DRAFT POWER IN SOUTH ASIAN FOODGRAIN PRODUCTION: ANALYSIS OF THE PROBLEM AND SUGGESTIONS FOR POLICY

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Chapter 1
The Context of the Problem

This study takes a look at the energy, land, and food connections as they express themselves in one major area of rural energy use -- that of mechanical energy for agricultural production. Specifically, we focus on the use of draft animals in agriculture. In order to keep the scope of the study, we limit specific examples to four countries in South Asia: Bangladesh, India, Nepal, and Pakistan.

We analyze this problem by taking into account the multiple resource constraints which rural people face and the situations of considerable economic and social tension and conflict within which these constraints are located. The intention is to draw some lessons for rural energy policy in the Third World in regard to the provision of adequate mechanical power for agriculture, and possible roles for U.S. policy.

Draft animals are the primary source of mechanical energy for agriculture in Asia, as well as much of Africa and Latin America. Therefore, this is a matter which affects the lives of billions of people who are dependent on the agricultural production both for sustenance and for income. They have gained additional importance and urgency in recent years because they are linked to the growing concern over the accumulation of greenhouse gases, especially methane. For instance, the Environmental Protection Agency recently issued a report entitled **Reducing Methane Emissions from Livestock: Opportunities and Issues**, which considered in detail the topic of cattle as they affect methane accumulations.

While most greenhouse gas accumulations are due to activities which take place in the industrialized countries, emissions of methane from cattle and from traditional rice culture are thought to be substantial. Thus, the problem of providing adequate, reliable and economical draft power, which was already very difficult and complex, now has yet another dimension: the problem of methane accumulations.

A great deal of the problem of policy is to try and locate energy problems involving traditional energy sources in the context of the overall economic and social situation in which rural people find themselves. This is not a simple setting. It involves constraints on many resources besides energy. It involves conflicts and tensions which range from gender issues within the family to class issues within villages to problems arising from the working of national and international economic systems.

The problem of adequate draft power for agriculture is connected to that of land and the priorities for its use, adequate feed to get optimum use of the draft animal population, distributional questions, such as lack of capital for the poorer section of farmers, and so on. The overall resource, economic and social considerations include the following:

1. Land: this includes land for food crops, for traditional energy sources (non-monetized fuelwood, grazing land), for monetized crops (including fuel-crops) which are destined for export from rural areas.
2. Labor: peak labor requirements for agriculture and domestic work, including gathering and preparation of energy supplies; cash requirements, requiring people to perform monetized labor.
3. Gender considerations: women and children perform much of the labor and the overwhelming proportion of the non-monetized labor in the Third World, the more so in rural areas. In these circumstances, investments which reduce the burden of women's work or which demand money resources generally controlled by men often confront a low priority among those with power over resources.
4. Urban-rural aspects: the general tendency for investments to be concentrated in urban areas. This tendency is very strong in the Third World, and even within urban areas, large investments are narrowly focused towards the elite.
5. Allocation of financial and foreign exchange resources: investments in the energy sector, including rural energy, are often constrained by shortages of capital, including foreign exchange. These shortages are exacerbated by the strong class and urban bias in investment patterns and in the spending of the foreign exchange which is available.

Evidently, the compass of these issues is large. Our focus here is the nexus between land, energy for traction, and agricultural production. We will only touch upon the other issues in passing, and only as they apply to the problem of mechanical energy in South Asian agriculture.

Chapter 2
Overview of Draft Energy South Asian Agriculture

Rural South Asia has about 700 million people, the overwhelming majority of whom are agriculturists. There is a variety of agricultural production systems, techniques, and products in this region. This diversity arises from a number of factors such as the variety of climatic zones and soils in the region, topography, the different levels of investment per unit of land and labor, population density, government policies regarding price supports for crops, and so on.

The principal food crops are rice, wheat, coarse grains, and pulses. The first three provide most of the caloric supply. They are grown under quite different conditions, generally, and have somewhat different structure of draft power use. Tables 1, 2, and 3 show production and yields of rice, wheat and coarse grains respectively in Bangladesh, India, Nepal and Pakistan. All three crops are important in India and Nepal, while wheat predominates in Pakistan and rice in Bangladesh.

The use of draft animals is prevalent in all three areas of foodgrain production. But there has been considerable mechanization of wheat production, particularly in areas where high-yielding varieties are grown for urban markets. Irrigation powered by diesel and electric pumps is common in certain regions, as is the use of tractors, though the use of such devices is generally limited to the better-off segment of farmers. India is the fourth largest user of chemical fertilizers in the world on an aggregate basis, though not on a per-person basis.[1]

Similarly, there has been some mechanization of rice cultivation. Coarse grains, which are principally grown for self-provision by poor farm households, rely almost exclusively on draft animal power.

Table 1
South Asian Rice Production, 1988

Country	Cultivated Area, 10^6 ha.	Yield, kg./ha.	Production, 10^6 tons
Bangladesh	10	2,190	21.9
India	41	2,487	102
Nepal	0.63	2,649	1.7
Pakistan	1.4	1,991	2.8

Source: FAO Production Yearbook 1988.

Table 2
South Asian Wheat Production, 1988

Country	Cultivated Area, 10^6 ha.	Yield, kg./ha.	Production, 10^6 tons
Bangladesh	0.6	1,754	1.0
India	22.6	1,995	45.1
Nepal	0.6	1,248	0.7
Pakistan	7.3	1,735	12.7

Source: FAO Production Yearbook 1988.

1 India is among the largest users of chemical fertilizers. In 1983-85 the U.S.S.R. used 23 million tons per year; the U.S.A. 17 million tons; China 17 million tons; and India 8 million tons.

Table 3
South Asian Coarse Grain Production, 1988

Country	Cultivated Area, 10^6 ha.	Yield, kg./ha.	Production, 10^6 tons
Bangladesh	0.05	777	0.04
India	39.0	732	28.6
Nepal	0.9	1,196	1.1
Pakistan	1.6	987	1.6

Source: FAO Production Yearbook 1988.

Despite the increasing use of farm machines, the single most important energy input for agriculture and related rural activities, food for draft animals, has not yet become a part of national or international energy accounting.

Many studies have shown the great importance of draft animals to agriculture and rural transportation; indeed, this is evident even to a casual observer of rural Asia. Yet, the primary energy needs of draft animals and the constraints that animal energy or peak power availability might pose for agriculture are not yet a systematic part of energy accounting or energy policy making. In fact there are considerable uncertainties as to the numbers of draft animals, the total amount of draft power which they represent, the total amount of energy inputs which are required, and the total energy output which these animals provide to rural agriculture and transportation. As Lawrence and Pearson have observed:

> In spite of the obvious economic importance of these [draft] animals they have been the subject of relatively few scientific studies compared with beef or dairy cattle and basic data relating to their work output and food requirements are often inadequate, lacking or inaccurate.[2]

A number of widely varying estimates of food intake per draft animal can be found in the literature. We have made a survey of the literature to come up with a plausible range to use for the purposes of this study. Such literature as does exist poses considerable problems for its use for deriving overall figures. For instance, one of the principal unknowns is the average weight of draft animals. Another set of unknowns relates to the distribution of weights of animals in various parts of South Asia. But, a considerable portion of the scientific literature on draft animals consists of measurements on a few tropical animals. The relation of the weight and feed requirements of this set of laboratory animals, such as the one at the Center for Tropical Veterinary Medicine in Scotland to the average draft animals is unknown. Thus, while there are many measurements of feed intake under laboratory conditions, their usefulness for deriving national and regional data is limited to providing a check on such field data as there are, and to helping determine the efficiency of draft animal work. (See Chapter 3.)

Makhijani and Poole cite a figure of 25 million Btu or about 26 Gigajoules per animal per year for food intake of draft animals in India.[3] Parikh uses a figure of 3.8 million kilocalories or about 16 Gigajoules per year for draft animals in Bangladesh.[4] Bangladeshi animals are, on average, probably smaller than those in most other parts of South Asia, however. The lower

2 Lawrence and Pearson; p. 703.
3 Makhijani and Poole, Table 2-1.
4 Parikh, pp. 345-6.

feed requirements in Bangladesh may also be due to a larger proportion of draft animals being cows, as compared to other South Asian countries.

Baldwin cites a considerably higher requirement of 2.5 to 3 kilograms per day of dry matter per 100 kilograms of live weight. For a 350 kilogram bullock, the lower figure of 2.5 kilograms per day amounts to about 3.1 tons per year. At 13 gigajoules per ton, we get an annual energy requirement of about 40 gigajoules per animal.[5] This figure is approximately the same as that given by Thomas and Pearson for Brahman oxen.[6] A.R. Rao has published a detailed analysis of the bioenergetics of bullocks used for draft power in Haryana, India. His estimate of the energy inputs to a bullock working an average number of days for a farm which uses only animal draft power (176 days) is about 30 gigajoules per year.[7]

Table 4 shows estimates of the contributions of various sources of energy in South Asian countries. There is considerable uncertainty about energy intake per draft animal. We have used a range of 20 to 40 gigajoules per animal per year for feed requirements. Only direct food intake of draft animals is included in Table 4.

Table 4 shows that, even when all urban use of modern energy forms and cooking and heating applications of traditional energy are included, primary energy for draft animals is among the most important uses of energy.[8] It constitutes at least 15% of all energy use if we take the lower estimates of intake per animal. If we use the higher figure of 40 gigajoules per animal per year, draft animals account for up to 35% of energy requirements.

Draft animals play an even larger role if we consider rural energy requirements. Table 5 shows estimates of rural energy use in South Asia. The primary energy intake of draft animals is in the range of 25% to 60% of total rural energy use.

We must remember that Tables 4 and 5 show only the direct annual intake of draft animals which actually work on the fields. It does not include the intake of young animals and cows which must be maintained in order for a system of draft animals to exists. However, both draft animals and the other animals needed for the system provide other benefits, such as dung for manure or fuel, leather, and milk. A detailed discussion is given in Chapter 3.

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5 Baldwin, footnote number 182.

6 Thomas and Pearson; Table 3. They cite a figure of 7.7 kuilograms of dry matter per day for Brahmans at rest at an ambient temperature of 330C. This works out to about 36 megajoules per year. However, Brahmans are generally larger than the average draft animal in South Asia, so that the average feed requirements for animals at rest would be somewhat lower than this.

7 Rao; p. 542.

8 Throughout this report we exclude food for human beings from energy system calculations. The criterion is that we include those energy inputs which serve human purposes but exclude the purposes themselves - and food belongs in the latter category.

Table 4
Energy Use Per Person in South Asia, Gigajoules per year, 1985[1]

Country	Modern	Traditional[2]	Draft animals[3]	Total (rounded)
Bangladesh	2	5	1.5 to 3	9 to 10
India	8	6	2.3 to 4.6	16 to 19
Nepal	1	12	3.5 to 7	17 to 20
Pakistan	7	6	1.9 to 3.8	14 to 16

Notes for Table 4:

1. Sources for the data on modern and traditional fuels. Modern fuels: World Resources 1988-89. For traditional Fuels: Bangladesh, Parikh, Table 11.5; India, Makhijani and Poole, page 23; for Nepal, Soussan, p. 51; for Pakistan, we have assumed that traditional fuel use per person is the same as that for India.
2. We use a range of 20 to 40 Gigajoules of primary energy per year per standardized draft animal. We equate cattle and buffaloes, though buffaloes probably provide more draft power and consume more food. Parikh uses an equivalent of 2 bullocks = 1 buffalo (Parikh; p. 345-6.) The rough and very approximate nature of the data and the lack of information on what proportion of buffaloes are actually used in agriculture means that only order of magnitude idea can be had from these figures in any case. For further discussion on draft animal energy requirements, see the text of this study.
3. Animal population data are taken from the FAO's Production Yearbook. This does not separate draft animals from other animals. Parikh cites a range of 30% to 50% for the proportion of cattle which are draft animals as the range that prevails in Asia (Parikh; p. 333). In surveys of several villages in Karnataka, N. Somasekhara reports ratios of 34% to 45% for the proportion of cattle which are draft animals (Somasekhara; page 29). Singh et al. cite a figure of only 63 million draft animals but give no source (Singh et al. Table 13). We assume that one-third of the cattle are draft animals.
4. 1987 figures for cattle and buffaloes from Table 88, FAO 1988 Production Yearbook. Population figures extrapolated to 1987 from World Resources 1988-89. The data are as follows:

   Bangladesh: cattle $22.6x10^6$; buffaloes $1.9x10^6$; total $24.5x10^6$. Population = $105x10^6$.

   India: cattle: $199.3x10^6$; buffaloes $74.2x10^6$. Total: $273.5x10^6$. Population $800x10^6$.

   Nepal: Cattle: $6.4x10^6$; buffaloes $2.9x10^6$; total: $9.3x10^6$. Population $17x10^6$.

   Pakistan: Cattle $17x10^6$; buffaloes, $13.7x10^6$; total, $30.7x10^6$. Population, $104x10^6$.

Table 5
Energy Use Per Person in Rural South Asia, Gigajoules per year, 1985[1]

Country	Modern	Traditional	Draft animals	Total (rounded)
Bangladesh	0.3	5	2 to 4	7 to 9
India	1	7	3 to 7	11 to 15
Nepal	0.2	8	5 to 10	13 to 18
Pakistan	1	7	3 to 5	11 to 13

Notes for Table 5:

1. All figures, except the totals are rounded to one significant figure. Totals are rounded to the nearest gigajoule.
2. We assume that 10% of the modern energy is consumed in rural areas where about 70% of the total population lives. We assume that 80% of the traditional energy and all the draft animal energy is used in rural areas. The overall uncertainty in the data on draft animals is such that using more refined assumptions about these parameters will not significantly improve the accuracy of the estimates in this table.
3. We have not included energy intake of animals needed for the draft animal system which do not take direct part in field work. See Chapter 3.

Another revealing way of examining the importance of draft animals is to compare the energy intake of draft animals with the total use of modern energy in agriculture. Consider the data for India as an example. The total use of modern energy in India in 1986 was 6160 petajoules.[9] Makhijani and Poole estimated that about 10% of modern energy use in India in the early 1970s was in rural areas, most of it for agriculture.[10] Goldemberg, Johansson, Reddy and Williams estimate that about 9.1% of modern energy in India was used in agriculture.[11,12] Using the latter estimate of 9.1% for modern energy use in agriculture in India, we get a figure of about 560 petajoules, compared to about 1,800 to 3,600 petajoules for draft animals. **Thus, draft animals consumed roughly three to six times as much primary energy as all commercial energy in agriculture in India.**[13] We shall see in Chapter 3 that when the feed requirements of the non-working young and the cows needed for reproduction are taken into account, inputs to the system of draft animals in India are five to eight times greater than modern energy inputs.

It is clear from the data that we have cited and analyzed that the energy intake of draft animals is of fundamental importance to rural life in South Asia (and a number of other parts of the Third World) and to agricultural production.

As is well known, actual energy intakes are not the only consideration. There are other very crucial aspects to the understanding of the role of draft animals, the needs for mechanical power, and the implications for agricultural and energy policy. They are:

1. **Useful energy output**: We must evaluate the efficiency of the use of draft animals in agriculture and compare this, when appropriate, to other means of obtaining draft energy as supplements, complements, or substitutes.

2. **Useful energy requirements**: The useful energy needs for agricultural operations are not met for a large numbers of poor peasants who do not possess sufficient numbers of draft animals or who cannot provide enough feed for the animals that they do have. This may be in part due to scarcity of available land, and/or fodder, reflected in high prices for both, out of reach of poor peasants.

3. **Peak power requirements**: Various agricultural operations have peak power requirements without which these operations cannot be done efficiently.

4. **Peak labor requirements**: Peak labor requirements may be reduced by the use of additional mechanical power in certain operations such as harvesting or threshing. On the other hand, intensification of cropping made possible by the use of additional

9 World Resources Institute and International Institute for Environment and Development, World Resources 1988-89, Basic Books, New York, 1988 (hereafter referred to as World Resources 1988-89); p. 307.

10 Makhijani and Poole; p. 23.

11 Goldemberg et al., 1988; p. 199. The date is not specified, but from the context it appears that the data are for the early 1980s.

12 World Resources 1988-89 (p. 310) gives an estimate of 1% for modern energy use in agriculture in India in 1970 and 2% for 1980. This is almost certainly wrong.

13 This does not include the use of chemical fertilizers. The use of chemical fertilizers in India in the mid-1980s was about 800,000 tons. The most energy intensive is nitrogen, the use of which amounted to The energy for the manufacture of nitrogen fertilizers is about 80 gigajoules per ton, so that fertilizers add about 50 gigajoules to the total energy use in agriculture. Thus, the addition of this item does not qualitatively change the conclusions in regard to primary energy use. It would however affect useful energy calculations, depending on how we assessed the useful energy value of chemical fertilizers.

mechanical power may increase overall labor requirements and, possibly, peak labor requirements. In other words, the question of mechanical power is closely linked with the question of rural employment.

Useful energy requirements, and peak power and labor requirements will vary depending on the kind of crop, the number of crops per year, weather patterns, the nature of the soil, and topographic conditions, whether and what kind of irrigation system is used, and the variety of seeds and associated requirements of industrial inputs.

Chapter 3
Power and Energy Output and Needs

Efficiency Considerations

We will first evaluate the efficiency of a prototypical system where draft power is provided by bullocks. We will first consider efficiency on the basis of the requirements of sustaining a single bullock.

We define efficiency as the ratio of the work done by the draft animal to the energy value of the feed. Marginal efficiency is defined as the additional work output for an additional unit of energy input. A higher figure of net efficiency is obtained if we include considerations relating to dung. Some of the energy intake which does *not* appear as work output can be recovered in the dung and reused as fertilizer or as a source of energy, it is reasonable to subtract the practically collectible portion of the dung from the energy intake when computing the efficiency of the animal in those instances where dung is actually collected and used in one of these ways.

A typical bullock in South Asia is capable of producing about 300 to 400 Watts of continuous power (about one-half horsepower).[14],[15] It is capable of several times this effort for a short period. On an annual basis, the actual average power output is likely to be considerably below the capacity of the animal for continuous work, because animals work on light loads for a considerable portion of the time.

A thousand hours of work per year (6 hours per day for about 175 days)[16] and 250 watts of average output, is about the maximum that such an animal will provide in energy output per year. Under these assumptions, the annual output of energy amounts to 250 kilowatt hours or 0.9 gigajoules. This is a practical upper limit for the annual energy output of an average bullock.

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14 Makhijani and Poole, Table 2-1; Baldwin, footnote 182.

15 The power output may be somewhat higher in northwestern India and Pakistan where animals tend to be larger than the average. For example, Lawrence and Stibbards cite the power output of Brahman cattle weighing 380 to 500 kilograms as being "up to 490 W." The power output of buffalo weighing up to 650 kilograms is cited as being as much as 735 watts, or almost one horspower. (Lawrence and Stibbards; p. 32). But animals tend to be smaller in most of South Asia. The feed requirements would also be higher for larger animals, but the implications of varying sizes and types of animals for agricultural economics particularly as they affect land and labor productivity deserve to be examined.

16 Rao; p. 541. Rao estimates that "[b]ullocks are used for about 176 days per year on bullock-operated farms and for about 80 days per year on tractorised farms."

To get the upper limit of efficiency estimates, we take the input to be 20 gigajoules per animal per year, the lower limit of our estimates for energy intake (see Table 4 above). About 25% of the input energy can be collected as dung and used as fuel, so that the net energy input is about 15 gigajoules.

For an output of 0.9 gigajoules, we get an estimate of the efficiency of draft animals of 6%. If we ignore dung recovery, then the efficiency would be 4.5%. This is about the upper limit of a range of efficiencies which one might calculate for draft animal use in agriculture.[17]

Under many circumstances, draft animals do not work as many as 1,000 hours per year. This might happen under circumstances where there might be mechanical farm equipment as a complement for animals or where the work on farms involves high peak energy outputs. The latter is the case for instance in wet rice cultivation. Animals may do lighter work for a large proportion of working time which means reduced total energy output. We have taken some of this into account by assuming an average output of 250 Watts, compared to a potential continuous output of 350 Watts. Finally, animals which do not have adequate feed would not provide the energy outputs which we have assumed above. Under these circumstances, annual efficiency would be lowered.

We also need to take into account the other animals which need to be maintained to reproduce the stock of draft animals. This consists of three components:

1. Calves must reach a minimum age and size before they can work effectively.
2. A certain number of cows must be maintained for the purpose of reproduction. (These cows provide milk as a by-product of considerable value. It should be noted however, that animals used for large-scale commercial milk production are usually not the ones also used for reproduction of farm animals, at least in India. In fact, in most of India, the main milch animal is the buffalo, while the main draft animal is the bullock.)
3. There are female calves in excess of those needed to maintain the reproductive system for draft animals. These calves can be used for milk or beef production, but they are generally not used for farm work.[18]

Rao has made estimates of the first of these three components:

> A 3-year old bullock will have consumed 54,666 MJ of feed and its caretaker 1788 MJ of food for a total input of 56,454 MJ [before an animal can begin to provide work output]. The scrap value of cattle slaughtered and fully used for meat, leather, bone meal, etc. has been estimated to be 18,300 MJ/tonne of beast. Thus, a 400 kg bullock has a value of 7320 MJ, reducing the fixed energy embodied in the bullock to 49,134 MJ. This fixed input will be spread over 10 years of working life. Thus, the embodied energy of a bullock will be used at the rate of 4913 MJ per year.[19]

An additional 5 gigajoule energy input per year increases the range of energy inputs required per year from 20 to 40 GJ to 25 to 45 GJ per year.

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17 Our estimate of efficiency is comparable to that provided by other sources. On a daily basis Rao estimates the efficiency of an adequately fed bullock as 8.6% (Rao; p. 542). Taking into account that bullocks work about 175 days per year, this gives an efficiency estimate of 4% on an annual basis. Lawrence and Smith estimated the efficiency of draft animals on a daily basis as 10%, which gives an annual efficiency estimate of about 5%.

18 In many areas, females are also used as draft animals. Mathers, et al cite a widely varying use of females in the draft animal mix, from a low of about 6% in India to over 60% in Thailand. This is influenced by many factors such as land availablity, dietary preferences, and other cultural factors.

19 Rao; p. 542.

We have not come across any estimates of energy requirements for the other two items in our list which involve cows. We might ignore the third item in most circumstances as excess female calves which are not retained for reproduction are generally sold for meat. Thus, this part of the cattle population can reasonably be assumed to be a part of agricultural output for which there are inputs of fodder, grazing land, and labor, relatively independent of the draft animal system.

The second factor may involve considerable amounts of energy. However, in order to make a reasonable estimate, a breakdown of the purpose of female cattle population is required. Generally, the number of cows devoted to reproduction of male cattle would be several times smaller than the draft animal population.

We do not have estimates for this portion of energy inputs to draft animals systems. On an order of magnitude basis it will certainly be considerably lower than the inputs to the working animals. For lack of data, we might assume the net energy inputs for cows needed to maintain the bullock population as about equal to that needed by young non-working males - that is, about 5 gigajoules per year per working bullock.

This gives us a range of energy inputs per draft animal for the entire system as 30 to 50 gigajoules per year. The energy output is in the range of about 0.5 to 1 gigajoule per year. Thus the overall efficiency of the system would be on the order of 1% to 3%. Of course, this is a rough range of figures, given the considerable uncertainties in the data.

Power Requirements

Poor farmers often experience severe shortages of draft power at peak periods in the farming season. These may occur during certain land preparation activities, such as ploughing or puddling, or during harvesting. Shortages of draft power are also felt in case there are unmet irrigation needs in the context of available water supply. Finally, unavailability of mechanical energy may prevent increases in cropping intensity.

These shortages arise from two related basic causes. First, small farmers are too poor to purchase and install an adequate amount of farm power, whether this is in the form of draft animals or farm machinery. Second, their land holdings may be too small to allow economical use of even small equipment. The latter constraint applies more to mechanical equipment than to farm animals because farm animals come in small increments of power.

Table 6 shows the installed capacity of animal draft power per hectare in four countries in South Asia. The figure for average installed power on U.S. farms (excluding motor vehicles) is shown for reference.

Since Table 6 does not include farm machinery, it does not represent the averages for these countries, but rather the typical circumstances of the middle or upper middle peasant on non-mechanized farms.[20] Available data indicate that tractors are used on the order of 10% of the cultivated land in India and Pakistan. We have adjusted the figures for installed power per hectare by attributing 90% of the cultivated area to draft-animal-powered farms.

The installed power per hectare is low on the average. When we take income differences and other local conditions into account, we may infer that in a great many situations, shortages of draft power for small farmers are likely to be considerable. This, in turn, is likely to have a considerably deleterious effect on land and labor productivity.

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20 For Pakistan data see Rahman; Qureshi; Salam. For India see Singh Shrivastava; Sorokin.

Table 6
Draft Animal Power in South Asian Agriculture

Country	Cultivated Area, 10^6 ha.	Draft animal power, 10^6 kW	Specific power draft animals, kW/ha.[4]
Bangladesh	9.2	3.0	0.36
India	169	33.9	0.22
Nepal	2.3	1.2	0.57
Pakistan	20.8	3.8	0.2
U.S.A. (machines)	190	266	1.4

Notes for Table 6:

1. The data on the number of draft animals are from the notes to Table 4. We assume that each animal has an "installed" capacity of one-half horsepower or about 0.37 kW. The actual average power output over long periods of work may be somewhat lower, perhaps on the order of 0.25 kW. One indication of the degree of uncertainty in the above estimates is provided by citing a different estimate by Singh et al. They assume the total number of draft animals in India in 1981 to be 63.3 million with a total power of 18.6 million kilowatts (Singh et al. Table 13). Since their estimates for the number of draft animals as well as the power per draft animal are lower than the figure we have used, the result for total power is much lower. However, Singh et al. provide no source for their figures, nor do they discuss the method by which they arrive at their estimate. Hence we have not used this data in this paper.
2. The data for farm machinery in the U.S. are provided for comparison. These data also reflect installed horsepower. The utilization the installed capacity in terms of maximum power needed over short periods to installed horsepower will be less unfavorable to draft animals because the ratio of peak output to average output is larger for draft animals relative to farm machines. Source of data for U.S. farm machines: U.S. Statistical Abstract, 1989; Table 333.
3. Land use data from FAO Production Yearbook, 1988.

Consider the following example, based on personal observation.[21] In much of the Deccan plateau in southern India, the rains are highly variable, the soils are clayey and, after a long and searing dry season, difficult to plough. In parts of Maharashtra, proper ploughing which would turn up the portions of the soil still containing some moisture after the dry season requires about 3 horsepower, which is about 3 pairs of bullocks. Most farmers do not own three pairs of bullocks, not only because of a shortage of capital, but also because of a shortage of feed to sustain so many draft animals. The average installed horsepower of bullocks in India is only one-third of a horsepower per hectare and many poor peasants would have considerably less than this. Agricultural requirements in much of the Deccan are also increased by the need for irrigation to allow reliable yields and multiple cropping.

The contrast between well-watered and ploughed fields and unirrigated, under-ploughed fields is dramatic. The former can produce two or even three crops, with yields of two or three tons per hectare per crop. The latter produce a few hundred kilograms of coarse grain per year, and as little as 100 to 200 kilograms per hectare in poor years.

To begin with, let us calculate the energy inputs and outputs of the irrigated farm with no shortages of draft power and compare it to the unirrigated farm with inadequate power. First, the irrigated farm:

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21 Crop yields assumed in this example are based on national statistics, taking account of the fact that irrigated fields with adequate inputs have yields considerably greater than average, while poor peasants fields without adequate inputs will have yields considerably below average.

We assume that the level of power availability is 1 horsepower per hectare, and that a total of three pairs of bullocks are available, which is the minimum requirement for adequate tilling. This means that the bullocks would work three hectares of land, assuming 1 horsepower per pair of bullocks. We will use the systemic energy inputs in the range of 30 to 50 GJ per bullock per year, which includes energy inputs for non-working animals associated with a draft animal system.

The energy input per *pair* of bullocks would be about 60 GJ to 100 GJ per year. Approximately 50% of the energy input exits the animal as dung. We also assume that 50% of the dung is collected so that about 25% of the energy input is recovered as dung for domestic energy use. Thus, the net energy input to the animals is 45 to 75 GJ per year per hectare.

About half the energy input is used in field operations, a quarter in crop processing (i.e. 75% in agricultural production) and the rest in transportation.[22] Thus the draft animal input to agricultural production is about 34 to 56 GJ per year. For two crops per year and an irrigation requirement of 10 GJ per hectare per crop, a crop yield of 2,500 kg/hectare and a crop residue to crop ratio of 2,[23] we get the following energy balance for an irrigated farm work by draft animals and diesel irrigation:

Table 7
Annual Energy Input for a Two-Crop Irrigated System, GJ/ha/year

1. Draft animals	34 to 56
2. Diesel irrigation	20
3. Fertilizer input: 200 kg urea/ha/year:	30
Total energy input	**84 to 106**
Energy outputs	GJ/ha./year
1. Food: 5 tons/ha/year @ 14 GJ/ ton	70
2. Crop residues: 10 tons/ha/year @ 13 GJ/ton	130
Total energy output	**200**

The energy inputs of about 100 GJ per year per hectare in this scheme produce an energy output of 200 GJ per hectare per year. The net gain is about 100 GJ and the ratio of output energy to input energy is about 2.

Next consider a rain-dependent farm producing a small grain like *jowar*. We assume that an average amount of draft power for India on farms without mechanical power is available on this farm. This amounts to about 0.3 horsepower per hectare, or one horsepower corresponding to one pair of bullocks for three hectares. There is only one crop per year on such a farm, typically, with an output on the order of 500 kilograms per hectare.

Table 8 shows the inputs and outputs for such a farm:

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22 N. Somasekhara, Rural Energy, Sterling Publishers, New Delhi, 1985, hereafter referred to as Somasekhara; p. 37.

23 For traditional crops, the residue to crop ratio is approximately 2.5 (Parikh). We use a ratio of 2 here because we assume the use of some HYV crops which generally have a smaller residue to grain ratio.

Table 8
Annual Energy Input for a One-Crop Unirrigated System, GJ/ha/year

1. Draft animals	11 to 19
2. Total energy input	11 to 19
Energy outputs	GJ/ha./year
1. Food: 0.5 tons/ha/year @ 14 GJ/ ton	7
2. Crop residues: 1.25 tons/ha/year @ 13 GJ/ton	16
Total energy output	**23**

The upper limit of the ratio of output to input is about two, whereas the lower limit of the ratio is only 1.2. Moreover, the total production per unit of land in a land-scarce situation is clearly of paramount importance, and on this score also the rain-fed system is not adequate. Indeed, one of the most important advantages of the first system is the increased production per unit of land. The ratio of annual energy output of the two-crop irrigated farm to the unirrigated one-crop farm is almost nine to one.

In poor years, crop production might fall to 200 kilograms per hectare or less, and the highest energy output to input ration falls below 1. It is easy to see that when outputs are so low, the system is catastrophic for both humans and animals.

While this is an extreme example of the effects of the shortage of draft power in South Asian agriculture, similar figures would apply to considerable areas, since the Deccan itself is a large portion of South Asia, and many other areas are similarly semi-arid.

There are two principal differences between the farms in the above examples. The first is the use of irrigation and fertilizer inputs; the second is the availability of sufficient draft power. These two are not necessarily connected, though the completion of adequate ploughing and post-harvest operations in a timely fashion requires the availability of sufficient power and sufficient energy at critical times. Moreover, the availability of adequate power need not be in the form of machines in the specific instance. However, we will see that land constraints place a limit on the increases in draft power via animals that can practically be made available, especially in view of the competition for land for other purposes such as the production of food and fuel.

A similar problem confronts many small farmers in rain-fed rice culture. Rice culture is generally wet paddy cultivation, in which draft animals predominate. The draft power requirements in wet paddy cultivation are high in that the effort required to plough and puddle wet, muddy fields is considerable.

Shortages of draft animals at critical times are common. Poor farmers who do not own enough or even any draft animals must not only pay to rent them, they often borrow the money needed for this at high interest rates from moneylenders. They are also often forced to wait till the farmers who do own the cattle and rent them out have completed their own farm operations. One example of the relative prices of draft animals and labor in a rice-growing area on India's west coast is as follows: The price of a day's labor in the peak season was about $0.70. The rental for a pair of bullocks with a plough for a day was $2, excluding labor.[24] Of course, people cannot be substituted for draft cattle in puddling rice fields. They are complementary inputs, whose relative prices are nonetheless instructive.

It is not necessary to increase the amount of power available to farmers to accommodate the needs of tilling and irrigation at once. Pingali, Bigot and Binswanger have pointed out that in land-scarce situations biological technology changes generally precede mechanical technology changes and the reverse is true of land-abundant areas:

> The history of North America and other land-abundant areas shows that where farming systems have allowed or required mechanization, it has often preceded by decades the adoption of any biological technology. In land-scarce countries, such as Japan, however, biological technical change occurred toward the early part of the twentieth century, while the widespread use of mechanical technology was a more recent phenomenon.[25]

As a specific example, Goldemberg et al. have pointed out that considerable improvements in traditional rain-fed rice culture are possible without the addition of farm machinery, but with additional chemical, human labor and animal labor inputs. Increasing indirect energy inputs for fertilizers and pesticides from 331 MJ per hectare to 4,570 MJ per hectare, human labor from 725 hours per hectare to 983 hours per hectare, and animal labor from 342 hours per hectare to 440 hours per hectare is postulated to increase paddy yield from 1,860 to 3,500 kilograms per hectare.[26]

This means that by increasing energy inputs by about 8 GJ per hectare (about 4 GJ for indirect energy and 4 GJ for draft animals), the output (including crop residues) could be increased by about 66 GJ, a ratio of output to input of about 8.[27]

Poor peasants confront considerable obstacles to increasing mechanical power availability on three counts:

1. They do not have adequate access to capital to increase chemical inputs.
2. They do not have adequate draft power to increase animal labor inputs without additional capital.
3. The problem of shortages of draft power at crucial times is often accompanied by shortages of human labor at peak periods.

Operations like transplantation or harvesting and threshing need to be done within short periods. Small farmers who cannot afford to hire labor, and who are obliged to rent cattle with money borrowed at huge interest rates, also often suffer crucial labor shortages.

Borrowed grain or money is also often needed in order to be able to eat at all during the rainy season. Due to the high interest rates, farmers borrow as little as they can, minimize food intake, and thus are not able to work at their best. They also often plant early maturing varieties of crops in order to minimize borrowing even though such varieties usually have

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24 1976 data, personal observation.

25 Pingali et al.; p. 9.

26 Goldemberg, et al.; p. 276.

27 We assume that the 98 extra hours of draft animal labor require the full support system, meaning that the total energy input for 1,000 animal-hours per year would be 30 to 50 GJ. Thus 98 hours of additional draft animal labor would require 3 to 5 GJ, with 4 GJ being the average figure. We assume a crop residue to crop ratio of 2:1.

much lower yields. Finally, the rainy season is also a time of the peak incidence of water borne diseases, further cutting into much needed working time.

Fulfilling peak labor requirements from within the family under these very difficult circumstances provides an impetus to poor families to have large numbers of children. Of course, this same impetus also results in considerable surplus labor at other times of the year.

Given unmet peak labor needs, the alleviation of these problems is connected with the enormous amounts of time which women must spend on gathering fuelwood and other traditional fuels, as well as water carrying food processing, including cooking and other household activities. As with alleviation of peak power shortages, reducing the time and drudgery that accompanies the gathering and preparation of traditional fuels could, in many circumstances, lead to increased availability of labor for agriculture and increased productivity. These shortages occur despite efforts by the poor to stockpile fuel for the agricultural season, and the greater availability of water during the peak season. Thus, in many circumstances, the problems of creating local fuel supply through woodlots, of adequate draft power and of adequate labor are closely connected. (See Chapter 4.)

The magnitude of mechanical power requirements for productive agriculture is a critical factor in improving both land and labor productivity in South Asian agriculture. This is especially so for two somewhat different situations. First, shortages of draft power affect a large number of small farmers who cannot afford adequate draft power either in the form of draft animals or farm machinery. They are forced to rent draft animals which puts them at a serious disadvantage. It increases their cash requirements, and all too often the money they must borrow from moneylenders at exorbitant interest rates. It also causes delays in critical operations, since those who own draft animals give priority to their own operations before renting out to others.

A critical need of small farmers, therefore, is to improve output within the framework of the present cropping intensity. Second, there is the larger category of farmers, which includes small farmers, who need additional draft power to improve the technology as well as cropping intensity. This would apply to irrigation, to relieving peak labor shortages, and to accelerating certain farm operations such as harvesting and threshing to permit double cropping.

Chapter 4
Draft Animals, Land, and the Rural Energy System

The feed for draft animals comes from five sources:

1. crop residues;
2. fodder grown on grasslands, grazing on grasslands and uncultivated marginal lands, such as hillsides;
3. grazing on fields which are fallow during the dry season;
4. fodder produced from trees and from forest areas generally;
5. grain and other high-quality feed. This is a small proportion of the total.

There is great uncertainty about the relative magnitude of these sources. Indeed, even the numbers of draft animals themselves are highly uncertain. J.K. Parikh has used an assumption of 25% to 30% of the energy requirements of draft animals come from grazing for Bangladesh.[28] Some of this grazing is on land which is fallow during the dry season which would belong to the owner of the cattle. However, much or most grazing may take place on common grassland which have soils which are too poor to sustain cultivation of crops.

We can make an order of magnitude estimate of the amount of uncultivated land involved in grazing draft cattle. Let us begin with the figures for India, as an example. Our estimate of the total feed for draft animals is in the range of 1,800 to 3,600 petajoules per year. The total number of cattle are triple the number of draft animals (according to the assumptions used here to derive the numbers of draft animals).

Since grazing requirements of non-working cattle tend to be considerable lower than those for draft animals, we can make an order of magnitude estimate of feed requirements as being roughly double the amount needed for draft animals alone. Thus, the energy requirements for all cattle are on the order of 3,600 to 7,200 petajoules per year.

If we assume that one-fourth of the requirements come from grazing in fields and that half of these grazing requirements come from grazing on lands other than fields (including common lands), then the energy requirements met from land that serves as pasture can be estimated.

These assumptions lead to an estimate of energy needs from pastures of 450 to 900 petajoules per year. Marginal lands, such as those on which cattle graze, are low productivity areas. Assuming figure of one ton of dry matter per hectare per year (which may be on the high side) and an energy value of 13 gigajoules per ton, we get an estimate of the amount of pasture land, including marginal land needed, to meet the energy requirements of 35 to 70 million hectares. The total grazing requirements are likely to be even larger, since we have omitted other animals such as goats and sheep.

There is, of course, considerable uncertainty in this range of figures. For instance, the dry matter available per hectare may be considerably different than one ton. We do not have any data on dry matter production on grazing land. Further, the regional differences in availability of grazing land and its productivity are likely to be considerable, so that in many areas there may be very serious shortages of grazing land. Finally, the proportion of feed from common grazing lands may be either greater or lower than the one-eighth we have assumed here (half of 25%).

We can get an order of magnitude consistency check on the range of estimates by examining land use data. These are shown in Table 9.

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28 J.K. Parikh; p.346.

Table 9
LAND USE IN INDIA

CATEGORY	1972 (1000 ha)	1987 (1000 ha)
Total Area	328,759	328,759
Arable and Permanent Crop	165,260	168,990
Permanent Pasture	12,960	12,000
Forests and Woodland	63,690	67,100
Other (wasteland, parks, etc.)	55,409	49,229

Source: FAO Production Yearbook 1988.

The total amount of land classified as "permanent pasture" was only 12 million hectares in 1985. However, "other" category, including wasteland in was about 49 million hectares. A great deal of the land classified under this "other" category is truly waste land with little or no production. This would apply to considerable areas of desert in western India (and in Pakistan). However, some portion of this consists of marginal, uncultivable land which may provide some food for ruminants. However, such land is unlikely to be productive at the rate of 1 ton of dry matter that we have assumed in making our estimate of land requirements for grazing. Thus, while land in the other category may be used for grazing, the number of animals it could sustain even at a marginal level would be much smaller than that in our calculations. Or conversely, the amount of land required to provide the 25% of the feed requirements would have to be considerably larger.

A good portion of the land needed for grazing probably comes under the classification as "forests and woodland" in Table 9 above. In India, as in most of South Asia, much of the land in this category is not dense forest. On the order of half of the 67 million hectares listed this way may actually serve functions such as grazing and even cultivation of food crops.

In conclusion, the total land available for pasture as such appears to be considerably short of the requirements, if one-fourth of the caloric requirements are assumed to come from this source. A considerable amount of land in the "other" and "forests and woodland" categories is being used as grazing land.

Table 10 shows estimates of grazing land requirements and land use data for Bangladesh, India, Nepal and Pakistan.

Table 10
Pasture Available and Land Areas Needed for Grazing

Country	Cattle Energy, petajoules	Grazing Land requirements, 10^6 ha.	Permanent Pasture available, 10^6 ha.
Bangladesh	300 to 600	3 to 6	0.6
India	3,600 to 7,200	35 to 70	12
Nepal	120 to 240	1 to 2	2.0
Pakistan	400 to 800	4 to 8	5.0

Notes:

1. Data for cattle are drawn from Table 4. The energy requirements per head of draft animal are taken as 20 to 40 GJ per year.
2. Draft cattle are assumed to be one-third of total cattle. The total energy requirements for all cattle are assumed to be double those for draft cattle alone, since fodder is preferentially given to draft animals in most situations outside of dairy farming operations.
3. Production of dry matter per hectare of pasture assumed = 1 ton = 13 GJ per year.

The need for grazing land is greater than these approximate figures suggest. As discussed above, cattle are inadequately fed, and this reduces the power availability for agriculture. It may also reduce the efficiency of the use of cattle in agriculture, since more of the energy intake is used for basic metabolic upkeep. This shortage of mechanical power, in part due to the unavailability of feed, is of long-standing. As Marvin Harris noted in 1966:

> At present cattle are fed largely according to season. During the rainy period they feed upon the grass which springs up on the *uncultivated* hillsides....But in the dry season there is hardly any grass, and cattle wander on the *cropless* lands in an often half-starved condition. True there is some fodder at these times in the shape of rice straw and dried copra, but it is not generally sufficient, and is furthermore given mainly to the animals actually working at the time.[29]

These facts have great bearing not only on agricultural policy, but also on other aspects of rural energy production and use. The land used for grazing and fodder production is often marginal land which could not sustain crop production, but may very well be suited to the planting of village woodlots for fuelwood production. Thus there are many situations where there is a direct conflict between the need for grazing cattle and increasing fuelwood production, under the present arrangements for the use of common lands.

This tension between draft power for agriculture and land for fuel is made more severe not only by the time and trouble it takes to gather fuel requirements for the family, but also by the fact that in many areas there are serious shortages of mechanical power for agriculture, especially at peak periods.

Draft Animals and Woodlots

It is clear that in any circumstances where there is serious pressure on land resources, it is going to be difficult to find the land for woodlots without depriving farmers, including poor farmers, of grazing land. Uncultivated, deforested hillsides and other marginal lands are vulnerable to erosion. They are precisely the areas where trees and forests might produce a

29 Harris; p. 55.

whole host of well-known benefits. But they are also precisely the areas where cattle graze in the rainy season in many areas. Policies which reduce present access of the poor to grazing land or to fuelwood gathering rights on these hillsides would most harm those sections that they purport to help. These policies would also hurt some short term interests of other farmers because their cattle also graze on marginal common lands. Indeed, they have more cattle and in this sense have more to lose from these lands being put to other uses.

The implications for land use of various approaches to meeting the draft power needs of agriculture is important to patterns of domestic fuel use. Crop residues and dung constitute a major portion of fuel use, especially in wood-short areas. This use of crop residues reduces the ability of farmers to feed their animals or to increase the number of animals. Similarly, the use of dung as fuel reduces organic nitrogen for the fields, thus requiring increased use of inorganic fertilizers use or producing reduced yields.

In this context, the success of woodlots for fuel is intimately tied to the implementation of policies for the provision of animal feed to replace that available from common grazing lands. We should also note that fuelwood is also used directly to cook fodder for cattle, contributing to the overall energy requirements of the draft animal system. If woodlots can be integrated with schemes to increase the affordable availability of feed for animals, then they would become much more feasible as one land-use conflict would have been resolved.

On a technical level this problem is not a difficult one. Instead of focusing on single-purpose trees, it is necessary to plant trees or forests which can meet a multiplicity of needs. In particular, plans for planting fuel-producing trees on marginal lands or common lands must also include varieties that can produce fodder. Ideally, a mix of trees should be planted so that they can meet diverse needs for fuelwood, fodder, timber and food.

Many plans along these lines have been proposed. Goldemberg et al. have suggested "two-tier" forests which would accommodate both fodder and fuel requirements:

> Fortunately, the fuel-fodder conflict can be resolved, for instance, by growing two-tier forests in pasture land with the shorter plants producing fodder and the taller trees, fuel. If this approach is adopted forest area [in India] can be increased to about 29 percent [from 20 percent] of the total geographical area, i.e., approximately a 50 percent increase.[30]

Another way in which such forests could alleviate the fuel-fodder conflict is in situations where crop residues which could be fed to animals are used as fuel. Adequate supplies of fuelwood and more efficient cooking stoves (both desirable for other reasons as well) could increase supplies of crop residues available for animals.

30 Goldemberg, et al.; p. 271.

Chapter 5
Animals and Farm Machines: Complements, Supplements, Substitutes

Whether to use more cattle or farm machines has been a much-debated question in agriculture. However, this discussion has proceeded in the absence of any overall assessment of mechanical energy requirements, and overall land requirements for draft animals. Further, there are many combinations of animals and machines which would make sense under the great diversity of conditions in agricultural and the overall rural economy in the Third World.

Let us first consider the advantages and disadvantages of draft animals. This will illuminate what ways in which animals and machines can be used more effectively to provide the additional power needed for agriculture.

Draft animals have the following salient advantages which have led their use to be so widespread:

1. They reproduce themselves and do not require large capital outlays *if* an appropriate stock of animals is maintained.
2. They provide cow-dung as fuel (or return nutrients to the soil), milk, meat, and leather.
3. They are flexible in that they can be used for many different purposes such as ploughing, threshing, irrigation, and transportation.
4. They can be obtained in small unit sizes (in terms of power per unit), a big consideration for small farmers.
5. They are not dependent on external supplies of fuel, so that the element of risk in fuel cost is minimized.
6. They largely involve non-monetized energy sources, and use non-monetized labor which is available especially in the off-season.
7. They can provide peak power at several times the average power over short periods.

Despite these advantages, the number of draft animals is not large enough to fulfill energy needs for agriculture in South Asia. This is because the principal advantages of draft animals can accrue only to farmers already possessing cattle and adequate amount of cultivated land to provide fodder and off-season grazing land. Initial capital outlays for acquiring cattle are substantial, and their maintenance can involve considerable monetary costs if the farmer does not possess enough land to produce the required fodder. Thus, the monetary costs of draft animals can be considerable and often out of the reach of the small farmer. As we have seen, even in those cases where farmers do have cattle, their numbers frequently fall short of meeting the needs of present cropping intensity, much less increasing it.

One indicator of the difficulties of small farmers in acquiring sufficient draft power is the fact that in South Asia draft cattle population has been increasing far slower than rural population. In India, the growth of the cattle and buffalo population during the 1980s has been about 0.6% per year,. The figure for Bangladesh is .8% per year. In Nepal cattle population has actually declined by about 14% from 1980 to 1988. Among the countries discussed here, Pakistan is the only one to have seen a substantial and consistent increase in cattle and buffalo population of 2% per year during 1980-1988.[31] There is some uncertainty in these data for cattle population.

The poor overall efficiency of draft animals and the substantial land requirements for maintaining them are largely responsible for the shortage of draft power in land-scarce situations. Of course, these shortages affect those who have small parcels of land more severely. This raises the question of a role for farm machinery for small farmers and others who need to increase mechanical energy inputs to agriculture but are restrained by the expense of feed or by shortages of fodder or grazing land.

The efficiency of modern energy use in farm machines is typically an order of magnitude greater than farm animals, even under conditions in the rural Third World where electricity distribution losses tend to be high and where machines tend to be among the older and less efficient models that are available.

As we have discussed, the total intake by the draft animal *system* per draft animal in India is in the range 30 to 50 GJ per year per draft animal, and the output is in the range 0.5 to 1 GJ per animal per year. Thus, the total annual energy output of draft animals in India is 45 to 90 petajoules corresponding to inputs in the range 2,700 to 4,500 petajoules per year.

Modern energy use in Indian agriculture is 560 gigajoules. Assuming an average efficiency of 15% to 20% for modern energy, the inputs of modern energy provide useful energy of about 84 to 110 gigajoules. That is even though draft animal inputs are five to eight times greater, modern energy use in rural India provides a comparable or larger amount of useful energy to agriculture. This is largely due to the fact that animals eat all year and work only a small fraction of the time, while machines use no energy when they are not running. Table 11 summarizes these figures.

Table 11
Comparison of Energy Inputs and Outputs for Modern Energy Sources and Draft Animals

Energy Source	Energy Input, GJ	Efficiency, %	Energy Output, GJ
Modern Sources (oil, electricity)	560	15 to 20	84 to 110
Draft animals (system basis)	2700 to 4500	1 to 3	45 to 90

However, average efficiencies do not tell the whole story. The system of draft animals exists and is the mainstay of agriculture in South Asia. Thus, a crucial question is: what is the marginal efficiency of feed? *In other words, given that feed is insufficient, how much could energy output be increased by increasing the quality and quantity of feed during the peak agricultural season?*

Experimental work done at the Centre for Tropical Veterinary Medicine in Edinburgh, Scotland, indicates that the marginal efficiency of feed for an animal doing heavy work during

31 FAO; p. 245. The figure for India in the FAO table for 1988 is an "unofficial figure," while that for Nepal is an FAO estimate.

the work day is about 18%.[32] (In this calculation, energy intakes during non-working hours and non-working days are ignored.) *Thus, the output resulting from additional high quality feed to existing animals can be obtained at marginal efficiencies comparable to farm machines. This indicates that the expansion of traction energy output by increasing feed availability to existing animals should be a much higher priority than expansion of energy output from draft animals by increasing animal population.* **This approach also reduces the build-up of methane per unit of useful energy output.**

This addresses to some extent the problem of the poor peasant who does have some draft animals. However, it still begs the question of where the additional feed is to come from, especially if it is to be high quality feed. It also leaves out the problems of those who have no animals, or where draft power is seriously inadequate for traction power, for irrigation, or for compressing work at peak time into fewer days to enable double cropping.

Let us first consider some aspects of farm machines before we address these issues. The difficulties with modern energy sources are well known. Farm machines require considerable monetary investment and usually come in much larger sizes than animals, though it is possible and often desirable to reduce the size of machinery. That is, while draft animal system can be acquired half horsepower at a time, the smallest machines are typically several horsepower or even several dozen horsepower. Further, the availability and price of oil or electricity is a source of considerable uncertainty. Finally, oil and electricity both involve considerable amounts of foreign exchange. It should be noted, however, that for specific applications, the price per horsepower of machines can be considerably lower than for draft animals.

Despite these disadvantages, modern energy sources have some powerful advantages: high efficiency, and very low land requirements. The scarcity of grazing land and fodder, the very substantial needs for additional power for increasing land and labor productivity as well as employment means that modern energy sources can be used to increase agricultural productivity, especially for poor peasants who do not now have adequate draft power, and for those who need additional power for increasing cropping intensity and land productivity per crop.

Farm machines can be used with the explicit purpose of getting over the chicken-and-egg problem of shortage of fodder and grazing land leading to inadequate draft power and low output. Increases in crop output on land of farmers who have no cattle or very few cattle, that is selectively on the lands of the poorest farmers, creates the prospect of providing crop residues to those who have larger numbers of farm animals. Thus, shortages of fodder and grazing land could be alleviated and the income of poor farmers can be increased simultaneously.

The following ways in which animals and farm machines can be used as supplements, complements and substitutes emerge from these considerations:

1. The use of farm machines on farms of farmers who do not have farm animals or who have the potential of producing crop residues in excess of the requirements of their own animals. This would alleviate shortages of grazing land and of fodder for farmers who have larger numbers of farm animals, providing a reinforcing increase of energy output for this group as well.

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32 Lawrence and Smith, p. 51. The authors cite measurements showing that during heavy work the energy inputs were 36,226 kilojoules and the output 6,400 kilojoules, for an efficiency of 17.7%. Light work required about as much energy input, but the output was only 1,955 kilojoules, for an efficiency of 5.4%

2. The cultivation of high quality feed for sale during the peak season so as to increase energy output of farm animals in areas where this is limited by shortages of adequate feed in the peak season.
3. The use of farm machines to substantially increase the total amount of draft power available in areas where such needs cannot be met by improvements in output per animals or modest increases in animal population.
4. The use of farm machines to reduce peak labor requirements to enable increases of cropping intensity.

A considerable amount of this has already been happening, of course, as output has increased substantially over the past few decades. But agricultural policy needs to be made explicitly in light of the needs for peak power and useful mechanical energy output. In land-scarce South Asia there is a need to devise strategies to increase draft power output without increasing substantially the numbers of draft animals.

Chapter 6
Conclusions

There has been a considerable amount of work pointing out the importance of draft animals in rural energy as well as in agriculture. Yet research remains at a very early stage, with little field data and practically no integration of the problems of traditional draft power with the rest of rural energy policy. This is so even though crop residues, a principal source of energy for draft animals, are no different from energy sources which are already taken into account when used as cooking fuel. For that matter, crop residues can be used for conversion to electricity or other modern fuels.

The first and perhaps most important policy conclusion of this inquiry is that no sound long-term energy, agricultural, or rural land-use planning is possible without considering the land and energy requirements for draft animals and, indeed, for all livestock. Statistics on the use of wood, crop residues and animal dung as fuel enabled the beginning of systematic policy study of rural domestic energy needs. For the same reason, we need to expand energy statistics to include the energy intakes of draft animals.

We have seen that there are considerable uncertainties in the energy intake of animals, in energy output, and hence in efficiency. Some work has been done in each of these areas, but little of this is specific enough to guide policy for particular regions. The quantity of data for animal energy intake, the sizes of animals, and their energy output under varying conditions in Third World agriculture is very limited. Considerable effort needs to be put into expanding the amount of information and to improving existing estimates. Improvements are needed not only for average national statistics, but even more importantly for energy requirements for specific regions. Conditions vary enormously from one region to the next, by crop type, by varieties of soil, by topography and so on. Therefore, regional data are essential for sound policy here as with other traditional energy sources.

There appear to be severe land constraints on grazing land in most of South Asia. Here too the data are very inadequate. Since improving the productivity of land, attempting to put land into multiple uses in order to resolve food-fodder-fuel conflicts are very crucial considerations for policy, improved data on land use, are critically important not only for draft animals, but for the entire draft animal system and milk and meat production system. It is also important to document the actual production of dry matter per unit of grazing land so that assessments can be made of alternative economic uses of this land and their implications for the provision of sufficient draft power for agriculture.

Increasing draft power availability in ways which are compatible with production increases, distributional considerations and environmental protection will also require data and analyses on related areas. There are pressing needs in the following areas, even though some data does exist in each of them at least for some countries:

- Correlations of ownership of draft animals with land ownership, income, and marketable crop production.
- Ratio of draft animals to other cattle, and relative feed requirements.
- Data on draft animals other than cattle which are regionally important (camels, for instance).
- Analyses of the energy inputs and outputs on farms with mixed animal and farm machine use, as it relates to patterns of production, cropping intensity, land ownership, and peak labor requirements.

A second major conclusion is that mechanical energy outputs for agriculture can be used to complement, supplement, and replace draft animals, so as to meet various economic, technical and environmental criteria. Increased use of farm machines appears to be desirable for (i) small farms which have shortages of installed mechanical power which cannot be overcome by improving draft animal feed quantity and quality, (ii) irrigation; (iii) meeting power needs not met by draft animals so as to enable increases in cropping intensity.

This conclusion arises in large measure from two considerations. First the efficiency of modern energy sources is far higher than that of the draft animal system. Second, the constraints on land are so severe that it is unlikely that most small farmers could meet the mechanical power requirements by increasing draft animal population.

Our third major conclusion is that increasing the energy output from the present stock of draft animals is a much sounder way than increasing the draft animal population because the marginal efficiency of the improving feed quantity and quality to the existing stock is several times greater than increasing animal numbers. Thus, this approach can provide increases in useful energy output from draft animals with the smallest pressure on land resources. Our analysis indicates that the following should be investigated in more detail to address the problem of increasing the mechanical energy from draft animals on South Asian farms:

1. Increases in feed quantity and quality for existing draft animals, especially during the peak season to take advantage of the high ratio of marginal efficiency to average efficiency of draft animals (in contrast to machines where this ratio is close to 1).
2. Increases in commercial production of high quality feed for existing draft animals, so as to enable the increases discussed in item 1 above.
3. Plantation of mixed forests to increase land availability for fodder production in ways compatible with other needs. This may enable modest increases in farm animal population under some circumstances which may be more economical than farm machines.

Not all of these approaches would be suitable in all areas, of course. There will be climatic or other ecological limitations in some instances. For instance, it may not be possible to grow forests with the desired variety of trees to accommodate multiple uses. The problem of competition between land for food and land for growing high quality feed for draft animals must also be addressed. There is certainly no single solution for all farmers or regions. However, the need for additional power for traction, irrigation, and, in many situations, for post-harvest processing together with the severe nature of land constraints, points in the direction of increasing the efficiency of the use of the present stock of animals. This needs to be complemented with the use of small farm machines in a wide variety of situations.

This approach maximizes the output which the existing system can provide while seeking to improve the overall energy efficiency of agricultural energy use and to provide additional mechanical energy without increasing grazing land requirements substantially. It also meets the needs of limiting methane emissions which are an important environmental concern related to schemes for substantially increasing draft power by increasing draft animal population. Hence land constraints and global environmental considerations both point to increases in the use of modern energy sources. While this means increases in fossil fuel use in the short- and medium-term, the equipment and infrastructure would be compatible with the use of fuels derived from biomass and other forms of solar energy in the long term. Specifically, solar energy can also provide mechanical energy for a wide variety of applications as it becomes commercial. This can include electric farm machines.

The approach of maximizing the power and energy output from the existing farm animal population is needed to take the best advantage of the enormous investment that already exists in the present system. We need not have such a constraint in the long-term, where the combinations of farm animals and farm machines used to meet agricultural mechanical energy requirements could be considerably different even for farmers who depend mainly on animals today.[33]

It is important to note in this context that the primary increases in power availability on farms in South Asia have come from increasing machines, both irrigation pumpsets and tractors. For instance, while the increase of draft animals is generally slower than population, tractors and irrigation pumpsets have grown rapidly. In Pakistan, electric motors and diesel engines grew from about 178,000 in 1978/79 to 225,000 in 1982/83 while tractors went from 76,000 to 91,000.[34] This is in part due to government encouragement of large farm machinery. It is however, also a reflection of the reality of shortages of land and feed for draft animals.

There are a considerable number of practical difficulties facing the approach outlined above. For example, small farmers often do not have enough land to make it practicable to purchase farm machinery and use it economically on their farms alone. A second, related, problem is that poor farmers do not have adequate access to credit.

Increasing the use of oil also increases foreign exchange requirements, which can be a constraint. However, it should be noted here that agricultural use of modern energy sources is only around 10% of total modern energy use, even though 60% or more of the people depend

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33 There may also be some scope in areas with severe land constraints for improving the efficiency of the draft animal system by increasing the proportion of female draft animals. This reduces the number of animals which need to be maintained for the system as a whole, even though females have a smaller power output per animal and may not be suitable for all tasks. See Mathers, et al. for technical details.

34 Qureshi; Table 3.

on agriculture for a living. Thus, the internal allocation of modern energy sources and internal distributional considerations are at least as much of a problem as foreign exchange constraints. *Increasing the efficiency of use of modern energy sources in urban areas even modestly can allow for substantial increases in the amounts of modern fuels available for rural use.*

Another difficulty, noted above, is that the present approaches to mechanization in India and elsewhere have generally emphasized larger tractors. This makes it even more difficult for smaller landowners to take advantage of machines.

Many of these issues can be framed in one question: what package of economic policies is needed to increase the mechanical power available to small farmers so that they can meet their present farming needs and also the need to increase land and labor productivity?

In looking at the problem in this broad way we can make the connection between traction needs for field work, the energy needs for irrigation, and post-harvest energy requirements for activities such as threshing.

One way to solve the various problems facing the increased use of farm machinery on small farms is the use of equipment-hire systems. Since the same equipment can be used on many farms, the total installed horsepower requirements and corresponding total capital requirements are considerably reduced.

Equipment-hire systems have been tried out in a number of different contexts. In fact, they operate without formal public policy input in South Asia. Pingali et al. have pointed out that past experience indicates that successful equipment-hire systems have been private rather than public sector or cooperative sector enterprises.[35] For instance, public sector and cooperative sector enterprises tend to be located in one geographical area, so that the use of equipment is limited. Equipment that is taken from one area to the next for hire can take advantage of seasonal differences, thus maximizing use and reducing per hour costs. A second disadvantage has been that public systems have not provided incentives to operators to work long days during the peak season, which is essential to economizing on the amount of equipment that is needed to service a given land area.

We have not come across any equipment-hire scheme that has been designed explicitly to meet the power needs of small farmers, in situations where they could clearly use more mechanical energy inputs but cannot afford to do so. For instance the considerable class of farmers who now must rent bullocks or who cannot plough their land adequately due to draft power shortages belong in this category.

An approach of creating private equipment-hire enterprises that could meet the needs of such farmers by providing credit to create such enterprises could be married to simultaneous provision of agricultural credit to small farmers with the express purpose of enabling them to make use of such services. This would assure a market for the entrepreneurs without tying them down to a bureaucratic mode of operation, and it would meet the capital needs of small farmers to use the services without having to go to moneylenders.

U.S. Policy

There is an urgent need to incorporate draft animals energy use and land requirements into international statistics on energy and land. This naturally involves the United Nations and its

35 Pingali et al.; Chapter 12.

agencies, which are the prime compilers of such statistics. However, U.N. agencies can only compile the statistics which countries collect. An obvious role for the U.S. would be to provide the financial and technical assistance which many countries would need to collect such data and also to U.N. agencies which would compile and analyze it.

In view of the great importance of increasing draft power on farms from a number of points of view, the various means to do this which are compatible with global environmental protection are another area of interest. As noted, the U.S. Environmental Protection Agency has already prepared a study on the role of ruminants in methane accumulations. That study noted the desirability of improving data on numbers and sizes of animals, their feed intake, and methane emissions.[36] But the study did not consider in any detail the needs for draft power, and how such needs could be met while minimizing methane accumulations in the short-, medium- and long-term. Indeed, there is practically a note of resignation on this score:

> The demand for draft power also has an important influence on animal populations in developing nations, and many of these are used for draft power. An increasing human population will likely increase the need for draft power, while mechanization could reduce the demand for animal draft power. However, the costs of equipment, maintenance, and fuel limit the potential impact that mechanization will have in the short term.[37]

Whether this rather pessimistic conclusion is warranted can only be determined after a more definitive study. But it is clear even at present that draft power shortages already exist, and that these shortages can be addressed by a variety of means, many of which have been discussed here.

The modern fuel requirements of farm machines are not great compared to the use of fossil fuels even in Third World countries. Further, the marginal efficiency of existing cattle use of improved feed is high. These two facts alone give more room for hope that an adequately designed program, well targeted to the potential beneficiaries could go a considerable distance in meeting draft power needs, and improving land and labor productivity within broad environmental constraints.

Finally, an adequate program that addresses short-term needs could create the long-term potential for using a considerable amount of the output of crop residues and other non-food biomass in modern conversion facilities. This would greatly improve both the efficiency of rural energy use and the availability of useful energy to meet the diverse energy needs of agriculture and other areas in the rural Third World.

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36 Gibbs et al; p. 31.

37 Gibbs et al; p. 30.

Appendix:
Land Use Data

Table A-1
LAND USE IN BANGLADESH

CATEGORY	1972 (1000 ha)	1987 (1000 ha)
Total Area	14,400	14,400
Arable and Permanent Crop	9,112	9,164
Permanent Pasture	600	600
Forests and Woodland	2,229	2,115
Other (wasteland, parks etc)	1,450	1,512

Source: FAO Production Yearbook 1988.

Table A-2
LAND USE IN NEPAL

CATEGORY	1972 (1000 ha)	1987 (1000 ha)
Total Area	14,080	14,080
Arable and Permanent Crop	2,082	2,339
Permanent Pasture	1,700	1,990
Forests and Woodland	2,340	2,308
Other (wasteland, parks etc)	7,558	7,043

Source: FAO Production Yearbook 1988.

Table A-3
LAND USE IN PAKISTAN

CATEGORY	1972 (1000 ha)	1987 (1000 ha)
Total Area	79,610	79,610
Arable and Permanent Crop	19,109	20,760
Permanent Pasture	5,000	5,000
Forests and Woodland	2,768	3,140
Other (wasteland, parks etc)	50,211	48,188

Source: FAO Production Yearbook 1988.

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