Resources Technology and Environment in Agricultural Development

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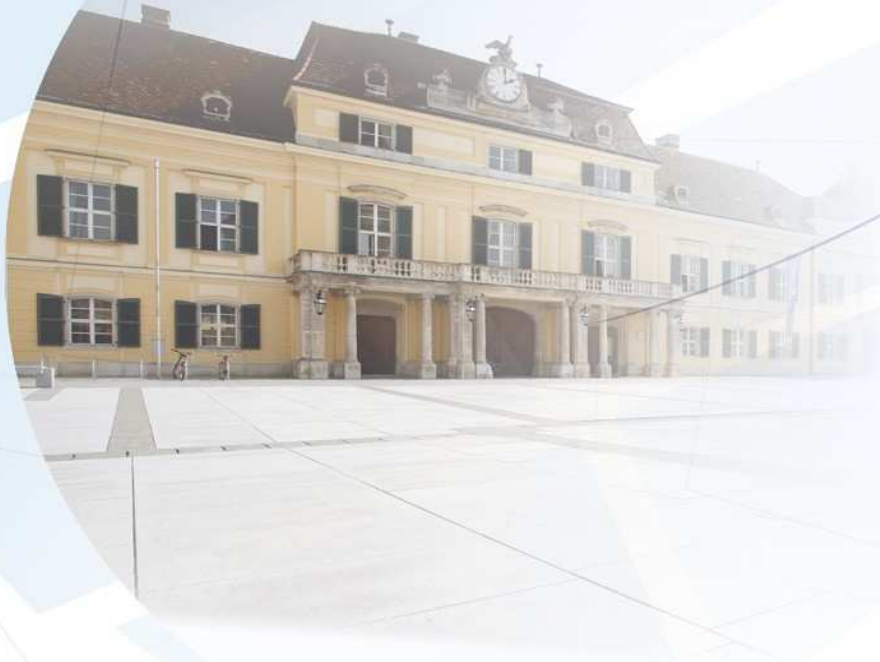

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RESOURCES TECHNOLOGY AND ENVIRONMENT IN AGRICULTURAL DEVELOPMENT

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PREFACE

IIASA's Food and Agriculture Program is undertaking research on a complex set of issues grouped under the title: "Limits and Consequences of Food Production Technologies". The fundamental question addressed in this research is 'what long-term technical development paths are feasible and likely for increasing food production, based on the present availability of resources (including energy), the long-run feedback on the environment, and the short-run pressures reflected in current agricultural policies'[1].

The objective of the research on this set of issues is to construct a model, or family of models, which will increase understanding of the resources-technology-environment (R-T-E) system in agricultural production, thus providing guidance to policies to make the system more serviceable in meeting rising world demands for food. As indicated in the quoted statement, the focus is on the behavior of the R-T-E system over the long-term. It is not necessary for our purposes to define the long-term precisely, but we think of it as a period of 2 to 3 decades.

The aim of this paper is to provide an intellectual background that will be useful to the modelling effort. To this end the paper seeks to identify the principal elements in the R-T-E system, to describe the relationships among these elements, and to analyze the forces which move and modify the system through time.

Throughout the analysis major emphasis is given to the role of relative prices of agricultural resources as signals to farmers of relative resource scarcity. This reflects the author's orientation and training, but it means that the analysis is not directly applicable to centrally planned economies. Farmers in those economies will feel many of the same sorts of resource pressures as farmers in market economies--for example, the increasing cost of energy--but the indication of those pressures and the modes of response to them are different. This limitation of the analysis should be kept in mind.

ACKNOWLEDGMENTS

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RESOURCES TECHNOLOGY AND ENVIRONMENT IN AGRICULTURAL DEVELOPMENT

Pierre Crosson

Description of the R-T-E System in Agriculture

Function of the System

The function of the system is to produce food and fiber in response to effective demand for these commodities. The emphasis is on effective demand to distinguish it from what might be called the latent demand represented by presently unmet nutritional needs of hundreds of millions of people too poor to buy enough food. It is noted below that we expect latent demand gradually to become effective demand as income of the poor rises. However, government policies to improve nutrition by direct transfer of food to poor people also transform latent into effective demand.

Performance of the Function

The system performs its function by combining land, water, fertilizer and so on (resources) in specific ways (technology) to produce the kinds and quantities of food and fiber for which there is effective demand. The production process may have effects on the land, water, atmosphere, and associated forms of life perceived to be either detrimental or beneficial from a social standpoint. In this paper, we deal only with the detrimental effects since it is those which excite concern and may lead to corrective action.

Relation of System Components

The resource, technology and environment components of the system are linked by a set of interdependent relationships. The quantity, quality and terms of availability of resources affect the kinds of technologies employed, but these technological choices also can affect the terms of availability of resources. For example, wide adoption of land-using technologies likely will increase the relative scarcity of land, while the sustained growth of a land-saving technology, such as irrigation, will in time, increase the relative scarcity of water. These technological choices also affect the environment, as noted above, setting up feed-back effects on both the resource and technology components of the system. For example, the technologies chosen may lead to increased erosion, which both reduces the fertility of the soil and accelerates the siltation of reservoirs, drainage ditches, and irrigation canals. The resource base thus is impaired and the productivity of the R-T-E system is reduced. The environmental impacts may affect technological choices both indirectly through these effects on the resource base and directly through public policies restricting the use of the damaging technologies.

Actors in the System

The system is driven by decisions made by an hierarchy of actors. The prime mover is "the farmer", defined as whoever makes the decisions about what to produce and how much, on which specific piece of land, the resources to be employed, and in what combination. Obviously "the farmer" may be a single individual living on and working the land, or "he" may be a committee in a district office. What distinguishes the farmer from the other actors in the hierarchy is that his decisions directly set the production process in motion.

We assume that the farmer's decisions are rational in the sense that he will seek to maximize the return to him through time from the production process. In market economies the return may simply be the farmer's net income from farming. In centrally planned economies, the return may be in higher salaries, bonuses, opportunity for advancement, enhanced prestige for a job well done, or the accumulation of savings for re-investment in the farm enterprise.

In either type economy rational decision making involves looking beyond the present crop year, i.e., the farmer is aware that the decisions he takes this year may have consequences extending over several or many years. To the extent that those consequences affect the return to him he will try to take them into account, discounting them implicitly or explicitly so that alternative decisions can be compared. If the consequences do not affect the discounted return to the farmer, he will ignore them, even though they may adversely affect other parts of the R-T-E system, or the larger society of which the system is a part.

Environmental consequences of production in particular may be of this sort.

Rational decisions also take account of risk. Farmers are particularly exposed to risk because of the relatively long time (a single growing season at least) between the beginning of production and the collection of the output. In that time the weather may change in unfavorable and unpredictable ways, prices of products may fall or input prices rise, credit may become very expensive or not available, supplies of crucial inputs may be interrupted, strikes may occur at harvest and so on. Farmers have differing attitudes toward risk, but all will take it into account, seeking to reduce their exposure to its adverse consequences.

In the case of the poor farmer, this may mean continued reliance on traditional seed varieties and mixed cropping systems even though exclusive cropping of higher yielding varieties would seem to offer a higher return. From the poor farmer's standpoint, however, the new technology is likely to be riskier than the traditional one. It would involve practices with which he is not familiar, and the monocultural system tends to be more vulnerable to attack from insects and disease than the traditional system. There is thus a greater likelihood of loss as well as of gain from the new system. But the poor farmer operates so close to the margin of subsistence that the consequence of loss would be disaster. He therefore weights the probability of loss more heavily than the probability of gain and opts for the traditional system.

Of course, poor farmers will respond to new technology. The spread of the Green Revolution among them is proof of that. The element of risk may impede the rate of response, but this does not reflect irrational behavior. This point would not need emphasis, except that the view still is sometimes expressed that poor farmers in developing countries are so locked in tradition that they will not respond to new technology even when it is in their interest to do so. Close analysis of such instances usually shows that in fact, the new technology was not in the farmers' interest, with high risk often a major reason. We take it as axiomatic, therefore, that as a group, poor farmers are as able to calculate their interests and to pursue them rationally as any other group.

The non-farmers in the hierarchy of actors affecting the R-T-E system do so indirectly. They do it by influencing the conditions which determine the return to the farmer from the production process. These actors include extension agents and vendors of inputs working directly with farmers, managers of irrigation systems, bank lending officers, ministers of agriculture and finance, researchers in national and international agricultural research institutions, officials in environmental protection agencies and in international lending institutions, and the collectivity of anonymous individuals whose behavior in national and world markets affects the prices of agricultural commodities and inputs.

The behavior of the non-farm actors transmits signals to the farmer which guide his decisions about what to produce, how much to produce, which resources to use, in which quantities, and how to combine them. In market economies, the signals typically will be prices of commodities and inputs, but they also will include regulations, for example those restricting the use of certain pesticides; subsidies to encourage greater use of certain inputs; cost-sharing arrangements or other financial inducements to encourage adoption of certain practices, and so on. In centrally planned economies, prices, of course, will have less weight than in market economies, major emphasis being given instead to production quotas and allotments of inputs.

Many of the important signals transmitted to farmers are incidental results of actions taken with other things in mind. For some important inputs, for example, farmers are price takers in the sense that their demand for the input has no appreciable affect on its price. Energy is such an input. In general, the demand by farmers for energy is so small relative to total demand that it has no measurable effect on the price of energy or on other terms of energy availability. With respect to the price of petroleum, policies of the OPEC countries and world growth of demand for petroleum are the dominant forces, by comparison with which the demand by farmers is trivial.

There are many other examples of actions designed for some other purpose but which nonetheless transmit important signals to farmers. Credit policies designed to restrain inflation likely will increase interest rates or result in credit rationing; in either case, they reduce the attractiveness of investment in new farm technology. Similarly, policies to protect domestic industry against imports likely will raise the prices of some farm inputs.

These unintended signals may drown out others designed by public officials to induce specific actions by farmers to improve the performance of the R-T-E system. In fact, this likely explains many instances of the failure of farmers to respond to public policies: they are not getting the message because contrary signals are coming through more loudly and clearly. The existence and power of these unintended signals constrain, in some instances severely, the ability of policy makers to deliberately change the behavior of the R-T-E system.

Movement of the R-T-E System through Time

There are several factors bearing upon the movement of the system, which, in this paper, we chose to treat as part of the structure within which the system functions. These factors condition the performance of the system in important, even critical ways, but in this paper, we take them as given. They are world economic growth, the growth of effective demand for food, population growth, the technical ability of farmers to manage new technology, and what we shall call the energy imperative.

World Economic Growth

We assume that the world economy will continue to grow at a rate not much different from that achieved over the last couple of decades, and that the distribution of growth among countries will be about the same as in that period. Some will view this as a question begging assumption, arguing that the events of the last few years portend a period of at least sluggish growth, and at worst the breakdown of the world economy. We do not agree with this argument. While the rate of economic growth has slowed in the 1970's, it can be argued that performance was remarkably good in view of the shock delivered by a 4 to 6 fold increase in petroleum prices. Given the pivotal role of energy in the world economy, such an increase might have been expected to be far more disruptive that it was. We expect energy prices to continue to rise, but not so much in so brief a period as in the recent past. Consequently, the shock to the world economy will be less and there will be time to adjust to less energy intensive patterns of resource use without significant sacrifice of economic growth.

Growth of Effective Demand

We assume that over the next several decades, world effective demand for food will grow somewhat faster than world population; that is, somewhat in excess of 2 per cent per year. Most of the growth in demand will occur in the developing countries because that is where population is growing most rapidly and where the income elasticity of demand for food is highest. The large reservoir of latent demand in those countries, reflecting malnourishment among the poor, suggests that the income elasticity of demand will remain high at least for several decades. As per capita income grows, then assuming the poor share reasonably in the growth, the reservoir of latent food demand will gradually be drained off into effective demand. However, the reservoir is presently so large that even with quite high per capita income growth among the poor--3 to 4 per cent per year, for example--it likely would take several decades to eliminate the nutritional deficit.

Apart from efforts to overcome nutritional deficiencies, we assume that the demand for food in both developed and developing countries will grow because rising per capita income will stimulate a shift toward diets richer in animal protein. Accordingly, the demand for animal products and for feed grains and high protein feed supplements, such as soyabeans, likely will grow faster than the demand for food generally.

We assume that the growth of world demand for food will transmit signals back to the farmer that will induce appropriate production responses with respect to both amounts and kinds of food. It is not necessary to inquire here what form the signals take It is enough to assume that they will be heard and heeded[2].

The only assumption we make about prices of farm outputs is that their effect on the growth of demand will be insignificant relative to the effects on demand of population and per capita income growth. We thus do not rule out the possibility that real prices of agricultural commodities might rise or fall, but we assume that any such changes will not significantly affect the growth of demand.

Underlying this assumption is yet another: that there is sufficient productivity potential in present agricultural technologies, and in those in an advanced stage of development, to offset most of such increases in real prices of resources as might occur over the next 2 to 3 decades. Obviously we think this assumption is justified for purposes of this paper. However, in the discussion of U.S. agriculture, we note that unless new high yielding technologies not now on the horizon are developed, then rising pressure on land resources may result in rising real prices of agricultural commodities. We note a similar possibility in some developing countries where damage to irrigation systems from increasing erosion may sufficiently restrict the growth of production to result in higher prices. Should these things come to pass, world prices of agricultural commodities might rise. Under our assumption, however, the effect on demand of such an increase would be small relative to the effect of rising population and per capita income.

Population Growth

The R-T-E system will be powerfully conditioned by the growth of world population. The role of population in the growth of demand already has been mentioned. But population growth also influences importantly the size and other characteristics of the agricultural resource base. Population growth expands the supply of labor, an important agricultural resource in both developed and developing countries. Over the last several decades, the increasing value of labor has stimulated a steady shift toward labor-saving technologies in developed countries; this likely will continue, although the rate may slow. In the developing countries as a whole, population growth assures that the supply of agricultural labor will grow for several more decades, despite continued rapid migration from rural to urban areas. In south and much of southeast Asia, where the supply of potential agricultural land is small, man-land ratios, already high, will rise higher, pushing farmers in those regions toward labor-using, land-saving technologies. In Latin America and Africa, where the supply of potential agricultural land is more abundant, pressure on the land base likely will be less severe, although still rising.

We take these effects of population growth on the R-T-E system as given; that is to say, we take account of the effects in moving and changing the system but we assume no feed-back from the system to population growth.

Ability to Use New Technology

We also take as given the ability of farmers to adopt new technology. This may be an arguable procedure, but we believe it is defensible on two grounds. The farmer stands at the center of the R-T-E system. His production decisions, prominently including his choices among technologies, are the prime movers of the system. If the system is to adequately perform its function of supplying the rising world demand for food and fiber, then over time farmers must steadily replace less productive technologies with more productive ones. Without replacement, efforts to expand production would soon encounter rapidly diminishing returns to labor and other variable resources, costs of production would rise, and the growth of demand could not be accommodated without subsidies to consumers that eventually would become intolerably high.

Thus, adequate performance of the system requires that the farmer be able to manage new technology. If we do not assume that he has this capacity then in modeling the system we must differentiate those situations in which he has it from those in which he does not, and in those where he lacks the capacity, we must include mechanisms which will provide it. This course would lead to great complexity in the modeling process, with little if any improvement in the results. In the first place, without intensive investigation there is no way of knowing in specific situations whether farmers do or do not have the capacity to manage new technology. In the second place, the ways in which farmers learn to manage new technology are various and not well understood. Hence, even if situations where they lack this capacity could be identified, there is no convincing way of modeling the learning process.

This would not be an argument for avoiding the capacity-to-manage-new-technology issue if there were clear evidence that farmers lack this capacity. In this case, either the issue would have to be tackled or the whole modeling enterprise abandoned. However, the evidence does not indicate lack of capacity. It suggests, on the contrary, that the farmer has it or can acquire it when it is in his interest to do so. This is the second ground for assuming the presence of this capacity. The evidence supporting the assumption comes from experience with the rapid spread of the Green Revolution in Asia and Latin America, and from the earlier adoption of new technology in the developed countries. The evidence with respect to Asia and Latin America has been reviewed elsewhere, and will not be repeated here[3]. We do not argue that all farmers everywhere can instantaneously extract the full productive potential of new technology as soon as it becomes available. The argument instead is that they can learn to do this sufficiently well so that if a steady stream of new, economically attractive technologies is forthcoming, farmers will adopt them fast enough to accomodate expected increases in world demand without increasing production costs. We do not pretend to fully understand the processes by which farmers acquire the necessary technical know-how. It is sufficient that they can be assumed to have it.

The Energy Imperative

If the R-T-E system is to accomodate rising world demand for food and fiber it must incorporate increasing amounts of effectively used energy per hectare and per person employed in agriculture. This is particularly true in the developing countries. In those countries, the potential is small for increasing production based on human and animal energy unaccompanied by more inanimate energy. No doubt improved nutrition of agricultural workers would permit them to work longer and harder, thus contributing to expanded output. However, measured against the increased demand for food and fiber over the next several decades, this potential source of increased production is trivial. In addition, the average number of days worked per year in agriculture in the developing countries likely could be increased. However, a major obstacle to doing this is the shortage of inputs complementary to labor, and energy is one of those inputs. Increased double cropping, for example, could increase the average number of days worked per year, but more double cropping would require more energy for driving irrigation pumps and tractors and in the form of fertilizers and pesticides.

The statement above about the requirement for more energy was deliberately put in terms of effectively used energy per hectare and per person. There are many ways in which the amount of effectively used energy could be increased. Increasing the amount of fertilizer and mechanization per hectare and per person obviously would do it. However, the amount of effectively applied energy can be increased also without using more energy in total. For example, increasing the percentage of nitrogen fertilizer applied which is taken up by the plant will do this, as will measures reducing the amount of irrigation water used per hectare for given yields.

In principle, the increased amounts of energy can tap sources other than fossil fuels. Improvements in photosynthesis would increase the amount of the sun's energy effectively used by crops, thus substituting for other sources of energy in stimulating plant growth. Enhanced capacity of legumes to biologically fix nitrogen would reduce the nitrogen fertilizer requirement for those crops and also for a following crop, such as maize. Developing the capacity of maize and other grains to biologically fix nitrogen of course would dramatically reduce the requirements of those crops for nitrogen fertilizer. Use of animal dung and other forms of bio-mass to generate methane is yet another alternative, as is the use of grains and other crops to produce "gasohol".

Thus, from a technical standpoint, the R-T-E system need not rely on existing patterns of energy use, so heavily weighted with fossil fuels, in satisfying the energy imperative. There are alternative patterns that technically will do the job. But alternatives that fail to increase the amount of effectively used energy per hectare and per person, are not among them.

Present State of the R-T-E System: A Synopsis

The agricultural resources of the R-T-E system, the technologies employed, and the environmental consequences of their use vary widely, within countries and across countries. There are some important features in common, however. Since the end of World War II, in most countries, including most developing countries, a far greater proportion of the growth of agricultural output came from increasing yields and less from expanding the land base than ever before in human history. Certain features of the R-T-E system, as perceived by farmers, induced the system to move along this path. In densely populated regions, such as western Europe, south Asia, parts of southeast Asia, China, Taiwan and Japan, pressure on the land was high, and in some of these countries it was rising rapidly because of high population growth. This pressure increased the relative scarcity of land and moved these countries to adopt relatively land-saving, i.e., yield increasing, technologies. In Asian countries, where labor was relatively abundant, labor substituted for land. In labor-scarce regions, mechanization substituted for both labor and land.

In the United States, land was abundant relative to labor, but government policies designed to reduce output by removing land from production nonetheless encouraged the shift to land-saving technologies observed in most other countries.

In many parts of the world, the shift was encouraged also by the availability of large amounts of unappropriated water which could be used for irrigation. In most countries, most of this water was provided by publicly financed projects at negligible cost to the farmer.

Finally, the shift to land-saving technologies was strongly encouraged by the development of high yielding varieties of grain and by the availability of large amounts of cheap energy. There was strong complementarity between the high yielding varieties and energy in the form of fertilizer, pesticides, and fuel to drive irrigation pumps and farm machinery. This complementarity, taken in combination with the availability of cheap water and high and mounting pressure on the agricultural land base, sent a powerful and consistent stream of signals to farmers all over the world telling them to adopt relatively land-saving technologies.

Through most of the period since World War II the signals generated by concern with the environmental impacts of the technologies adopted were weak. This was true in spite of mounting evidence that the technologies were exacting rising environmental costs as a result of erosion, fertilizer and pesticide pollution, salinization of soils and water because of irrigation, loss of animal habitat and disruption of ecological systems associated with large irrigation systems, destruction of entire species with resulting diminution of the genetic pool of plant and animal life, and other damages. There were two fundamental reasons why these rising environmental costs had little effect on farmers' choices among technologies. First, most farmers did not perceive the environmental costs as threats to their own interests because the costs were borne by somebody else; hence the farmer had no incentive to change his practices to reduce or eliminate the costs. Second, even when farmers, and other members of the society, perceived the environmental impacts as threats, they lacked effective means to force corrective action on those farmers responsible for the damage. The damages of concern occurred because farmers were using air, water and land resources as dumps for their effluents. The people damaged either had no property right in these resources, or if they had a property right, they had no easy way to enforce it against the farmers. In the first instance, the only recourse was public pressure for legislative or administrative action to force farmers to alter their practices; in the second instance, legal action was required. While both of these courses of action were used increasingly, particularly after the mid-1960's, they proved cumbersome and expensive, and by and large, did not send strong signals to farmers to adopt less environmentally damaging technologies.

By the mid-1970's the R-T-E system in most countries was characterized by far more reliance on land-saving technologies--as measured by the ratio of all other inputs to land--than at the end of World War II. The transformation was most marked in the developed countries, but most of the developing countries also had moved a significant distance along the same path. The keys to the transformation were cheap energy and the availability of high yielding technologies. Thus the sharp increase in energy prices since 1973 subjected the system to a severe shock. Although subsequent performance of the system showed it was not derailed by the shock, the prospect for continuing increases in the real price of energy necessarily raises questions about the system's future course. Moreover, mounting public concern with the environmental impacts of current agricultural technologies suggests that societies will find ways to make these concerns register with the farmer, inducing or requiring him to adopt less environmentally damaging practices.

There is strong evidence, in short, of fundamental change in the resource and environmental conditions shaping farmers' choices of technology, indicating that the R-T-E system may be shifting from the course it has followed for the last several decades. That possibility, and alternative paths of the system, are examined in the next section.

Future State of the R-T-E System

Resources

The prospect for rising real prices of energy is the most obvious factor bearing on the future course of the R-T-E system, although the changing relative scarcities of fertilizer, water, land, and labor also are of major importance. We deal first with energy.

Energy

The price of energy typically is the most important single indicator to the farmer of energy's relative scarcity. However, under some circumstances, energy may be absolutely scarce in the sense that farmers cannot get more of it at the existing price, or at any other price. Rationing schemes based on fixed quotas may have this effect. A study by Dvoskin and Heady suggests that in the United States, farmers are more sensitive to rationing limitations on energy supply than to higher prices, given plausible alternatives for each[4]. The study showed that in the U.S. reducing the supply of energy to agriculture by 10 per cent would have a much stronger effect on patterns of resource use and costs of production (for a given level of output) than an increase of 100 per cent in the real price of energy. The reason is that the price elasticity of demand for energy in U.S. agriculture is low--about -.05. Thus doubling the real price reduced total energy demand by only 5 per cent.

In the future, there may well be either deliberate or unplanned interruptions in energy supply to farmers, as happened in 1973 and 1974 with the OPEC embargo on petroleum exports. Such situations could impose an absolute scarcity of energy, which, judging from the Dvoskin and Heady results, might have a more profound impact on farmers than a sharp increase in price. However, we do not expect that over the next several decades there will be a fixed limit to the supply of energy available to farmers, in the world as a whole or in any significant number of countries. This is not to say that there will not be efforts in some countries to ration the supply of energy. We expect, however, that this will not be typical practice in most parts of the world. Moreover, where rationing is undertaken as a permanent policy we expect that black markets for energy would arise, in which case the black market price would be the main indicator to the farmer of the real scarcity of energy. Accordingly, while we recognize that absolute scarcities of energy may arise from time to time reflecting interruptions in production, and that some countries may pursue energy rationing as a permanent policy, we believe that over the long term, for the world generally and for the most countries, the price of energy will be the best indicator of its relative scarcity to the farmer.

There is a widely held consensus that the real price of energy (the nominal price deflated by an index of the general price level) will rise over the indefinite future. While the basis for the consensus is not entirely clear, it seems to rest on two underlying assumptions:

1. That OPEC will maintain its ability to effectively control the world price of petroleum, and
2. that world growth in demand for energy will exceed the growth of supply.

These assumptions are not independent of one another. The slower the growth in demand, or the faster the growth in non-OPEC sources of supply, the greater the difficulty OPEC would have in controlling the price. Or should the cohesiveness of OPEC weaken, for whatever reason, the supply of energy would increase faster relative to demand and the price would fall, or not rise as much as it otherwise would.

We accept the consensus that the real price of energy will rise, while noting that the basis for the consensus is by no means granite hard. In particular we believe that the possibility of discovery of substantial new sources of petroleum may be underrated. However that may be, in this paper we go along with the accepted view.

A review at Resources for the Future (RFF) of several studies of future energy prices indicated general agreement that in the U.S. the average real price will rise roughly 2 per cent per year between the mid-1970's and 2000. There also was agreement that the real price of natural gas will rise more than 2 per cent annually--some 5 to 9 per cent was the range--and that the price of electricity will rise less than 2 per cent. Prices of other energy sources are expected to rise at rates between those for electricity and natural gas.

We have no basis for judging whether the pattern of energy price increases in other countries will resemble that for the U.S. Opinions vary, with some expecting more rapid increases and some perhaps expecting less. If there are studies of this, or a consensus regarding it, we are unaware of them. For the purposes of this paper, we believe this is not a serious limitation and we assume simply that over the long term, the average real price of energy world-wide will rise on the order of 2 to 3 per cent a year. For the U.S., however, the relatively fast increase in the price of natural gas has special significance for irrigation; this is discussed below.

In the developing countries firewood is a major source of energy, especially in rural areas. In his survey of world environmental problems, Eckholm cites scattered but apparently hard evidence that the real price of firewood is rising in important parts of Asia, Africa and Latin America[5]. In some of these areas the price of firewood has risen substantially faster than the price of kerosene, despite the run-up in prices of petroleum products since 1973. The principal resource cost of firewood affecting the price is the labor time required to collect it (which may say something about the alleged surplus of unskilled labor in developing countries), and in some areas transportation. However, as Eckholm and others have vividly demonstrated, the deforestation resulting from collection of firewood also is exacting high environmental costs. If these costs were taken into account, the price of firewood certainly would be higher than it is, although it would not necessarily have risen faster in the last several years.

The combination of continued population growth in rural areas of most developing countries and rising real prices of alternatives to firewood suggests that the real price of firewood in those countries will continue to rise.

Fertilizer

The assumed increase in energy prices would put upward pressure also on fertilizer prices, particularly of nitrogen. Natural gas, coal or naptha may be used as feedstock to produce nitrogen fertilizer. In each case, the cost of the feedstock is an important element in the total cost of the fertilizer. For example, about 53 thousand cubic feet (Mcf) of natural gas are required to produce a metric ton (MT) of nitrogen fertilizer in the form of anhydrous ammonia[6]. At $330 per MT (above the 1978 price but less than in 1974/75) and with natural gas at $1.75 per Mcf (the target price in the U.S. energy legislation passed in 1978), the cost of natural gas could be 28 per cent of the price of the fertilizer. The proportion of course, will vary with different prices of natural gas and of fertilizer. It is clear, however, that a sustained increase in the price of natural gas would soon put upward pressure on the price of nitrogen fertilizer.

The World Bank projects rising real prices for fertilizers, in part reflecting higher energy prices but also the assumption, based on recent experience, that real construction costs for new fertilizer capacity will rise. Judging from a study done by the International Fertilizer Development Center substantial additions will be made to world fertilizer capacity over the period to 1985. The study indicates that capacity to produce nitrogen and phosphate fertilizers will grow approximately in step with demand, but that demand for potassium fertilizer will marginally outpace growth of capacity. These projections suggest that prospective demand-supply balances for fertilizer would not strongly affect prices one way or another, at least over the next 5 years or so. However, the prospective rise in energy prices, and the increase in construction costs anticipated by the World Bank, point to rising fertilizer prices despite the supply-demand balance.

Water for Irrigation

In many parts of the world the relative scarcity of water for irrigation likely will increase over the next several decades. There still are substantial amounts of unappropriated ground and surface water, but much of it likely is not as accesible as water developed so far since the more readily available sources would be developed first. Thus more limited accessibility probably would increase the cost of future supplies of irrigation water even if nothing else tended to do so. There are two other factors, however, which also will tend to raise the cost, namely the rising price of energy and increasing demands for water for non-agricultural uses. An additional factor in some areas is the increasing depth to groundwater, which raises the cost of pumping.

Many surface irrigation systems depend on gravity to spread water on the fields. Such systems obviously require little if any man-made energy. Irrigation with groundwater, however, requires energy for pumping. This form of irrigation has become increasingly important in the last several decades, in part at least because of the availability of cheap energy. Most of the considerable expansion of irrigation in the U.S. since 1960 was based on groundwater. This was true to a large extent also of the spread of the Green Revolution in the Punjab region of India and Pakistan and in parts of Mexico. The prospective rise in the real price of energy inevitably will tend to make irrigation with groundwater more expensive.

The growing demand for water for urban and industrial uses will reinforce this tendency. In the U.S. the fastest growing urban centers are in the arid west, and already water is being transfered from agricultural uses to serve the needs of those centers. In the developing countries, urban population is growing at 5-6 per cent annually, and while the rate may slacken somewhat, total urban population in those countries likely will more than double in the next 15 years. Per capita supplies of water in urban areas already are inadequate to meet public health needs and satisfy other demands. Efforts to overcome these deficits and accommodate the future growth of demand likely will increase the scarcity value of water to agriculture.

The way in which the increasing scarcity of water will be signaled to the farmer will depend in good measure upon the source of supply. The signal will be clearest where groundwater is the source and the farmer pays for the cost of the well and for pumping. In this case, the increased cost of energy registers directly in the farmer's calculations of how much water to pump, or whether to invest in a well at all. If the groundwater table is declining the effect on the cost of pumping also is clearly apparent to the farmer.

Where the water is supplied by surface systems its increasing scarcity may not be reflected in its cost to the farmer. In most countries, surface irrigation systems are financed with public funds and managed by public agencies. In these systems, charges for water typically are designed to recover only a part of the costs of operating the system, and in some systems, no charges are levied at all. Moreover, the amount paid by the farmer usually is based on a fixed ration of water (or fixed proportion of whatever is available) determined by the amount of land he has. Rarely does he have the option of taking more or less, depending upon his judgement of his needs, and paying accordingly.

It probably is fair to say that the procedure for allocating water in surface systems, and the negligible role assigned to prices, reflect a widely and deeply held view that as a resource water is different from most other resources used by farmers. And indeed it is. Because it moves by natural processes from place to place, it is difficult to establish unambiguous property rights to water. The potential for conflicting claims to the resource, therefore, is high. To hold these conflicts in check, or to resolve them when they arise, requires a large measure of public intervention in management of the resource, if not outright public ownership of it.

There is no reason why public management per se should rule out the use of price as a device for allocating water in surface irrigation systems. By long tradition, however, this has not been done, in part perhaps because the view that water is not just a resource like any other, makes water pricing a politically sensitive issue. Another likely reason is that public enterprises frequently charge less than the scarcity value of the service provided, whether it is water, transportation, communications or whatever.

So long as this tradition prevails, the increasing scarcity of water provided by surface irrigation systems will not be signaled to the farmer by way of prices. Instead, the rising scarcity likely will be measured by increasing conflict between rival claimants for water, both among farmers and between farmers and other segments of the society. Many farmers who would like to have more water will not be able to get it, while those with firmly established rights will have no incentive to change their practices to reflect the higher social value of the resource. In time, the discrepancy between the socially optimal uses and actual uses may become so glaring as to force a change in the water management system. Unless that happens, however, the rising real scarcity of water provided by surface irrigation systems likely will have only weak impact on farmers' choices among irrigation technologies.

Land

The potential for expanding the supply of agricultural land varies widely from country to country. In western Europe, south Asia, Indonesia, Japan and China, the potential is more limited than in the United States, the Soviet Union, most of Latin-America and Africa. For given prices of the commodities the land can produce (assuming that price is the relevant signal to the farmer), the potential supply of land depends upon the costs of production on that land. To the farmer, the relevant costs are those for acquiring, clearing and preparing the land for production as well as direct production costs. If environmental costs, such as erosion, infringe on his operations, he will take them into account; otherwise he will not. The society must, however, at least eventually. Consequently, the society's estimate of the amount of potential agricultural land may be less than the sum of the estimates of individual farmers.

An important element in the cost of potential agricultural land is its opportunity cost. This of course depends upon the value of the competing services the land can provide, and probably is a main reason why the potential supply of agricultural land in western Europe and Japan is relatively low. Because of high population density and advanced urban and industrial development, the land in these areas has higher value in urban and industrial uses relative to its use in agriculture than in other countries where population density (although not necessarily the level of industrial development) is less.

Population and industrial growth will continue all around the world, with rates of increase highest in the developing countries. It is likely, therefore, that the opportunity cost of agricultural land will rise generally. In areas such as south Asia where pressure on the land already is high, the increase in opportunity cost may be particularly marked because the elasticity of supply is relatively low. However, even in areas where the potential supply of agricultural land is relatively large, competing demands for the land likely will significantly increase its opportunity cost within the next several decades[7].

Labor

If economic growth continues in most countries, and we assume that it will, then real agricultural wages will rise. Whether they will rise relative to the prices of other resources used in agriculture, however, is quite uncertain. Whatever may be the outcome in this respect, it seems clear that agricultural wages will not rise as much relative to energy prices as they did in the two decades ending in 1973. The reason, of course, is that real energy prices declined in that period, and real wages rose, while energy prices are expected to rise in the future. Unless real wages grow substantially faster than in the past, their growth relative to energy prices will be less than it was. We see no reason to expect acceleration in the growth of agricultural wages, at least not on a scale that would maintain the earlier rate relative to energy prices. One of the factors spurring the growth of agricultural wages in most countries was the large gap between urban wages and those earned in agriculture. This gap has been substantially narrowed in many countries because of high rural-to-urban migration. Consequently, the potential growth in agricultural wages represented by the difference between them and urban wages is less now than it was two decades ago.

All of this obviously is very impressionistic. It seems sufficient, however, to warrant the conclusion that in the future agricultural wages in most countries will not grow as fast relative to energy prices as they did between the end of World War II and 1973. The implication is that farmers will favor more labor-using, energy-saving technologies in the future than they did in that earlier period.

Future State of the R-T-E System

Technology

The analysis of the previous section indicates that the prices and other terms of availability of agricultural resources likely will be less favorable to land-saving technologies in the future than they were prior to 1973. In particular, the expected reversal in the trend of real energy and fertilizer prices points to this conclusion, although the increasing scarcity of water also supports it. The conclusion would not apply equally in all countries, and in some it might not apply at all, particularly where pressure on the supply of land is high. Nevertheless, it seems to broadly characterize the resource situation likely to face most farmers in most countries for the next several decades.

How might the technological choices of farmers be affected by this situation? To answer this question it is useful to begin with analysis of U.S. agriculture. There are several reasons for this. One is that the energy intensity of U.S. agriculture is one of the highest in the world. Hence, the effects of the reversal in trend of energy prices should be especially marked in the U.S. In addition, irrigation from both ground and surface water is important in the U.S., permitting analysis of the effects of the emerging pattern of resource availability on choices between irrigated and dryland farming. Finally, the author is most familiar with the situation in the U.S.

We do not argue that the U.S. experience will be typical of that of world agriculture generally. The U.S. resource position is different in some respects from that of some other important regions, the most notable being the relatively greater abundance of land in the U.S. Nevertheless, we believe that there will be strong similarities in the way farmers in the U.S. and in other countries will respond to the emerging pattern of resource scarcities. In any case, the analysis is not limited to the U.S. Some attention is given also to the situation in developing countries and in western Europe.

It is true that the energy intensity of U.S. agriculture is high in comparison with that of other countries. Nevertheless, the direct cost of energy used by U.S. farmers may not be as large a percentage of the total cost of production as is commonly believed. A study by Rask and Forster of production costs on a representative 240 hectare maize-soyabean farm in Ohio indicated that direct energy costs were about 25 per cent of the costs of maize production (excluding the cost of land), and about 7 per cent of the cost of soyabean production[8]. When indirect energy costs (i.e., those reflecting the energy needed to produce machinery and other inputs) were included, the percentages of energy costs in total costs rose to one-third for maize and 20 per cent for soyabeans.

As indicated, the costs of land were excluded in these calculations. In another study of the same type of farm, however, Rask and Forster found that land costs were about 37 per cent of total costs of maize production and 37 per cent of total soyabean costs[9]. Using these percentages for land costs, the direct and indirect costs of energy would be 24 per cent of total costs of maize production and 13 per cent of total soyabean costs.

Of the major crops produced in the U.S., maize probably is the most intensive user of fossil fuel energy, primarily because of the large amount of nitrogen fertilizer applied to it[10], and the fuel required for drying. The percentage of energy costs in total costs of wheat production, (the other major crop along with soyabeans) is closer to the percentage for soyabeans than for maize.

The relatively low percentage of energy costs in total costs of production suggests that the price elasticity of demand for energy in U.S. agriculture also would be relatively low. A number of studies indicate that this is in fact the case[11]. The implications of this for farmers' choices among technologies are explored in a number of studies reported in Lockeretz et al. The results of the studies are varied, and not always completely consistent, but in general, they indicate that even sharp increases in real energy prices would induce only moderate shifts toward less energy intensive technologies. While adjustments would be significant, they would not constitute a technological revolution. The studies also suggest that the immediate adjustments would be less pronounced than those occurring over the long-run, as would be expected.

The study by Rask and Forster of the effects of higher energy prices on tillage technologies indicated that doubling the real price of energy would have no appreciable effect on farmers' choices among three tillage technologies, ranging from conventional tillage (mold-board plowing) to a no-till system. The reason is that the percentages of direct and indirect energy costs are about the same in the three technologies. The other study by Forster and Rask cited above explored the effects of higher prices for nitrogen fertilizer on a representative maize-soyabean farm in Ohio[12]. They found that raising the price of nitrogen from $330 per metric ton (well above the mid-1979 price) to $550 decreased the optimal application rate per acre of maize land by only 7 per cent, which reduced yields of maize only 1 per cent. The price of maize in this calculation was assumed to be $98 per metric ton, somewhat above the mid-1979 price. The principal effect of varying the price of nitrogen was not on the amount of nitrogen applied to maize but rather on the amount of land in maize and soyabeans. With maize at $98/MT, soyabean at $330/MT, (well below the mid-1979 price) and nitrogen at $330/MT, 82 per cent of the land would be in maize and 18 per cent in soyabeans. With nitrogen at $550/MT the percentages of land in each crop would be 61 and 39, respectively[13]. A shift in this direction of course would be expected since nitrogen applications on maize are much higher than on soyabeans.

While the Rask-Forster study shows that the main effect of varying the price of nitrogen is on the distribution of land between maize and soyabeans, it also shows that this effect is relatively less pronounced than variations in the relative prices of maize and soyabeans. As noted above, with maize at $98/MT, soyabean at $184/MT and nitrogen at $330/MT the distribution would be 82 per cent maize and 18 per cent higher (still well below the mid-1979 price) the land in maize would drop to 53 per cent and soyabean land would rise to 47 per cent.

The study by Dvoskin and Heady, cited above, is consistent with that of Rask and Forster with respect to the effects of higher energy prices on the amounts of fertilizer applied per hectare. Doubling the real price of energy from 1974 levels would reduce per hectare application of nitrogen fertilizer in U.S. agriculture generally by only 5 per cent. The percentage reduction on maize would be less than 6 per cent. Because the total amount of land in crops would increase, the Dvoskin-Heady study shows that doubling the price of nitrogen would have only a negligible effect on the total amount of nitrogen applied. It should be noted, however, that the study assumes that the total amount of production of each crop is invariant to the price of energy and fertilizer. It thus does not permit shifts to less fertilizer intensive crops, which the Rask-Forster study showed would occur. If the Dvoskin-Heady model were modified to permit such shifts, it likely would show that the total amount of nitrogen applied would in fact decline with a doubling of the prices of energy.

The Dvoskin-Heady results indicate that the most significant effect on U.S. agriculture of doubling the price of energy would be on the distribution between irrigated and dryland farming. Compared to the so-called "base run" results of their model, (with energy prices at 1974 levels and all other input prices at 1972 levels), a 100 per cent increase in the price of energy would reduce the amount of irrigated land by 22 per cent (2 million hectares) and increase the amount of unirrigated land by 2.6 per cent (3.4 million hectares).

A study by Lacewell, Condra and Fish[14] of the effects of higher energy prices on irrigated farming in Texas gives results which at first blush appear inconsistent with those of Dvoskin and Heady. Lacewell et al. show that an increase in the price of natural gas from $.80 to $2.12 per Mcf would have no effect on the amount of irrigated land[15]. The principal consequence would be a modest shift from production of maize to the production of grain sorghum and wheat. Production of cotton and soyabean would not be affected. An additional increase in the price of natural gas to $2.47 per Mcf would reduce the amount of irrigated land by 15 per cent, all of it in cotton, which would go out of production. Thus, in the area studied by Lacewell et al., a 100 per cent increase in the price of natural gas would have no effect on the amount of irrigated land, in contrast to the finding of Dvoskin and Heady that a 100 per cent increase in the price of energy generally would reduce irrigated land in the country as a whole by 22 per cent. In the study by Lacewell et al., even a 200 per cent increase in the price of natural gas (from $.80/Mcf) produces a smaller relative decline in the amount of irrigated land than a 100 per cent increase in energy prices generally would have in the country as a whole, according to Dvoskin and Heady.

These differences between Lacewell et al., and Dvoskin-Heady may be more apparent than real. Lacewell et al. show that raising the price of natural gas from $.80 to $2.12 per Mcf would reduce net returns per acre by 40 per cent. They assert that this would have "...very serious economic implications concerning the viability of existing farm firms" (page 154), and it is easy to believe this. Farmers who already have invested in irrigation equipment might well continue for a period to irrigate as much land as before despite the higher price of energy, so long as they were able to cover their variable costs. Over the long term, however, many of them surely would be reluctant to maintain the same level of investment in irrigation, given such a sharp decline in the rate of return on the investment.

Thus, the long term effects of higher energy prices in reducing the amount of irrigated land in Texas likely would be more pronounced than the short term effects shown by Lacewell et al. The Dvoskin-Heady study assumes that farmers have time to adjust their investment position to the higher level of energy prices. In a long term perspective of the sort taken in this paper, therefore, the Dvoskin-Heady and Lacewell et al. results are not as far apart as may appear at first.

The distinction between the short term and long term impacts of higher energy prices on farmers' choices between irrigated and dryland farming clearly is important. We think the distinction probably is relevant also to choices among technologies appropriate for dryland farming. The finding of Rask and Forster that doubling energy prices had no appreciable effect, either short term or long term, on choices among tillage technologies on maize-soyabean farms in Ohio contradicts this. However, there are two characteristics of the Rask-Forster study suggesting that the contradiction may not be serious. First, the study considered only three technologies, all of which used about the same amount of energy. It is not surprising, therefore, that higher energy prices would have little effect on choices among the technologies. Second, the study showed that higher energy prices would substantially reduce net return to the farmer, both in the short and in the long term. In all the alternatives examined except one, net returns would remain positive. In the long run, however, they would be lower by amounts ranging from 55 per cent to 96 per cent.

We think it unlikely that farmers would quietly accept permanent reductions in net returns of this magnitude. Either they would leave farming, or they would search for ways to economize on the high priced energy resources without sacrifice of yield (an alternative not included in the Rask-Forster analysis), or they would look for lower priced or more productive sources of energy, also not among the alternatives considered by Rask and Forster. Since we assume that the R-T-E system will in fact respond adequately to rising demand for food and fiber we rule out the exit from agriculture as a response to higher energy prices. The focus instead is on the other two alternatives.

There appear to be two principal ways in which American farmers could achieve greater economy in the use of high priced energy sources:

1. By reducing losses of nitrogen fertilizer, i.e., increasing the percentage of nitrogen applied which is taken up by the plant, and

2. reducing losses of irrigation water applied, thus reducing the amount of energy needed for pumping.

It is estimated that 30 to 60 per cent of the nitrogen fertilizer applied to crops in the U.S. is lost, primarily because of leaching and denitrification[16]. These data must be interpreted cautiously because they are based on experimental conditions, which might not be exactly those faced by the farmer. Nevertheless, the data suggest that reduction of losses of nitrogen could significantly reduce the amount of nitrogen applied without adversely affecting yields. Most of the nitrogen applied in the U.S. is in the ammoniacal form, but within 1 to 4 weeks it is biologically converted to the nitrate form (nitrification). Nitrate is highly soluble; hence that part not taken up by the plant may be lost in surface or sub-surface run-off, or to deep percolation. Nitrate also is subject to denitrification, in which form the nitrogen escapes as gas.

Nelson et al. point out that the conversion of ammoniacal N to nitrate can be inhibited by chemical means, and they present the results of field studies in Indiana designed to test possibilities for doing this. The studies showed significant reduction in losses on N applied to maize and wheat, with no sacrifice in yield. In fact, yields increased. Nelson et al. do not discuss the economics of these practices, and we assume that they are not now economical on a wide scale. Otherwise, they would already be in wide use, or there would be evidence that they were spreading. We do not know of such evidence. The point here is that there are promising field level results showing that these practices have high promise for reducing losses of applied N. With additional research the practices may provide farmers an economical way for continued high level use of nitrogen fertilizer despite its rising price.

Gilley and Watts cite a number of studies showing losses of nitrate nitrogen to deep percolation in irrigated areas ranging from 29 to 100 pounds of N per acre[17]. Total amounts of N applied per acre are variable, depending upon the crops and soils. However, Dvoskin and Heady, in the base run of their model referred to earlier, showed average applications of N of 40 pounds per acre on all crops in the U.S. For maize grain the application rate was 89.9 pounds per acre. These figures indicate that in irrigated areas a large proportion of the nitrogen applied may be lost to deep percolation. The losses occur because more water is applied than can be held in the rootzone of the plant. Gilley and Watts argue that the losses can be reduced by scheduling the application of water so that a greater proportion of it is taken up by the plant. They cite data showing that in Nebraska scheduling applications of water with center pivot systems reduces the amount of water applied by 20 per cent, with an equal saving in energy used. They do not discuss the economics of irrigation scheduling practices, but these practices are in fact spreading in the western part of the United States. The main reason seems to be farmer response to the rising cost of pumping groundwater, but judging from the data presented by Gilley and Watts there may be important advantages also in reducing losses of nitrogen to deep percolation.

Irrigation scheduling is only one of the possibilities discussed by Gilley and Watts for reducing the amount of energy used in irrigation, without reducing the amount of water effectively used by the crop. Others include improvements in the efficiency of pumps, reducing pressure in sprinkler systems, and increasing the efficiency of irrigation in surface irrigation systems. Although the principal interest of Gilley and Watts in these alternatives is their potential for saving energy, they all will also save water. Gravity flow surface systems use little if any purchased energy, but improvements in the efficiency of water use in these systems has potential for saving much water. Gilley and Watts assert that in the U.S. the efficiency of surface systems varies between 30 per cent and 70 per cent, with an average of 60 per cent. They do not define "efficiency", but their discussion suggests that it refers to the percentage of water applied to the field which is effectively used by the plant. According to Gilley and Watts, techniques for collecting run-off and returning it to the field could increase the efficiency of surface systems from the present 60 per cent to 85 per cent.

Of course, none of these technologies for reducing the amounts of energy and water used in irrigation are costless. More efficient pumps are likely to cost more than presently installed pumps, and reduced pressure systems may not give a uniform coverage of the land as high pressure systems. The larger drop size with low pressure systems also may compact the soil, increasing run-off, and perhaps may pose an erosion hazard. Center pivot or sprinkler systems, required for application of the water scheduling concept, require larger investments than surface systems. The run-off reuse system, while not described by Gilley and Watts, evidently would require some method for collecting run-off in an impoundment and for then returning it to the field.

All of these alternatives to present irrigation technologies thus would require the substitution of other inputs--most obviously capital, and perhaps labor as well--for energy and water. As the relative price of energy and scarcity of water rise, these substitutions will become increasingly attractive. As noted above, center pivot systems and water scheduling practices already are spreading in the western U.S.

In the preceding paragraph, reference was made to the increasing scarcity of water, rather than to its price. This was because the prices charged for water delivered from publicly owned irrigation systems in the U.S. have little relation to the cost of the water, hence cannot be relied on to signal to farmers the increasing real scarcity of the resource. For water delivered by these systems (to our knowledge all are surface water systems, but there may be exceptions) farmers will have weak incentives to adopt water saving technologies, such as the run-off reuse system. The increasing scarcity of water in these systems will show up in forms other than in the price of the water. One form, already evident, is increasing reluctance in the executive branch of the federal government to build such systems because of their high and for the most part unrecoverable costs. So far the Congress has resisted the efforts of the executive to cut back on these projects, but in our judgement the trend is with the executive. If this is correct, then in time the increasing scarcity of water to farmers will take the form of absolute scarcity--fewer new irrigation systems will be built so the absolute quantity of water available will be less.

The failure of the cost of water to reflect its true scarcity value is characteristic of publicly owned systems in the U.S. Much of the irrigation in the U.S., however, is from individually owned wells, or from privately owned irrigation companies. The cost of water from these sources generally will rise with its increasing real scarcity, indicating that farmers receiving water from these sources will have incentive to adopt water and energy saving practices.

In addition to the search for ways to economize on high priced forms of energy, farmers in the U.S. likely will also give increased attention to forms not based on fossil fuels. So-called "organic farming" is one possibility. Lockeretz et al. did a careful study comparing organic farms with conventional farms in the American cornbelt[18]. Each group of farms were mixed crop-livestock enterprises. The organic farms had an average of 173 hectares, conventional farms 194 hectares. With very minor exceptions the organic farms used no inorganic fertilizers, insecticides, or herbicides. All of the conventional farms used these materials; they also used significant amounts of manure, but not as much as the organic farms. Because they rotated maize with legume hay (as a source of nitrogen) and required feed for their animals, the organic farms had only 52 per cent of their cropland in row crops (maize and soyabeans) compared to 73 per cent on the conventional farms.

Comparisons were made of the operations of the two groups of farms in 1974 and 1975. On average for the two years the per acre value of crop production on the conventional farms exceeded that on the organic farms by 11 per cent. However, production costs were lower on the organic farms, so that the average net returns for the two years were the same for both groups of farms. The organic farms used only 43 per cent as much energy (measured in BTU's) per dollar of crop production as the conventional farms, but they used 11 per cent more labor. The organic farms were depleting soil stocks of P and K, while the conventional farms were in balance with respect to these nutrients. Replacing the P and K deficits would have decreased the net returns of the organic farms by a little less than 4 per cent.

The Lockeretz et al. study suggests that organic farming may have promise as a way of substituting other forms of energy for fossil fuels. There are three conditions, however, which likely would severely limit wide-scale adoption of organic farming in the U.S. One is that the amount of nitrogen in all the manure now produced in the country is a small proportion of nitrogen now applied in the form of inorganic fertilizer. Hence even if all this manure could be collected for use by farmers, its contribution to satisfying the demand for nitrogen would be minor. A second limitation is that the cost of transporting manure is so high that, if it must be moved more than a few kilometers, it cannot compete with inorganic fertilizers, even at the high prices for the latter prevailing in 1974 and 1975. This was not a problem for the organic farms in the Lockeretz et al. study because they had sufficient livestock to produce enough manure close to where it was needed. Many crop farms, however, have few or no animals and would have to depend upon manure produced elsewhere for their supply of nitrogen. Under present conditions this would not be economical for most of them. Third, for a crop like maize, or any other requiring supplemental nitrogen, organic farming is a more land-using technology than conventional farming. The need to rotate a legume with maize means that for a given amount of maize production more land is required than if the nitrogen is provided in inorganic form. In effect, organic farming substitutes land for inorganic nitrogen. There are currently about 30 million hectares planted to maize in the U.S. Much, although by no means all, of this land is in continuous maize, with heavy usage of inorganic nitrogen. If organic farming were substituted for this system, a substantially greater amount of land would clearly be required to produce the same amount of maize, although we are not able to say precisely how much more.

The greater land requirement of organic farming would not necessarily limit its widespread adoption in the U.S. Much would depend on how much the price of nitrogen fertilizer rises and on the supply of potential cropland relative to competing demands for the land. We return to this latter point below. The point here is that the land-using nature of organic farming must be kept in mind when considering the possibility of large-scale adoption of the technology.

Animal wastes, crop wastes, grains or other organic materials may also be used to produce energy in other forms, such as methane gas, or in liquids such as methanol and ethanol. In principle, farmers could substitute these organic sources of energy for fossil fuels. A study by Miranowski et al. of the use of crop and animal wastes to generate methane on a representative family farm in Iowa indicated that energy prices would have to increase more than five times from 1976 levels to make this economical[19]. We have not systematically examined other evidence on the economics of methane generation on American farms, but our strong impression is that the results reported by Miranowski et al. are representative of the present situation for most farms[20].

There appears to be rapidly growing interest in the midwest and southwest of the U.S. in the use of grain to produce ethanol as an "extender" for gasoline. In a 10 ethanol to 90 gasoline ratio the resulting "gasohol" can be used directly in any vehicle or machine operated by gasoline, and apparently gives good performance. Gasohol is not presently competitive with gasoline in the U.S., but increasing prices of gasoline are rapidly reducing gasohol's disadvantage.

In assessing the likelihood of large-scale production of gasohol, however, it is important to note that the technology for producing it, like organic farming, is land-using. Gasohol substitutes land for gasoline. We have no precise idea how much land would be required to produce the ethanol necessary to replace 10 per cent of all the gasoline now used in the U.S., but it surely would be millions of hectares[21].

This analysis suggests that increasing prices of energy and scarcity of water in the U.S. would tend to move farmers toward adoption of more land-using technologies. This tendency would be particularly marked with widespread adoption of organic farming or use of biomass to produce methane gas or gasohol, but it would be present also if the principal response were to economize on water and fossil fuel sources of energy.

The tendency toward land-using technologies would be offset if the productivity of presently used technologies were to rise in step with the prices of energy, fertilizer and water, but there is no reason to expect this. On the contrary, there is evidence that the rate of increase in productivity of presently used technologies is slowing in the U.S. The growth of crop yields slackened substantially since the early 1970's. Wheat yields reached a peak in 1972 or 1973 to which they have not yet returned. Yields of maize were a record in 1978, but exceeded the previous peak reached in 1973 by only 4 per cent, a marked reduction from growth rates achieved prior to 1973. Yields of other grains showed growth patterns similar to those for wheat and maize. Soyabean yields continued to rise after the early 1970's, but at a slower rate than previously.

Crop yields are only a partial indicator of productivity; moreover, in the U.S. the recent performance of yields was influenced by a number of years of bad weather and by the lower fertility of land brought into production after 1972. It is significant, however, that yields of maize in 1978 were only marginally above those of 1973, even although the weather in 1978 was exceptionally good for maize, and the amount of land in the crop was about the same as in 1973.

In any case, there is nothing about the performance of productivity or yields in the U.S. in the 1970's to suggest that productivity might accelerate to keep pace with rising energy and fertilizer prices and water scarcity. There is no present evidence, therefore, that productivity growth will offset the tendency of these resource conditions to move farmers toward adoption of land-using technologies.

How far they move in this direction will be affected by the potential supply of cropland in the U.S. A survey conducted by the U.S. Soil Conservation Service in 1977 indicated that there were 165 million hectares of cropland in the country and about 16 million additional hectares of land in pasture, forest and range with high potential for conversion to cropland. High potential land was that which could be economically converted to crops under the price, cost and yield conditions prevailing in 1976. In addition, there was a larger amount of land with medium potential for conversion to cropland. The economic conditions necessary for converting this land were not specified.

Studies underway at Resources for the Future indicate that, if American farmers adopt relatively land-using technologies, the demand for cropland in 2000 would exceed the present supply plus the land with high potential by at least 10 million hectares and possibly by much more[22]. These projections <u>do not</u> assume a shift to organic farming or an important increase in the use of grain to produce gasohol. Should either of these developments occur, the demand for cropland would be greater than projected by RFF.

It cannot be assumed that all of the 16 million hectares of high potential land would be available to farmers; some millions of hectares of it would likely be claimed by rising urban and other competing demands for land. Consequently, to meet the projected demands for cropland, millions of hectares of land with only medium potential for crop production would have to be converted to that use.

Under the assumed conditions with respect to technology and prices of resources, the real costs of production on the converted land would be higher than on land already in crops. Prices of U.S. agricultural products, therefore, would be higher. Several different consequences might follow from this. If costs of production in other countries were to rise more or less in step with those in the U.S., then world food prices would rise and people would spend a greater proportion of their incomes on food, or eat less, or perhaps both. If costs in other countries did not rise as fast as in the U.S. then the U.S. probably would lose some of its present share in world markets and world food prices would not rise as much.

A third possibility is that the tendency for U.S. production costs to rise would spur development of new technologies that would offset the tendency. The history of agriculture in the U.S. and other countries, indeed the history of economic development generally, indicates that this is a strong possibility. The empirical evidence is strong that emerging resource scarcities induce research and development efforts leading to new technologies which either make more productive use of the increasingly scarce resources or replace them with cheaper substitutes[2 3].

Of course it takes time to mobilize and direct the necessary research and development effort, so there may be a lapse between the first signs of emerging resource security and the availability to the farmer of new technologies. In the case of American agriculture this lapse may be prolonged because of the abrupt shift of the resource situation from one of relative abundance of land to one of increasing relative scarcity. For decades the main problems of American agriculture were how to deal with surpluses, not how to overcome resource scarcity, and the direction of research reflected this situation. Consequently, research in some areas that have high potential for increasing productivity, such as improved photosynthesis, did not get the support it would have received had the resource situation been different. It will take time to rearrange research priorities to respond to the switch in the resource situation from abundance to scarcity.

In summary, it is likely that the emerging long-term situation with respect to prices and availability of energy, fertilizer and water will encourage American farmers to adopt technologies using relatively less of these resources and relatively more capital (particularly in irrigation), labor and land. The relative increase in labor and land will be greater to the extent that farmers adopt organic farming, but even if organic farming does not spread, there likely will be some substitution of land for energy, fertilizer and water.

We do not expect these shifts in technology to be so marked as to transform agricultural production and resource use in the U.S. It is likely that in the first decade of the twenty-first century American agriculture will be recognized without difficulty by anyone who knows it today. The relatively low shares of energy, fertilizer and water in total costs of production, and the promising possibilities for economizing on these resources point to this conclusion. Widespread adoption of organic farming would upset the conclusion, but we do not expect organic farming to spread widely. The cost of transporting manure will likely remain a major obstacle. The rising price of energy, which increases the attractiveness of organic farming to the farmer with many animals, at the same time makes the practice less attractive on a wide scale by increasing the cost of transport. The land-use requirements for organic farming, when added to all the other competing demands for the land, also argue against its viability on a wide scale.

This broad perspective suggests that the technological responses of American farmers to rising prices or scarcity of energy, fertilizers and water will exert increasing pressure on the nation's land base. By the end of the century, in fact probably well before that, this pressure will result in rising costs of production unless new, yield increasing technologies are developed and widely adopted. The pressure of rising costs may itself call forth the necessary technological response. However, this is not certain, and in any case the response may not be in time to completely offset the tendency of costs to rise. It seems likely, in short, that American agricultural capacity will be under steadily rising pressure for the next several decades.

Technological Responses in other Countries

Given the emerging situation with respect to energy, fertilizers and water, there are two characteristics of American agriculture suggesting it will move toward more land-using technologies:

1. The apparent lack of potential for high productivity growth with existing land-saving technologies; and

2. the existence of relatively large amounts of land which could be converted to crops.

In thinking about the likely technological responses of farmers in other countries to the emerging pattern of resource scarcity it is useful to compare those countries with the U.S. with respect to the two indicated characteristics.

Obviously such a comparison cannot be done for each country, a task well beyond both the scope of this paper and the capacities of the author. Fortunately such detail is not needed for our purposes. An impressionistic survey will do.

With respect to potential for productivity growth with present technology and potential supply of agricultural land most countries will fall in one of four categories which we call:

1. Low productivity potential/high land potential
2. High productivity potential/high land potential
3. High productivity potential/low land potential
4. Low productivity potential/low land potential/

The U.S. is in the first category. Farmers in other countries in the same category would be expected to respond roughly in the same way as American farmers to the emerging pattern of resource scarcity. Farmers in countries in other categories would respond in different ways, which we can specify at a general level.

More than other countries, Canada and Australia seem to resemble the U.S. with respect to the two characteristics. Their agriculture is highly developed, yields are relatively high, but not rising as rapidly as they were, and the potential supply of agricultural land seems to be relatively abundant. Accordingly we put these two countries in category one, and we assume that their farmers will respond much like those in the U.S. to the emerging pattern of resource scarcity.

Argentina and Brazil and most other Latin American countries appear to belong in the second category[24]. In these countries, present levels of energy and fertilizer use, and irrigation, are lower per hectare of agricultural land and per farm worker than in the U.S. This suggests that the marginal productivities of energy, fertilizer and water are higher in these countries than in the U.S. If this is true, then the rising prices, or scarcity, of these inputs would not discourage their use in those countries to the same extent as in the U.S. Put somewhat differently, in category 2 (and 3) countries, the attractiveness of land-saving technologies would be diminished less than in the U.S. by rising prices, or scarcity, of energy, fertilizer and water.

This argument needs elaboration. The marginal productivities of these yield increasing inputs are not determined simply by the quantities of them relative to land and labor. The prices of the inputs in relation to agricultural commodity prices are crucial. In addition, the inputs must be available when and where they are needed, and in the required quantities; and farmers must know how to use them productively. We stated early in this paper that we assume that the growth of demand for food and fiber will transmit signals to the farmer which will induce an appropriate production response, and that he will have the capacity to adopt new technology. We also noted our assumption that price would be the main indicator to the farmer of the scarcity of energy, meaning that at the given price he could buy as much energy as he wanted. We extend this assumption now to fertilizer.

We thus assume the conditions necessary to assure that the marginal productivities of energy, fertilizer and water are higher in category 2 (and 3) countries than in the U.S. Of course, in an analysis of potential for agricultural development in these (or any other) countries this assumption would be quite illegitimate. In such an analysis investigation of the conditions affecting commodity prices and the supply to the farmer of high productivity inputs would be crucial. This paper, however, is concerned with a different set of issues: *given* increases in demand and emerging patterns of resource scarcity, what kinds of technology will farmers choose? For this purpose the assumption is legitimate. Nevertheless, it is reassuring to note that since the mid-1960's, *including the period since 1973*, fertilizer use in the developing countries (virtually all of which we place in category 2 or 3) has grown much more rapidly than in the U.S. This of course is what would be expected if the marginal productivity of fertilizer were higher in those countries than in the U.S.

The countries of the Indian sub-continent, Indonesia and China appear to be category 3 countries. Their levels of use of energy, fertilizer, and water are much lower per person in agriculture than in the U.S., and their uses of energy and fertilizer, but perhaps not water, are also lower per unit of agricultural land. Moreover, the potential supply of agricultural land appears to be much less in these countries than in the U.S.

Category 3 countries, therefore, have relatively high potential for increased productivity with present technologies, and relatively low potential for bringing in more agricultural land. Under these circumstances, farmers in these countries would be less likely than American farmers to substitute land-using for land-saving technologies in response to rising prices, or scarcity, of energy, fertilizer and water. Judging from announced plans for massive investments in irrigation and greatly increased use of fertilizers, governments in these countries also perceive the long-run resource situation as one calling for continued reliance on land-saving technologies.

This, of course, is not to say that these countries will simply travel down the same technological path the U.S. began to follow 30 years ago. The vastly greater supply of labor in these countries relative to other resources assures that this will not happen. This difference in resource endowment will be reflected in these countries in greater reliance on labor and animal power and less on mechanization than in the U.S. This is not to say that mechanization will not occur. It already has, and can be expected to continue. In India, for example, the number of tractors increased from 54 thousand to 500 thousand between 1966 and 1978, and the Fifth Five Year Plan calls for continued rapid mechanization[25]. However, there is evidence that the pace of mechanization in some category 3 countries was accelerated by exchange rate and credit arrangements which, from a social viewpoint, overvalued tractors and other farm machinery relative to labor and bullocks. Studies of the social economics of bullocks vs. tractors in Pakistan suggest that under conditions of the late 1960's the rate of tractorization in that country was excessive. The results of studies in India, while not as clear on this issue, nevertheless point to the same conclusion[26].

The increase in the price of energy would increase the value of bullocks and labor relative to tractors in category 3 countries. Higher energy prices, therefore, may induce these countries to move more slowly toward mechanization than would otherwise be the case. The issue is complicated, and firm judgements about likely rates of mechanization are impossible without investigation of specific conditions. Mechanization may often be necessary to achieve double-cropping because it permits more rapid land preparation than a combination of bullocks and labor. The relative scarcity of land in category 3 countries indicates that opportunities for double cropping should not be missed. For the same reason, the opportunity cost of the land required to grow feed for bullocks may be high, a point in favor of tractorization.

On balance, it is virtually certain that mechanization will continue in category 3 countries, but the pace likely will be slower than it otherwise would have been because of the rising price of energy. However, because the social value of mechanization may have been overhauled, at least in some of these countries, the social cost of slower mechanization (or higher energy prices) may well be less than the private costs.

Much attention is being given in category 3 countries to development of energy alternatives to fossil fuels. Work probably is most advanced on the technology and economics of generating methane gas from biomass, primarily animal dung, although crop residues or other vegetable material may also serve as feedstock. According to reports, methane generation at the village level is widely used in China; it is spreading also in India[27].

Biogas (as the technology will henceforth be called) has some attractive features as an alternative energy source in category 3 countries. It can substitute for kerosene and firewood, both of which likely will be increasingly expensive for the foreseeable future. The advantage with respect to firewood is increased from the social standpoint because of the high and rising social costs of deforestation. The technology relies on locally available resources for feedstock, an important advantage in large countries where transport systems are underdeveloped and overworked. The technology is relatively simple, although perhaps not so simple as sometimes supposed, a point touched on below. And the opportunity cost of the dung used for feedstock is low because most, if not all, of its nutrient content is available in the slurry produced by the process.

Despite these advantages, the technology has not spread as rapidly in India as might have been expected[28]. There seem to be a number of reasons. A common problem is maintaining the correct temperature in the digestor. This has proved difficult in northern parts of India because of seasonally colder tempertures, but the problem is not confined to those areas. There is some evidence that maintaining the correct temperature may present a more complex problem, and require a higher level of management skill, or technology to substitute for management, than has commonly been believed.

There appear to be economies of scale in the process, suggesting that plants to serve an entire village would have some economic advantages relative to family size plants[29]. However, village size plants obviously require more social organization than family size plants. Resources must be mobilized to build and run the plant, and to collect the dung required to feed it; and a system for distributing the gas and the slurry (or fertilizer) must be developed. That such village level plants have not spread suggests either that they in fact are not economical, or that the organizational problems of building and managing them have not been solved, or both.

The social advantage of biogas as an alternative to firewood evidently has not weighed heavily in the development of the technology. This is not surprising. The social advantage, no matter how great, counts for little in the calculation of individuals considering whether to build a biogas plant because any given individual reaps only a small part of the social gain. Public officials should have a larger appreciation of the social advantage, but even for them the advantage may appear distant and abstract.

Despite these drawbacks, research and development is proceeding on biogas technology, and the prospect of rising fossil fuel prices, and the rising social costs of deforestation, likely will add a constant spur to the effort. We think it likely that the major difficulties with the technology gradually will be overcome and that the use of biogas will spread. Its increasing availability likely will have small impact on farmers choices of technology, however. The principal use of biogas for the foreseeable future will be in home heating and cooking, not for directly productive purposes on the farm.

Much attention also is being given in India to development of various kinds of solar power as alternatives to fossil fuels. Some of these alternatives, for example, solar cookers, would substitute primarily for firewood and kerosene for home uses, and like biogas, would have no impact on choices among farm technologies. Others, such as generation of electricity by photo-voltaic cells, could substitute for diesel fuel as a power source for irrigation pumps. To the extent that such alternatives prove viable, however, they would reinforce, not offset, the tendency for farmers in category 3 countries to adopt more energy intensive, land-saving technologies.

Irrigation already is very important in category 3 countries, and India at least has plans for substantial additions to the presently irrigated area[30]. These plans have been developed since the increase in energy prices in 1973; presumably Indian planners consider that irrigation must play a major and increasing role in Indian agriculture despite the high energy prices and prospects that they will rise higher. Obviously the planners also think that the water resources of India are sufficient to support the projected expansion of irrigation.

Thus, agricultural policy in India is designed to encourage farmers to adopt land-saving technologies, despite rising prices of energy and fertilizer and increasing scarcity of water. We believe the policy is in accord with the emerging pattern of resource scarcity confronting Indian farmers and with the productivity potential of the land-saving technologies available to them. So far as the resource position and technology determine the outcome, the policy should succeed.

Although the development of land-saving technologies in category 3 countries will place major emphasis on irrigation, we expect significant development also of technologies appropriate for dry-land farming. This is based on two features of the current situation in (at least some) category 3 countries. One is that even the ambitious plans for expanded irrigation likely will not meet the agricultural production goals of category 3 governments. Second, many farmers in many potentially productive areas in these countries will not be reached by irrigation. Not only would these farmers thus not reap the benefits of irrigation, they may be significantly disadvantaged by it. The production increases resulting from the spread of irrigation and complementary technologies could lower the prices these farmers receive for their crops. Unless their productivity increases proportionately, they will suffer a loss in real income. Thus there is a strong equity argument for development of technologies appropriate for dryland farming.

In recognition of these two conditions , there is much research under way to develop both crop varieties that can thrive in areas of slight rainfall and technologies that increase conservation of soil moisture in these areas[31]. These technologies would be land-saving, in the sense that they would give increased yields resulting, at least in part, from a greater amount of effectively used energy and water (and perhaps other inputs) per hectare. We are not clear on the role of fertilizer in these technologies, but it is clear that they would permit greater utilization of the sun's energy to stimulate plant growth.

We are not prepared to speculate on the relative importance of irrigated and dryland farming in the future expansion of agriculture in category 3 countries. Much will depend on the success of the research effort to develop higher yielding technologies for rain-fed areas and on the efficiency with which water is used in irrigated areas. The increasing resource scarcities should spur efforts along both these lines, but we are not able to judge the likely outcome.

Western Europe is the major region classified in category 4: low productivity potential/low land potential[32]. Current technologies in western Europe are highly land-saving, befitting the resource endowment of the region. Fertilizer applications per acre vary from country to country, but on average for the region as a whole, they are higher than in the U.S. Mechanization is well advanced, although we are not sure how it compares with the U.S. on a per hectare and per person basis. Labor in western European agriculture is more abundant in relation to land than in the U.S. Insecticide applications per acre are much less in western Europe than in the U.S., reflecting differences in the cropping pattern. Cotton and maize receive much the greater part of the insecticides applied in the U.S. Cotton is of no importance in western Europe, and maize is much less important, relative to other crops, than in the U.S. Irrigation is of scant importance in western Europe for climatic reasons.

Agricultural technology in western Europe, therefore, is more land-saving than in the U.S. in the sense that the quantities of key inputs are greater per unit of land than in the U.S. The implication is that the marginal productivity of these inputs is low. In this case, the rising prices of energy and fertilizer would induce farmers in western Europe to seek ways to use these resources more sparingly, substituting other inputs for them, and to search for less expensive forms of energy. Unlike American farmers, those in western Europe are not likely to find land-using technologies an attractive way to go because of the already relatively high and rising value of land. As in the U.S. there may be possibilities for reducing nitrification losses of nitrogen by more timely applications or use of nitrification inhibitors. We are not sufficiently familiar with western European agriculture to judge how large these and other opportunities for economizing on nitrogen, or other inputs, may be.

Mixed crop-livestock farms are more common in western Europe than in the U.S., and this may increase the feasibility in Europe of organic farming as a response to higher prices of nitrogen. The relatively greater abundance of labor in European agriculture also would favor this. Inclusion of a legume in rotation with a main crop probably could not be a part of a region-wide organic farming system, however, because of the greater land requirement.

Thinking about likely technological responses of western European farmers to rising prices of energy and fertilizer is complicated by uncertainty over the long term course of policies in the European Community (EC). The Community currently maintains agricultural commodity prices well above world levels, and this undoubtedly explains in part the large amounts of fertilizers applied by farmers in the Community. There is growing concern in the Community about the high costs of this price policy, and some evidence that over the long term the policy will be changed to permit a slow decline in real prices. If this happens, there likely will be a readjustment in the structure of EC agriculture. Less efficient farmers would decide to leave agriculture, permitting an expansion of average farm size with consequent capture of scale economies. This might be associated with a more rapid rate of mechanization, but it may simply be a matter of better utilization of the existing stock of farm machinery. In any event, the increase in efficiency would provide a cushion to absorb the shock of rising prices of energy and fertilizer. So long as the cushion lasts, the rising prices of inputs and declining prices of outputs likely would have only a mild, and gradually felt impact on farmers' choices among technologies and on production.

Over the long term, if the EC adopts a policy of gradually declining real prices of farm commodities toward world levels, then the continued rise in energy and fertilizer prices would begin to have serious impact. It is not easy to see what the outcome might be. Such is the scarcity of land that a shift to land-using technologies is not likely to prove viable even with much higher prices of energy and fertilizer. Organic farming likely could spread, to the extent it did not require a legume-main crop rotation, but we are unable to judge the potential limits of this technology in western Europe. The prospects of rising costs and declining prices might spur research on new technologies, which if successful, would stave off the otherwise sure decline in production. Should such technologies be developed they surely would be of the land-saving sort.

On balance, we expect changes in EC agriculture to reflect changes in Community price policies as well as rising prices of energy and fertilizer. The major change may be a faster shift toward fewer and larger farms rather than technological responses to higher prices of energy and fertilizer. One thing seems clear: while new or modified technologies may substitute other inputs, including other forms of energy, for fossil fuels, these technologies will be land-saving, not land-using.

This completes the discussion of the future behavior of the technological component of the R-T-E system. Perhaps the main conclusion of the discussion is that the emerging pattern of resource scarcity confronting farmers around the world does not portend a major technological transformation over the next several decades. The discussion suggests that the major change may be in the U.S. and other category 1 countries. In these countries, the low additional productivity potential of present energy intensive technologies and relatively abundant land suggests that farmers' response to the emerging pattern of resource scarcity will be movement toward more land-using technologies than they employed up to the early 1970's. In category 2 and 3 countries, the combinations of potential productivity growth of present technologies and potential supply of land, while different, suggest for each category that farmers will rely increasingly on energy intensive, land-saving technologies, particularly in category 3 countries where land is relatively scarce. In the category 4 countries of western Europe structural change in response to changing EC price policies may be more important than technological change in response to rising prices of energy and fertilizer.

Future State of the R-T-E System

Environment

Agricultural production may damage the environment. The damages result from erosion, use of fertilizers and pesticides, irrigation and land clearing. These damages are part of the social costs of agricultural production in precisely the same way that the fertilizers and other resources used by the farmer represent social costs. The difference is that the farmer must pay the full social cost of the fertilizers and other resources he uses, but he does not pay the full social cost of environmental damages[33]. Indeed, he may pay none of them. Consequently, in making choices among alternative technologies the farmer has no incentive to take proper account of environmental costs. Someone else pays them.

Although the individual farmer has no incentive to incorporate the environmental costs of his activities into his calculations, the costs imposed by farmers as a whole may in time infringe upon his decisions. This can happen in one or both of two ways. If the costs take the form of damages to the agricultural resource base, the deterioration in the base will in time force adjustments upon the farmer. For example, erosion resulting in accelerated siltation of reservoirs will reduce the supply of irrigation water, inducing farmers to adopt more water-saving technologies or shift entirely to dryland farming.

The use of certain insecticides may increase resistance of insect pests to those insecticides, forcing a shift to different insecticides or to other modes of pest control. In this case, the resource damaged is the genetic vulnerability of the insects. That vulnerability represents a resource in the sense that so long as it exists the insect population can be held at a predictable level by the use of insecticides.

The use of organophorous insecticides may affect the farmer's choice of technologies by increasing the cost of labor. Many of these insecticides are acutely toxic to humans; hence they pose dangers for those who use them. Farm workers required to apply these materials may demand higher wages as compensation for the increased risk, thus inducing farmers to use less of the dangerous insecticides, or finding some less labor intensive method of applying them.

Environmental damages to the agricultural resource base thus may affect farmers' choices among technologies quite independently of any public action to reduce the damages. Public action may occur, however, and this is the second way in which environmental costs can feed back on farmers' technological choices. Public action may be provoked by damage to the agricultural resource base, or by damage to other resources valued by the society.

The two ways in which environmental costs may affect farmers' choices among technologies are not independent of one another. Public actions taken to reduce damage to the resource base will, to the extent that they are effective, weaken the effect of those damages on farmers' choices. Public action is not inevitable, however, or it may be delayed until serious damage has been done to the resource base, or it may not be effective. Consequently, in the discussion that follows we consider both of the feedback effects from the environment to farmers' choices among technologies.

There is much evidence, and even more strong feeling, that in many parts of the world the environmental costs of present agricultural technologies are high. The evidence is scattered and fragmentary, and covers the full range of the kinds of environmental costs of agriculture: effects of erosion in reducing soil productivity, silting reservoirs, causing flooding and so on; illness, deaths, and possible mutagenic and carcinogenic effects of pesticides; also destruction of useful predator insects and build-up of insect resistance from use of these materials; nitrate poisonings of animals and human babies, and accelerated eutrophication of water bodies because of phosphorous fertilizers eroded from fields; illnesses, such as schistosomiasis, associated with the spread of large irrigation systems; also the effects of large reservoirs in disrupting entire ecosystems because of changes in the water regimen of river valleys; increasing salinization and water-logging of soils resulting from irrigation; extension of deserts due to overgrazing; and destruction of animal habitat, sometimes with the loss of entire species of plant and animal life, resulting from land clearing or draining[34].

There are major problems in evaluating this evidence; consequently it is difficult, apparently impossible, to form a consensus about the seriousness of present environmental damages of agriculture. Knowledgeable people hold widely varying views on this.

The evidence is difficult to evaluate because there is no commonly accepted measure of environmental costs. These costs are real, but they are not priced; hence we have no way of weighing them against other costs of agricultural production, or against one another, or even against themselves at different times. The lack of a pricing system for environmental costs reflects the difficulties the people who bear the costs have in charging them against the farmers. Often, the bearers of the cost do not own the land, water, air, ecosystems, or whatever, which transmit or absorb the impact of the damaging materials. Consequently, they cannot charge the farmer for his use of, or damage to these resources. Even when the bearers of the costs own the resource, as the public may be said to "own" a governmentally built and operated reservoir, they may not be able to charge farmers for their use of or damage to the resource, because of the difficulty of identifying each farmer's use, or damage.

It is not impossible in principle to price environmental costs. For example, research can determine the relationship between soil loss and decline of yield, permitting a quite straightforward pricing of the costs of erosion so far as loss of soil productivity is concerned. Even this relatively simple problem, however, is not as easily resolved as this suggests. The soil loss in any year constitutes a permanent loss of productivity; hence the value of yield losses in all future years must be calculated and discounted to express them in present values. The choice of the discount rate is crucial, and the one used by the farmer may not fully reflect the social interest in the productivity of the soil.

The problem of choosing a proper social rate of discount has generated a considerable literature which need not be reviewed here. The existence of the literature is sufficient evidence that the problem is not easily resolved. But apart from this conceptual issue--still dealing with the relatively simple problem of pricing the cost of erosion in terms of loss of yield--doing the necessary research on a scale relevant for policy making likely would be very expensive. The relationship between soil loss and yield loss is highly variable, depending fundamentally on the amount of remaining top soil, the nature of the underlying material and other factors, such as climate, affecting the rate of soil generation. Typically, these conditions vary widely over any area large enough to be of interest for policy.

Clearly, establishing a price for the social cost--actually only one part of the social cost--of erosion would not be easy. Pricing other kinds of environmental costs would be even more difficult. For example, when considering the costs of land clearing, or draining, or building a reservoir, how does society set a numerical value on reductions in the gene pool caused by elimination of species of plants and animals? How are the environmental costs of pesticides to be priced if they take the form of birth defects or human deaths?

The difficulties in pricing environmental costs of course do not mean that societies are unaware of these costs, or that they will not take measures to lower the costs, or at least restrain their increase. Governments in many countries already are taking such actions, and can be expected to increase them. The difficulties in pricing, however, mean that these actions are, and will be, taken without clear indications of the importance of the various environmental costs.

This has an important implication for this paper. If environmental costs were priced, we could reasonably assume that those prices would weigh heavily in government policies to bring the costs under control. Moreover, the existence of these prices would help environmental protection agencies to form a public consensus in support of the policies. If, for example, the costs of erosion on each farm in the nation were known (or could be as readily determined, say, as each farm's cost of fertilizer) then it would be much easier than it is to mobilize public opinion in support of a policy to require farmers to bear these costs. In addition, it would be more difficult for farmers to resist such a policy since the costs attributable to each would be clear to everyone.

Thus, the lack of prices for environmental costs not only makes it more difficult for governments to know what to do; it also makes it more difficult to organize a consensus around whatever policy eventually is agreed upon within the government. Since nobody knows for sure what the costs are, one estimate often seems as good as another. Farming interests can argue that the costs are low, so few or no controls are necessary, and environmental control agencies find it difficult to make a convincing case to the contrary.

The absence of prices for environmental costs therefore deprives us of important guides to speculation about how these costs might "feedback" by way of policy on farmers' choices among technologies. We must make guesses about the priorities policy makers will have with respect to these environmental problems, when the policy makers themselves have no clear indication of what the priorities should be. In addition, we must speculate about the success the policy makers might have in mobilizing the public support necessary to make the policies effective in actually changing farmers' practices. This involves political processes not easily understood in any one country at present. Trying to understand them in many countries in the distant future obviously leads one onto treacherous ground.

The questions we address are the following: assuming farmers in various countries adopt the kinds of technologies discussed in the previous section, what effects will those technologies have on the environment, and how will those effects subsequently modify farmers' technological choices through (a) changes in the resource base and (b) government policies?

We concluded that in the U.S. farmers would adopt more land-using technologies than in the past, and that by the end of the century tens of millions of additional hectares of land would be brought under crops. Prices of fertilizers and pesticides although rising, should continue to favor increased per hectare application of these materials, but at a much slower rate than in the past, and at a slower rate than if farmers were to adopt more land-saving technologies.

The additional land will be converted from forest, pasture and range, and the switch to crops will greatly increase erosion from this land, unless stringent control measures are taken. Moreover, the survey by the U.S. Soil Conservation Service of erosion potential of land in the U.S. suggests that erosion from the converted land also would be greater per hectare, than erosion from land now in crops. A study at Iowa State University of the economic and environmental costs of converting land to crops confirms this impression[35].

The study by Rask and Forster, referred to in the previous section, of the effects of higher energy prices on choices among tillage technologies indicated that the effects would be trivial. However, two of the three technologies they considered, a form of minimum tillage and no-tillage, are much less erosive than the third technology, conventional tillage with a mold-board plow. Minimum tillage, and to a lesser extent no-tillage, has been spreading rapidly in the U.S. in the last 10-15 years, although the reasons have not been systematically studied as far as we know. One of the reasons may be the reduction in erosion with these tillage systems. While firm data on the effect of erosion on productivity in the U.S. are limited, the amount of erosion over a long period of years has been sufficiently great that there must be areas where additional erosion would significantly reduce yields. Where this is the case, farmers would be aware of it.

This suggests that the effects of erosion on soil productivity likely will induce farmers to make greater use of minimum tillage and no-tillage systems (henceforth collectively called conservation tillage) than would otherwise be the case. These tillage systems are particularly likely to be used on the land converted to crops from forest, pasture and range. To the extent that conservation tillage is adopted the amount of erosion will be less than it otherwise would be. The potential for reduced erosion with conservation tillage is very large--50 to 90 per cent on a per acre basis.

Thus we expect the damages of erosion to soil productivity to "feedback" on the technological choices of American farmers. But the effect, by this argument, will be on choices among tillage technologies, not among land-using and land-saving technologies. The erosion damages would not offset the effect of higher prices of energy and fertilizer, and scarcity of water, in moving farmers toward more land-using technologies.

Whether the resulting amounts of erosion in the U.S. would be so high as to prompt strong government action to control it is quite uncertain. Under existing federal law each state is required to formulate a plan for control of non-point pollution, including sediment and other pollutants originating in agriculture. So far it is not obvious that these plans will call for significantly stronger measures to control erosion than at present. Whether this will change over the longer term is quite uncertain. If conservation tillage continues to spread and by the end of the century has been adopted on as much as 50-60 per cent of American cropland--a reasonable expectation given present trends--then the amount of erosion in the U.S. likely would not be much more than at present. In this case, the public perception of the erosion problem might be about the same as it is now, suggesting that there would be no strongly felt need for additional erosion control policies that would inhibit the movement of farmers toward more land-using technologies.

However, even if the amount of erosion were unchanged by 2000, policy makers and the public might perceive the problem to be more serious than at present. Maintenance over the next two decades of present annual rates of erosion might begin to reduce the productivity of the land enough to arouse public support for stronger erosion control policies, even if the effects of sediment on water quality do not. Should this happen, what policy instruments might be employed? Direct controls or taxes on sediment leaving the farm would be politically unpalatable and administratively unwieldy. In our judgement, they are unlikely. The more probable course would be a combination of policies providing incentives to farmers to adopt conservation practices such as terracing, measures to promote even more rapid spread of conservation tillage, and research to develop more productive land-saving technologies, thus reducing the demand for the more erodible land. The last mentioned policy, to the extent that it were successful, would tend to offset the effect of the emerging pattern of resource scarcity in moving farmers toward more land-using technologies.

For the last decade the principle trends in use of pesticides by American farmers have been the rapidly increasing use of herbicides, both in absolute amount and in the relation to other pesticides, and the increasing substitution of organophosphorous insecticides for the organochlorines. The growth of herbicide use must in large part reflect the spread of conservation tillage, since with this technology herbicides substitute for cultivation in weed control. If conservation tillage continues to spread, then continued growth in herbicide use can be expected. The substitution of organophosphorous compounds for organochlorines began initially because of the build-up of insect resistance to DDT and other organochlorines. Subsequently, the substitution was encouraged further by bans placed by the Environmental Protection Agency (EPA) on a number of important organochlorine compounds, including DDT.

The evidence so far indicates that most of the herbicides in wide use in the U.S. have few harmful effects on the environment. The compound 2-4-5T seems to be an exception but its use on crops is very limited. Should continued and expanded use of herbicides in time prove to have serious harmful effects this could have major impact on farmers' choices among technologies. As noted, herbicides are essential to conservation tillage. Should concern about the environmental effects of herbicides seriously limit their use farmers would not be able to adopt conservation tillage on the scale suggested above (using it on 50-60 per cent of cropland). In this case the threat of erosion damages would emerge as a major issue.

The shift from organochlorines to organophosphorous compounds seems likely to continue. The EPA takes pesticides seriously, as its various regulations banning use of them indicates. However, the Agency recognizes the economic importance of pesticides to U.S. agriculture, as it must under the law, and is most unlikely to take actions which would lead to massive abandonment of these materials. There is a widely held view in the chemical industry, however, that the regulatory environment created by the Agency could lead to slower development of new compounds than would otherwise occur. There is evidence supporting this view. Should it be correct, farmers likely would be induced to adopt more sparing use of pesticides and to begin to substitute other methods of pest control for the chemicals now in use.

So-called bio-controls are an example of such an alternative. There are still unsolved economic problems limiting the spread of this alternative (as well as of others going under the general heading of integrated pest management) for use on main crops. However, there appear to be genuine alternatives for simply using smaller amounts of presently available chemicals without significant sacrifice of yield. The key is to time spraying for maximum effect, i.e., to achieve maximum insect kill per unit of insecticide. To do this requires knowledge about the life cycles of particular insects and information about their numbers in particular fields at particular times. Research can provide the knowledge and so-called "scouts", people who enter the fields to count the insects and observe their condition, provide the information.

Increasing awareness among farmers of the value of more sparing use of insecticides in avoiding, or at least delaying, the build-up of insect resistance may also stimulate the spread of less insecticide intensive practices. For this to happen, however, most, if not all, of the farmers in the area afflicted by the given insect would have to agree to adopt the practices. If a few or perhaps even one should refuse, the effectiveness of the practice for the others would be reduced, if not completely negated. This is the so-called "free rider" problem: some farmers may choose to stay out of the organization, hoping to reap its benefits without having to pay any of its costs. There is no general solution to the problem. However, the experience of farmers in Texas in organizing to promote low insecticide intensity practices for control of the cotton boll worm indicates that solutions are possible.

On balance, it appears that public policies to control insecticides, and perhaps concern about increasing insect resistance, will encourage farmers to adopt less insecticide intensive practices, thus reinforcing the effect of the emerging pattern of resource scarcity in moving farmers toward more land-using technologies. The use of herbicides can be expected to increase with the spread of conservation tillage, which, is neutral with respect to whether technologies are land-using or land-saving.

In the U.S. the two principal environmental effects of irrigation are the build-up of soil and water salinity and the increase in costs of pumping because of the common property nature of ground water. Salinity build-up presents a "double-bind" type problem. If a farmer does not properly drain irrigation water from his fields or put on enough water to leach the salts from his soils, they will become increasingly saline and his yields will fall. If he does do these things properly, the salt from his fields will be carried away in the irrigation return flow and constitute a hazard to the next user of the water.

The farmer himself has an interest in controlling the first kind of salinity problem, since it is his yields which will otherwise suffer. However, the degree of control which is optimal from the farmer's standpoint may not be the same as the socially optimal amount, the same problem which arises with respect to erosion control.

The farmer has little if any interest, however, in reducing the problems his practices cause the downstream user of the water, particularly since the only way he can alleviate those problems is by exacerbating his own.

The salinity problems of irrigation in the U.S. seem to be most acute in the Colorado river basin, and in the Trans-Pecos region of Texas. At least, those are the areas where the problems have been most studied. In the Trans-Pecos region, where irrigation is mostly from groundwater, the water has become so saline that land has been going out of irrigation for some years. Judgements of the severity of the problem in the Colorado basin vary, but there seems to be a consensus that it is sufficient to justify public action to bring it under control. The problem has been a major issue in U.S. relations with Mexico for years, and under an agreement reached several years ago the U.S. now is taking steps to reduce the salinity content of Colorado river water entering Mexico.

The increasing scarcity value of water for irrigation in the western United States may make the salinity problem worse. The various practices for economizing on the use of water all involve applying less per hectare without reducing the amount available to the plant. The implication is that less would be available for leaching of salts. Over the long term this could lead to a sufficient build-up of salts to adversely affect yields, thus reducing the advantage of irrigated relative to dryland farming. The effect of increasing salinity, therefore, would reinforce the effect of increasing water scarcity in moving American farmers toward more land-saving technologies.

The common property problem affecting irrigation with groundwater would have the same effect. The problem arises when a group of farmers tap a common aquifier. Since no one owns the water in the aquifier no one can be sure of how much water will be available to him in the future. Consequently no one has incentive to take account of the future value of the water in deciding how much to pump "today". The result is a rate of pumping which from the view of the social interest in the resource is excessive.

Irrigation with groundwater in the U.S. is most common in the High Plains region of Texas, New Mexico, Oklahoma, Kansas, Nebraska and Colorado. Ground water tables in this region are falling, indicating that pumping rates may be excessive. The powers of the various states in the region to regulate groundwater use differ (the federal government has none), but in none of them is there yet evidence of a strong movement to reduce pumping. Tentative proposals to do this in a few of the states have met strong farmer resistance.

We have argued that the prospective rise in the price of energy and increasing scarcity of water would induce farmers to adopt water-saving techniques, which in groundwater areas would reduce pumping. Thus the discipline of the market would reduce the severity of the common property problem affecting groundwater. In this event mobilizing public support for strong action to deal with the problem likely would be difficult. If this is correct, the problem would have little if any feedback on farmers' choices among technologies.

The severity of the environmental impacts of fertilizer use in the U.S. has been discussed for years. It often is argued that sustained use of fertilizers will in time adversely affect soil quality, although we have seen no convincing evidence of this. There is evidence of nitrate concentrations in some ground and surface waters which exceed the limit set by the Public Health Service, and accelerated eutrophication is evident in some places. So far, however, no federal, and to our knowledge, no state action has been taken to regulate fertilizer use. We anticipate that the amounts of fertilizers used in the U.S. will continue to rise, although at a much slower rate than in the past, and this may in time stimulate public action to control use of these materials. We are sceptical that this will happen, however, in part because increased erosion control will reduce the severity of the fertilizer problem. In any event, should such controls be applied, they would reinforce the effect of the emerging pattern of resource scarcity in moving farmers toward land-using technologies, thus exacerbating the erosion problem. The nation, therefore, would have to weigh the cost of increased erosion damages against the higher costs of fertilizer pollution. No one can be sure where the balance would be struck, but our guess is that the increased cost of erosion would be perceived as more important.

In summary, the shift of American farmers toward more land-using technologies would threaten to greatly increase the costs of erosion. Since the farmer himself would bear some of these costs, he would have incentive to adopt less erosive conservation tillage technologies. The remaining amounts of erosion, however, might still appear excessive from the social standpoint, prompting public action for greater control. These actions might include increased research to develop more land-saving technologies, a policy likely to be greatly encouraged anyway by the rising economic cost of land-using technologies. Other policies to control erosion probably would be neutral with respect to farmers' choices among land-using and land-saving technologies.

The feedback of increasing use of insecticides on build-up of insect resistance may induce farmers to organize to adopt less insecticide intensive practices, and EPA regulations of insecticide use would strengthen this tendency. Both sorts of feedbacks of environmental costs of insecticides, therefore, would reinforce the effect of the emerging pattern of resource scarcity in moving farmers toward more land-using technologies. That movement, and the resulting wider adoption of conservation tillage, would stimulate rising use of herbicides. So far there is little evidence that the increased use of herbicides will affect either the resource base or stimulate public action for greater control, but there is more on this below.

The adoption of water-saving technologies may worsen the salinity problem in the western U.S., thus reinforcing the tendency toward more land-using technologies. Water-saving technologies would lessen the common property problem of groundwater use, reducing therefore the likelihood of public action to control the problem. There is no convincing evidence that sustained use of fertilizers damages the resource base, and the effects of fertilizer use on water quality, in our judgement, will not likely be perceived to justify strong public action to control use of these materials. Should such action be taken, it would reinforce the tendency toward adoption of more land-using technologies.

On balance, therefore, it appears that the movement of American farmers toward more land-using technologies would feedback on the resource base and by way of public policy in such fashion as to strengthen the attractiveness of those technologies. However, there are two caveats to this conclusion. The combined effects of the rising economic costs and rising erosion costs of those technologies may so stimulate the development of land-saving technologies as to alter the conclusion. The other caveat concerns the environmental costs of herbicides. Should these costs in time appear to be much higher than now is the case, prompting strong action to restrict their use, the spread of conservation tillage would be brought to a halt. The erosion costs of land-using technologies then would likely be seen as a major problem, prompting strong public action to control them. What form that action would take cannot now be foreseen, but direct controls on farmers' practices, or banning the spread of cropping to particularly erodible land would be a possibility. Unless even stronger efforts were made to develop land-using technologies, the result likely would be sharply higher costs of production and a decline in the share of American exports of grains and soyabean in world markets.

The environmental costs of farmers' choices of technologies are more varied in the developing countries than in the U.S., they likely will also become more serious in some respects, and they almost surely will be more difficult to control. We venture the judgement that the costs of erosion and irrigation will have more impact on farmers' choices, both by way of effects on the resource base and through public policy, than the costs of pesticide and fertilizer use. Present per hectare applications of pesticides and fertilizers are much lower in the developing countries than in the U.S., and even with rapidly increasing use of these materials' application rates, on average, will not be markedly greater by the end of the century than in the U.S. at the present time. Since present application rates in the U.S. have not had a major impact on farmers' choices of technologies, we infer that similar application rates in the developing countries likewise would not have major impact on farmers' choices. There is a qualification to this conclusion. The unintended effects of pesticides in tropical and semi-tropical areas might be more severe than in temperate areas, for reasons which we have discussed elsewhere[36]. Consequently, application rates which would pose relatively low environmental costs in temperate areas might exact higher costs in tropical or semi-tropical areas. Nevertheless, in our judgement, the difference in costs is not likely to be so great as to significantly affect farmers' choices among technologies.

This judgement is based in large measure on the fact that use of fertilizers and pesticides has relatively small effect on the parts of the resource base that enter directly into the farmers' calculations. Conceivably the greater risks of handling organophosphorous compounds could raise wages, inducing farmers to use less of these materials. Increasing insect resistance might have the same effect, assuming farmers could overcome the problems of organizing for area-wide adoption of less insecticide intensive practices. But many of the costs of pesticide use, such as the unintended destruction of valuable forms of plant and animal life, do not directly affect the farmer, and virtually none of the costs of fertilizer do. If these costs are to have major impact on farmers' technological practices in the developing countries, it must be by way of public policies. We suspect that in those countries the costs will not appear so high as to lead to such policies. This is particularly likely to be true in category 3 countries (high productivity potential/low land potential) because the pressures to adopt land-saving technologies will be especially strong in those countries. Policies to seriously limit the use of pesticides and fertilizers in category 3 countries likely would impose high economic costs, as well as higher costs of erosion (because the policies would push farmers toward more land-using technologies). In category 2 countries (high productivity potential/high land potential) the pressure to adopt land-saving technologies will be less, but even in those countries the economic and erosion costs of serious limitations on use of pesticides and fertilizers would be high.

The effectiveness of those policies is another question. Technical solutions to deforestation are relatively easy: control additional cutting of trees and plant trees and other vegetative cover on presently denuded land. Implementation of such policies is quite a different matter. The record is clear that most developing countries lack either the resources or the political will or both to effectively limit access of rural people to forested areas when the demand for firewood is high. This is understandable. For the great mass of these people alternative fuels are more costly than firewood, or simply not available, and people must cook their meals and heat their homes.

We suspect that the only long term solution to the deforestation problem, and the resulting erosion problem, is development of alternative fuels for home heating and cooking. As noted in the previous section biogas is such an alternative, and we expect the rising costs of deforestation, as well as the rising cost of fossil fuels and firewood, to spur development of biogas technology to make it more attractive to rural people throughout the developing world. It is likely, however, that the erosion costs of deforestation will continue to rise before biogas, or any other alternative fuel, can be brought into wide use.

The effectiveness of conservation tillage in reducing erosion in the U.S. suggests that these practices might serve also for dealing with the problem in the developing countries. There is in fact evidence that forms of conservation tillage suited to low capital/high labor resource position of developing countries can significantly reduce erosion[37]. So far as we know the economics of these practices have not been investigated so it is not clear to what extent the practices might spread of their own accord; nor is it clear what policies might be most effective in promoting wider adoption.

In the Himalayan foothills of India, where erosion problems are severe, there appears to be strong complementarity between the availability of water for irrigation and soil conservation practices. Farming in this area is on terraces. It is observable that terraces with water for irrigation are built and maintained in such a way that erosion is minimal. The availability of irrigation water permits double cropping, indicating high value to the farmer of both the water and the land. The value is sufficiently high to justify the investment by the farmer (mostly his and his family's labor) to construct the terrace so that is slopes slightly inward, thus virtually eliminating runoff and erosion at the same time. Terraces lacking irrigation, however, are seen to be outward sloping, an easier form to build and maintain, but also one that promotes erosion.

This suggests that policies to provide irrigation in such areas not only would increase production by permitting double cropping, but also would reduce erosion. How widely in the developing countries such policies might be applicable, however, we are unable to say. The availability of water and the cost of providing it under conditions of hill agriculture clearly could be seriously limiting.

It is hard to avoid the impression that the costs of erosion in the developing countries will be high for a long time, and that policies to reduce them will prove difficult to implement. Already high and still mounting population pressure on the land, particularly in category 3 countries, the absence of alternatives to wood for fuel, land tenure systems limiting access to less erodible land, and the weakness of public administration in many of these countries all suggest that the erosion problem will be serious and long-lasting.

Continued erosion, by accelerating the siltation of reservoirs, in time would reduce the supply of irrigation water, thereby impeding the spread of land-saving technologies in the developing countries. This would be especially serious in category 3 countries because of the relative scarcity of land in those countries. Erosion might also increase the importance of irrigation from groundwater relative to irrigation from reservoirs since groundwater is not as vulnerable to erosion damage. Since farmers typically bear a larger share of the costs of irrigation from groundwater than from surface water, this shift might result in greater economy in the use of water than otherwise would occur. In this case, the loss of irrigation capacity to erosion would not be a net loss, and the effect of erosion costs in impeding movement to land-using technologies would be weakened.

The environmental problems of irrigation in the developing countries include not only salinity and the common property problem of groundwater, as in the U.S., but also public health and ecological effects of large reservoir systems. As in the U.S. the salinity problem will be most severe in arid regions where water is scarce and evaporation rates high. Also as in the U.S. the solution to the problem is to provide adequate drainage and enough water for leaching.

Increasing salinity clearly damages the resource base, but the individual farmer, particularly if he is served by a surface system, may be able to do little about it. Typically, he has little control over the amount of water he receives, so planning the application of water for leaching likely will prove difficult. In addition, his resources may be too limited to build an adequate drainage system, and in any case this likely would be highly inefficient if not simply unfeasible for each farmer to do on his own.

Salinity control, therefore, typically is a public responsibility in the developing countries. There is much evidence that to date this responsibility was not always fully met. The situation now seems to be changing, however. In India, Pakistan and Egypt, for example, much more attention is being given to drainage in the design of new irrigation prospects than in the past. This apparently reflects awareness that in previous projects failure to make adequate provision for salinity control had exacted high costs. Of course, constructing irrigation systems with provision for adequate control of salinity adds to the costs of the systems. However, when the controls are built into the system from the beginning, they typically will add less than 5 per cent to total costs[38].

We expect this trend toward increased control of salinity to continue. The technical aspects of the problem are well understood, and most developing countries have, or can acquire, the necessary managerial expertise. What was lacking in the past was the incentive to make the investments in drainage and the sometimes hard decisions with respect to water allocation required to achieve adequate salinity control. However, the large investments in irrigation already made and planned, plus the rising economic value of water, should increase the incentives of managers of large irrigation projects, and of their political superiors, to take the necessary control measures. As noted above, this seems already to be happening in some important countries. It seems justifiable to conclude, therefore, that the salinity costs of irrigation are not likely to rise so high in the developing countries as to significantly impede the movement of farmers in those countries toward land-saving technologies.

The construction of irrigation systems based on large reservoirs may damage the agricultural resource base in various ways, e.g., reduced productivity of farmers suffering from schistosomiasis or malaria, submerging under the reservoir of previously productive land, lowered fertility of land downstream from the reservoir because of reduced deposits of nutrient bearing sediment. The value of the submerged land probably--one would think certainly--would be taken into account when planning the system, but the other costs might be overlooked or undervalued. In any case, the existence of these costs is not likely to affect farmers' choices of technology. If the costs have this effect it will be because of public action to control them, and the only feasible action having this effect would be to not build the project.

Other costs of such projects may include destruction of unique ecological systems, damage to downstream fisheries because of alterations in stream flow, increased erosion damage from tidal action in coastal areas, and so on. These costs, like those impinging directly on the agricultural resource base, would not affect farmers' choices among technologies unless they were perceived to be so high as to prohibit construction of the project.

From the standpoint of this paper, therefore, the question is whether these various costs will be perceived to be so high that some large reservoir based irrigation systems will not be built in the developing countries which otherwise would be built. If the answer to the question is yes, then it would follow that the various environmental costs of such systems would impede the movement of farmers to more land-saving technologies.

It certainly is conceivable that in some instances the costs will appear to be so high that projects will not be undertaken that otherwise would be. Given the strength of the conditions favoring land-saving technologies in developing countries, however, we think such instances will have small effect in limiting the spread of irrigation. Some of the costs, such as those resulting from destruction of ecological systems, will be so hard to measure that they likely will weigh little in the calculations. Where the costs are more apparent, policy makers are likely to respond by looking for ways to reduce or avoid the costs, without reducing the amount of irrigation. The costs of controlling schistosomiasis or other water related diseases, for example, may appear low in comparison with the cost of abandoning the project entirely. Where the possibility for directly reducing the costs appears insufficient policy makers may look for opportunities for expanding irrigation with groundwater. Where such opportunities exist, the reservoir based surface system could be abandoned without sacrifice of the advantages of increased irrigation. Of course groundwater systems may impose some of the same environmental costs as surface systems, but typically these costs are much lower with groundwater systems. We think this may in fact favor the spread of groundwater systems relative to surface systems at a faster pace than otherwise would occur.

The spread of groundwater irrigation in the developing countries may be limited by the common property problem. However, we do not know how serious this problem presently is perceived to be in those countries, nor do we have a basis for judging how this perception may change in the future. Of course the mere spread of groundwater irrigation, which we expect to be considerable, would increase the probability that the problem would become more serious. Whether it may become so serious as to significantly limit groundwater development, however, we are unable to say.

On balance, we think that environmental costs of fertilizer and pesticide pollution, and of irrigation, are not likely to be perceived by either farmers or policy makers in the developing countries to be so high as to seriously impede the movement of farmers in those countries toward more land-saving technologies. The costs of erosion, however, likely will excite mounting concern and stimulate policies to bring the costs under control. We think the problem may prove quite intractable, and the policies only partially effective at best. The resulting damage to reservoirs would limit the supply of irrigation water, thus impeding the spread of land-using technologies. In category 2 countries, where the supply of land is relatively great, the result likely would be greater use of land-using technologies than the emerging pattern of resource scarcity alone would suggest. In category 3 countries, where land is relatively scarce, the decreased attractiveness of land-saving technologies likely would mean simply that the quantity of agricultural production would be less and its cost higher than the emerging pattern of resource scarcity alone would suggest. The implication is that over the next several decades erosion may pose a major hazard to agricultural expansion in category 3 countries.

Discussions with people at the Organization for Economic Cooperation and Development, the U.N. Economic Commission for Europe, and the Commission of the European Economic Community indicate that in western Europe, the collection of category 4 countries, the environmental costs of agriculture generally are considered to be low. Such literature as we have seen on the subject supports this view. Since we do not anticipate major expansion of European agricultural production or fundamental shifts in agricultural technologies, we do not expect environmental costs in these countries to become important enough to impinge significantly on farmers' choices among technologies.

Overall Perspective on the Future of the R-T-E System

This survey points to a number of general conclusions about the future behavior of the R-T-E system.

1. Given the underlying conditions specified at the outset, the major force shaping farmers' choices among technologies will be the emerging pattern of resource scarcity. The dominant element in this pattern is the rising real price of energy from fossil fuels. The amount of the rise is uncertain, although we do not expect an explosive increase, and it will vary according to the source of energy. However, it likely will be pervasive and long term, affecting farmers in all countries to greater or lesser degrees.

   Real prices of fertilizer are expected to rise, in part in response to the rise of energy prices. The rising price of energy also will tend to increase the cost of groundwater for irrigation, while greater inaccessibility of water supplies and rising competition for water for non-agricultural purposes likely will increase the real scarcity value of water in many countries. Pressure on the land also will mount, especially in category 3 countries where pressure already is high and potential for bringing additional land under crops is low.

2. Farmers' responses to the emerging pattern of resource scarcity will vary, depending upon the specific resource situation in each country, or group of countries. In the U.S. and other category 1 countries the likely response will be to adopt relatively land-using technologies, in contrast to the trend of technology in those countries prior to 1973. In category 2 countries the still high productivity potential of energy and fertilizer, combined with relative abundance of land suggests that those countries will adopt technologies which are more land-saving than those in the U.S., but

more land-using than those in category 3 and 4 countries. In category 3 countries the scarcity of land and the still high productivity potential of energy, fertilizer and water indicate that those countries will continue to move toward highly land-saving technologies. Category 4 countries, most of which are in western Europe, face increasing real scarcity of all agricultural resources. The likely pattern of change in those countries is very slow growth in production, no major changes in technology, and a continued, perhaps accelerated trend toward fewer and larger farms.

3. The feedback effects of environmental costs, by way of damage to the resource base and public policy, will condition but not override the technological trends set by emerging resource scarcity. If there is an exception to this it likely would be in the U.S. The trend in that country toward land-using technologies could be blocked if concern about environmental costs of herbicides should lead to major restrictions on their use. In that case, the spread of conservation tillage would be halted and the costs of erosion resulting from land-using technologies likely would mount steeply. The effect of this situation on farmers' technological choices is unpredictable, but it is likely that the volume of agricultural production would be less and its cost higher than would otherwise be the case.

4. The emerging pattern of resource scarcity does not portend a major technological transformation of world agriculture. In category 2 and 3 countries the productivity potential of present technologies is high enough to justify their continued use for a long time; and in category 1 and 4 countries opportunities for economizing on use of fossil fuel energy, fertilizer and water indicates that these resources will continue to be of major importance over the period addressed in this paper. However, alternatives to fossil fuels almost surely will be of increasing, although not dominant importance. There likely will be some limited spread of organic farming in the U.S. and perhaps in category 4 countries as well. Energy from biomass almost surely will become more important, substituting to a limited extent in some countries for fossil fuels, and perhaps on a larger scale for firewood in developing countries. Direct uses of solar energy, e.g., with photo-voltaic systems, also may be of significance by the end of the period addressed here.

A major question with respect to trends in technology is whether research will produce major new alternatives within the next 20-30 years. In the U.S., rising demand for food exports, combined with the apparently low potential for productivity growth with existing technologies, suggests that real costs of agricultural production could rise over this period, perhaps sharply. Development of new land-saving technologies such as increased photosynthetic efficiency, could prevent this, and the prospect of increasing economic and environmental costs could spur this development. In our judgement, it is likely that in time such technologies will in fact be developed, but it appears that much research needs to be done, some of it of a basic kind. Consequently, the timing of the emergence of fundamentally new technologies is unpredictable.

NOTES

1. Ferenc Rabar, Program Leader, Food and Agriculture Program, Research Plan 1980, page 43.

2. The country models constructed as part of the Food and Agriculture Program's Task 1 contain demand functions for agricultural commodities which will generate prices over time. These prices might be used as the signals to the farmers operating in the R-T-E (Task 2) system model. Possibly the Task 1 and Task 2 models could be linked in such fashion that the growth of demand could become endogenous to the Task 2 model. In this paper, however, we treat demand as exogenous.

3. Pierre Crosson (May 1975) Institutional obstacles to the expansion of world food production. Science.

4. Dvoskin, D. and E. Heady (1977) Economic and environmental impacts of the energy crisis of agricultural production. Agriculture and Energy, edited by W. Lockeretz. New York, San Francisco, London: Academic Press.

5. Erik Eckholm (1976) Losing ground, chapter 6. New York: W. W. Norton.
   The United Nations Environmental Program has sponsored studies, not yet published, done subsequent to Eckholm's work which confirm his finding that real prices of firewood are rising.

6. Gilley, J.R., and D.C. Watts (1977) Energy reduction through improved irrigation practices. Page 200, Agriculture and Energy, edited by W. Lockeretz. New York, San Francisco, London: Academic Press.

7. Work underway at Resources for the Future indicates that by 2000 the demand for cropland in the U.S. could exceed the present supply, plus 16 million hectares of additional land with high potential for conversion to cropland, by tens of millions of hectares. This, combined with continued growth in demand for urban, industrial and recreational uses, suggests that the real cost of land for use in agriculture could rise substantially in the U.S. over the next several decades.

8. Rask, N. and D.L. Forster (1977) Corn tillage systems - will energy costs determine the choice. Agriculture and Energy, edited by W. Lockeretz.

9. Forster, D. L. and N. Rask (1977) Changes in fertilizer usage and crop production under scarce energy supplies. Agriculture and Energy, edited by W. Lockeretz.

10. In the Rask and Forster study of tillage systems the cost of nitrogen was almost half of the direct cost of maize production.

11. See the reference in footnote 4 to Dvoskin and Heady, who found the price elasticity of demand for energy to be -.05. Miranowski et al., found it to be less than -.01 on a representative maize-soyabean farm in Iowa. J.A. Miranowski, E.R Pidgeon and D.V. Peterson (1977) Economic feasibility of methane generation and livestock and crop waste recycling for a typical Iowa family farm. Agriculture and Energy, edited by W. Lockeretz.

12. Forster, D.L. and N. Rask (1977) Changes in fertilizer usage and crop production under scarce energy supplies. Agriculture and Energy, edited by W. Lockeretz.

13. These percentages are for a single farm. On a national basis the shift to soyabean would be less because as production of that crop increased, its price would fall relative to the price of maize.

14. Lacewell, R.D., G.D. Condra and B. Fish (1977) Impact of natural gas curtailments and price increases on irrigated agriculture in Texas. Agriculture and Energy, edited by W. Lockeretz.

15. According to Lacewell et al., the price of natural gas to farmers in the study area in 1976 was approximately $1.30 per Mcf.

16. Nelson, D.W., et al. (1977)Conserving energy with nitrification inhibitors. Agriculture and Energy, edited by W. Lockeretz.

17. Gilley, J.R., and D.G. Watts (1977) Energy reduction through improved irrigation practices. Agriculture and Energy, edited by W. Lockeretz.

18. Lockeretz, W., et al., (1977) Economic and energy comparison of crop production on organic and conventional Corn Belt farms. Agriculture and Energy, edited by W. Lockeretz.

19. Miranowski, J.A., et al., (1977) Economic feasibility of methane generation and livestock and crop waste recycling for a typical Iowa family farm. Agriculture and Energy, edited by W. Lockeretz.

20. However, for farms with a large feedlot operation use of manure to produce methane may presently be economical. Verbal communication from Robert Taylor, Texas A & M University.

21. In a combination of maize, current varieties of sweet sorghum and wheat, 20-40 million hectares would be required. With a new variety of sweet sorghum now being developed in Texas, 5-10 million hectares probably would suffice. Estimates from Robert Taylor, Texas A & M University.

22. The studies assume the same growth in world demand for food as in this paper and that the U.S. maintains its present position in world markets for grains and soyabeans.

23. For an analysis of this process in agriculture see Hayami, Y., and V. Ruttan (1971) Agricultural development: an international perspective. John Hopkins Press.
For the same argument with respect to general resource scarcity see Barnett, H., and C. Morse (1963) Scarcity and growth. Resources for the Future: John Hopkins University Press.

24. The Soviet Union may belong in this category also; we are not sufficiently acquainted with the situation in that country to be sure.

25. Ramesh Bhatia (1977) Energy and rural development in India: some issues. Agriculture and Energy, edited by W. Lockeretz.

26. Ramesh Bhatia (1977) Energy and rural development in India: some issues. Agriculture and Energy, edited by W. Lockeretz.

27. We are not familiar with the situation in other category 3 countries with respect to the use of biogas.

28. The subsequent discussion of the technology is focused on India.

29. Sanghi, A.K., and D. Day (1977) A cost-benefit analysis of biogas production in rural India: some policy issues. Agriculture and Energy, edited by W. Lockeretz.

30. We are not familiar with planning for additional irrigation in other category 3 countries.

31. ICRISAT, located in Hyberabad, India, and one of the family of international food research institutions, is devoted full time to research along these lines.

32. Japan also is a category 4 country; however Japan is not a major factor in world agricultural production. We are not familiar enough with the technological and resource situation of Eastern Europe to know how it should be classified.

33. This assumes that the prices of fertilizers and other resources reflect their social costs. For a variety of reasons this may not be true. To the extent that it is not, the farmer's use of these resources will be different from the socially optimal use in precisely the same sense that his use of environmental resources is not socially optimal.

34. For a useful review of the evidence on present damages to the environment from agricultural and other rural activities all around the world, see Erik Eckholm (1976) Losing Ground. W.W. Norton.

35. Amos, Orley, Supply of Potential Cropland in Iowa, Ph.d. dissertation in Economics, Iowa State University, Ames, Iowa, 1979.

36. Crosson, Pierre, and Kenneth Frederick (1977) The world food situation: resource and environmental implications for the developing countries and the United States. Resources for the Future Research Paper R-6.

37. Greenland, D.J. (1975) Bringing the Green Revolution to the shifting cultivator. Science 190 (4217), pages 841-844.

38. Verbal communication with Asit Biswas, IIASA.