ENERGY FOR AGRICULTURE IN PAKISTAN

Muhammad Jameel
International Institute for Applied Systems Analysis, Laxenburg, Austria

RR-82-20
May 1982

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria

International Standard Book Number 3-7045-0040-2

Research Reports, which record research conducted at IIASA, are independently reviewed before publication. However, the views and opinions they express are not necessarily those of the Institute or the National Member Organizations that support it.

FOREWORD

The unique contribution of energy to human civilization lies in its having enabled Man to intensify his activities in time and in space – the two ultimate limiting dimensions of human endeavor. Agriculture has benefited in both dimensions: supplementary energy makes it possible to produce more from a given piece of land and to grow more crops within a given time interval. The dramatic increase in the world's population over past decades has thus been supported by a much slower increase in the amount of land cultivated.

In many developing countries, particularly in Southeast Asia, arable land cannot be expanded much further without incurring disproportionate costs. Intensification of agriculture has thus become imperative, in which energy – directly and indirectly – plays an important role.

Since the International Institute for Applied Systems Analysis is conducting major research programs dealing with both energy and agriculture (the former investigating the issues of world energy supply and demand looking 50 years into the future, the latter examining the adequacy of potential food supplies to meet present and future demands), the future of the involvement of energy in food production has also been investigated, and this report is one product of this line of thought.

Will it be practicable to feed and clothe the increased world population in, say, the year 2000? This report presents a method for looking into this question, and examines one particular country, Pakistan, in detail. Several scenarios with different combinations of agricultural technologies are developed and the energy implications of each are discussed quantitatively. Notwithstanding the possible and indeed desirable efforts at conserving major commercial energy inputs into the agricultural system, the report concludes that it will take considerably more direct and indirect energy per hectare of cultivated land in order to achieve the productivity required to meet the needs of the population by the turn of the century.

WOLFGANG SASSIN
Acting Leader
Energy Systems Group

CONTENTS

ENERGY FOR AGRICULTURE IN PAKISTAN

Muhammad Jameel
International Institute for Applied Systems Analysis, Laxenburg, Austria

SUMMARY

Traditional agriculture relies heavily on animal energy, i.e. bullocks or horses to till the land and to draw water; men for seeding and harvesting; dung for manure, and so on. The productivity of this mode of agriculture, in terms of yield per hectare per year, is proving insufficient to support the growing world population. Fortunately, the introduction of high-yield and early maturing varieties of crops have made it possible to enhance land productivity substantially, but at a cost: heavy applications of chemical fertilizers, pumps to draw underground water, mechanization to help multi-cropping, etc. All these measures require, directly or indirectly, energy from oil, gas, or electricity. With sharply rising fuel prices, it is of interest to examine the use of energy in agriculture, as in other sectors of economy.

A large number of studies have been performed to assess the energy requirements of agriculture in different countries using various agricultural practices. This report is also a step in the same direction: it analyzes energy use in agriculture at present and attempts to project its evolution to the year 2000. The perception of future is aided by a scenario approach: three different development paths for farm mechanization and two for the supply of macronutrients are considered. The energy implications of each "future" are examined in detail.

The results show that the present expenditure of commercial energy goes almost entirely into the production of fertilizers and for irrigation/drainage, the former accounting for approximately 45%, and the latter for 40% of total primary energy input to agriculture; the remainder is shared by tractors, threshers and pesticides. For the year 2000, energy data for the different scenarios are presented, but the major share will again be taken by fertilizers, followed by irrigation and drainage. The greatest savings in energy are therefore also to be effected if the use of chemical fertilizers is reduced, and if water resources are conserved. These measures should however be taken in ways that do not adversely affect agricultural productivity.

1 INTRODUCTION

For proper growth and good yields, plants need suitable environments (almost invariably soil), prescribed movements within narrowly defined times of the year (hoeing, sowing, cutting, etc.), water (from rainfall, canals, wells), nutrients (particularly nitrogen), sunlight, carbon dioxide, and help in reducing competing organisms (through the use of herbicides, insecticides, etc.). Among these, sunlight and carbon dioxide are abundantly available and are not considered limiting factors in most situations. What agricultural man has to think about are land, labor (aided by animals and machines to varying degrees), water, fertilizers, seeds, and pesticides. Each of these inputs has a common physical denominator – energy. People and animals need energy for maintenance and work; machines require energy to be produced and operated. Water, fertilizers, pesticides, etc., all require primary energy inputs in one form or another.

This study aims to assess this common denominator of agricultural activity in a developing country at the end of the 1970s and at the turn of the century. The approach adopted for looking into the future is a bottom-up one, viz:

(i) to examine existing nutritional conditions and to project their evolution over time;
(ii) to assess the implications of the future nutritional intake in terms of required levels of production of various agricultural commodities;
(iii) to translate these production levels into input requirements according to various technological or economic options; and finally
(iv) to aggregate the energy equivalents of the various inputs.

The main question addressed in this report is therefore: What are the energy requirements implied by the need to provide a reference average diet to the people of Pakistan in the year 2000 under different scenario assumptions related to the degree of mechanization, fertilizer application, and other similar parameters? Given this objective, attention is focused on the physical inputs necessary to produce the estimated quantities of wheat, rice, milk, etc., which will be required in the year 2000. Economic, cultural, and social issues, though important, are only indicated in context, and no attempts is made to anticipate their probable resolution. Instead, the technological choices that society might make, either freely or under socioeconomic pressures, are reflected in the different scenarios whose energy implications are examined. No particular "future" is singled out as desirable or probable, although the principal characteristics of each are indicated.

End-use estimates are made, wherever possible, in contrast to the more widely used "demand projections" based essentially on a judgmental extrapolation of past trends. For a developing country, the planning process ought to begin with an assessment of actual societal needs, and should then proceed to a formulation of means to approach their fulfilment coherently and expeditiously. For this purpose, the patterns of the past are not always useful guidelines at all, and might in fact lead to unbalanced development. Of course, the projected growth rates of different activities that emerge from end-use considerations should be viewed against the corresponding historical data in order to ensure that national effort is directed to the areas where it is needed most. This briefly is the raison for the methodology used in this work.

2 ASSESSMENT OF FOOD REQUIREMENTS

An agricultural system is assumed to have the following functions:

(1) to feed the growing population with a balanced diet, i.e. adequate quantities of carbohydrates, proteins, fats, minerals, and vitamins;
(2) to provide raw materials such as cotton for industry; and
(3) to generate an export surplus.

Let us first look at the primary objective of agriculture – the production of adequate food supplies for the population. For comparison, the food consumption patterns of Pakistan and a few other selected countries/regions are presented in Table 1. Since the intake of minerals and vitamins is strongly dependent upon dietary habits, cooking practices, etc., and also because the minute quantities normally required to not pose any *production* problem, attention is focused on energy*, protein, and fat.

TABLE 1 Food consumption patterns of selected countries.

	Intake per capita per day (1975–77)				
	Energy	Protein (g)		Fat (g)	
Country/region	(kcal)	Vegetable	Animal	Vegetable	Animal
India	1949	43.2	5.2	22.4	7.0
Pakistan	2255	46.3	15.6	22.0	19.4
Africa	2308	46.7	12.0	32.4	10.9
Japan	2847	44.6	41.8	37.0	35.3
Western Europe	3378	41.0	53.2	48.4	89.7
North America	3519	33.7	72.0	62.3	100.0

SOURCE: FAO (1980).

The quantities in Table 1 are averages for whole populations. In developing countries, however, nutritional deficiency is further aggravated by inequitable food distributions among the various segments of society, as has been described in a number of studies such as that of Muhammad *et al.* (1976). The discussion of maldistribution, however, is beyond the scope of this report, which seeks to quantify the physical inputs required to meet *total* production targets, a necessary though not sufficient condition for attaining adequate nutritional levels for everyone.

With the above caveat, we note from Table 1 that while the energy and vegetable protein intakes are comparable, there is a wide disparity in the consumption of animal products. It may be argued that the North American dietary pattern is wasteful and even unhealthy, but there can be little doubt that the diet of the average Pakistani is deficient in animal protein. The average nutritional requirement of a "normal healthy person" has

*In literature on nutrition, the term "food calorie" is sometimes used to designate 1000 calories. In this study, we adhere to the usage in physical sciences, i.e. a calorie is the amount of energy required to raise the temperature of 1 g of water through 1 °C.

TABLE 2 Average daily human nutritional needs.

Source/country	Energy need (kcal)				Protein need (g)			
	Child (10 yr)	Adult male (30 yr)	Adult female (30 yr)	Pregnant or lactating	Child (10 yr)	Adult male (30 yr)	Adult female (30 yr)	Pregnant or lactating
US Food and Nutrition Board	2400	2700	2000	2400	36	56	46	70
UK Department of Health and Social Security	2400	3000	2200	2550	60	75	55	65
UN Food and Agriculture Organization[a]		3200	2300			46	39	
Central America[a]		2700	2000			65	60	
German Democratic Republic		2700	2300			85	75	
India		2800	2300			55	45	
Philippines		2400	1800			53	46	

[a]Age of adults is specified as 25 years.
SOURCE: Burton (1976).

been the subject of many studies, but no absolute figures can be quoted because of the variety of factors that must be taken into account, such as age, sex, body weight, climate, occupational activity, etc. A typical spread of requirements, worked out in different countries and by different organizations, is displayed in Table 2.

Despite considerable variations, the average adult needs are taken here to be 2900 kcal and 65 g of protein for a male; 2200 kcal and 50 g of protein for a female (with an extra allowance during pregnancy and lactation); and for a ten-year-old child 2400 kcal and 50 g of protein. Assuming that the population of Pakistan in the year 2000 will have about the same age and sex distribution as in the base year (1977), and by adding a margin to cover pregnancy and lactation, we arrive at the following average per capita requirements for the whole population:

energy: 2500 kcal/day
protein: 60 g/day

Allowing for possible losses in cooking and the low nutritional value of vegetable protein (if not properly balanced with respect to the required amino acids), 2600 kcal and 75 g of protein at the kitchen door can be considered a reasonable and realistic target for the year 2000. These are average figures for the whole of Pakistan, but if maldistribution still persists, substantial segments of the population will remain undernourished. However, these projections do anticipate significant overall improvements in national nutrition after 1977.

3 PRODUCTION REQUIRED FOR DIRECT HUMAN CONSUMPTION

In order to translate the nutritional requirements given in Section 2 into the production targets of specific commodities we look at how the food requirements have been

TABLE 3 Nutritional composition of various foods.

Commodity	Remarks	Energy content (kcal kg^{-1})	Protein content (% by weight)	
			Vegetable	Animal
Wheat flour	4/5 of field produce appears as edible flour	3600	11.5	
Rice (milled)	5/6 of field produce appears as milled grain	3600	7.5	
Maize		3500	8	
Other grain	Average values	3300	7	
Pulses	Average values	3400	22	
Vegetable oil		8800		
Refined sugar	Sugar cane processed yields 8.5% by weight of refined white sugar	3900		
Milk, fluid	1/5 is fed to calves or wasted	650		3.5
Milk, dried		6500		35
Beef/mutton (average cut)	1/5 of carcass weight is waste	2600		15
Fish	1/10 is waste	1300		18
Poultry meat	1/10 of dressed bird is waste	1300		12
Eggs	1/10 is waste	1400		11

SOURCES: McGraw-Hill (1977), PARC (1980), and Woolley (1977).

met in the recent past. Table 3 displays the nutritional content of the major food items consumed in Pakistan, as well as the losses that are inevitably incurred. Table 4 presents a breakdown of the food supply (per capita per day) for 1967–2000 in the convenient form of "percentage calorie vectors" and "percentage protein vectors"; e.g. for every 100 kcal consumed, 44 are contributed by wheat, 12 by rice, 15 by sugar, etc.

During 1967–77, for which available data have been analyzed, the calorie and protein vectors exhibited a remarkable stability despite a 28% increase in GNP per capita, and a 10% (9%) increase in the calorie (protein) intake per capita over the period. This has led us to respect the resilience of popular taste; hence the figures presented for the year 2000 in Table 4, except for the somewhat enhanced role of poultry products which is expected on other grounds. These values enable us to estimate the production levels of major commodities required *for direct human consumption* using a projected population of Pakistan of 139 million (World Bank 1979); those for other items such as pulses and coarse grains have been calculated by balancing the residual needs for vegetable protein, calories, etc. The results of this exercise are presented in Table 5; the requirements for animal feed and export are discussed in the following sections.

4 ANIMAL FEED REQUIREMENTS

4.1 Cattle and Sheep

Substantial increases in milk and meat production are expected over the next two decades, both to satisfy the domestic demand, and perhaps also to establish an export

TABLE 4 GNP and food supply per capita: Pakistan 1967–2000.

		1967	1970	1973	1977	Envisaged for the year 2000	Comments
GNP/cap (rupees, 1960)		490	526	567	625	1095	Trend extrapolated to the year 2000
Food supply/cap/day:							
Energy (kcal)		2045	2226	2205	2255	2600	See Section 2
calorie vector (%)	wheat	42	44	47	45	45	See Section 3
	rice	12	12	10	10	10	"
	sugar	17	15	14	16	15	"
	milk		8	8	8		See protein vector
	others						
Protein (g)		56.9	60	60.7	62	75	See Section 2
protein vector (%)	vegetable	74.5	76	77	75	74	See Section 3
	animal	25.5	24	23	25	26	"
animal protein vector (%)	milk		62	61	60	57	"
	red meat		19.5	19	20	22	"
	fish		6	8	8	10	"
	poultry		1.6	2	2.4	6	"
	others						

SOURCES: Past data derived from FAO (1980), Agricultural Statistics of Pakistan (1978); projections by the author.

TABLE 5 Food supply for direct human consumption in the year 2000.

Commodity	Energy (10^{12} kcal)	Protein (10^3 t) Vegetable	Protein (10^3 t) Animal	Quantity needed for consumption (10^6 t)	Production requirement implied (10^6 t)
Wheat	59.4	1900		16.5 (flour)	20.6
Rice	13.2	275		3.7 (milled)	4.4
Maize (50% direct human)	2.1	50		0.6	1.2
Other grains (50% direct human)	1.3	30		0.4	0.8
Pulses	6.2	400		1.8	1.9
Sugar cane	19.8			5.0 (sugar equivalent)	60
Vegetable oil	10			1.2	
Milk (fluid equivalent)	10.7		580	16.5	20.6
Red meat	3.9		225	1.5	1.85 (carcass)
Fish	0.7		100	0.56	0.63
Poultry meat	0.2		20	0.17	0.19 (dressed)
Eggs	0.5		40	0.37	0.41

surplus. In fact, one might think of a country's cattle as a virtually "renewable" energy source on a local scale, e.g., exporting meat to buy oil! Indeed, this has quite favorable commercial energy economics (see Appendix), the secret being to let the ruminant do the value-adding. However, the quality of meat presently available in Pakistan would not be acceptable internationally, so that organized cattle farming needs to be developed with improved breeds. This new industry would take the usual penetration time and, with vigorous methods of persuasion and state initiative, Pakistan could expect an export potential of about 10% of domestic market by the year 2000.

To quantify these considerations, it is assumed that, in addition to the domestic requirement of 1.85 × 10^6 t carcass weight, 0.15 × 10^6 t could be exported, giving a total of 2.0 × 10^6 t of carcass to be produced annually. A breakdown of meat produced in 1977 (Agricultural Statistics of Pakistan 1978) shows that about 53% was from large animals (cattle, buffaloes) and 47% from small animals (sheep, goats); among the large animals, buffaloes and cattle contributed half of the meat each. The average weight of a carcass is about 11.5 kg for small animals, 82 kg for buffaloes and 114 kg for cattle, the lower figure for buffaloes being due to a tendency to slaughter young males. The annual offtake rate is about 50% of the total population of small animals, 10% for cattle, and 19% for buffaloes.

For small animals, no significant organized improvements are being made at present, nor planned for the future, so that no change in either average carcass weight or offtake rate is assumed. For large animals, however, there should be an increase in both indices as a result of better feeding and improved management. The following average figures are projected for the year 2000 in the light of present practices and existing interest in cattle breeding techniques.

	Average carcass weight (kg)	Offtake rate (%)
Buffaloes	100	30
Farm cattle (fattened)	200	100
Other cattle	140	15

It is further assumed that economic pressures will reduce the relative consumption of "small meat" from the present 47% to about 40% by the year 2000. With these assumptions in mind, the projected populations of small and large animals in the year 2000 are presented in Table 6.

It can be seen from Table 6 that the projected annual growth rate of buffaloes needed over the next 20 years is much higher than the rate achieved in 1971–76. Sustained effort is obviously required. In this report, however, we are concerned with the assessment of the necessary *physical* inputs, so we can assume that this effort will be made, and proceed to estimate the feed requirements of these animals.

TABLE 6 Actual and projected animal populations of Pakistan.

	Base year 1977 (10^6)	Year 2000 (10^6)	Projected annual growth rate (%)	Historical annual growth rate, 1971–76 (%)
Sheep and goats	48	130	4.4	8.6
Buffaloes	11	25	3.6	2.1
Farm cattle	0	1	–	–
Other cattle	15	17	0.5	0.3

SOURCE: Past data from Agricultural Statistics of Pakistan (1978); projections by the author.

An economical and manageable size for a cattle farm is about 500–1000 head (Williams *et al.* 1975), so about 3000–6000 such farms will need to be established by the year 2000, preferably located near a railway or road network for rapid transportation to ports or domestic consumption centers. In addition to hay, crop residues and other green fodder, the farm animals should be fed some fattening grain such as corn, preferably grown on the farms themselves. It is estimated (Williams *et al.* 1975) that cattle convert about 15% of the feed energy into meat. Using the calorific values of meat and maize, and assuming that corn grain supplies one-third of the total feed energy, an amount of 0.3×10^6 t of maize will be required as feed for farm cattle.

For off-farm sheep, cattle, and buffaloes, however, maize cropping, which requires both irrigation and fertilizers, may not be practicable. However, a new variety of grain called *triticale* (triticum = wheat + secale = rye) has been developed which has the grain qualities of wheat and the hardiness of rye. It can grow in dry areas and without much artificial fertilizer. While it may not yet be acceptable for human consumption, it is an excellent crop for pasture lands and provides a protein-rich grain supplement to hay and other fodder. Research on triticale is already under way in Pakistan (Naqvi 1980), and it should prove valuable in increasing the body weight (and so carcass weight) of sheep, cattle, and buffaloes reared on rangeland. It is assumed that the feed requirements of these animals will be met, as at present, by grazing and fodder grown on marginal land.

So far, the meat requirements have been discussed and attention is now turned to milk. Base year statistics (Agricultural Statistics of Pakistan 1978) indicate that 16% of the total cattle population and 33% of the total buffalo population is in milk, the average yield being 1630 kg yr^{-1} for cows. Figures for sheep and goats are not available, but from other data a whole population average of 10 kg yr^{-1} per animal may be inferred. The annual milk production from the animal populations shown in Table 6 would then be as follows:

Sheep/goats	1.3×10^6 t
Buffaloes	13.4×10^6 t
Cows	2.4×10^6 t
Total	17.1×10^6 t

This falls short of the anticipated milk demand by about 17%, so that organized dairy farming (with more productive buffaloes) and possibly some imports will also be needed. The maize feed of dairy animals is estimated at 0.9×10^6 t by using a figure of 11.5% for the conversion efficiency (Williams *et al.* 1975) from feed energy to milk calories, assuming that maize supplies 33% of the energy and that half of the milk shortfall will be met by imports. In total, therefore, 1.2×10^6 t of maize will have to be grown annually for animal feed by the year 2000.

4.2 Poultry

While ruminants can digest and convert roughage and cellulose, which are of no use to humans, poultry have to be fed grains and fish concentrates and thus, in some respects, compete with humans for food. However, they are more efficient converters of feed and, in any case, this is mostly obtained from broken grains and other unusable material inevitably produced during the milling of rice and grinding of wheat. The figures used in this report (see Table 3) are about 20% for wheat and 16% for rice, including about 5% for seed. Since there is always some waste which cannot be used for feed, it can be assumed that 8% of rice and 10% of wheat produced are potentially available for feed, of which roughly 75% may be allotted to poultry. Using the relevant production estimates from Table 5, it is expected that 1.6×10^6 t of "waste" from wheat and about 0.3×10^6 t from rice could be available for poultry feed; to this may be added 0.2×10^6 t from other grains, making a total of 2.1×10^6 t.

It is estimated (Holmes 1977, USNAS 1977) that broilers and layers require an amount of feed about 2.5 times the weight of dressed meat or eggs yielded. Since we have projected (Table 5) an annual requirement of 0.6×10^6 t of poultry produce by the year 2000, about 1.5×10^6 t of feed will be required, of which about 10% (0.15×10^6 t) could come from fish meal. Thus grain waste will be sufficient to meet poultry feed requirements.

4.3 Fish

The production of fish in 1977 was about 0.233×10^6 t of marine and 0.033×10^6 t of freshwater fish. The marine fish catch is very poor considering the length of coastline of over 1000 km. In contrast, another Asian country, Thailand, which has 3000 km of coastline, landed as much as 2.2×10^6 t of marine fish. Baluchistan, which has the major share of coastline, contributed less than a third of the total marine catch. Attention is now being given to the promotion of both freshwater and marine fisheries, the latter particularly along the Mekran coast. Considering the present low level of productivity, it should not be too difficult to raise the catch over the next two decades to the 0.8×10^6 t required for human consumption and fishmeal preparation. The finance required will be a small proportion of national resources, and the purchase of modern trawlers could easily be financed under an existing loan scheme of the Agricultural Development Bank of Pakistan. Surprisingly the share taken by fisheries *dropped* (Agricultural Statistics of Pakistan 1978) from 3.7% of the total credit granted in 1976–77 to 0.5% in 1977–78. Active promotion of the industry is therefore indicated, and there do not appear to be any physical limitations to growth.

Estimates of energy required for fishing vary widely (Leach 1975, Bardach 1980), depending upon country and the type of fishing, such as deep-sea or not, size of trawlers, etc. Assuming half the US average energy consumption per tonne of fish caught (Leach 1975) as nearly appropriate for Pakistan in the year 2000, we arrive at a requirement of 0.6×10^6 t of oil.

5 TOTAL PRODUCTION TARGET

In order to arrive at a total agricultural production target, we will now proceed to estimate the requirements of plant-derived material for industry and export. The major agricultural exports, by value, are rice and cotton; carpets are also agriculturally based but the requirements are assumed to be met by the sheep population. Sugar cane supplies industry, but that has been taken into account. The remaining items are rice (for export), cotton (for domestic industry and export), oilseeds, fruits, and vegetables.

5.1 Rice for Export

In 1977, the base year, 0.9×10^6 t of rice were exported, i.e. roughly 30% of total produced. With active export promotion, perhaps roughly the same percentage may be maintained, so that an annual export of about 1.8×10^6 t of rice by the year 2000 can be expected.

5.2 Cotton

The domestic requirement for textiles may be expected to increase rapidly, but the effect is likely to be offset by a decrease in exports as competition becomes more rigorous. Thus, it might not be prudent, even if it were possible, to plan for an increase in cotton production by more than 60% by the year 2000. Even that would require an annual growth rate higher than the average achieved in 1970–77. The target annual production is then 0.8×10^6 t of cotton lint by the year 2000.

5.3 Oilseeds

The principal oilseeds grown in Pakistan are cotton-seed, rape/mustard, ground nuts, etc. The quantities produced at present are not sufficient to meet domestic requirements, so that nearly 0.35×10^6 t of edible oil (a little more than half of which is soybean and the rest palm oil) have to be imported. Some substitution of palm oil could perhaps be made by sunflower oil, but not to any significant degree. It would be fruitful to make an effort to increase public acceptance of rape/mustard oil by necessary deodorization but without hydrogenation, and we therefore anticipate an increase in rape/mustard production from about 0.24×10^6 t in 1977 to 800,000 t in the year 2000. Having an oil content of 40%, this would then meet about 30% of the projected vegetable oil requirements. Other minor oilseeds will not be considered separately; their input requirements will be included by an *effective* increase in rapeseed production to 0.9×10^6 t.

5.4 Fruits and Vegetables

Fruits are "permanent" crops and do not require tilling, sowing, or fertilizers every year. They are also capable of obtaining their own water requirements from the ground although under Pakistan's conditions, the water needs to be supplemented by some irrigation. More orchards need to be planted in order to meet domestic demand and possibly to generate an export surplus. The area under fruit crops is therefore expected to double by the year 2000, i.e. an increase of 0.25×10^6 ha.

Vegetables occupy less than 0.15×10^6 ha of land, and are usually grown on any available ground in villages or around towns. They do require good land and a lot of care but do not contribute significantly to commercial energy input requirements.

Neither fruits nor vegetables are therefore considered as a separate category, so that any energy requirement is assumed to be included in a an aggregate increase of the final total.

5.5 Total Requirements

Direct human needs, animal feeds, industrial, and export needs are all added together and presented in Table 7. Note that since the feed requirements of cattle and poultry have been incorporated in agricultural crops, meat, milk, etc., they are no longer presented separately.

TABLE 7 Annual agricultural production of Pakistan (actual 1977 and targeted 2000).

Commodity	Production in base year, 1977 (10^3 t)	Production in year 2000 (10^3 t)	Annual growth rate (%)	
			Projected	Historical
Wheat	8750	21,000	3.9	4.0 (25-yr av.)
Rice	2840	6200	3.5	5.4 "
Maize	790	2600	5.3	2.8 "
Other grains	710	1000	1.4	2.4 "
Pulses	830	1900	3.6	1.2 (10-yr av.)
Sugar cane	30,000	60,000	3.0	3.0 "
Oilseeds (rape/mustard equivalent, excl. cotton seed	350	900	4.2	1.9 "
Cotton	500	800	2.1	1.0 "
Fish	267	1000	5.9	6.2 (8-yr av.)
Fruits and vegetables	1700	Not projected separately		

SOURCE: Base year production figures taken from Agricultural Statistics of Pakistan (1978); average for year 1976–77 and 1977–78 has been calculated where applicable. Projections are by the author. Historical growth rates derived from PARC (1980) and from Agricultural Statistics of Pakistan (1978).

In order to meet the production targets indicated in Table 7, there are three distinct ways to tackle the problem:

(i) to increase the physical size of the areas cultivated;
(ii) to increase the cropping intensity by bringing a greater proportion of the cultivated area under multi-cropping;
(iii) to increase the yield per unit area.

A glance at the production targets shows that reliance on alternative (i) alone is out of the question; this would require roughly three times the base year area, which is simply not available. Emphasis will therefore have to be placed upon the last two courses of action, i.e. to increase the effective *cropped* area and to improve yields through better farm management and higher inputs of water, fertilizer, pesticides, etc. Physical inputs are considered in detail below, but it must be stressed that the improvement of crop practices is equally important, including (a) more careful preparation of land; (b) the maintenance of recommended seeding densities; (c) timely applications of water and fertilizers; (d) regular weeding; (e) ensuring proper plant spacing, etc. These measures are a matter of training, care, attention, and somewhat increased labor, and could increase productivity levels even *without* additional commercial inputs. This message must be effectively carried down literally to the grass roots; without better agricultural practices, the 'green revolution' will not have the desired results and may even have a *negative* effect. For example, if a field has not been weeded, the fertilizers will provide nourishment to the weeds which would compete with the food crop more effectively than before!

With these few words on the importance of better farm management, we can now proceed to the main task of this report, i.e. the estimation of the physical inputs and their energy equivalents. We start with the consideration of land requirements.

6 LAND REQUIREMENTS

The evolution of land utilization in Pakistan over the six-year period 1971–77 is presented in Table 8. It can be seen that whle the total cultivated area increased only marginally, the area multi-cropped registered an average growth rate of 6% per year; this is the right trend and should be encouraged. The distribution of areas under different crops, and the changes needed over the next two decades, are discussed below.

TABLE 8 Evolution of land use in Pakistan, 1971–77.

	1971	1973	1975	1977	Average annual growth rate 1971–77 (%)
(1) Estimated total arable land (10^6 ha)	30.3	30.4	30.6	30.6	
(2) Actually under cultivation (10^6 ha)	19.1	19.3	19.7	19.9	1
(2a) Of which fallow (% of 2)	25	24	24	24	
(2b) Of which irrigated (% of 2)	68	69	68	69	
(3) Area sown more than once (10^6 ha)	2.3	3.0	2.8	3.2	6
(4) Total cropped area (2 – 2a + 3) (10^6 ha)	16.6	17.6	17.7	18.3	2

SOURCE: Agricultural Statistics of Pakistan (1978).

6.1 Wheat

The area under wheat increased from about 4.1×10^6 ha in 1950–55, to 6.3×10^6 ha in 1975–79 (PARC 1980), i.e. an increase of a little over 50% in 25 years. However, over the period 1977–2000, it is unrealistic to predict an equal increase in area because any new land available will naturally be less accessible and more difficult to bring under cultivation. One possible and logical step would be to bring some of the presently unirrigated land under irrigation in addition to opening up new areas. It is thus assumed that by the year 2000, the irrigated area will increase by 33% and that the unirrigated area will *decrease* by 25%, giving a net increase of only 1.2 X 10^6 ha under cultivation; the implications of this projection will now be discussed.

The 1977 yields of wheat reached 1700 kg ha^{-1} on irrigated and 640 kg ha^{-1} on unirrigated land. Although the high-yield varieties of wheat give best results with ample water, we can anticipate an increased yield on unirrigated land, say to 1000 kg ha^{-1}. The rest of the requirement will have to be met from high-yield varieties grown on irrigated land. The situation is summarized in Table 9.

TABLE 9 Wheat: area, total production, and yields in Pakistan.

	1977		2000		% increase	
	Irrigated	Unirrigated	Irrigated	Unirrigated	Irrigated	Unirrigated
Area (10^6 ha)	4.8	1.6	6.4	1.2	1.2	(–) 0.8
Total production (10^6 t)	8.1	1.0	19.8	1.2	4.0	0.8
Yield (kg ha^{-1})	1700	640	3100	1000	2600	2000

It can be seen that the average yield of irrigated land must increase to about 3100 kg ha^{-1} by the year 2000. This is by no means an unattainable target (the *present* figures for Mexico, France, and the UK being 3500, 5000, and 5100 kg ha^{-1} respectively; FAO 1979), but will doubtless require better land management and higher inputs of fertilizers, etc. Much higher productivities have been achieved in 55 demonstration farms (Muhammad 1978); the national average yield (duly weighted with the area contributing to wheat in each district) obtained was 4165 kg ha^{-1} on irrigated land (with application of 135 kg ha^{-1} of nitrogen and 67.4 kg ha^{-1} of phosphate) and 2305 kg ha^{-1} on unirrigated land (with application of 55.6 kg ha^{-1} of nitrogen and of phosphate). The yields achieved on demonstration farms are often much higher than national averages, and serve to illustrate the productivity *potential* of the land. The yields envisaged here, both for irrigated and unirrigated land, are therefore well within the domain of feasibility, provided adequate inputs, particularly of fertilizers, are supplied. Other inputs will be discussed separately below.

6.2 Rice

The production target for rice in the year 2000 is 6.2 X 10^6 t as compared with 2.9 X 10^6 t in 1977. The main varieties grown are the aromatic Basmati and the high-yield IRRI, the former being the favored export variety. Therefore, while the production of Basmati, even with its lower yield potential, must continue to be encouraged, efforts should also be made to extent IRRI almost exclusively to other areas. It should therefore be possible to meet the target without a large increase in crop area and with modest increases in the yield of non-IRRI varieties. This rather low target for rice is assumed

TABLE 10 Rice production in Pakistan.

	Base year, 1977[a]				Year 2000				% Annual increase of totals
	Basmati	IRRI	Other	Total	Basmati	IRRI	Other	Total	
Area cropped (10^6 ha)	0.52	0.76	0.54	1.82	0.8	1.5	0.12	2.42	1.2
Total produced (10^6 t)	0.61	1.5	0.74	2.85	1.4	4.6	0.2	6.2	3.4
Yield (kg ha^{-1})	1200	2000	1400	1570	1700	3050	1700	2560	2.2

[a]Average of 1976–77 and 1977–78.
SOURCE: Agricultural Statistics of Pakistan (1978).

because it is, and is likely to remain, a crop of secondary importance relative to wheat. Table 10 presents the projected area increases required to meet the demand. It is hoped that a doubling of the area under IRRI will be accompanied by a 50% increase in that producing Basmati, with a reduction in the cropping of other varieties. Marginal increases in yields per hectare of non-IRRI rice are expected; the yield of IRRI will need to be increased by a little more than 50% to 3050 kg ha^{-1} using more and better applied fertilizers. For comparison, the average rice yield in Japan is over 6000 kg ha^{-1}, and in the US and Egypt about 5000 kg ha^{-1}.

The total increase in cropped area should be 0.6 $\times$ 10^6ha, of which half may be assumed to be double-cropped with wheat so that only 0.3 $\times$ 10^6ha of virgin land would need to be brought under cultivation.

6.3 Maize and Other Grains

A substantial increase in maize production over base year production is anticipated, mainly due to its use as fattening feed for farm cattle. The production requirement can be met by increasing the irrigated area to 0.7 $\times$ 10^6ha with an average yield of 3400 kg ha^{-1} (the corresponding figure in the US in the late 1970s being around 5000 kg ha^{-1}). The unirrigated area may be maintained at its present level, but yields should be increased from about 750 to 1100 kg ha^{-1} through better techniques and more extensive use of fertilizers. Since maize needs a lot of nutrition, it is not advisable to double-crop it with another major crop, but preferably with legumes, partly for human consumption and partly to be ploughed under as green manure.

The anticipated increase in production of other minor grains is not great, and this could be met by the acquisition of an additional 0.1–0.2 $\times$ 10^6ha of semi-arid land, possibly in Baluchistan. No appreciable commercial energy inputs will be required, except perhaps for the installation of some scattered tube-wells.

6.4 Sugar Cane

Over the ten years 1967–77, sugar cane production increased at an average annual rate of 3%, solely due to an increase in the area cropped. This trend cannot continue indefinitely, however, but the yield should also be increased. It is therefore assumed that by the year 2000 the yield will improve by about 50% to 55 t ha^{-1}, which is roughly the present Indian production level, but far below that of Egypt or the US. The total cultivated area required will then be 0.95 X 10^6 ha, i.e. just 0.15 X 10^6 ha more than in 1977.

6.5 Cotton

Here again, there is considerable scope for an increase in yield and we shall assume an increase of 60% over the projection period, so that the entire additional demand could be met without any further increase in area. The target cotton lint yield is 430 kg ha^{-1}, compared with Egypt's 680 kg ha^{-1} and Mexico's 900 kg ha^{-1}, figures achieved in the 1970s.

6.6 Fruit Orchards

An increase of about 0.25 X 10^6 ha under fruit orchards is required, which could be partly irrigated and partly rain-fed.

6.7 Overall Land Requirements

Pulses and rapeseed would mostly be double-cropped with major crops and so would not contribute to additional land requirements. Water and fertilizers would be needed, but to a much lesser extent than for the major crops; e.g. the optimum water requirement for rapeseed is about 0.3 ha-m ha^{-1} and pulses would need little, if any, nitrogenous fertilizer. The total additional land requirements are summarized in Table 11.

From Table 11 it can be seen that a rather modest increase in cultivated area will be sufficient to meet the production targets, provided water, fertilizer, etc., are supplied in adequate quantities for increasing the specific yields. The energy requirements for clearing this land, spread over 23 years, will be a small fraction of the total energy spent

TABLE 11 Land requirements for major crops (10^6 ha).

Crops	Cropped area in base year, 1977		Additional area by year 2000		
			Virgin land		Multi-cropped (irrigated)
	Irrigated	Unirrigated	Irrigated	Unirrigated	
Wheat	4.8	1.6	1.6	(–)0.4	
Rice	1.8	0.03	0.3		0.3
Maize	0.44	0.2	0.26		
Coarse grains	1.3			0.2	
Sugar cane	0.8		0.15		
Cotton	1.8				
Pulses and oilseeds	2.0				1.0
Fruits	0.25		0.1	0.15	
Total (major crops)	16.0		2.4	~0	1.3

in tilling, etc., during that period and is assumed to be included in the final aggregate increase. With regard to investment, the major share will be spent on the establishment of a water supply infrastructure, such as canals and tube-wells. At present, about 60% of the water used in farming comes from canals and the rest from wells. Since no more large-scale dams are planned, this proportion is likely to change in favor of tube-wells and the new land opened will probably depend more upon groundwater than canals. Let us assume that, out of the 2.4×10^6 ha of virgin land, 1.8×10^6 ha are irrigated by tube-wells and 0.6×10^6 ha by canals. The building of small dams and digging of canals are labor-intensive activities requiring comparatively little capital, so we can focus on the tube-well investment. Agricultural tube-wells have a delivering capacity of about 0.03 m^3 s^{-1} and work for about 1000 h per crop season. Taking an average of 1 ha-m ha^{-1} of water for all crops, we arrive at a requirement of one tube-well for every 11 ha, or a net increase of about 165,000 tube-wells by the year 2000. This implies an average annual increase of only 3% compared to an eight-year average (1969–77) of more than 8% per year (Agricultural Statistics of Pakistan 1978). Thus the investment required is well within national capability.

7 WATER REQUIREMENTS

Water and fertilizers are two major components of commercial inputs to agricultural intensification. In this section, we explore the implications of supplying recommended volumes of water to all important crops, as given in Table 12.

TABLE 12 Recommended water requirements of important crops in Pakistan.

Crop	Season	Water requirement (m)
Wheat	Rabi (spring harvest)	~0.5
Rice	Kharif (autumn harvest)	1.3–1.7
Sugar cane	Kharif	2–2.2
Cotton	Kharif	0.5–0.7
Maize	Kharif	0.5–0.7
Rapeseed and mustard	Rabi	~0.3

SOURCE: PARC (1980).

Calculation of the total water requirements in the two main seasons in Pakistan is now a matter of arithmetic, including a margin to cover losses and also crops not accounted for explicitly (including fruits and vegetables), although estimating this margin requires some care. The crops not included are pulses, fruits, and vegetables, since none of these requires large amounts of water. Together they account for about 30% of the cropped area and may be assumed to need about 0.3 m of water, divided roughly equally between the Kharif and Rabi seasons (i.e., $12 \times 10^9 m^3$ per season). Since evaporation in the fields is a surface phenomenon, it will be proportional to the area rather than the volume of water. In order to estimate the energy requirements of supplying the water, we have to make certain assumptions about the relative contributions of canals and groundwater, motor and pump efficiencies, etc., as follows.

(i) In the Kharif season there will be, as at present, considerably more canal water available, and the ratio of Kharif:Rabi water supply at the farm gate will be maintained near the present value of 3:2.

(ii) With increasing rural electrification, more electric- than diesel-operated tube-wells could be installed and the electric-to-diesel ratio will rise from the base year value of 5:9 to near equality (1:1). Moreover, electric pumps do somewhat more work than diesel pumps.

(iii) Surface irrigation will also require energy where pumping is involved, but the amount will be negligible in comparison with tube-well requirements.

(iv) About 30,000 kcal of useful energy are expended in lifting 1 ha-m of water through 1 m, allowing for pipe friction and the discharge velocity of water. The conversion efficiency from final to useful energy is taken as 65% for electric pump sets and 20% for diesel ones; these values are fairly typical.

(v) The water table is assumed to be at an average depth of 6 m; this value, inferred from 1977 energy consumption data, also seems reasonable from other sources. This leads to an oil consumption in pumping of 0.9×10^6 kcal ha-m^{-1}, which is comparable with estimates of 2.1×10^6 kcal ha-m^{-1} (Revelle 1976) from India where the water table is possibly much deeper.

(vi) The energy used by drainage tube-wells (in reclaiming land in waterlogged and saline areas) is considerable. The striking difference in load characteristics between drainage and irrigation tube-wells can be seen in electricity consumption statistics (WAPDA 1979, Energy Yearbook 1979). In 1977 drainage tube-wells consumed 120 MWyr of electricity while other electric (irrigation) pumps used only half as much. The load imposed by drainage tube-wells is expected *ad hoc* to double by the year 2000.

Based on the above assumptions, the final energy requirements for 1977 and 2000 are presented in Table 13. We see that energy requirements for irrigation are not high enough to necessitate conservation measures on that account alone, but there are other effects that ought to be considered. For example, indiscriminate irrigation practices

TABLE 13 Final energy demand for irrigation and drainage.

	Base year 1977			Projections for 2000		
	Kharif	Rabi	Total for year	Kharif	Rabi	Total for year
Total water at farm gate (10^6 ha-m)	6.2	4.6	10.8	10.5	7.5	18
from canals	4.4	2.8	7.2	5.4	3.6	9
diesel tube-wells	1.1	1.1	2.2	2.4	1.8	4.2
electric tube-wells	0.7	0.7	1.4	2.7	2.1	4.8
Energy consumed by irrigation (TW)						
diesel (10^3 toe)	98	98	196	225	175	400
electricity (MWyr)	31	31	62	110	90	200
Energy consumed by drainage (TW)						
electricity (MWyr)			118			250
Total electricity in agriculture (MWyr)			180			450

(especially in fields with inadequate drainage) could lead to a significant raising of the local water table, resulting in waterlogging. Also, excessive evaporation could raise the soil salinity. These two problems are already being faced in Pakistan today, so that water economy measures such as root irrigation (using plastic pipes) or sprinkler irrigation should be considered in future. It has been estimated by Gilley and Watts (1979) that irrigation efficiency improvements of 50% and above could be achieved through run-off re-use, sprinkler or trickler systems.

8 MAN- AND MACHINE-POWER

Much of the farming work in Pakistan is still labor-intensive with the aid of animals, usually bullocks; only 2×10^6 ha, i.e., about 10% of total cultivated area, had been tractorized in 1977. There are two schools of thought regarding farm mechanization in developing countries: one for and the other against.

The "pro" school maintains that farm machines (a) help in the rapid preparation of land for multi-cropping; (b) enable vigorous turning of the soil to kill weeds, air the soil and to improve porosity; (c) reduce the number of animals competing for fodder, resulting in better-nourished cattle; (d) improve water availability; and (e) release farm labor to more productive employment off the field.

The "con" group, on the other hand, disputes the validity or positive aspects of most of these points and emphasizes the negative consequences; e.g. that fewer animals would also result in less organic material for the soil, etc. While the controversy is unlikely to be resolved in the near future, it is axiomatic that what people actually do or have done over a sufficiently long period must essentially be profitable to them. Since there has been a definite trend towards tractorization in Pakistan, it must be advantageous to farmers in some way, and the process is likely to continue unless the state decides that it is against broader societal interests. Furthermore, the trend shown in Figure 1

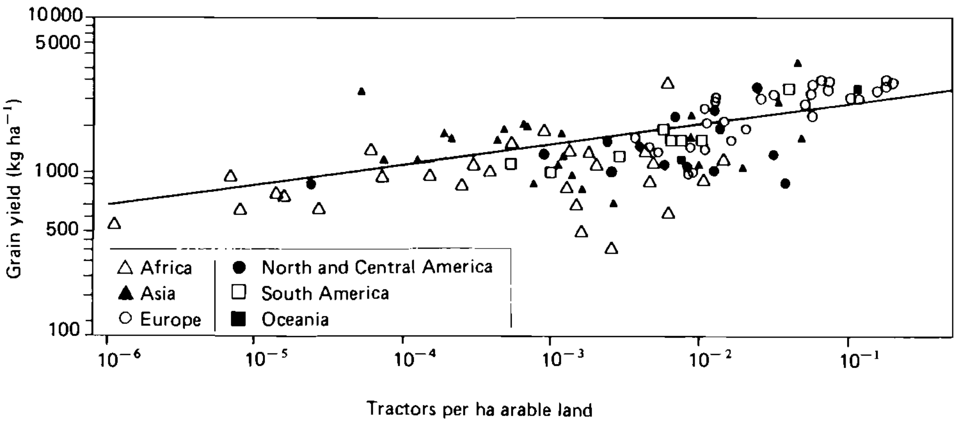

FIGURE 1 Yield of cereals per ha versus tractor use per ha of arable land (1970), using five-year averages of 107 countries. Source: Heumann *et al.* (1980).

does indicate an interesting correlation between productivity and the number of tractors per hectare, although of course the latter cannot be regarded as the sole, or even the main explanatory variable.

Since the issue brooks more than one opinion, we have explored three alternative futures:

Future A (high mechanization): Approximately 75% of the area under major crops (wheat, rice, sugar cane, and cotton) is expected to be mechanized by the year 2000, both for ploughing and harvesting; 50% of the remaining cropped area will be mechanized for tilling only. This can be assumed to be the upper limit because 33% of the total cultivated area is under farms of 5 ha or less whose owners are unlikely to opt for mechanization even under cooperative schemes.

Future B (low mechanization): 25% of the area under major crops and 20% of the remainder is mechanized. This would appear to be the lower limit since 10% of total cultivated area was already tractorized in 1977.

Future C (low mechanization, low tillage): The same degree of mechanization is projected as in Future B, but with 33% of the non-mechanized area cultivated with low-tillage techniques. Low tillage has the additional advantages of reducing soil erosion and damage to the biological components of the soil.

In order to assess the fuel requirements of each of these alternatives, we need estimates of useful energy requirements for farmwork (excluding irrigation, which has already been discussed); these are presented in Table 14, based on data collected by the Pakistan Agricultural Research Council (1980) for the average number of man- and bullock-hours needed for different types of work.

TABLE 14 Estimated average effort required per hectare for different farm operations.

Operation	Number of men	Pairs of bullocks	Hours worked	Total energy expenditure (10^3 kcal)[a]
Ploughing, planting, leveling	1	1	22	19.5
Sowing of wheat	1	1	5	4.4
Harvesting of wheat	4	–	12	1.2
Threshing of wheat	3	3	15	40
Winnowing of wheat	4	–	15	1.5
Sowing of rice	4	–	20	2.0
Harvesting of rice	5	–	20	2.0
Threshing of rice	4	–	12	1.2
Hoeing of sugar cane	4	–	20	2.0
Sowing of sugar cane	9	1	15	16
Cutting and stripping of sugar cane	25	–	32	20
Sowing of cotton	1	1	5	4.4
Interculture of cotton	4	–	20	2.0
Picking of cotton	5	–	10	1.0
Fertilizer spreading	1	–	3	0.15
Manure hauling and loading	2	1	5	4.6
Manure spreading	2	–	5	0.25

[a]Based on 25 kcal h^{-1} for humans and 430 kcal h^{-1} for bullocks as inferred by Revelle (1976).

For converting the above requirements into final energy inputs, the following factors need to be taken into account.

(1) With tractors, deeper tilling is possible and so the useful energy requirement is greatly increased, perhaps by a factor of 4.
(2) The actual useful energy available at the implement in contact with the ground is assumed to be 20% of the final energy input, which is typical of oil-powered machines.
(3) For harvesting and threshing, the increased yields required in the year 2000 need to be taken into account; the figures per hectare are multiplied by a factor of 2.
(4) The efficiency of harvesters/threshers is also assumed to be 20%, as in the case of tractors.

The factors assumed in (1) and (3) above may appear *ad hoc*, but they lead to a figure of 8×10^5 kcal of fuel energy per hectare of wheat cultivated, which is remarkably close to the 9×10^5 kcal ha^{-1} derived by Pimentel (1979) from US Department of Agriculture data. Thus the useful energy considerations correlate with actual energy consumption data from a highly mechanized country.

8.1 Final Energy Requirements for the Three Futures

The final energy requirements* of farming in the year 2000 for the three alternative scenarios are presented in Table 15, which also includes 1977 data for comparison.

TABLE 15 Final energy demand for farmwork excluding irrigation.

	Cropped area (10^6 ha)		Final energy required for tilling/harvesting (10^{12} kcal)			
	1977	2000	1977	2000		
				Future A	Future B	Future C
Wheat	6.4	7.6		4.6	1.5	1.5
Rice	1.8	2.4		0.9	0.3	0.3
Sugar cane	0.8	0.95		0.3	0.1	0.1
Cotton	1.8	2.8		1.1	0.4	0.4
Others (tilling only)	6.5	8.2		1.6	0.7	0.7
Total	18.3	22	0.85 (0.08×10^6 toe)	8.5 (0.8×10^6 toe)	3.0 (0.28×10^6 toe)	3.0
Additional pesticides[a]						1.4
Total (Future C)						4.4 (0.41×10^6 toe)

[a]Calculated @ 10 kg of pesticide for each hectare under low-tillage techniques and 24,000 kcal kg^{-1} for pesticides (Leach and Slesser 1976).

*A word is in order here about the omission of the energy requirements for the *production* of farm machinery which is usually included by authors in advanced countries (see, e.g., Pimentel 1979). The estimates are well known, but we do not envisage significant domestic production of tractors, etc., over the next two decades. Some threshers may be produced but the energy needed for that would be too small to change the picture.

Thus, we see that, solely on commercial energy considerations, the introduction of low-tillage practices will not be particularly advantageous unless a less costly way to control weeds than using pesticides is developed. One possible way is to focus on the genetic or hormonal control of weeds (Marchetti 1979). This is not likely to have an impact over the next two decades, however, so Future C does not appear to be feasible.

8.2 Financial Requirements

The larger tractors cost about 60,000 rupees (1977), and they can serve about 30–40 ha. The approximate number of tractors required in the year 2000 would thus be 450,000 for Future A and 160,000 for Futures B and C. In 1977 about 60,000 tractors were in use, so there will need to be a net increase of approximately 9% per year for Future A, and 4.4% for Futures B and C. Both figures are within the limits of possibility.

For estimating the total finance needed, we may assume that the working life of a tractor is 12 years. The total cost over the 23-year period (tractor prices are not likely to increase in real terms; the prices are assumed constant in 1977 rupees), will be 37 billion (10^9) Rs (1977) in Future A and 16 billion Rs in the other cases. Assuming a modest 4% annual investment growth rate in farm machinery, the 1977 commitment required to meet the cumulative figure is about one billion Rs (1977) for Future A, and 450 billion Rs for Futures B and C. These figures are to be compared with the loans of 325 million Rs granted in 1977–78 to farmers by the Agricultural Development Bank of Pakistan for the purchase of tractors, power tillers and attachments (Agricultural Statistics of Pakistan 1978); commercial banks give about two to three times as much. Thus, for Futures B and C, there do not appear to be any financial difficulties in implementation, but Future A may turn out to be resource-constrained.

9 NUTRIENT REQUIREMENTS

The significant increases in average yields discussed in Section 6 will not be possible without appropriate application of macronutrients such as nitrogen, phosphorus, and potassium. Nitrogen, the most important, will be discussed in detail.

9.1 Nitrogen

The dependence of crop yields on nitrogen application has been widely studied and reported (Hardy and Havelka 1975, Vohra and Robinson 1977, USNAS 1977, I Singh 1979). While there are differences in detail, two overall trends are clear.

(i) Beyond a certain value (between 70–80 kg ha^{-1} nitrogen applied), the marginal utility of fertilizer application begins to decrease.
(ii) Up to that value, the relationship is almost linear despite large variations in climate, soil, etc. Typical curves, adapted from the literature, are reproduced in Figure 2; the actual yields vary from crop to crop and from region to region, and those shown here are only indicative.

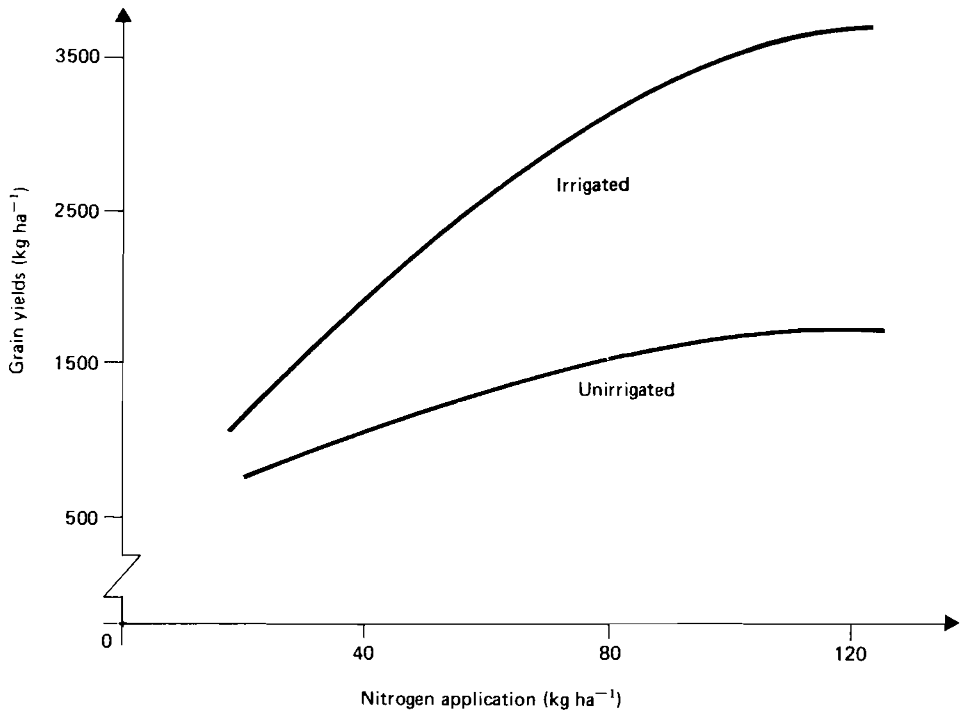

FIGURE 2 Typical response curves of high-yield varieties to nitrogen application.

The general trends depicted in Figure 2 are of little use to the farmer who needs to be told the specific needs of his crop under given conditions, but they are useful in the overall assessment of fertilizer requirements of a country or a region. The planned yield of wheat is 3100 kg ha^{-1}, of rice 3050 kg ha^{-1} and of maize 3400 kg ha^{-1}, but these figures are in the region of the upper right-hand corner of Figure 2, where data are least reliable. A reasonable estimate of fertilizers required is nevertheless 80–110 kg ha^{-1} under well irrigated conditions. This figure can be compared with the Ziauddin experiments reported by Muhammad (1978) in which an application of 135 kg ha^{-1} of nitrogen led to average wheat yields of over 4100 kg ha^{-1}. The total nitrogen need can therefore be estimated by taking an average value of 100 kg ha^{-1} for irrigated, and 50 kg ha^{-1} for unirrigated areas. Since the amount of nitrogen actually taken up by a plant is only 30–40% of that applied externally, the need for fertilizer could be significantly reduced if clear instructions are given to the farmers as to *when* and *how* to apply it. These figures are therefore somewhat overestimated and serve only to establish an upper bound to the annual nitrogen nutrient required by the year 2000. The various alternatives will be discussed below.

Using the above data, and assuming 16×10^6 ha irrigated and 6×10^6 ha unirrigated, the total nitrogen nutrient requirement works out to 1.9×10^6 t yr^{-1} by the year 2000. The consumption of industrially produced nitrogen in 1977 was about 0.6×10^6 t, of which nearly 0.35 $\times$ 10^6 t was produced within Pakistan; thus an average annual compound growth rate of 5.1% in consumption* and 7.6% in production can be expected.

Two scenarios will now be considered for meeting these estimated requirements.

Future D: The entire nutrient requirement will be met by chemical fertilizers.

Future E: The nutrient requirement will be met to the greatest extent feasible by manure/crop residues and only the balance by chemical fertilizers. As a variant of this future, the introduction of biogas plants will also be discussed.

Future D

We may assume that none of the plants producing fertilizers in the base year will still be operating in the year 2000. However, a number of new plants are nearing completion, under construction or firmly committed; their total capacity is 1.1 $\times$ 10^6 t of nitrogen nutrient per year. Assuming an average operating level of 80%, the annual production by these plants would be 0.88 $\times$ 10^6 t, leaving a shortfall of about 10^6 t. An additional annual capacity of about 1.2 $\times$ 10^6 t of nitrogen nutrient is thus required to meet the expected demand of 1.9 $\times$ 10^6 t yr^{-1}.

The average economical size of a natural gas-based fertilizer plant is 1700 t per day of urea, which translates into 0.29 $\times$ 10^6 t of nitrogen per year. Four such plants would thus need to be constructed between 1985 and 2000; at an estimated outlay of about 2.5 billion Rs (1977) per plant, this would mean an investment of 10 billion Rs over 15 years. This is a sizable amount, and is by no means a negligible fraction of Pakistan's investment resources (the total industrial investment in 1976–77 was little over 6 billion Rs). Such an investment may be unnecessary, as will be seen in the discussion of Future E, but could possibly be justified, without reference to domestic agriculture, as an export-oriented industry.

We will now proceed to calculate the energy input required for the production of 1.9 $\times$ 10^6 t of nitrogen nutrient; estimates vary from about 0.013 to 0.019 kcal kg^{-1} of nitrogen produced. From data available for Pakistan, a value near the upper end of the range is considered appropriate and, accordingly, the calculations are based on a mean value of 0.018 kcal kg^{-1}. The energy requirement for 1.9 $\times$ 10^6 t of nitrogen is 34.2 $\times$ 10^{12} kcal, or 3.2 $\times$ 10^6 t of oil-equivalent (toe), or (since most of the industrial feedstock and fuel needs are met by natural gas) 3.8 $\times$ 10^9 m^3 of gas. For comparison, the total consumption of natural gas in Pakistan was about 6 $\times$ 10^9 m^3 in 1977.

Future E

While discussing the nitrogen requirements of crops, alternatives to chemically synthesized urea or other compounds should also be considered and evaluated. Two of these are considered below.

Biological fixation of nitrogen: The most important nitrogen-fixing system is the *Rhizobium*–legume symbiosis in which the *Rhizobium* bacteria occur in the root nodules of leguminous plants such as pulses commonly grown in subtropical countries including

*The Fertilizer Board of Pakistan has projected an annual consumption of over 0.9 $\times$ 10^6 t by 1982–83, implying a much faster growth rate of around 9% per year in the short term.

Pakistan. The plant provides an environment for the bacteria which in return fix atmospheric nitrogen. It is estimated (Hardy and Havelka 1975) that on a global scale, *Rhizobium*–legume symbiosis contributes 40 × 10^6 t of nitrogen annually to grain legumes, as well as a major part of the 40 × 10^6 t of nitrogen fixed in permanent meadows; these quantities are the same as the 40 × 10^6 t of fertilizer nitrogen produced by man in 1974. Active research (Hardy and Havelka 1975, Nutman 1976) is underway – so far with little success – to establish an associative symbiotic relationship with non-leguminous plants, particularly cereal grains. The breakthrough, if and when it comes, will bring about a second "green revolution" in agriculture, but until then we must continue to rely upon externally applied nitrogen, except for the technique of green manuring in which legumes may be grown preceding or following a cereal grain crop and partly cut into the soil.

Animal and crop waste: Both animal and crop wastes are rich in nitrogen and are traditionally composted to make manure. However, crop residues such as rice stalks and bagasse also serve as fodder for farm animals and, since we anticipate a substantial increase in cattle and sheep numbers to raise the protein content of human food, crop residues would be better used as fodder, and only animal waste considered as a soil fertilizer. Table 16 lists estimates of daily manure production by major farm animals and their nitrogen and energy content.

TABLE 16 Quantity and nutrient content of manure produced by farm animals.

	Daily manure production (kg)					
Animal	Raw	Dry matter equivalent	Nitrogen (% of dry matter)	Phosphorus (% of dry matter)	Calorific value (kcal kg^{-1})	Annual nitrogen production (kg yr^{-1})
Beef cattle	13–29	2–5	3.5	1.0	2300–4700	25–64
Dairy cattle	35–60	5–6	2.7	0.5	4500	50–60
Sheep	2	0.7	4.0	0.6	4250	10
Horses	20	8.0	1.7	0.3	3900	50
Poultry	0.1–0.2	0.02–0.05	2.2–3.4	1.0	2700–3500	0.16–0.6

SOURCE: Vohra and Robinson (1977); adapted.

In order to estimate the amount of nitrogen nutrient available from animal waste, we can discount poultry manure which will be used for growing vegetables, etc., around poultry farms and villages. We may also make the following assumptions.

(i) Only 66% of manure is collected for systematic use, half of which is used as fuel and half as fertilizer;
(ii) Buffaloes produce more dung than cattle, so we can assume an average of 50 kg of nitrogen per year from large animals, and 10 kg yr^{-1} from sheep and goats (these figures are likely to be underestimates).

With these assumptions, and using the animal populations projected in Table 16, we arrive at a manure-nitrogen availability of 0.8 × 10^6 t yr^{-1}, i.e., almost the shortfall estimated if no additional fertilizer plants are commissioned after 1982! Thus, in this scenario, at most only one more factory will need to be built. The energy requirement will also be reduced from 3.8 to 2.1 $\times$ $10^9 m^3$ of gas. It may be further noted that these substantial investment and energy savings result from assuming that the existing pattern of dung consumption will continue, i.e. roughly half will be burned as dung-cakes and the other half used as fertilizer. Also, if biogas technology penetrates the market to any significant degree, even larger energy savings may be made.

We will now discuss the prospects for biogas technology. It is generally known (Van Buren 1979) that the slurry from a biogas plant is a better fertilizer than unfermented manure used directly. There is also an additional bonus of improved hygiene, and the biogas itself, which may be used as fuel for cooking, lighting, etc. The construction and principles involved in the operation of a biogas plant are also rather simple, so it is considered an "appropriate technology" for rural areas in less developed countries. We feel, however, that the introduction of biogas plants in Pakistan may be slow for various cultural, traditional, and even technological reasons, as listed below.

(i) The fermentation compartment of a biogas plant requires frequent inspection and maintenance, in the course of which persons have to climb inside the pit. It is hard to find men willing to do the job because of cultural shyness, since manure collection and dung-cake making is traditionally women's work, and even they do not find it pleasant. Similarly, the slurry has to be stirred frequently which again needs to be done by men.
(ii) The fermentation has to be anaerobic, so the compartment must be kept airtight, and requires careful management.
(iii) The production of methane proceeds properly only within certain ranges of temperature and pH; proper understanding of the methods and corrective measures that need to be made will take a long time to learn.

There are however better prospects for larger, quasi-commercial biogas plants associated with the organized cattle farms advocated in this report. These could be partially mechanized, thus reducing the need for manual handling of the waste. Even if our misgivings about biogas acceptability turn out to be unfounded, there would nevertheless still be *more* organic nutrient available, resulting in greater savings of synthetic urea.

9.2 Phosphorus and Potassium

The nitrogen-to-phosphate consumption ratio gradually declined from about 40:1 in the mid-1960s to about 4:1 in the late 1970s, and may fall further to about 2:1 by the year 2000, so we estimate a phosphate requirement of about 0.9 $\times$ $10^6 t\ yr^{-1}$ by the turn of the century, as compared with the 1977 consumption of about 0.13 $\times$ 10^6 t. The production of phosphate is much less energy-intensive than nitrogen, requiring about 3200 kcal kg^{-1} (Leach and Slesser 1976). At present, considerable amounts of phosphate are imported and no significant expansion in capacity is planned for the early 1980s. For energy calculations, however, we can assume that by the year 2000, about 75% of all phosphorus requirements will be met domestically. If so, the annual energy needed would be about 0.2 $\times$ 10^6 toe.

The potash requirements of different soil types vary considerably, but are generally an order of magnitude less than that of phosphate. It does not therefore figure significantly as an input requirement.

The total energy need for fertilizers in the two scenarios may now be summarized as follows:

Future D: 3.4×10^6 toe/yr;
Future E: 2.0×10^6 toe/yr (assuming no penetration of biogas technology).

10 OTHER INPUT REQUIREMENTS

We now turn to the consideration of the energy equivalents of other inputs, i.e. seeds and pesticides, and crop drying and transportation.

10.1 Seeds and Pesticides

The requirements of seeds and pesticides vary with different crops and environments. The data presented in Table 17 reflect the average seed rates in Pakistan, and the desired pesticide application rates for different crops. The total energy requirements for seeds and pesticides may be worked out at the average rate of 500 Mcal ha^{-1} for grains, 1300 for sugar cane and 300 for cotton. The total energy required is 9×10^{12} kcal, or about 0.8×10^6 toe.

TABLE 17 Seed rates and pesticide applications for different crops.

Crop	Seed rate ($kg\ ha^{-1}$)	Equivalent energy[a] (10^3 kcal ha^{-1})	Pesticides ($kg\ ha^{-1}$)	Equivalent energy[b] (10^3 kcal ha^{-1})
Wheat	70–75	350–375	–	–
Rice	10–12	50–60	15–20	360–480
Maize	30–35	150–175	20	480
Sugar cane (2 rattoons)	2300–3000	700–900	20	480
Cotton[c]	7–9	40–45	10	240

[a]The energy equivalent of seed was derived from the calorific value and adding 50% for the extra effort involved in producing seed.
[b]Pesticides are evaluated at 24,000 kcal kg^{-1} (Leach and Slesser 1976).
[c]Energy equivalent of cotton is calculated at 25% oil content.

10.2 Crop Drying and Transportation

Data in sufficient detail are not available to make a bottom-up estimate, but for comparison, we can look at the fractional energy consumption of a number of crops in the US for which estimates have been made (Pimentel 1979). The percentage of energy used in crop drying and transportation are 2.8% for wheat, 8% for rice and 3.6% for oats. The commercial energy used in crop drying and transportation is not expected to be more than 3% of the total used in agriculture because (i) due to the warmer climate of Pakistan, the moisture content of grains will be lower than in the US; (ii) solar drying will continue to be significant; and (iii) transportation distances are substantially shorter than in the US.

11 CONCLUDING REMARKS

The objectives of this study have been:

(1) to define the ultimate role of the agricultural system in Pakistan;
(2) to study the environment and constraints on the system;
(3) to translate the objectives into concrete production targets for specific crops for the year 2000;
(4) to identify the physical input requirements for meeting the set targets; and
(5) to evaluate the energy equivalents of the inputs.

The main results and conclusions are as follows. The total quantities of cereal grains, milk, meat, poultry, etc., required to provide adequate nutrition for the projected population of Pakistan of 139 million by the year 2000, are estimated and presented in Table 5. Since animals obtain their nutrition from vegetation, human food needs (both vegetables and animal origin, excluding fish) may be expressed in terms of agricultural production. Other non-food crops such as cotton are also needed, and some produce has to be exported to earn foreign exchange. These requirements are displayed in Table 7.

The physical input requirements are then analyzed: land, water, farm machinery, macronutrients, seeds, pesticides, crop drying and transportation. Energy requirements and, where appropriate, the financial implications of the various inputs are estimated. The report concludes with energy input estimates for seeds, pesticides, crop drying, and transportation; the possibility of off-farm employment for villagers and small-town dwellers is also briefly discussed.

The perception of the future is aided by a scenario approach, in which three possible development paths for farm mechanization (A, B, C), and two other paths for the supply of macronutrients (D, E) are considered. Alternative C, which envisages significant penetration of low-tillage technology, is not considered likely to be realized. The various different combinations of the other alternatives are listed in Table 18, and the energy implications are presented in Table 19.

It is evident from Table 19 that the largest amounts of commercial energy are expected to be used in fertilizer production, drainage and irrigation, tractors, seeds, and pesticides, roughly in that order. The greatest energy savings are accordingly expected if Pakistan restricts the use of man-made fertilizers and conserves water resources. As discussed in the text, both of these measures are possible and are indeed to be recommended for reasons other than commercial energy saving: water conservation to prevent waterlogging, and urea economy to enhance the organic quality of the soil. The adage "waste not, want not" is particularly relevant to these two vital inputs to agriculture. With regard to farm mechanization, energy considerations alone do not seem to disfavor strongly high tractorization, but other socioeconomic factors will probably steer the country closer to the low-mechanization future rather than towards the high one.

From the information presented, we may also derive energy ratios, i.e., the ratio of metabolizable energy produced by the whole agricultural system to the energy provided

TABLE 18 Characteristics of possible evolution paths of Pakistan's agricultural system.

Parameter	Base year, 1977	Year 2000			
		Future AD	Future AE	Future BD	Future BE
(1) Area cropped per year	18.3×10^6 ha	22×10^6 ha			
(2) Irrigation (the per hectare figures pertain to irrigated area only)	10.8×10^6 ha-m of water available at farmgate ($\sim$0.8 ha-m ha^{-1} yr^{-1})	Farm-gate availability of water increases to 18×10^6 ha-m yr^{-1} ($\sim$1.1 ha-m ha^{-1} yr^{-1})			
(3) Farm mechanization (the per hectare figures refer to entire cultivated area	60,000 tractors (3.3×10^{-3} tractors/ha)	3/4 of area under major crops mechanized; 1/2 of other area under tractors (20×10^{-3} tractors/ha)		1/4 of area under major crops mechanized; 1/5 of other area under tractors (7×10^{-3} tractors/ha)	
(4) Supply of nitrogen from chemical fertilizers (per hectare figures pertain to total cropped area)	0.6×10^6 t nutrient (32.5 kg ha^{-1} yr^{-1})	1.9×10^6 t (86 kg ha^{-1} yr^{-1})	1.1×10^6 t (50 kg ha^{-1} yr^{-1})	1.9×10^6 t (86 kg ha^{-1} yr^{-1})	1.1×10^6 t (50 kg ha^{-1} yr^{-1})
(5) P:N ratio	1:4	1:2	1:2	1:2	1:2

TABLE 19 Evolution of commercial energy use in agriculture.

	Base year, 1977	Year 2000: Future AD (high mech, high urea)	Future AE (high mech, low urea)	Future BD (low mech, high urea)	Future BE (low mech, low urea)
(1) Drainage tube-wells					
electricity (MWyr)	118	250	250	250	250
(2) Irrigation tube-wells					
electricity (MWyr)	62	200	200	200	200
diesel (10^3 toe)	196	400	400	400	400
(3) Farm machines					
diesel (10^3 toe)	80	800	800	280	280
(4) Chemical fertilizers					
mainly gas (10^3 toe)	650	3400	2000	3400	2000
(5) Seeds and pesticides (10^3 toe)	300[a]	800	800	800	800
(6) Other requirements (10^3 toe)[b]	75	300	250	250	200
(7) Total non-animal energy					
electricity (MWyr)	180	450	450	450	450
gas and oil (10^6 toe)	1.0	5.3	3.9	4.7	3.3
latent (10^6 toe)[c]	0.3	0.4	0.4	0.4	0.4
(8) Commercial energy use[d]					
(10^6 kcal ha^{-1})	~1.0	3.2	2.5	3.0	2.3
(9) Persons supported per hectare	4.0	6.3	6.3	6.3	6.3

[a] Seeds only; pesticides estimate included in "other requirements".
[b] Other requirements include transportation, crop drying, fishing, etc.; estimated figures.
[c] Energy latent in seeds.
[d] Electricity converted to thermal equivalent at 35% efficiency.

by man*. The ratios in Pakistan are presented in Table 20 and compared with other countries; if one also includes the human and animal energy expended, the ratios for Pakistan will decrease by 10–15%, assuming that about 65% of the annual effort exerted by farm labor contributes to agriculture and that the farm-related work of draft cattle averages 6 hours daily all year round.

TABLE 20 Energy output–input ratios for the total agricultural system.

China	1930	40	
Pakistan	1977	3.3	Commercial energy input only
Pakistan	2000 (high-energy future AD)	1.6	Commercial energy input only
Pakistan	2000 (low-energy future BE)	2.6	Commercial energy input only
US	1940	2.26	
US	1970	0.87	
UK	1950	0.41	
UK	1970	0.34	

SOURCES: Marchetti (1979), Steinhart and Steinhart (1974), Leach (1976), present work.

The difference between the energy ratios in the US and UK is due to the land scarcity in the latter, necessitating greater intensification of agriculture, and also the harsher climate. The higher ratios for Pakistan reflect the lower intensity of commercial energy inputs as well as the lower consumption of animal products: the conversion of plants to animal food may cost a factor of up to 20 in energy depending upon the type of animal product (milk, eggs, or meat) and the method of raising animals (grass-fed, feed-lot, etc.).

Let us now view agricultural energy use in the national context. In another study by the author (unpublished), it has been estimated that the final electricity demand of Pakistan in the year 2000 will lie between 2.7 and 3.3 GWyr, while all other forms of commercial energy will be 17–20 $\times$ 10^6 toe. Thus, if agriculture in Pakistan develops along the high-energy road, in 2000 it will account for about 15% of total electricity consumption and about 28% of all other forms of commercial energy; for the low-energy path, the respective figures will be 15% and 18%. For comparison, in 1977 agriculture used a little over 20% of the electricity and 12% of other forms of commercial energy. Thus, agriculture's share of the total electricity demand will decline, while its share of fossil fuels used is expected to register a sharp increase, mainly on account of agrochemicals produced domestically.

The above figures underscore the importance of analyzing agricultural energy requirements in a developing country with a largely agrarian economy; the situation is different in advanced industrialized countries, where agriculture typically accounts for only about 5% of the total commercial energy use. Thus, for Pakistan, it is logical to look for methods of saving energy in agriculture-related activities, just as in other sectors such as transportation, domestic consumption, etc. This should however be done in ways that do not compromise productivity; possible measures are indicated in Sections 7 and 9 of this report. If competition does develop among different energy consumers, it is obvious that agriculture deserves first consideration; indeed, something would be basically wrong

*Note that energy ratios greater than unity are possible because solar energy, freely available to man, is not included in the input.

with a nation's priorities if it cut down on supplies of electricity and motor fuel to tubewells and allowed, for example, office air-conditioners and automobile fleets to run unrestrained.

Finally, we would like to stress an obvious point: that the provision of energy and other inputs does not necessarily guarantee that production targets will be met. Farmers must be educated and encouraged to adopt improved cultivation practices. A major effort to translate available technical knowledge into practical information, and the effective dissemination of that information needs to be undertaken seriously and urgently.

ACKNOWLEDGMENTS

I have benefited from conversations with Professor W. Häfele and colleagues in the Energy Program. Dr. A. Muhammad and Mr. A.H. Qureshi have provided valuable research material. I am also indebted to Dr. C. Marchetti, Dr. A. Muhammad, Dr. K.S. Parikh, Mr. A. Husain, Dr. J. Parikh and Dr. A.M. Khan for their comments on the first draft of the paper. Whatever deficiencies remain, reflect the author's limitations.

Finally, I wish to thank Professors R. Levien and W. Häfele for the warm hospitality of IIASA.

REFERENCES

Agricultural Statistics of Pakistan 1978 (Food and Agriculture Division, Government of Pakistan, 1979).

Bardach, J.E. (1980) Economic Energy Use in Fish Production, P-80-2. East–West Centre, Honolulu, Hawaii.

van Buren, A. (Ed.) (1979) A Chinese Biogas Manual. London: Intermediate Technology Publications.

Burton, B.T. (1976) Human Nutrition. New York: McGraw-Hill.

Cleland, A.C. and M.D. Earle (1980) Energy use in the Food Manufacturing Industry. New Zealand Energy Research and Development Committee Report No. 54.

Energy Year Book 1979 (1980) Directorate General of Energy Resources, Pakistan.

FAO Production Yearbook 1979, Vol. 33 (1980) Rome: United Nations.

Government of Pakistan, Energy Year Book 1979. Directorate General of Energy Resources.

Hardy, R.W.F. and U.D. Havelka (1975) Nitrogen fixation research: A key to world food? Science 188: 633–43.

Heumann, Gisela, Weber, A., *et al.* (1980) Die Schleppermachfrage in einzelner Regionen der Welt. Agrarwirtschaft 29:129–41.

Holmes, W. (1977) Choosing between animals, in: Agricultural Efficiency. London: Royal Society.

Leach, G. (1976) Energy and Food Production. Guildford: IPC Science and Technology Press.

Leach, G. (1978) The energy costs of food production, in: F. Steele and A. Bourne (Eds.) The Man/Food Equation. New York: Academic Press.

Leach, G. and M. Slesser (1976) Energy Requirement of Network Inputs. Glasgow: University of Strathclyde.

Marchetti, C. (1979) On Energy and Agriculture: From Hunting–Gathering to Landless Farming. RR-79-10. Laxenburg, Austria: International Institute for Applied Systems Analysis.

McGraw-Hill Encyclopedia of Food, Agriculture and Nutrition (1977). New York: McGraw-Hill.

Muhammad, A. *et al.* (1976) Seed Protein Improvement in Wheat by Mutation Breeding. Vienna: IAEA.

Muhammad, A. (1978) Wheat Production in Pakistan. Pakistan Agricultural Research Council.

Naqvi, M. (1980) personal communication, 1980.

Nutman, P.S. (Ed.) (1976) Symbiotic Nitrogen Fixation in Plants. London: Cambridge University Press.
Pakistan Agricultural Research Council (PARC) (1980) communicated by A. Muhammad, Chairman.
Pimentel, D. (1979) Energy and Agriculture, in: Biswas and Biswas (Eds.) Food, Climate and Man. New York: Wiley.
Revelle, R. (1976) Energy use in rural India. Science 192:969–75.
Singh, I. (1979) Small Farmers and Landless in South Asia. World Bank Staff Working Paper No. 320.
Steinhart, J.S. and C.E. Steinhart (1974) Science 184:307.
US National Academy of Sciences (1975) Agricultural Production Efficiency. Washington, DC: NAS.
Vohra, P.V. and D.W. Robinson (1977) Feed, fuel and fertilizer, in: R.A. Fazzolare and C.B. Smith (Eds.) Energy Use Management. Oxford: Pergamon.
WAPDA Power Market Survey and Forecast of System Loads (1979). Pakistan Water and Power Development Authority.
Williams, D.W. *et al.* (1975) Energy Utilization on Beef Feedlots and Dairy Farms, in: W.J. Jewell (Ed.) Energy, Agriculture and Waste Management. Ann Arbor Publishers.
World Bank (1979) World Development Report. Washington, DC.
Woolley, D.G. (1977) Food-crop production, limitation and potential, in: E.R. Duncan (Ed.) Dimensions of World Food Problems. Iowa State University Press.

APPENDIX: ENERGY ECONOMICS OF ORGANIZED CATTLE FARMING

We estimate here the total commercial energy inputs required to deliver one ton of frozen beef to the port of exit in the year 2000. The major components that make up the total are: (i) energy embodied in the feed; (ii) energy required in processing and cold storage; (iii) transport fuel; and (iv) refrigeration during transport.

Feed Energy

Apart from non-energy-intensive fodder such as hay, it has been estimated in the text that 0.8×10^6 t of maize will be required to produce 0.3×10^6 t of export-quality beef, i.e., about 2.7 t of maize per tonne of beef. The commercial energy input per hectare will be

N-fertilizer: 100 kg ha^{-1} N @ 18 Mcal kg^{-1} N = 18×10^5 kcal ha^{-1}
Water (0.6 ha-m ha^{-1}): = 6×10^5 kcal ha^{-1}
Tilling and harvesting: = 6×10^5 kcal ha^{-1}

Assuming maize yield to be 3.4 t ha^{-1} (see text), the commercial energy required to produce 2.7 t of maize will be about 2.4×10^6 kcal.

Processing and Cold Storage

Estimates for this activity are based on the US and New Zealand figures given in Cleland and Earle (1980). In order not to err on the low side, the higher figures are taken for both electricity and fuel requirements. Converting to thermal requirements, one arrives at a figure of 1.8×10^6 kcal per tonne of carcass.

Transport Fuel

Although the cattle farms will be preferentially located near to ports, we again take an upper bound and assume that the average distance traveled by a carcass is 1000 km, of which 200 km is by truck and 800 km by train. Using internationally accepted averages, raised somewhat to take account of adverse road and vehicle maintenance conditions in Pakistan, one obtains a value of about 0.4×10^6 kcal per tonne of meat.

Refrigeration During Transport

Since the fuel requirements for meat processing are for hot water in scalding and cleaning, we need take only the electricity figure, which is itself likely to be an overestimate because the transit time will in general be shorter than the storage period. The energy then works out to be 10^6 kcal per tonne of meat.

Energy Balance

Adding all these figures, we arrive at a total of 5.6×10^6 kcal of secondary commercial energy (or, say, 6×10^6 kcal of primary) sequestered in delivering one tonne of beef carcass to the port of Karachi. In making each estimate we have tried to err on the high side. We have also not taken account of the dung which could be used to produce biogas and also to reduce the chemical fertilizer requirements. On the other hand, we have not accounted for the energy required in breeding and raising stock or the energy embodied in refrigerated trucks and wagons. The figure should therefore be approximately of the right order. As is made clear, the conclusion will not be materially affected even if the error is as much as 100%.

Now, if we further assume that the farm is not allowed any indigenous energy supply (i.e., it must compensate in thermal units for the gas and electricity used), then 4.1 barrels of oil must be imported in order to be able to export one tonne of beef. At 1979 beef prices and 1980 oil prices, one tonne of beef could buy about 50 barrels of oil. Thus there is a huge margin of "energy profit". The export of 0.3×10^6 t of beef envisaged in the text could earn 1.8×10^6 t of oil, which would be more than sufficient to meet the diesel requirements of the entire agricultural system of Pakistan, even in the high-mechanization scenario.

Incidentally, this example highlights the fact that in order to increase the total national wealth and individual productivity in a developing country, it is not absolutely necessary (contrary to popular belief) to veer away from agriculture towards manufacturing. What is important is to enhance the *value-adding capability* of each sector in that country.