.83			
b. Human labor		3.98		
c. Machine (fossil fuels)		.39		
1) fuel	.32			
2) manufacture	.07			
4. Pesticides (fossil fuels)		.1	.1	
a. Insecticides	.08			
b. Herbicides	.004			
c. Fungicides	.023			
5. Harvesting				
6. Agroprocessing				
B. Livestock Maintenance				95.33
1. Draft Animals			53.35	
a. Human labor		.78		

TABLE C.6a (continued)

(MTOE/year)

Components	From within Agricultural Sector	Net Into Agricultural Sector from Outside	Subtotals	Totals
b. Feed	52.58			
1) food which could be eaten by humans	8.07			
2) crop residues	33.43			
3) Pastures	11.08			
2. Milk Animals			41.98	
a. Human labor		.87		
b. Feed	41.11			
1) Food (which could be eaten by humans)	6.51			
2) Crop residues	23.5			
3) Pastures	11.08			
C. Total Used				132.07
D. Total from Outside Agricultural Sector - includes labor but not pastures		12.34		
E. Total from within	119.63			
F. Net into Agriculture from Outside - not including human labor		6.71		
III. Net Energy Available from Agriculture I.D - II.D				38.48
Net Energy Available (excluding food and milk)				

milk and cooking fuel. The energy equivalent for these outputs from agriculture also used fossil fuels, electricity and human labor from outside (equivalent of 127×10^{12} Kcal), the net energy available from the agricultural sector in India in 1972 was of the order of 396×10^{12} Kcal. Even if milk and food are excluded from the calculations, agriculture provided a net energy of 176×10^{12} Kcal to non-agricultural sector, mainly as cooking fuel. This shows that if a comprehensive view of agriculture as a user and source of energy is taken, the net energy contribution of agriculture is positive*.

* However, it must be emphasized that these calculations are in terms of gross energy inputs fo fossil fuels, dungcakes, etc. If current estimates of efficiency of utilization of different forms of energy is taken into account, the results will change as follows: Useful energy in fossil fuels and electricity @ 20% is equal to 13.6×10^{12} Kcal. Useful energy in dungcakes @ 11.2% is equal to 40×10^{12} Kcal, thus narrowing up the gap.

C.2 ENERGY AND AGRICULTURE IN BANGLADESH

Rodney Tyers (1978) has presented an excellent methodology and analysis of interactions of agriculture and rural energy economy of Bangladesh. As indicated in the Table C.7, 92% of all energy is drawn from indigeeous sources, including human and animal labor, cattledung and crop residues. It may be noted that a total energy equivalent of 146 X 10^{12} Kcal of crop residues are produced about 62% of which are used as cattle feed, 31% for cooking and about 7% for food processing These crop residues alongwith other fodder produce animal labor equivalent of 25.4 X 10^{12} Kcal and cattle dung equivalent of 31.8 X 10^{12} Kcal. Only 13.9 X 10^{12} Kcal of energy is used in the form of kerosene, diesel fuel and chemical fertilizers. Thus, from an energy standpoint, rural Bangladesh is "an almost closed ecosystem in which energy derived by people and animals from the photosythetic products of plants is used to grow and prepare food, which in turn provides an essential energy input to grow more food and so on in an endless cycle", Revelle (1977).

Tyers has used a dynamic model to project the supply of fuels as agriculture output increases in future in Bangladesh. He finds that when the supply of foodgrains is assumed to grow at 4.4% per annum between 1974075 and 1989-90, the corresponding projection for supply of fuels shows that fuels grow at 3.3% per annum. This is on account of following reasons: (a) the ratio of straw to grain by weight is lower in the improved grain varieties on which depends the increase in food productivity through tecnological progress, (b) with the area under jute declining owing to slack export demand, the availability of jute sticks as fuel grows more slowly. Thus, he finds that there will be a growing gap between the supply of traditional fuels and projected levels of demand which may have to be met through commercial fuels and chemical fertilizers.

Table C.7

Energy Sources and Uses in Rural Bangladesh, 1974-75[1]

	1 Agriculture	2 Food processing	3 Cook-ing	4 Light-ing	5 Paper pottery bricks	6 Trans-port	Total	%
Indigenous sources (10^{12} kcal.)								
Human labor[2]	9.3	1.2	4.9	–	0.14	1.4	17.0	12
Animal labor	21.3	–	–	–	–	4.1	25.4	17
Homestead wood & forest scraps	–	0.1	3.2	–	–	–	3.3	2
Cattle dung[3]	9.5	–	22.3	–	–	–	31.8	22
Crop residues	90.3[4]	10.6	45.2	–	–	–	55.8	38
Commercial sources (10^{12} kcal.)								
Cut firewood[6]	–	0.1	2.4	–	0.5	–	3.1	2
Kerosene, diesel fuel	0.33	0.24	0.5	5.0	0.73	–	6.8	5
Artificial fertilizer and pesticides	4.1	–	–	–	–	–	4.1	2
Total from traditional fuels (10^{12} kcal.)	9.5	10.7	70.7	–	–	–	90.9	62
Total from indigenous sources (10^{12} kcal.)	30.6	11.9	75.6	–	0.14	5.5	133.4	92

Table C.7 (cont'd.)

	1 Agriculture	2 Food processing	3 Cook-ing	4 Light-ing	5 Paper pottery bricks	6 Trans-port	Total	%
Total from commercial sources (10^{12} kcal.)	4.4	0.34	2.9	5.0	1.23	-	13.9	8
Total energy use (10^{12} kcal.)	44.5	12.2	78.5	5.0	1.37	5.5	147.2	100
Per capita daily use (10^{3} kcal.)	1.71	.47	3.02	.19	.05	.21	5.7	
Percent	30	8	53	3	1	4	100	

[1]The content of this table is drawn principally from Tyers, 1976, Energy in Rural Bangladesh (90)

[2]The estimates for energy in human and animal labor are based on the work of Revelle (1976) on rural India, assuming work energy per capita and per animal to be the same in Bangladesh.

[3]The allocation of dung between use as fertilizer and as dung is here drawn from the results of the MEM for 1974-75. It is reported by Smith (1975,) that less than half the dung available is used as fuel, however the model results indicate this portion to be about two thirds. This result is used here. Note also that the energy value of the dung applied as fertilizer is added into the agriculture column.

[4]Crop residues not directly burned as fuel are not added into this row or column, since they are generally fed to animals and thus already counted as work energy or the energy value

Notes to Table C.7 (cont'd.)

of dung used as fertilizer.

[5]Commercial sources do not include electricity. Although there is some rural electrification, the energy used in this form is estimated to be less than 0.01×10^{12} kcal. per year, based on the results of the Bangladesh Energy Study (1976).

[6]Cut firewood and combustible waste are estimated to be available from forested regions in quantities up to 16.6×10^{12} kcal. Based purely on roundwood yields, the Energy Study estimates the sustained availability from commercial forests at 1.8×10^{12} kcal., with 5.5×10^{12} kcal. in smaller wood.

TABLE C.7a

ENERGY SOURCES AND USES IN RURAL BANGLADESH, 1974-75[1]

	Million Tons of Oil Equivalent*/Year							
	1 Agriculture	2 Food Processing	3 Cooking	4 lighting	5 Paper Pottery Bricks	6 Transport	Total	%
Indigenous Sources	MTOE							
MTOE								
Human Labor[2]	.90	.12	.48	-	.01	.14	1.65	12
Animal Labor	2.07	-	-	-	-	.40	2.47	17
Homstead wood and Forest Scraps	-	.01	.31	-	-	-	.32	2
Cattle Dung[3]	.92	-	2.17	-	-	-	3.09	22
Crop Residues	8.78	1.03	4.39	-	-	-	5.42	
Commercial Sources								
MTOE								
Cut Firewood[6]	-	.01	.23	-	.05	-	.30	2
Kerosene, Diesel Fuel	.032	.02	.05	.49	.07	-	.66	5
Artificial Fertilizer and Pesticides	.4	-	-	-	-	-	.40	2
Total From Traditional Fuels (MTOE)	.92	1.04	6.87	-	-	-	8.83	62
Total From Indigenous Sources (MTOE)	2.98	1.16	7.35	-	.01	.05	12.96	92
Total From Commercial Sources (MTOE)	.43	.03	.28	.49	.12	-	1.35	8

Table C.7.4 (continued)

	1 Agriculture	2 Food Processing	Cooking	Lighting	Paper Pottery Bricks	Transport	Total	%
Total Energy Use MTOE*	4.32	1.18	7.63	.49	.13	.53	14.3	100
Per Capita Daily Use KGOE**	.17	.05	.29	.02	.005	.02	.55	
Percent	30	8	53	3	1	4	100	

[1]The content of this table is drawn principally from Tyers, 1976, Energy in Rural Bangladesh (90)

[2]The estimates for energy in human and animal labor are based on the work of Revelle (1976) on rural India, assuming work energy per capita and per animal to be the same in Bangladesh.

[3]The allocation of dung between use as fertilizer and as dung is here drawn from the results of the MEM for 1974-75. It is reported by Smith (1975) that less than half the dung available is used as fuel, however, the model results indicate this portion to be about two thirds. This result is used here. Note also that the energy value of the dung applied as fertilizer is added into the agriculture column.

[4]Crop residues not directly burned as fuel are not added into this row or column, since they are generally fed to animals and thus already counted as work energy or the energy value of dung used as fertilizer.

[5]Commercial sources do not include electricity. Although there is some rural electrification, the energy used in this form is estimated to be less than 0.01×10^{12} kcal per year, based on the results of the Bangladesh Energy Study (1976).

[6]Cut firewood and combustible waste are estimated to be available from forested regions in quantities up to 16.6×10^{12} kcal. Based purely on roundwood yields, the Energy Study estimates the sustained availability from commercial forests at 1.8×10^{12} kcal, with 5.5×10^{12} kcal in smaller wood.

* MTOE (million tons of oil equivalent) = 10.29×10^{12} kcals.

**KGOE (kilogram of oil equivalent) = 10.29×10^{3} kcals.

C.3 ENERGY CONSUMPTION AND AGRICULTURAL DEVELOPMENT IN TWO ADVANCED STATES OF INDIA

R.N. Senapati (1976) has presented an interesting analysis of the relationship of energy consumption and agricultural development in two advanced states, i.e., the Punjab and Haryana* in northern India. Table C.8 presents the changes in energy consumption in the two States over 1961-62, 1966-67 and 1972-73. To ensure comparability in the use of different sources of energy, energy inputs by different forms (electricity, diesel, draft power, etc.) have been converted into a common unit of million tons of coal replacement**. During the period of 1961-62 to 1966-67, energy consumption rose by 26%, while in 1972-73, the energy consumption was 16.1 mtcr which is more than twice the level attained in 1966-67. This shows that agriculture in Punjab and Haryana became more energy-intensive during the years 1966-67 and 1972-73.

As regards the relative share of different sources of energy in the total energy consumption, we observe that in 1961-62, draft power in the form of bullock labor accounted for 91% of the total energy consumption and it has declined over the years. In 1966-67, it is 74% of the total consumption, while in 1972-73, it has been reduced to only 39% pf the total consumption. This significant trand of decline in relative terms indicates the growing level of mechanization in Punjab and Haryana. But an important fact to be borne in mind is that the energy available from bullock labor has increased in absolute terms over the years, though not substantially. Then the additional requirements of draft power have been met by tractorization. The diesel oil consumption by tractors constituted only 2% of the total consumption of energy in 1961-62, while it has increased to 4% in 1966-67 and in 1972-73, it has reached 9%. As regards the consumption of electricity in 1961-62, its percentage to total consumption was 2. In 1966-67, it came to 3%, but om 1972-73, it has increased upto 7% of the total consumption. This shows the increasing use of electric pumpsets for irrigation purposes. The consumption of

* These two States produced a large share of wheat output and contribute significant quantities of marketed surplus in wheat and rice.

** This measurement has been used by the Fuel Policy Committee of India in their report available in 1974. This concept denotes useful energy by taking into account the higher efficiency figures of oil products as compared with coal. Thus, one million tons of high speed diesel oil and light diesel oil = 9 million tons of coal replacement (mtcr), 10^9 Kwh electricity = 1 mtcr, 1 million tons

TABLE C.8

TOTAL CONSUMPTION OF ENERGY IN AGRICULTURE IN PUNJAB AND HARYANA

(million tonnes of coal replacement-mtcr)

Energy input	1961-62	1966-67	1972-73
1. Electricity	.100	.257	1.12
	(2)	(3)	(7)
2. Diesel for oil engines	.110	.396	3.78
	(2)	(5)	(23)
3. Energy input for fertilizer production	.197	1.078	3.45
	(3)	(14)	(22)
4. Diesel equivalent of animal power	5.717	5.896	6.30
	(91)	(74)	(39)
5. Diesel for tractors	.169	.332	1.44
	(2)	(4)	(9)
6. Total energy consumption	6.293	7.959	16.09
	(100)	(100)	(100)
Indices of total energy consumption	100	126	255.73

Notes: -Figures in brackets indicate the percentage of that particular energy to the total consumption in that year.
One Million tonnes of high speed diesel oil and light diesel oil = 9 mtcr; 10^9 kwh electricity = 1 mtcr; 1 million tons of naphtha = 8.3 mtcr; 1.25 tons of naphtha is used as feedstock to produce one ton of nitrogen.

Source: R.N. Senapati (1976) p.176

TABLE C.8a

TOTAL CONSUMPTION OF ENERGY IN AGRICULTURE
IN PUNJAB AND HARYANA

(Tons of Oil Equivalent)

	1961 - 62		1966 - 67		1972 - 73	
Energy Input		%		%		%
Electricity	8358	2	21479	2	93605	5
Diesel for Oil Engines	12222	2	44000	5	42000	23
Energy Input for Fertilizer Production	23735	4	129880	14	415660	23
Diesel Equivalent of Animal Power	635220	90	655110	74	700000	39
Diesel for Tractors	18778	2	36889	5	160000	10
Total Energy Consumption	698313	100	887358	100	1789265	100
Indices of Total Consumption	100		127		256	

Notes:

Source: Senapati (1976) p. 176.

The original figures in MTCR (Million Tons of Coal Replacement) have been converted into TOE using the following assumptions:

1 TOE = 12000 Kwh
1 ton of diesel = 9 MTCR
and
1 ton of naphtha = 8.3 MTCR

diesel oil by oil engines has been marked by a sharp increase over the years. In 1961-62, its share in total consumption was only 2%, while its share increased upto 5% in 1966-67 and 1972-73, it jumped upto 23%. This fact is also supported by the substantial rise in the number of oil engines, i.e., 45.66% rate of growth (average annual compound) from 1966-67 to 1972-73. The phenomenal rise in the use of electricity and diesel oil demonstrates that mechnanized pumping has bee adopted on a massive scale in Punjab and Haryana between 1966-67 and 1972-73. Fertilizer consumption has also registered an increase over the years. Its relative share in 1961-62 in the total consumption of energy was 3% and it went up to 14% in 1966-67. In 1972-73, its share in the total consumption of energy is 22%.

In order to study the relationship between the changes in different forms of energy consumption and changes that have occurred in cropping intensity, yield and production, indices for the above items have been computed, taking base year 1961-62 as 100. One can note from the table (C.9) that the index for cropping intensity went up to 106 in 1966-67, while it increased again to 115.9 in 1972-73. Similarly in the case of yield, the index went upto 111.6 and in 1972-73, it reached 159.8. As regards production, it is 125.8 in 1966-67 while it went upto 186.5 As regards different forms of energy, draft power increased upto 105.8 in 1966-67 and again it increased upto 131.5. In the case of irrigation, the increase is really tremendous. Compared to 1961-62, it is 311 in 1966-67 and in 1972-73, it is 2333. As regards fertilizer, it is 547 in 1966-67 and 1949 in 1972-73. These indices indicate strongly that after 1966-67, the new agricultural strategy was heavily oriented towards more intensive efforts at irrigation and fertilizers. When the indices of total energy consumption and indices of croppping intensity, yield and production in different years are analyzed, one finds that compared to 1961-62, 26% increase in total consumption of energy in 1966-67 is associated with an increase in cropping in-

TABLE C.9

INDEX NUMBERS OF YIELD, CROPPING INTENSITY AND AGRICULTURAL PRODUCTION, Total Energy Consumption in Punjab and Haryana

(Base 1961-62 = 100)

Item	1961-62	1966-67	1972-73
Cropping intensity	100	106.0	115.9
Yield	100	111.6	159.8
Production	100	125.8	186.5
Total energy consumption	100	126.0	255.73
- Draft power	100	105.8	131.5
- Irrigation	100	310.7	2333.67
- Fertilizer	100	546.66	1749.64

Source: Statistical Abstracts of Punjab and Haryana, Senapati (1976).

tensity. But when we compare 1966-67 with 1972-73, we notice that the total energy consumption has increased by more than 100% while cropping intensity has increased by 9.34%, yield has increased by 43% and production has increased by 48%. However, this shows that between the years 1966-67 and 1972-73, more and more energy inputs have been applied to increase yield and production. Since agricultural production is a function of so many variables, it is difficult to single out the effects of energy inputs on total production yield. But one fact becomes eminently clear that the intensity of energy inputs has increased over the years.

C.4 ENERGY USE AT THE VILLAGE LEVEL:

In this section, we will present data on energy use in three villages based on comprehensive surveys involving researcher participation over a long period and data were collected by actual measurements rather than using the interview method, alone. The first study is based on the detailed survey of Pura village in Tumkur district of Kanataka state in South India. The second study is for Ulipur village in Bangladesh and the third is Pangama village in Nepal. In the first study conducted by the scientists of India Institute of Sciences, data on energy use in Pura have been collected for all the rural activities through repeated interviews. The Bangladesh study has used the method of participant observation in which the author himself stayed in the village for over eight months and data is based on actual observations and measurement.

Energy Use in Pura, South India*:

The energy activities in Pura are:** (a) agricultural operations (with ragi and rice as the main crops), (b) domestic activities, viz., grazing of livestock, cooking, gathering firewood and fetching water for domestic use including drinking, (c) lighting and (d) industry (pottery, flour mill and coffee shop). These activities are achieved with the following direct sources of energy: human beings, bullocks, firewood, kerosene and electricity.

An aggregate matrix showing how the various energy sources are distributed over the various energy-utilizing activities is presented in Table C.10 in the units appropriate to the sources.

Nothwithstanding the methodological and conceptual problems in converting the various sources to a common energy unit (e.g., kilocalories), there are three advantages in doing so: (i) an idea can be obtained of the relative contributions of

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* From Amulya K.N. Reddy and D.K. Subramaniam (1979), The Design of Rural Energy Centers, Proceedings of the Indian Academy of Sciences, September 1979.

** Transport is added in agriculture as the only vehicles in Pura are bullock cart which are used for transportin manure and farm produce.

TABLE C.10

ENERGY SOURCES AND ACTIVITIES IN PURA VILLAGE

	Agriculture	Domestic	Lighting	Industry	Total
Human hours	34848	255506	-	20730	311084
(Man hours)	(19914)	(82376)	-	(16485)	(118775)
(Woman hours)	(14934)	(113928)	-	(4245)	133107
(Child hours)	-	(29202)	-	-	(59202)
Bullock hours	5392	-	-	-	5392
Firewood hours (kgs)	-	207807	-	8930	216737
Kerosene (litres)	-	-	1938	156	2094
Electricity (kWh)	7264	-	3078	820	11162

* Transport has been included in agriculture because the only vehicles in Pura are bullock carts and these are used almost solely for agriculture-related activities such as carrying manure from backyard compost pits to the farms and produce from farms to households.

Source: Amulya K.N. Reddy and D.K. Subramaniam (1979)

of the various sources to the total energy consumption (ii) a summation over all sources contributing to a particular activity leads to the total magnitude of energy it now utilizes (iii) the total magnitudes of energy for the various activities facilitates a ranking of these magnitudes. Using the following conversion factors: 250 Kcal/man hour, 200 Kcal/woman hour, 120 Kcal/child hour, 2300 Kcal/bullock hour, 3800 Kcal/kg firewood, 860.4 Kcal/kWh electricity, and 8980 Kcal/litre kerosene, a source-activity matrix for Pura village has been obtained (Table C.11).

The matrix yields the following ranking of sources (in order of percentage of annual requirement): (a) firewood 89% (b) human energy 7% (c) kerosene 2% (d) bullock energy 1% (c) electricity 1%. The ranking of activities is as follows: (a) domestic activities 91% (b) industry 4% (c) agriculture 3% (d) lighting 2%.

Human energy is distributed thus: domestic activities 80% (grazing livestock 37%, cooking 19%, gathering firewood 14%, fetching water 10%), agriculture 12%, and industry 8%. Bullock energy is used wholly for agriculture including transport/ Firewood is used to the extent of 96% (cooking 82% and heating bath water 14%) in the domestic sector, and 4% in industry. Kerosene is used predominantly for lighting (93%) and to a small extent in industry (7%). Electricity flows to agriculture (65%), lighting (28%) and industry (7%).

There are several features of the pattern of energy consumption in Pura which must be highlighted.

(i) What is conventionally referred to as commercial energy, i.e., kerosene and electricity in the case of Pura, accounts for a mere 3% of the inanimate energy used in the village, the remaining 97% coming from firewood.* Further, firewood is

* Pura uses about 217 tons of firewood per year, i.e., about 0.6 tons/day for the village, or 0.6 tons/year/capita. The village has a population of 357 in 56 households in September 1977.

TABLE C.11

ENERGY SOURCE-ACTIVITY MATRIX (X 10^6Kcals/year) IN PURA VILLAGE

	Agriculture	Domestic	Lighting	Industry	Total
Human	7.97	50.78	-	4.97	63.72
(Man)	(4.98)	(20.59)	-	(4.12)	(29.69)
(Woman)	(2.99)	(22.79)	-	(0.85)	(26.63)
(Child)	-	(7.40)	-	-	(7.40)
Bullock	12.40	-	-	-	12.40
Firewood	-	789.66	-	33.93	823.59
Kerosene	-	-	17.40	1.40	18.80
Electricity	6.25	-	2.65	0.71	9.61
Total	26.62	840.44	20.05	41.01	928.12

Total energy = 928 X 10^6 Kcal/year; = 1/079 X 10^6 kWht/year; = 2955 kWht/day; = 8.28 lWht /day/capita

Source: Amulya K.N. Reddy & D.K. Subramaniam (1979)

TABLE C.11 a

ENERGY SOURCE-ACTIVITY MATRIX (TONS OF OIL* Equivalent/Year) IN PURA VILLAGE

	Agriculture	Domestic	Lighting	Industry	Total
Human	.8	4.93	-	.48	6.19
(Man)	.48	2.00	-	.4	2.89
(Woman)	.29	2.2	-	.08	2.59
(Child)	-	.72	-	-	.72
Bullock	1.21	-	-	-	1.21
Firewood	-	76.7	-	3.3	80.04
Kerosene	-	-	1.69	.136	18.27
Electricity	.61	-	.26	.07	.93
Total	2.55	81.68	1.95	3.99	90.19

Total energy = 928 X 10^6 Kcal/year; = 1/079 X 10^6 kWht/year; = 2955 kWht/day; = 8.28 lWht /day/capita.

Source: Amulya K.N. Reddy & D.K. Subramaniam (1979).

* TOE = 10.29 X 10^6 kcal.

viewed as a non-commercial source since only about 4% of the total firewood requirement of Pura is purchased as a commodity, the remainder being gathered at zero private cost.

(ii) Animate sources, viz, human beings and bullocks, only account for about 8% of the total energy, but the real significance of this contribution is revealed by the fact that these animate sources represent 77% of the energy used in Pura's agriculture. In fact, this percentage would have been much higher were it not for the operation of four electrical pumpsets in Pura which account for 23% of the total agricultural energy.

(iii) Virtually all of Pura's energy consumption comes from traditional renewable sources - thus agriculture is largely based on human beings and bullocks, and domestic cooking (which utilizes about 80% of the total inanimate energy) is based entirely on firewood*.

(iv) However, the environmental soundness of this pattern of dependence on renewable resources is achieved at an exhorbinant price: levels of agricultural productivity are very low, and large amounts of human energy are spent on firewood gathering for the average, about 2.6 hr and 4.8 km per day per family to collect about 10 kg of firewood).

(v) Fetching water for domestic consumption also utilizes a great deal of human energy (an average of 1.5 hr and 1.6 km per day per household) to achieve an extremely low per capita water consumption of 17 litres per day.

(vi) 46% of the human energy is spent on grazing livestock (5.8 hr/day/household) which is a crucial source of supplementary household income.

(vii) Children contirbute a crucial 30%, 20% and 34% of the labor for gathering firewood, fetching water and grazing livestock, respectively. Their labor contri-

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* Unlike some rural areas of India, dungcakes are not used as cooking fuel in the Pura region. In situations where agro-wastes (e.g., coconut husk) are not abundant, it appears that, if firewood is available within some convenient range (determined by the capacity of head-load transportation), dungcakes are never burnt as fuel; instead dung is used as manure.

butions are vital to the survival of families, a point often ignored by population and education planners.

(viii) Only 25% of the houses in the 'electrified' village of Pura have acquired domestic connections for electric lighting, the remaining 75% of the houses depend on kerosene lamps, and, of these lamps, 78% are of the open-wick type.

(ix) A very small amount of electricity, viz., 30 Kwh/day, flows into Pura, and even this is distributed in a highly inegalitarian way - 65% of this electricity goes to the 4 irrigation pumpsets of 3 landowners, 28% to illuminate 14 out of 56 houses, and the remaining 7% for one flour-mill owner.

It may be noted that the energy use in agriculture is dominated by human and animal labor and the only mechanization in the agricultural sector is the operation of four electric pumpsets for irrigation. It may be mentioned that there is not sufficient data to assess the role of agriculture as a producer of energy since details about production and use of crop residues is not available. It is not clear how much of the "firewood" used for cooking includes crop residues and other agricultural wastes. In an earlier version of this study, it was pointed out that 5656 hours (about one-third of total man-hours used in agriculture) were spent on irrigation, while only 16 bullock hours were spent on irrigation. It is not clear as to what the sources of irrigation were in this case. It was estimated that about 80% of bullock hours were spent on ploughing and harrowing and about 5% on transport. A total of 7264 Kwh of electricity was used for pumping for irrigation. The electricity consumption in agriculture is equivalent to running four 3.75 Kw pumpsets for about 1.3 hours per day, which is a very low utilization factor.

Energy Use at Ulipur, Bangladesh: This unique study by John Briscoe (1979) was conducted using the method of participant observation in which the author stayed in the village for one year. The study population consisted of 8 Hindu fishing families and 40 families of Muslim agriculturists of Jelepara and Ali Sardar Somaj in Comilla district in Bangladesh. The study included 330 people, 48 cattle and 43 acres of land. The study throws a great deal of light on ownership of energy producing assests and the processes of generation and use of energy by various households of different economic status/occupation. We will only summarize a few important observations of this study as these relate to the role of agriculture as a user and source of energy.

Table C.12 shows that as much as 54% of the total annual use of fuel in Ulipur comes from crop residues. Of the annual fuel use of 1615 X 10^3 Kcals/person/year, Amon nara* contributed as much as 633 X 10^3 Kcals (38.3%). The other major crop residues are Kher* from Amon, Aus and Boro paddy, jute sticks, etc. Doinshah, which is a leguminous plant which is sown on small ridges separating individual plots, contributes about 5% of the total energy. Shares of firewood are: from village trees 11%, from the river 4.4% and purchased from the market 5.2%.

From the viewpoint of the agricultural sector, one of the most important contributions of thestudy is to highlight the complex system of alternative uses of crop and animal residues and the pattern of their present and future uses. Each crop produces several products, each of which can be used for several purposes. For example, deep water Amon paddy produces leaves which are usually used for fodder but sometimes for fuel; grain which is used for grain, but can also be used as animal feed; rice husk which is usually used for fuel but sometimes for fodder, Kher, the upper, tender, straw, which is usually used for fodder but sometimes also used for fuel or a a compost; and nara, the lower coarse straw which is usually used for fuel but is also used for compost and occasionally for

* Amon, Aus and Boro are different names for paddy, depending on season and duration of crop. Nara is the tough straw which remains in the field after paddy is harvested. Kher is the more tender straw which is carried from the field with the harvested paddy and which remains after the threshing of grain. Yield of nara is 4.12 Kg per Kg of Amon paddy. Yield of Kher is 0.66 per Kg of Amon paddy, 0.86 Kg per Kg of Aus paddy and 1.5 Kg per Kg of Boro paddy.

TABLE C.12a

ENERGY USE IN ULIPUR, BANGLADESH

		(Tons of Oil Equivalent/year)*
A.	ENERGY USE INTO AGRICULTURE	
	Seeds	1.07
	Chemical Fertilizers**	.47
	Manures	4.52
	Human Labor***	7.15
	Animal Labor***	1.30
	Total	14.51
B.	NET ENERGY OUTPUT FROM AGRICULTURE	
	Foodgrains	8.05
	Milk	.087
	Meat	.04
	Construction (Animal Residues)	.23
	Fuels	
	- Animal Residues 1.48	
	- Crop Residues 28.59	
	- Doinsha 2.59	
	32.66	
		32.66
	Total	41.07
C.	TOTAL FUELS USED IN THE VILLAGE (includes Fuelwood)	52.96

Source: J. Briscoe (1979)

* 1 TOE (1 ton of oil equivalent) = 10.29×10^6 kcal.

** Chemical fertilizers are the only energy inputs from outside the agricultural sector.

*** These figures are for energy expended in useful work. The useful work output is estimated at 25% of these energy inputs.

construction and animal fodder. Jute sticks (materials left after the fibrous cash crop is removed) are used as construction material and as fuel.

In the study population, there were 10 bullocks and other cattle who consumed energy equivalent of 10,589 Kcals per day on average. The shares of different items were Kher* 50%, water hyacinth 30%, paddy weed 18% and paddy leaves 2%. It was assumed that all 10 bullocks are working animals and 20 cows work half as much as bullocks, thus giving estimates of 12,000 "bullock hours" (4 hours a day for 150 days). His estimates show that the total expenditure of work in animal labor was equivalent to 13.4×10^6 Kcals per year. The useful work output of cattle is assumed at 25% of the energy intake and estimated at 3.35×10^6 Kcals. Land preparation accounts for 83% of this work output, the rest going to threshing. In the case of human labor, 73.6×10^6 Kcals are expended in useful work, of which 25%, 18.4×10^6 Kcal is assumed as useful output. Besides work output, cattle also produce dung which is used as fuel or fertilizers. The energy equivalent output of dung is as follows: in 10^6 Kcals, 15.2 as fuel, 46.5 as fertilizer, 2.4 in construction and 1.6 as waste. The energy output in terms of milk was 0.9×10^6 Kcals and meat output was 0.4×10^6 Kcals per annum. In Ulipur, chemical fertilizers are used only on a few Rabi (winter) crops such as mustard and wheat. A total of 354 Kgs of urea (46%N) and 483 Kgs of triple superphosphate (47% P_2O_5) were used during the year. Assuming energy requirements of 25.4×10^3 Kcal/Kg of N and 2.4×10^3 Kcal/Kg of P_2O_5, the total energy input in terms of fertilizers was 4.8×10^6 Kcals per annum. Energy input in terms of seed is estimated as 11×10^6 Kcals per annum. Although human excreta is not collected, it does enhance the output of crops, poultry and fish, indirectly.

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* Kher, the tender, upper straw is mainly used as fodder. In Ulipur, around 80% of Kher from Amon paddy and 72% of Kher from Aus and Boro paddy were used as fodder. The remaining Kher is used as fuel.

In terms of agriculture as a source of energy, agriculture provided food, milk, meat, as well as 336 million Kcals of energy as fuels for cooking and heating. In addition, 141 million Kcals were used within agriculture as inputs as seeds, human labor, animal labor and manure. The only input into the agriculture system was 4.8 million Kcals of chemical fertilizers. Thus, agriculture made a net contribution of more than 330 million Kcals per year in addition to providing human food.

The major focus of this study is the control of production and the distribution of energy in Ulipur. The social organization of the village determines the control and distribution of energy resources. The study closely examines this social structure and the flow of energy in the village. Changes in social structure are analyzed and the effects on energy-use patterns, discussed.

A census of each family an its assets was taken and thereafter detailed information was collected from each family every two weeks. As noted earlier, by far the largest component of energy use in rural areas of the Indian Subcontinent is fuel for cooking food. A shortage of fuel is becoming a crucial problem for landless families. The data also showed that their productivitiy is very low. This is partially due to declining productivity of the land, and over-fishing and the resulting declining yields of fishing waters. Although the energy system is frugal, with almost all products and by-products being used, the amount of food which must be consumed by a person or an animal to produce a unit of useful work is high. The energy input per unit foodgrain output is higher than in the U.S. and the efficiency of cooking is very low, with about 3 calories of fuel being used for each calorie of foodgrain cooked, which is higher than U.S. energy consumption for cooking and refrigeration combined.

To understand why particular materials are produced, the pattern of land-ownership and tenancy is important because the controller of the land determines the cropping pattern. Each crop produces several products which may be used for several purposes.

The data show that ownership of energy producing resources is highly concentrated, 16% of the families own 80% of the trees, 55% of the cropped land and 45% of the cattle. Families from different classes use similar per capita quantities of energy for cooking food and thus have a similar cooking efficiency, although they use different types of fuels for cooking. The poorest families have to supplement their fuel with fuel bought in the market.

The traditional social organization of this area is vertical, with patron - client relations between the landowners and their tenants, servants and laborers, artisans and servicing groups. This system had some benefits for everyone. The landowner was assured laborers and followers in village disputes. He is able to extract the surplus value of labor and ensure stability. Poorer families reduce their risk and gain security and prestige from their role as patrons. There is evidence that this apparently stable system may be changing.

In Ulipur, the disappearance of slack resources has been an important factor in changing the nature of social organization. In the 1960s, fishing was considered exclusively a Hindu occupation with the relationship built up during the sale of the catch forming the basis for the integration of the Hindus into village society. As productive employment has become more difficult to obtain, as real agricultural wages have declined, the Muslims have begun to compete with the Hindus for fish. This has forced the Hindus into a more marginal position. They have lost their function and rights in the Ulipur community and are forced to buy fuel that they could previously collect from the then abundant crop residues.

Due to increasing population, the crop residues surplus has declined. As fuel becomes scarcer and market relations in agriculture spread, the tenuous claim of the Muslim poor to the fuels generated by those who still have land, is going to become still weaker. As slack resources become scarce, the peasants are forced into the cash economy.

The introduction of HYVs, which has not yet happened in Ulipur but will soon, is expected to lead to a rapid disintegration of the traditional system. As average productivity increases land values rise and sharecropping decreases. Wages are no longer tied to productivity. Because the poor have less access to new technology than the rich, the gap between the rich and poor widens and the proportion of landless laborers increases. Also HYVs provide far less crop residue for fuel which disproportionately hurts the poor and landless.

An additional cause of social change has been the increase in formation of extra-village links by the richer peasants which has led to a decline in their participation as patrons.

Gradually, the old vertical social structure has been replaced by a more horizontal structure with many more transactions taking place between members of the same class.

Briscoe concludes his study by emphasizing the political and social effects of various development schemes. Technical development has serious effects on distribution and welfare. As with HYVs, many technologies, such as Gobar gas plants and solar dryers which the rich have more access to, deprive the poor of residues formerly surplus which they depended on. Originally designed to help the poor, many technical developments have ended up widening the gap between rich and poor and have left the poor acutually poorer. In order to benefit, the rural poor , the rural elite must be bypassed, an extremely difficult operation. Programs must be carefully targeted to those they are designed to help.

Energy Use in Pangama, Nepal: The study on Nepal has been conducted by Deepak Bajracharya for Pangma village in Eastern Nepal. Data has been obtained by detailed questionnaires and using time and motion studies through the participant observation method. The data reported is for 14 households most of whom own land. The average amount of land in which rice is cultivated is 0.98 hectares and each household also possesses 0.25 hectares used for cultivation of millet and maize. The main types of fuel energy used in the area are kerosene for lighting, fuelwood for cooking and space heating. The main energy inputs into agriculture are human labor and bullocklabor. Kerosene consumption varies between 9.2 litres per year to 37.8 litre per year and it is assumed that 1 litre of kerosene can provide 70 hours of lighting. The average fuelwood consumption is estimated at 753 per household per month. The minimum is 436 Kg (family of 2) and maximum 1300 Kg (family of 8). In terms of consumpton units (assuming 1 unit per adult and 0.5 units per child below 14) the average is 160 Kg per consumption unit per month. This 160 Kgs of monthly consumption corresponds to 24.3 Kgs of foodgrains cooked. In calorific terms, the average fuelwood consumption corresponds to 0.75 million Kcals per month per consumption unit or 25000 Kcals per day per consumption unit.

It has been shown that percentage allocation of male labor is: agriculture 39.5%, cottage industries 10.2%, domestic 9.2% and miscellaneious (public construction, porterage, fencing, etc.). In the case of female labor, half their time is spent on domestic work, around 30% in agriculture and the rest in cottage industries and miscellaneous.

On average, each household possesses 1.6 cows. 2 bullocks and 0.7 buffaloes. Including the number of small cattle, goats, pigs, etc., the number of animal units per household averages 7.2. On average, each household gets about 3300 per year of manure (inclusive of vegetable wastes). On the average 4 pieces of

ordinary wooden ploughs, 1.8 pieces of yokes and 2.1 pairs of plough strings and 1.1 pieces of 'dade' (for level ploughing) are required per year. On average, 8.8 hours of male labor are required for making one plough.

Energy utilization in agriculture for major crops is given in Table C.13 It may be noted that in KGOE per hectare, energy input is 686 for rice, 657 for maize and 446 for millet. Since the yield rate for millet (2350 Kgs/ha) is much higher than those for rice and maize, energy input per ton is (190 KGOE) for millet, and highest for maize (438.5 KGOE). Animal labor accounts for 83-85% of energy input for rice and maize while the share in millet is 55.5% of the total. In terms of hours, human labor hours in rice and maize were about 4 times the bullock hours spent while in the case of millet, human labor hours were more than 16 times the bullock hours spent per hectare. That is to say, in millet although bullock labor is half that used in other crops, human labor utilization is much higher than in other crops.

It may be noted that this study is also incomplete in the sense that it does not describe the availability and use of crop residues, use of animal manure, etc. However, available data does provide some idea of energy inputs in agriculture of hill areas.

TABLE C.13

ENERGY INPUTS IN MAJOR CROPS IN PANGAMA, NEPAL

	Per Hectare		
	Rice	Maize	Millet
A. Crop Yields (Kgs/ha)	2112	1501	2350
B. Energy Inputs per hectare			
Human Labor			
Hours	2797	3118	5402
KGOE	103	115	198
Percent of total	15.0	17.5	44.5
Animal Labor			
Hours	778	723	330
KGOE	583	541	247
Percent of total	85.0	82.5	55.5
Total Energy			
KGOE	686	657	446

Notes: 1. Source: Deepak Bajracharya (1979)

2. Implicit conversion factors are: .357 KGOE per hour of human labor; .75 KGOE per hour of animal work.

3. 1 KGOE (kilogram of oil equivalent) = 40.818 X 10^3 BTU (British thermal unit).

ENERGY AND AGRICULTURE DEVELOPMENT

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