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RESOURCE AND ENVIRONMENTAL CONSTRAINTS ON SUSTAINABLE GROWTH IN AGRICULTURAL PRODUCTION: Report on a Dialogue

November 27-28, 1989

Edited by
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The 21st Century Project
Hubert H. Humphrey Institute of Public Affairs
and
Center for International Food and Agricultural Policy
University of Minnesota

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Ruttan — I'd like to introduce Ed Schuh, who is the Dean of the Hubert H. Humphrey Institute of Public Affairs, and is our host. He has such nice facilities over here that he rents them out. I invite him to welcome us and he gives us a discount on the rent. As you know, Ed has had a long career at both the national and international levels. He has served as Deputy Assistant Secretary in the U.S. Department of Agriculture; and with the World Bank; with the Ford Foundation in Brazil. This is his second incarnation at the University of Minnesota. He was head of the Department of Agricultural and Applied Economics here before going to the World Bank.

Schuh — It's nice to have you here. The Humphrey Institute recently opened what's called the Humphrey Forum, which is an exhibit forum, commemorating Hubert Humphrey. It's not a museum. It's on the ground floor and when you have a break, go down and take a look at it. It's really a very interesting educational medium because it uses interactive computers and VCR's to tell the Humphrey story. And if you get a chance to browse around the building, there are also some other very interesting facilities. We host a lot of conferences such as this to try to provide intellectual leadership on important public issues such as the issue that you will be addressing. I will not take any more of your time. We are glad to have you with us.

Ruttan — Let me say just a little bit about the background to today and tomorrow's discussion. A little over a year ago, Bob Herdt of the Rockefeller Foundation suggested, in a phone conversation, "Don't you think it's about time to start thinking about the issues that are going to confront agricultural development as we move into the first or second decades of the next century?" We both had a feeling that most of us are spending a lot of our time working on the immediate problems. Very little attention is being given to the issues that will confront us as we move into the next century. I suggested that rather than organizing a big conference, we hold several "consultations" among small groups of knowledgeable people. We would use the consultations to sort out the issues and then decide if there is a basis for a more formal conference.

The first of the consultations was on biological and technical constraints on crop and animal productivity. We were concerned with the fact that, in spite

of what we are told about the promise of biotechnology, the timing of any substantial impact on agricultural production seems to be receding.

We also were concerned with what appears to be the slowing of yield gains. For example, yields in rice maximum yield experiments at the International Rice Research Institute (IRRI) have not risen for about 20 years. And while maize yields in the United States continue to rise at about one bushel per acre per year, that is a much smaller percentage increase than 20 years ago. We will be sending a copy of the report on the first consultation to you in a few weeks.

For the second topic, the one that we will be talking about today, we agreed that it is important to ask about the implications of a series of environmental changes, including what an economist would term the macro-environmental changes, such as global climate change, as well as the micro-environmental changes arising from intensification of agricultural production such as erosion, salinization, and groundwater contamination. What are the implications of such changes for agricultural research priorities? How should one change the agricultural research portfolio given what we think we know, or ought to know, about these environmental changes. These are the issues for this dialogue.

The next consultation will deal with the prospects of a health crisis in rural areas--particularly in developing countries. When one considers a series of events like malaria resurgence, failure to make progress in parasitic disease, the health effects of environmental changes, and AIDS, it is not too difficult to envisage a world in which there will be a lot of sick people in villages a generation from now--possibly enough sick people to affect agricultural production. Such a scenario may not be too far-fetched. One can find villages like that today in Uganda. We are also thinking of a final conference dealing more with institutional issues related to agricultural and rural development.

In order to structure this consultation, I will attempt to organize the discussion in about four blocks. The first block will center around what we really know about global climate change. What can we really say that we know as compared to what we think or hope? In that group, I have Dean Abrahamson, Norman Rosenberg, William Clark, and Steve Sonka. I'll be asking Dean to start off the discussion.

The second block will center around the impact of global climate changes on agriculture and natural resources. I'll ask Steve Rawlins to be the transition between the first and the second group. Then we have Paul Waggoner, Margaret Davis, Robert Chen, Zbigniew Bochniarz, and Pierre Crosson. I visualize Pierre's presentation serving as a transition to the issues of micro-environmental change.

Pierre has been concerned not only with some of the implications of the macro changes, but he has also done a great deal of very excellent work on soil erosion. I will then ask Pedro Sanchez to discuss some of the problems associated with tropical soils and tropical ecologies and Bill Larson and H. H. Cheng to discuss temperate region soil problems. Richard Jones will be concerned with pests and pathogens that arise from both global climate change and some of the micro-environmental change. Bob Munson will reflect on some of his concerns about soil fertility.

Finally, we'll move toward a discussion of the implications for agricultural research. I have asked Gene Allen to do some thinking about research implications from a state perspective. Steve Rayner is concerned about decision making under the kinds of uncertainty arising from the changes we will be discussion. I've asked Steve Rawlins to reflect on the research implications from a federal perspective.

GLOBAL CLIMATE CHANGE

Greenhouse Gases and Climate Change

Ruttan — Dean, the baton is in your hand.

Abrahamson — At current growth rates in the emissions of greenhouse gases, we can expect increases in concentrations equivalent to a doubling of the pre-industrial concentration of CO_2 (carbon dioxide) by early in the next century -- by about 2030. Most of the general circulation models show an equilibrium heating -- an increase of annual average global temperature -- of someplace in the neighborhood of 3°-5° Celsius for a doubling of CO_2 concentration. Because of the large heat capacity of the oceans, and the time to transfer heat into the oceans, there is an ocean thermal delay generally represented as 20-40 years. That is the reason for the lag between the atmospheric concentration of greenhouse gases and the observed increase in atmospheric temperature.

There are a number of biogeochemical feedbacks that are not incorporated into the general circulation models. Those are not well understood. One estimate published last year by Lashoff (1989) suggested that when you take these feedbacks into account, that could lead to a global heating equivalent to that shown by the general circulation models themselves. If that should be the case, then if we permit emission rates to continue at their present levels, we could well be committed to a warming of 6-8° within the next three or four decades. Some of these feedbacks have a long-time constant. Some of them don't.

The global heating, the concentration of greenhouse gases and the resultant climate change is, for practical purposes, irreversible. It's not irreversible, of course, in geologic time frames. But in time of social or economic or political relevance it can be considered irreversible. The issue differs from most conventional environmental issues in that there are, for practical purposes, no scrubbers -- there is no simple technical fix. There are some exceptions with chlorofluorocarbons and some of the other industrial chemicals. This means that in order to reduce emission rates the level of activities that are producing these gases must be reduced.

Finally, I find it hard to convince myself that we aren't already committed to a warming of 3-5° Celsius as an equilibrium warming because of gases already in the atmosphere, plus those certain to be released while we debate policy response and implement it.

What about uncertainty? The basic physics of the greenhouse effect is very well known. That is that there will be climatic change resulting from greenhouse gas emissions is a certainty. How much and when is not at all certain.

Now I want to refer to the tables that I handed out (Tables 1 and 2). We started last spring to put together a faculty seminar here at the University that will consider implications of climatic change for Minnesota. This is the first draft of a scenario for climatic change for Minnesota. It has not yet been reviewed. It was done a couple of years ago by a colleague of mine, Peter Ciborowski.

We were deliberately conservative -- we didn't take the high end of the scale in terms of temperature or precipitation. The base case suggests an average temperature increase of one degree by the turn of the century and three degrees by 2030; additional frost-free days by 2030; a decline in degree heating days; an increase in the degree cooling days; a two or three weeks earlier snow melt; 10 or 20 additional July days over 90°F; a reduction in summer soil moisture of 25 percent; and increased drought frequency and decreased runoff. My own view is that it's apt to be much more extreme than this, but I tend to be a little more pessimistic than some.

In 1987, there was a conference in Villach, Austria sponsored by the World Meteorological Organization and UNEP and a couple of other organizations. Several of you were there. That group put together a scenario. I won't go through it in detail, but they projected larger temperature increases at high latitudes than at low, and more in winter than in summer. Precipitation changes are also indicated (Table 3).

In a review published in 1987 by the National Academy of Sciences, the question of likelihood was addressed. Large stratospheric cooling was regarded as virtually certain and global mean surface warming very probable.

They suggested a range for an equivalent doubling of CO_2 as 1-1/2° to 4-1/2° Celsius. Global mean precipitation increase is very probable. Reduction of sea ice is very probable. Polar winter surface warming very probable. Summer continental dryness and warming are likely in the long-term. And rise in sea level is probable.

The impacts of climatic change are probably non-linear. Some of the physical impacts, sea level rise, for example, may be a linear function of average warming over some range, but the impacts of the sea level rise will be highly non-linear. I can't think of any impact that scales linearly with temperature.

The policy situation is evolving very rapidly. You don't hear any talk anymore about winners and losers or adapting. You did a few years ago, but that talk pretty much disappeared as soon as the impacts associated with the rates of climatic change were understood.

We clearly know enough to know that the emissions of greenhouse gases have to be reduced and have to be reduced substantially. Various estimates have been made of the reductions in emissions of greenhouse gases that would be necessary to stabilize their atmospheric concentrations. The one that the EPA published not quite a year ago is typical. They suggest a reduction in CO_2 emissions of between 50-80 percent; a 10-20 percent reduction in methane; elimination of the long life CFC's and reduction of nitrous oxide of, as I recall, 85 percent. Thus very, very substantial reductions in these gases are required to stabilize atmospheric greenhouse gas concentrations.

There are bills pending before the Congress and in other legislative bodies that range all the way from stabilizing emissions to reductions of 20 percent or so by the end of the century. About 60 percent of the greenhouse gases appear to come from fossil fuels. The rest are distributed over a number of other sources.

We also know that we must cope with the substantial unavoidable climatic change at the same time. At the same time that we will be trying to restructure energy production and use to reduce emissions it will be necessary to try to cope with unavoidable climatic change. Both of these activities are potentially disruptive -- socially, economically, politically, ecologically. And both are very expensive.

Crosson The draft report that Martin Parry put together for the IPCC does talk about winners and losers so far as agriculture is concerned. The argument is that after reviewing all the material there would be no reason to assume much effect on global agricultural capacity with an equivalent doubling of CO_2. Although there clearly would be some regions that would lose, there would

be others that would benefit. There was this kind of standoff so far as global agricultural capacity was concerned.

Abrahamson If you consider local effects only, everybody won't come out equally. Minnesota won't fare the same as Kansas, for example. I'd also suggest that if you postulate some new equilibrium climate and we move into that equilibrium slowly, then I think you can conjure up credible winner scenarios. If the rates of climatic change are as high as they now appear, then I find it difficult to imagine that the disruption associated with these high rates of change would be anything but serious.

Crosson I was only responding to your statement that the notion of winners and losers is no longer a part of the discussion.

Rayner I clearly move in different circles from Dean because I hear the issue of winners and losers discussed quite extensively. I think it's an issue which is seldom thought through adequately. Certainly, as Dean says, in the short-term it looks like there will be winners and losers. There is considerable uncertainty about when the doubling equivalent would be reached. Dean mentioned 2030. I've heard dates that put it much further back in the next century. And of course there's also uncertainty attached to the ocean water buffering effect. What is meant by short-term and long-term varies. But more to the point, we should stop thinking about winners and losers in absolute terms. It may well be that there are no absolute winners over the present situation, but some people are going to lose more than others.

Furthermore, we have to bear in mind that there are going to be winners and losers for preventive policies as well as from adaptive strategies. The cost of prevention may prove to be extremely high. EPA's estimates for protection of the United States coast line from sea level rise, for example, is quite an impressive figure. But it is quite moderate by comparison with the costs of completely reconfiguring the U.S. energy system. So there are going to be winners and losers in the sense that there are going to be large transfers of wealth involved in whatever response we make to climate change -- whether it's essentially a preventive or adaptive strategy. It's worth bearing in mind as we have these discussions that some are going to be, in net terms, better off and some worse off whatever we do.

Rawlins In both the Global Change Working Group of the Committee on Earth Sciences and in the Impacts Assessment Panel of the IPCC, where I've been serving as a USDA representative, there is debate about winners and losers. But there is considerably more debate about the credibility of the projections for global warming. The report Scientific Perspectives on the Greenhouse

Problem,[1] just published by the George C. Marshall Institute of Washington, D.C. is one example of the critical look now being taken at the scientific underpinning for these projections. The earth is a very complex system. The simplistic models of this system on which global warming projections are now being made are not capable of taking into account all of the complex interactions that could influence the results.

We know with certainty that the atmospheric concentrations of carbon dioxide, methane and nitrous oxides have increased, and that they will, most likely, continue to increase for some time to come. What the consequences of these increases will be is less certain. Our simplistic models predict that the physical consequence of these increased concentrations acting alone should be global warming. The question is, are they acting alone?

To illustrate just how little we know about the complex earth system, consider the carbon cycle. We've lost about 130 teragrams of carbon from fossil reserves and from cement manufacture. We've lost another 150 to 160 teragrams from land use changes, including deforestation. The atmosphere has gained only 60 teragrams. The remainder went somewhere. Obviously the ocean is a big sink. The only other sink is the biosphere. Recently, oceanographers have decreased their estimates of the sink capacity of the ocean, leaving a large quantity of carbon unaccounted for. Could it be that the 25% increase in atmospheric carbon dioxide concentration we have already experienced could have increased the biosphere capacity to fix carbon? We simply do not know. Both the ocean's and the biosphere's capacity to fix carbon are dependent upon complex processes that are affected by temperature and carbon dioxide concentration. The amount of carbon that ends up in the atmosphere is a small residual left over from some very large and dynamic processes that we're only beginning to understand. The error in estimating this residual could be huge.

Contrary to Abraham's comment that there is no debate about winners and losers, I hear a lot more debate about this, and about uncertainties of our projections now than I did six months or a year ago.

Ruttan — How strongly does the rate of change that Dean emphasized affect the conclusions that we draw?

Rawlins — Of course the less the rate of change the easier it will be to adapt to. We should not, however, assume that all changes will have negative impacts. The direct effect of carbon dioxide concentration increase on crop production, taken by itself, could be positive. Martin Parry's draft report referred to by Crosson takes this into account. [The proceedings of the Coolfont workshop

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[1] Scientific Perspectives on the Greenhouse Problem (Washington, DC: George C. Marshall Institute) **(to be completed).**

were used by Parry. The Coolfont report is as yet unpublished. Parry's report is a better reference.]

Rayner — For both forestry and agriculture?

Rawlins — They considered only agriculture.

Rayner — But that's highly uncertain because all of the experiments that are being done in CO_2 fertilization and we've done a lot at Oak Ridge, are being done under very artificial circumstances.

Rawlins — Some experiments being conducted by ARS in cooperation with DOE now use a free air release of carbon dioxide in an open field.

Rayner — Well, they haven't all been completely enclosed, but they've been small plots about the size of this room. They're quite artificial, particularly from the point of view of the effects of pests.

Rawlins — Of course, I certainly agree with that.

Rayner — The importance of the impact of pests on CO_2-fertilized plants is that the pests must eat a lot more plants to get the same amount of nutrition. The whole thing is very up in the air as to whether there would be any benefit. We just don't know.

Rawlins — I agree. We don't know. Pest interactions need to be taken into account. We're studying pest effects whether we want to or not in the FACE (Free Air Carbon Exchange) experiment being conducted by DOE, Brookhaven National Laboratory, ARS and the University of Arizona at Maricopa, Arizona. To overcome the problems of chamber walls carbon dioxide is released from standpipes encircling 20-meter-diameter plots. But leaf temperatures of the high carbon dioxide plots run higher than the surrounding plants, which selectively attracts insects.

Ruttan — We're going to come back to this issue again. Dean, do you have any comment before I move to Norm Rosenberg?

Abrahamson — Just a couple of things. One is that future emissions are under our control. We can't continue present trends. The other thing, is the time perspective. I consider short-term a few hundred years. And I certainly am not impressed with arguments about time periods shorter than a couple decades.

Rayner — The problem is though, Dean, that the policy decisions are made by institutions today that don't have time frames of several hundred years. We are stuck with their time frames as far as decision making is concerned on those issues.

Abrahamson I appreciate that fully. Even though I'm in the School of Public Affairs and supposed to understand how these institutions work, I try to forget from time to time.

Chen Your base case is for a changed climate. Is there a base case for an unchanged climate?

Abrahamson I don't think it's very likely. We must do everything we can to reduce the rate of emissions. We have to move away from the fossil fuels as rapidly as possible. I don't care what the cost is, the cost of not doing anything is in my view so large that we simply don't have that option. We're going to have to cope with whatever climatic changes are already in the mill. If we're lucky and if all uncertainties come out at the low end and we're vigorous in terms of reducing emissions, we might limit the change to a couple of degrees.

Davis I want to respond to Dr. Chen's questions about a continuation of the present climate. The present climate is variable. We don't know whether the changes we've seen since the beginning of the century are actually an incipient greenhouse effect or whether they're a natural trend. But there is something to be learned from the past record. The rate of warming from 1900 to 1950 was rather similar to the lowest rate of possible response to increased CO_2. We only need to look at the response of agriculture to the series of droughts during the 1930s, 1940s, and 1950s to give us some idea of the best possible case scenario.

Skepticism About Climate Models

Rosenberg That leads in very nicely to what I thought I would salvage from my little presentation because Steve Rawlins covered much of what I wanted to say. Let me begin in response to some of Dean's comments. I agree that if the current rate of emissions of greenhouse gases continues, that there will be a significant impact on the global climate system. I'm that convinced of the physics of the process. But I don't have much faith in much of the detail that's available to us right now. I'm very skeptical of the kinds of numbers that Dean used in his scenario.

They say there are two things that you shouldn't have to watch being made -- laws and sausages. I would add global climate models as a third. The modeling effort is intellectually stimulating, but very, very flawed. The kinds of numbers that are being quoted are very shaky. For example, the GFDL model which predicts the extreme heat and dryness in the mid-continent of North America produces radically different results than does the NCAR climate model, largely because of the way the two models parameterize soil moisture in the spring. Just a simple thing like whether the soil is full of water or not creates a tremendous difference in the outcome of the models.

Laschoff's analysis indicates that if all of the feedbacks are positive, then the greenhouse effect will be much more severe than even the GCM modelers predict. But, on the other hand, some negative feedbacks are possible, too, and we just don't know which ones are going to play out.

The models need to be improved and those who are working on the models understand this full well. It's the people, often on the policy side, on the advocacy side, and in the media, who grab the worst case and run with it. After all, it's much more interesting to know that the Midwest is going to turn into a permanent desert than it is to speculate about half a degree increase or decrease in temperature. The scientific basis on which so many of these projections are being made is still very weak. We have to be very skeptical and remain skeptical.

Clearly one of the few things we know for sure is that plants respond to elevated levels of carbon dioxide. There is a greater rate of photosynthesis and there is an effect on the stomatal functioning that causes plants to use less water. You're right, of course, Steve (Rayner), that most of the studies have been done in laboratories and growth chambers. What will happen at a field level outdoors is uncertain, but something will happen. The point that Steve Rawlins made -- that only 60 gigatons have accumulated in the atmosphere while 300 have been emitted -- is relevant. The oceanographers are now becoming convinced that the capacity of the oceans to absorb carbon dioxide is much more limited than they had originally thought. That tells me that, since the CO_2 is not going to outer space, it's going into the terrestrial biosphere. But we don't know whether it's into forests or tundra or peat bogs or into that one percent per annum yield increase that the plant breeders take credit for. I suspect that the CO_2 "fertilization effect" is built into that yield increase that we've seen over the last 50 or 60 years.

Another important point is the rate of change. Surely if that rate of change is very rapid, we're going to have more problems than if it is slow. That would be true for agriculture. And it would be true for forests, water resources, and everything else that worries us. The temperature records produced by the group at East Anglia (Jones, Raper, et. al 1986) and at the Goddard Institute for Space Studies (Hansen and Lebedeff 1987) show that there has been a net change in mean global temperature of slightly more than half a degree Celsius over the last 100 years (Figure 1). A portion of that is probably due to the urban "heat island effect," so the real number is probably smaller.

This temperature rise could be the result of normal climate variability. It could be an indication of a greenhouse effect. I find it rather upsetting when scientists grab hold of one side of an issue and quote only that which seems to support their argument. Lawyers are paid to be advocates and they do the best they can to make sure that information supporting their case is the only

information to reach the judge and the jury. However, what is laudable behavior in an advocate is not necessarily laudable in a scientist. Now I believe the temperature record is essentially correct. I believe that there has been a global warming trend over the last 100 years. But when we see that data for the continental United States shows no change in temperature over exactly the same period of time, it should cause some doubt. The continental United States has the best geographical distribution of temperature and precipitation measurement stations anywhere in the world. That record shows no change in temperature and no change in precipitation.

The counter-argument is that the U.S. is only one small portion of the world. But it is one portion of the earth's surface where "greenhouse warming" is predicted, by some GCM's, to be most apparent. And yet we don't find it. We find cooling in many places in the world where we expected warming and we find the greatest warming in the tropics where no warming was expected. My point is that the state of the science is really far too weak to support the kinds of major policy decisions that are being proposed right now by many advocates.

A number of analysts at RFF are now engaged in a study, with support of the Department of Energy, which is intended to overcome some of the methodological limitations that characterize most prior studies of possible "greenhouse" impacts on agriculture and other industries. One of these limitations stem from reliance on GCM scenarios. The recent EPA study used two GCM scenarios and came out with a number of projections about changing crop yields, changing water resources, energy requirements, and so on. Since the scenarios themselves are so uncertain, particularly with respect to regional detail, those who wish to diminish the significance of such studies can wave them away by arguing, "Well, the scenario is unreliable." There is no perfect way to generate climate change scenarios. In our study we take a different approach; we analyze how a particular region of the U.S. -- in this case the four-state region of Missouri, Iowa, Nebraska, Kansas -- would respond to a replay of the 1930s exactly as it occurred.

I don't want to take up a lot of time going into more details, but in order to overcome the reliance on GCM's, we use a real climate analog. In most impact studies the climate expected to occur 50 or 70 years from now is imposed on the world of today. We call that the "dumb farmer scenario." The results assume a passive response -- no adaptation, no change in technology or management. However, we know full well that people are going to adapt. It's ridiculous to think that if climate is changing, people would not be searching for ways to adjust and adapt. So we're trying to establish a base description of this region and how it functions. We will also try at first to see what happens to the "dumb farmer." We will compare that model with one in which we put in the adaptations and adjustments that can be done with today's technology and today's knowledge base. That is the "smart farmer scenario." Finally, when this is accomplished, we're going to

try to anticipate what the agriculture, forestry, water resources, and the energy demands in this region will be like 20 to 40 years from now by which time, presumably, a significant climate change will have happened. Again, we will apply a serious climate change -- that of the 1930s decade. The 1930s were very severe. The GCM's are sufficiently credible in indicating warming and drying in this region so that we cannot ignore the possibility. We feel that if people can adapt to this worst case, there is some reason for optimism.

Finally, I would like to refer to some work reported in a book, Greenhouse Warming: Abatement and Adaptation (Sedjo and Solomon 1989) based on a symposium that RFF organized about 1-1/2 years ago. Many of us believe that, no matter what attempts are made to control greenhouse emissions, the reasonable and pragmatic thing to be doing now is to prepare for some (hopefully moderate) climate change. If, indeed, the climate does not change beyond its current normal oscillations and variability, we will, at least, have learned how to deal better with that variability. Droughts, floods, and cold spells are happening now. We don't have to invoke the greenhouse effect to justify concern about the sensitivity of the world food system to climatic stresses.

Let me respond in two ways. Growth chamber and greenhouse research with carbon dioxide fertilization has also shown that CO_2 moderates the effect of drought stress, salinity stress, and to some extent, phosphorus deficiency. The case for nitrogen is less clear. Under these stresses plants don't do so badly if they're fertilized with CO_2 as they do if they are not. So there is a kind of natural feedback by which elevated CO_2 concentrations might reduce the impacts of certain environmental stresses.

Some time ago I wrote (Rosenberg 1982) that if the atmospheric CO_2 concentrations were to increase, there should be a rapid response in the rate of photosynthesis which would lead to greater biomass and, ultimately, to deeper and better root systems. Isn't it possible that with deeper, more vigorous root systems soil formation and mineralization would be accelerated? I speculated that a CO2 increase, all other things equal, would have the effect of improving the condition of forests, especially by increasing soil organic matter content and water-holding capacity.

Sanchez

I don't think there's any question that plants respond to CO_2, and that they're more drought and cold tolerant. But that additional growth requires additional nutrients. In the liberally fertilized fertile soils of the U.S., that may be sufficient to account for additional yield increases. But in natural systems there might be a limit to how much plants can respond to additional CO_2 if you don't have additional nitrogen and phosphorus and other mineral nutrients coming into the system.

Rosenberg Let me respond in two ways. The growth chamber greenhouse research with carbon dioxide fertilization has also shown that CO_2 moderates the effect of drought stress, salinity stress, and to some extent, phosphorus deficiency. Nitrogen is less clear. The plants, under these stresses, don't do as badly if they're fertilized with CO_2 as they do if they don't have that CO_2. So there is a kind of natural feedback that could perhaps answer your concern.

Another thought that occurred to me some time ago is that if the CO_2 level were to increase, I would assume that there would be a rapid response in terms of biomass. There would be an increase in photosynthesis which might lead eventually to a deeper and better root system. Plants would get bigger. If their root systems are more vigorous, isn't it possible that soil formation and mineralization would be accelerated? I speculate that a CO_2 pulse, all other things equal, would have the effect of improving the condition of the forest -- more organic matter, more soil, and more water-holding capacity.

Davis I don't think it's clear that that would be the effect because the change in the CN ratio in the litter might affect mineralization rates on the forest floor. But exactly how it would affect it is unclear. Many of these forests are more strongly nutrient limited than moisture limited.

Ruttan Do we know anything about the behavior and impact of soil micro-organisms? I haven't read all the literature, but it seems to be rather empty.

Davis I don't think anyone's done any experiments with enhanced CO_2 in an intact forest soil. The only comparable experiments that I know of are in the tundra. There the overall productivity has not gone up, but the species composition has changed. In the forest you might expect species to respond differentially. But it's not clear what will happen.

Munson Is there any long-term evidence that as you increase the organic matter in high fertility fields that you do enhance yields by raising the level of CO_2. I don't believe there is any solid evidence.

Abrahamson Norm, I didn't understand what you said when you were talking about the carbon cycle. Are you suggesting that there has been an increased amount of carbon sequestered in the biota? What's the evidence for that?

Rosenberg None that is yet reliable. But we know that half the carbon emitted by man's activity into the atmosphere does not remain there.

Abrahamson Of course, it's going someplace. That's true. But the rate of carbon uptake and the amount of carbon sequestered are quite different things. I'm not aware of any evidence whatsoever that there have been additional carbon sequestered in the biota or soil.

Rosenberg I don't think there is any direct evidence. It's one of the most difficult things to establish whether yields are increasing due to higher levels of CO_2 given all the natural variability in yields. I agree that I don't know of any evidence that this is happening. But I do know arithmetic. And it's either in the oceans or it's on the land. And the oceanographers have reduced their estimates of the oceanic uptake of carbon dioxide quite considerably from what it was 10 years ago.

Rawlins I think that is a very important point. No comprehensive inventory of soil carbon storage exists, particularly including carbon below the plow depth. We know, however, that even in forests half of the carbon is in the soil. It's just not as visible and as easily counted as that in the trees. In one instance where deep cores were take from rangeland on Blackland soil at Temple, Texas, 15 times as much carbon was stored in a hectare of soil as exists in the atmospheric column above it. Although not all soils are this high in carbon, these data illustrate that soil carbon storage can be large. A small percentage change in soil carbon storage of this magnitude would have a big impact on the atmospheric concentrations. We are aware of the fact that surface soil carbon is lost when soils are plowed. But what happens to deep soil carbon storage? If in response to the 25 percent increase in atmospheric carbon dioxide that has occurred since pre-industrial times, plant roots grow deeper and are more prolific, isn't it possible that the soil carbon reservoir is being filled, not depleted?

Crosson Is soils science sufficiently well-developed so that you could theoretically say that it's possible for the soils to absorb these greater amounts of carbon?

Sanchez I could try that. Stan Buol and I were asked to make an estimate of what would happen to soils assuming a three-degree temperature increase. First the three-degree increase is no big deal in terms of releasing additional nutrients. Second, there would be a net loss of carbon to the atmosphere because of additional temperature. But we estimated that the amount of additional litter that would be needed to counteract that loss would be on the order of about 500 kilograms per hectare per year. The question is whether the CO_2 fertilization effect would be sufficient to counteract that.

Cheng Let me respond on some of the soil carbon issues. One of the major deficiencies when we look at the biosphere is that we only considered the plant part and do not look at the micro-organisms. That's one of the areas where I've seldom seen any good data or even estimates. But what we do have certainly suggests that they may account for a large component of carbon even when compared to plants. One of the things we need to look at is the seasonal effect of the micro-organisms. It could be that they might absorb more carbon because of the activity in the summertime. So there could be seasonal variations. We need to look at the seasonal effect rather than just constant accumulated effect.

Larson — The rule of thumb here in the Midwest is that we've lost a third to a half of our carbon in our cultivated soils. That may be a hundred tons of carbon per hectare. That's a lot of carbon. Our studies pretty well agree that, under a given management system, the carbon level in the soil is in equilibrium with what is put back. If you plow back two tons per acre, you get a certain equilibrium level; if you plow back four tons, you got another level. Experiments that I did in Iowa 20 years ago clearly show that. With modern tillage practices and modern residue practices, there's a good chance that we can increase the carbon content of the soil. There's some evidence that that's happening. It is a research issue that we need to look at, not only what these carbon levels are, but try to develop management practices that will increase it.

Cheng — I wanted to raise another question. Norm, you were talking about plant response to CO_2. The CO_2 fertilization effect is probably slowing the atmosphere accumulation of CO_2 below what it would otherwise be. From an agricultural production point of view, we know that the effect will be an increase in biomass. But will that necessarily translate into crop yield increase?

Rosenberg — Yes, I think so. Everything I've seen indicates that for the economic crops -- corn, soybeans, and millet -- the C_4 plants -- there is an increase of 5-15 percent in harvestable product; in the case of C_3 plants -- soybeans, wheat, barley, potatoes, etc. -- the increases range from 30-80 percent with doubled CO_2 concentration.

Cheng — In yield?

Rosenberg — In yield! The only thing that would stop the biomass increase from turning into a yield increase would be a blocking of translocation, perhaps by starch accumulation -- i.e., the lack of a sink for the photosynthate. And there seems to be some evidence that this does not really happen. I saw a paper recently that suggests that kind of blocking mechanism is not interfering with the conversion of photosynthate into harvestable yield.

Global Climate Change and Agricultural Production

Ruttan — I originally scheduled Bill Clark as the second discussant. But I think the accident of his late arrival is working out better than my original agenda.

Clark — What Vern and I negotiated about two months ago was to take a step back from the initial focus on global climate change and try to sketch a framework of resource and environment constraints that might impinge on agriculture production and agricultural policy over the long run. This may violate the first precept of agricultural policy analysis, which is don't go long and

large -- focus at the farm level. What I will try to do is sketch a framework within which I trust anything we say and most of what we don't today and tomorrow might fit. It's put forward as an effort to provide some sort of a counter force to the pressure to focus too heavily on the very important issue of climate change. The issue is not so much whether immediate climate change effects are going to be large or small, but rather to say large or small relative to what? That is, when and where might climate-mediated constraints come to the top of that list even though they may rank relatively low at other places and times.

My basic point of departure is a historical perspective: agricultural activities, broadly conceived, have been the primary transformer of the global environment for all of human civilization until very recently. One can still argue today that, at a global level and averaged over more than 10 or 12 years, it is still basic land use transformation activities that have been, if you had to rank them, the single largest transformer. Obviously, fossil fuel emissions, climate change issues, and ozone depletions give one pause. But if one tallies across lots of environments, it's a statement that could be argued.

An equally defensible contention is that agriculture has been the sector primarily affected by environmental change around the world over the last several centuries. There may be impacts elsewhere -- on transport, on habitation, on human health -- but the place that so many of these changes come to roost first is, not unexpectedly, on human activities related to agriculture and natural resources. Now, what that means is that the coupling between agriculture and environment, over large scales and the long-term, is a two-directional issue.

As we go to the notion of constraints around which this consultation is organized, it becomes important then to look at agricultural activities as a source of many of the resource and environmental changes and in turn the impact of these changes back on agriculture. Agricultural activities can be impacted in two ways that involve the environment and resource base. One is directly -- climate changes, and crops grow differently. The other is indirectly as society becomes concerned about environmental degradation caused by agricultural or other natural resource exploitation activities and adopts policies with multiple impacts.

An old example but a useful one is the banning of DDT several decades back. It was not that there were such bad impacts of DDT directly on the agricultural sector. Rather society, at least in North America, decided that there were other environmental consequences of the use of this chemical in agriculture and in health. Decisions were made which then had potentially severe impacts on the agricultural sector. I do think we've got to be careful as we consider this second class of constraints where policies initiated to

protect or regenerate a component of the environment have immediate negative impacts on agricultural production.

As I tried to figure out what Vern was doing with this workshop, it seemed to me that it is the notion of constraints -- translated into an effort to understand when and where we might expect environmental constraints to become important enough to change agricultural production or policies affecting agriculture.

Somewhere in the course of Vern's writing up the results, if not in our talking about them, one has to think about taxonomy. First we have to end up, implicitly at least, with a list of which constraints belong on the list. What kind of constraints should we be check-listing to see whether these will end up having a big or a little impact on agricultural production and policies in given places. Second, we have to identify the kinds of human activities and natural processes that might be changing the nature of these constraints -- increasing them, decreasing them, or mitigating them. Third, we also need to say something about the rates of change of those constraints and the activities that generate or remove them. We need to get a feeling for which of them are changing very quickly and which of them are changing very slowly. Those that are changing relatively rapidly may be expected to pose greater challenges to production and policy than those that are moving slowly enough that we can adapt our practices and policies as we go. Finally, we have to ask what these possible constraints mean in particular agricultural production settings -- to particular farmers, researchers, extension agents, and national policy bodies. An effort should be made to do some first-order guessing as to which kinds of places on earth might be expected to be incurring the same kinds of constraints at the same time.

Let me say a couple words on each of those categories. I'll say very little about what's forcing them. Rather, I will talk about how we might try to think about the rates of change in those constraints and their sorting out in different parts of the world. As part of some other work that I and others are doing, I have come out with a list -- which anyone is free to steal, savage, or amend -- of eight different categories of broad constraints on agricultural production and policy in the large and over fairly long periods. They are grouped by order but they are not priority ranked. In all of these categories -- which will be obvious things like land, water, and energy -- it turns out useful to talk separately about the quality and quantity aspects.

Land can clearly be a constraint. The area available for agriculture is limited. This is reflected in the arguments about slowing deforestation and in the notions that habitation is encroaching on the most productive land. The area available is the quantity dimension. The quality dimension is where all the issues of soil productivity or fertility come in and the various ways in which the location properties of land can be assessed -- the erosion, the

salinization, acidification, compaction, and another class of things that we talk about when we talk about soil degradation.

The second, fairly obviously, is water. In quantity terms -- how much can we get. The answer to how much can we get must be viewed in terms of some sort of a supply function -- that is, how much could we get if we were willing to pay a certain something for it, broadly conceived in terms of trade-offs against other things society wants? Simply put, the quantity competition is for irrigation water, for groundwater, and other uses. Quite independent of the issue of climate change, the constraints on quantities of water for running agriculture is likely to be one of the dominant constraints faced in many parts of the world at certain periods over the next century. (Not all parts of the world and not all periods.) There's also a quality issue involved here. We know that there are places where the quantity of water available is perfectly sufficient but is quality, in terms of salinity or the toxicants it carries or in some cases the human pathogens that live in it, represents a real constraint on agricultural production.

Third on my list is energy. The quantity issues include how much is going to be available to the agricultural sector and at what prices. The quality issues include what kinds of energy will be available -- low head hydroelectric, liquid fuels, high grade or low grade solid fuels, or others. For some regions, some of these seem to sit very low on the list of present or likely future constraints. For others it is one of the dominant impediments to doing certain kinds of things in agricultural production that you would like to be able to do, but you can't because of quality or quantity shortfalls in energy.

The fourth is fertilizers or generic nutrient additives. The quantity issue is, again, how much can you get at what price. A quality issue, which we usually don't tend to think of enough, is what fraction of it is lost? What fraction ends up being a potential pollutant rather than an incorporated nutrient in the plant? This is far enough from my own area of work that I don't even know the proper literature. But there is a lot of work being done on capturable forms of nutrient additives versus forms that when you plop it down most of it goes into the air or into the groundwater. There are also some other quality issues. The one Europe may be facing now is the trace metal pollutants in fertilizers which end up as a residual in the soil slowly or incorporated in plant tissue. That's surely a quality issue that we need to be looking at over the long run. On European country recently decided that within this century it will be facing a situation where it must stop eating its own foods because the heavy metal content in them exceeds safety standards. Alternatively, the country can revise its environmental regulations to raise the limit on heavy metals. Either way is going to be desperate news for the policy-making apparatus of the country. When you have once imposed X parts per trillion of cadmium as a health limit, it's going to be real difficult to come back later and say, "We fooled you. That was an arbitrary limit.

It should have been twice as high. We can go on with business as usual." That is not a popular way to win an election.

Fifth is the biocides issue. Again, the quantity dimension is how much can we get at what price. Obviously use can be constrained, as in the DDT case, for reasons other than direct negative impacts on agriculture. On the quality side, we need to be thinking about things like to what extent is this biocide something that kills absolutely only the beast you wanted to kill versus a broad-based one. To what extent is it one to which pests have built up a lot of resistance and therefore has lots of spill-over effects. Again, those sorts of issues, talked about specifically in policies about pesticides, don't tend to come into the broader discussions of the sort that we're dealing with here. They probably need to be.

Climate is sixth. The quantity dimension must be things like temperature, precipitation, and evapotranspiration. The quality, and this is where the categories begin to be strained, includes seasonality -- the difference, in a sense, between X centimeters of rain distributed evenly over the year and it coming in utterly useless and indeed counterproductive spurts which, as you've heard this morning, is one of the concerns that comes up in this issue of climate change.

The seventh is biodiversity. And this is an area where there's been a lot of special pleading that I don't think has been particularly useful. Biodiversity has been reaffirmed as a good in itself -- it is a cornucopia that we can't afford to spend one unit out of. But if the quantity is the number of species, the quality issues are things like supply of natural predators on the pests we're after. Do we still have them or have we lost them? What about future cultivars -- the genetic base from which the new crops of the future will come? There is the old argument about possible pharmaceutical supplies. But there is also a quality issue in biodiversity. One of our challenges is to move from the broad brush prescription to never deplete biodiversity to a quantifiable notion of which aspect, which kinds of biodiversity, are most important. This list will contain certain sorts of predatory insects and certain first, second, or third cousins of things we know are cultivatable. We should begin focusing very tightly on those because we're going to be no more successful in preserving biodiversity for itself than we are in preserving land or anything else for itself. We've got to be more specific -- and the specificity must come from the agricultural production sciences rather than the other groups flailing around about doing something in this area.

Finally, though it bewilders me, agricultural output often gets left off lists like this. On the quantity side there is the same old issue of how much can you supply at what costs given all the other constraints society has loaded onto the system. There are also a set of quality issues, some of which are the obvious ones that all agricultural production people worry about -- what is the value added in a market sense by its attractiveness, its taste, and its

nutritional value. We might also want to be a little more concerned about the portion of the crop, and its basic carbon and energy values, that are wasted, both in the field, and in the process of moving it to the table. We might also want to look at toxicity. I think more and more we are going to be faced with notions of different qualities of agricultural produce simply in the sense of whether a case can be made that it's pure: whether it's natural, a popular notion right now, or whether it is in fact loaded with some at least noteworthy quantities of trace metals, organic compounds, biocide residues and the like. These issues are talked about in very narrow circles. They don't tend to get raised in general discussions of the sort that we're trying to have here.

That's the list. Obviously, there can be subdivisions within each. But I do think it would be a mistake, at least for the larger Rockefeller consultation exercise, if we were to become preoccupied with any one of these areas, even where there's a window of opportunity to move rapidly in one of these areas like climate change. Rather, we need to be looking at something like this list as a way of trying to specify for particular regions and times the changing hierarchy of constraints.

As one moves to the notion of what belongs high on a list of potential constraints, at least until you find a reason to drop it off, I would emphasize things like energy use, fertilizer use, and biocides use. These are growing at extraordinarily high rates relative to anything we've had, say, over a 30-, 40-, or 50-year period in the past and are plausibly accelerating. Changes in things like land area and quality and even water availability are happening at rates that are significantly slower.

Finally, I argue that some sort of a taxonomic effort might provide us with a smallish number of groups in which we might expect, should we ever begin to assemble the data, that the rankings would tend to be more similar within than between groups. One such taxonomy comes from some of Pierre's work that I find useful -- this very simple notion of taking a two-dimensional matrix in which population density is plotted on one axis and wealth per capita or per square kilometer or level of technological development is plotted on the other. If you had a third axis, which we both agreed we wouldn't try to do, you would probably want something about the nature of the landscape. Agroclimatic zones as indicators of basic biological productivity potential actually works pretty well as a sorter. But even just taking those four grids -- high and low on the population density and wealth density -- tends to produce a nice basis for ordering different countries or regions.

The research my students and I are beginning to do now, looking forward at some plausible trajectories into the future, suggests that those categories hold up well under various versions of the scenarios that might develop. Even when they break down we're finding it a better guide than nothing in efforts

to look ahead to the kinds of policy problems that might be confronting clusters of regions 20 or 30 years into the future.

Rayner — Bill, I think your list is an interesting one. Taxonomies are a useful way to begin looking at problems, but I have a concern about the lists that you've given us in that it seems to me that the categories you've created there are very much dominated by a kind of supply-side view of the agricultural system. Do you not think that it would be important in looking at constraints on production to consider not just the numbers of people, but the age ranges of people and the kind of different nutritional demands that they're going to have?

And secondly, given what we know from the intervention in markets in terms of subsidies and taxes, including price support systems, forced delivery and biased exchange rates, the actual structure of markets, transportation, and trading arrangements also represent very real constraints upon agricultural output. It seems to me that to supplement your list, we need to look more carefully at the demand side of the agricultural system.

Clark — I couldn't agree more that somebody should do that. I took Vern's instructions to address the resource and environmental constraints on agriculture in this session, and to ignore some other things he's addressing in other sections. Besides, I knew you would be here so that there wasn't a chance that I wouldn't be reminded properly and articulately that too often sessions like this have started and ended by saying, "Well, of course we know that the social, institutional, and human dimensions are important, but for a moment let's just concentrate on the technical resource ones," and so on.

Rayner — I'm wondering how, given Steve's concerns there, to what extent we as a group feel comfortable narrowing it in that way.

Clark — Perfectly legitimate. I merely reply, if the brief had been broader, I would have had a very different list of things.

Rayner — You went to the trouble to find out from Vern in more detail what his agenda was?

Ruttan — We are thinking of a fourth meeting that will address institutional issues in more depth. But we wanted to make sure we had the environmental and technical issues as background for that meeting.

Crosson — Well, I didn't hear Bill limiting his comments to institutional issues. Steve, if I heard him correctly, he is saying there are things happening on the demand side that have an important bearing on the emergence of the various environmental constraints on agricultural production. If we believe that global demand for food, for example, will grow, by 1-2 percent a year over

the next 50 to 70 years, the implications of that for emerging constraints in agriculture is vastly different than of demand growing by 2-4 percent.

Ruttan — If population growth rates in Africa south of the Sahara were closer to one percent than four percent, it would have a dramatic impact on our perception of how to achieve sustainable growth in agricultural production.

Clark — In my notes for this I had two columns, to the second of which I only briefly alluded. One was the resource/environmental constraints -- the list of eight that I just read. The second was the determinants of changes in those constraints. That is exactly where I have put in the notions about whether you need a lot or a little; ability to pay a lot or a little; the structure of the labor force, and these sorts of issues. So, I see it at least as a compatible direction for the discussion to go.

Munson — I presume when you're talking about nutrients and the need, you're talking about worldwide, and you said they are increasing. And the reason I raise that question or point is that in the U.S., for example, phosphate use actually peaked in 1977. Nitrogen and potash use peaked in 1981 and have been declining since. And I suspect the same holds for the pesticide total usage.

Clark — Well, you know, it may well be that the trends you note will hold both in this country and elsewhere. A couple of years back effort was made by the natural sciences community to try to say something usable about what kinds of chemical inputs into the environment that might be occurring over the next 100 years. We got the scenarios worked out pretty well for things like greenhouse emissions, but very poorly for things like the pesticide use or nutrient releases.

We went through an exercise, Vern got partially involved in it as a correspondent, trying to say for the various scenarios that are out there from official and unofficial organizations, what can they tell us about the likely rates of change? For whatever it's worth, when that stuff was worked through the meat grinder, the 1975 to 2075 vision for North American fertilizer use implied a 1-1/2 fold increase. Most of the increase occurs over the next decade or two. This is a lot smaller than the increases of four and five and eight times that are foreseen for other continents.

Ruttan — A friend of mine recently did a comparison for Minnesota and Saxony (Germany). Fertilizer inputs per hectare in Saxony are about four times higher than in Minnesota. Given the changes in population densities around the world, agriculture in terms of input use, will look more like that in Saxony, Japan, or the Netherlands than in Minnesota 50 years from now.

Clark — When we completed that exercise, even though the numbers are poorly grounded, nobody could erect for us a continent scale scenario for fertilizer that brought levels of fertilizer application on a kilograms per hectare basis

100 years from now up to present European lands. This is quite interesting given the problems Europe is confronting today with its groundwater and its heavy metal toxin build-ups. It is important that we discover where they come from. One can generally subtract for fossil fuel, industrial material, and come out with a residual. The point is that such a study hasn't been done. It's hard to find anyone who really wants to do it. It is something that isn't getting written up in the literature. This is a kind of report you get from skulking around the health bureaus and asking lots of questions. But it's the kind of study that just seems to me to be enormously important.

Larson — Well, the cadmium story in my opinion has been overdone. But I'm not saying that it isn't a problem in Denmark or in Europe. It is! But I think it's probably been overdone.

Rawlins — Are they using sewage sludge?

Clark — Yes. Of course in Denmark.

Sanchez — That's a source of cadmium.

Clark — But nobody has sorted out the relative importance of the several sources. I raise it only to say that, whatever its scientific foundations, it is typical of the kind of issue that is going to jump right out of the science arena and into the policy arena. It will then be thrown back to the scientists as a mess that has to be disentangled -- probably with an inadequate data base and too much pressure for instant results. Given the predictability that it will become an issue, it's the sort of thing that one might want to put in place as a relatively low key research program that would provide the data needed to tell the story right rather than merely responding because the Greens party this year says that the phosphate merchants are poisoning us.

Sonka — I don't know if labor should be considered a resource constraint in this context, but in the United States, and the other developed countries, the 1990s will be a period of labor scarcity.

Clark — There is a strong historical precedent in this argument because one of the constraints we will face is not only the numbers, but the quality issue. This includes education and training, health, and others. These are obviously constraints in some parts of the World. If I'd have been smarter, they would have been in there the first time.

Sanchez — As population increases more, more of the world's agriculture is going to look like that in Japan, the Netherlands, and Saxony. What about places where population is already extremely high such as China and Bangladesh? Do we expect them to go to an even more intensive, high input system of agriculture?

Clark — This is one of the big questions. We have examples of countries which starting out under high population density and very low input intensity have made a transition to what may be ecologically sustainable forms of agriculture. They have done that by going the intensification route. I have tried to work through as an intellectual exercise, routes of development, and especially rural development, for our high population density low income density areas that don't involve radical intensification in input use and increases in the value added capacity of the agricultural prediction in the rural areas and, for the life of me, I can't see one that works. Even solution of the food problem may not solve the labor absorption and the income generation problems. When one thinks about the environmental problems associated with agriculture likely to confront areas like that over the next 20, 30, 40 years, you just have to work within the constraint of finding alternative ways of producing a lot more value on the same land. Hopefully, these economies will develop in a manner that will enable them to get some of the people off the land so that they don't get caught in this horrible partitioning of units of production down below usable scale. But that's tricky. When you then start looking at the levels of inputs that would be required under the systems we know about to produce the levels of output or value added we're talking about, they include extraordinarily high densities of fertilization, biocides, and in some cases energy application that will have some really very serious regional scale environmental implications.

Sanchez — So alternative agriculture, as we understand in this country, doesn't seem to have much of a future in your scenarios.

Clark — Well, you know, so much comes under alternative agriculture. But I don't see it solving the income generation problem for enough people.

Ruttan — We'll move on to the agricultural issues in a minute. But I have two questions that I'd like to get Dean and Norm and/or Bill to respond to. The first concerns the investments that would be required either to reduce the sources of global temperature change or to respond to temperature change. We have now brought up the issue of the kinds of investments it would take just to sustain present per capita income levels, or to raise them at some acceptable rate, in most of the world. If we honestly attempt to face these issues we must be talking about levels of saving and investment that our societies are not yet prepared to achieve.

The second question may not appear sensible to the people on the physical science side, but I've often wondered -- economists often think in terms of optimum -- is there an optimum level of CO_2 and associated greenhouse gases? It strikes me that we often start out by asserting that there was a golden age, between 1850 and 1900, when the CO_2 level was about right. If we had been doing an experiment, we would have designed it to answer the question of whether we would be better off by reducing or enhancing the CO_2 level.

Jones To answer that question you have to ask, "better for whom or for what." From a biologist's standpoint you assume that all animals and plants have evolved with a certain level of CO_2. That suggests that the optimum is what it is at a given time in evolution.

Ruttan But apparently it came down from some higher level in the distant past.

Abrahamson It was higher.

Rosenberg That's a tough question. But let me take a crack at the second point. In an adjoining state you have a well-known climatologist, Reed Bryson, who 10 or 15 years ago was telling us that we were heading into the next ice age. I don't think there's anyone who can dispute that argument because we know we're in an interglacial period right now. When the fact that the climate was not getting colder was thrown at Bryson, he answered (in essence), "Well, it's probably the CO_2 that's masking the cooling effect." Whether he's right or wrong doesn't matter at this point, but clearly, climate does change. Suppose we decide that we like the climate the way it is and suppose we're farsighted enough and our models are good enough to show us how to stabilize climate the way we like it. Then we might even be advised to pump still more carbon dioxide into the atmosphere to give us a little extra greenhouse effect. Unfortunately, we don't know just how to fine-tune the system. But if we were confident that more CO_2 would not produce significant climate change, I would say let's pump the stuff into the atmosphere. I can't see where it would do us any great harm. We are existing in a room now with a CO_2 level considerably above the ambient, and I don't see that it's hurting anybody.

Just to finish this thought. The concentration today of 350 parts per million is not threatening and does not appear to be threatening. It's conceivable that we could go to 400 or 450 parts per million without running into any real threat in terms of the biology or the agricultural effects. However, if the concentrations rose toward 600-800 parts per million, there could, indeed, be certain species or subspecies that experience significant negative effects.

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Abrahamson The first question is about the increasing demands for investment and savings. I would guess that we're talking about diverting about the same amount of resources that we're now spending on defense. To the optimal

level of CO_2 question, I would respond again by stressing the rate issues. If rates of change are such that significant climatic change occurs in a time less than the lifetime of people or trees, there will be trouble. I don't think the issue of optimum is an interesting question. Much more interesting is what rates are tolerable or what are the costs associated with adapting to or mitigating the various rates.

Chen — In response to that, it does depend whether you're moving to something good or bad. If you're moving quickly to a better world, some people may be harmed, but perhaps there will be fewer objections. It does matter whether the transition involves a positive or negative change. I don't think it's valid to say you should only look at rates.

Abrahamson — I don't say only look at rates. There may be other things. There may be threshold phenomena that you need to be concerned about. I'm worried that you're beginning to sound a little bit like Budyko, the Russian climatologist, who argues that the next century or so is going to be pretty bad. But in another 100 years, if we keep on growing fast and if we keep on warming fast enough, things are going to get better. We should just accept the transition and get through it as quickly as we can. That argument is just silly!

Ruttan — Let me turn to Steve Rawlins now to discuss some of the agricultural implications.

Rawlins — We've already discussed a number of issues that I think are important. I'd like to add three points.

First of all, the comment Bill just made is important. Not only is agriculture responsible for some of the constituents that are capable of changing global environment, it is could be seriously impacted by these changes. Uncertainty about future environmental factors that could affect food security is frequently used as a primary justification for the U.S. global change research program. But the resources available for direct study of food security issues are small. In the past USDA has not assumed primary responsibility for assessing either agriculture's contributions to global environmental change, or the effects of these changes on agriculture. But the atmosphere is changing.

I returned to the ARS National Program Staff a year ago at a time of awakening to global change issues. Dr. Orville Bentley (Assistant Secretary of Agriculture for Science and Education) had just learned that USDA was not represented at the organization meeting of IPCC at Geneva, and wanted to know why. He informed the Department of State in no uncertain terms that USDA would be represented in the future, and he appointed some staff members to do the representing. Up until then, Dr. Norton Strommen, Chief Meteorologist with the World Agricultural Outlook Board, an agency serving under the Assistant Secretary for Economics, was being called upon to

represent the Department on nearly all issues related to agricultural weather and climate. The midwest was just emerging from a devastating drought, and you can imagine that Norton could not cover everything. Dr. Gary Evans, ARS Deputy Administrator, was given the responsibility for developing a USDA Strategic Plan for Global Change Research and for coordinating USDA representation on national and international planning groups. As a member of Gary's staff, I was asked to chair the plan development process. Until then, without the needed people to cover all of the bases, USDA had taken a back seat, basically monitoring what was going on in CES and other groups. Since then, Dr. Evans has been given the assignment as Special Assistant to the Assistant Secretary for Global Change Issues, and chairs a very active working group from all USDA agencies to make certain USDA carries its share of responsibility for global change research.

Allen — Steve, I'd like to know who came to the conclusion that agriculture shouldn't be involved.

Rawlins — I don't think anyone really made a decision that USDA should not be involved, I think it was just a matter of too many issues and too few people. Norton Strommen had traditionally represented the Department on agricultural weather and climate issues, and when new issues related to climate came over the Secretary's desk they were routed his way. He chaired the USDA Climate Coordinating Committee, which includes Science and Education Agencies, but this was insufficient to handle all of the rapidly emerging issues.

Ruttan — Has the Department yet developed an agenda for research that will enable it to deal with this nexus between climate change and agriculture?

Rawlins — Yes, the USDA Strategic Plan is nearly complete and makes a good start in this direction. But we have a long way to go. It's my personal opinion that we have some substantial barriers to overcome.

The second point I'd like to make is this. Although USDA at one time was the elite research agency in government, research is now only a small part of the USDA agenda -- representing something on the order of two percent of the budget. We have to be realistic. If you were the CEO of an enterprise having a division that represented only two percent of the action, how much attention would it get from you? I think it's going to be very difficult to generate the budget required from within USDA to adequately address the global change issues without some strong support from outside. Each year every agency within USDA competes for budget. For the last few years there has been strong pressure to keep the departmental budget constant. It will be very difficult for a small program to obtain a substantial increase if it has to come at the expense of other programs within the Department. Our best hope is to build strong cooperative linkages with other members of the science community, obtaining their support for our budget. Perhaps this is

an issue that should be addressed as an institutional problem in a subsequent dialogue.

Rosenberg I think in fairness one should point out that a lot of the research that's been done over the last 10 or 15 years on the direct carbon dioxide effects on plants has been done by USDA. But it has been done with DOE money. This tells you something about the level of importance attributed to this work by the USDA establishment.

Rawlins This is a problem. USDA scientists are sought out by others because of their scientific credentials for dealing with the environmental issues we're facing. USDA has not been successful in obtaining funds to pursue these issues directly. Other agencies are successful in obtaining the funds, but they often lack the scientific expertise needed to solve the problems. USDA is not viewed by everyone as being unbiased in addressing environmental issues. Some perceive agriculture as being part of the problem, not part of the solution. That's an image we need to do something about. I don't think agricultural scientists deserve this image, but again, we are only a small part of a very large Department that has constituencies who take adversarial positions on environmental issues. The constituency for agricultural science must be extended beyond those who live on farms. A substantial part of the scientific expertise capable of dealing with environmental issues in the managed ecosystem are within the agricultural science community.

Ruttan I have a couple questions, but I'd like to direct one to Gene Allen because you're been sitting on the NAS/NRC Board on Agriculture. The Board came out with this dramatic proposal for a $500 million increase for agricultural research. This is a relatively large increase for agriculture. Did the set of issues we are discussing enter into that proposal?

Allen It's one of the six categories that has been targeted for increased support. It's even broader because many of the things that are targeted, such as plant systems, are related to these issues.

Rawlins The Board on Agriculture report has been helpful. It has helped to gain attention and visibility for agricultural research.

The third point I'd like to make is that food security is the real issue we need to be concerned with. It's related to the question of who is our constituency. We need to ask ourselves some tough questions. What is our central concern? Is it **FOOD** or is it **FARMERS**? If it is food, we may design a very different production system than if it is farmers. When we talk about environmental and technical constraints on sustainable growth in agricultural production we need to know what kind of an agricultural system we are talking about. How far are we willing to allow ourselves to depart from the traditional system, with food production being carried out by farmers? Are

we willing to consider alternative systems that might completely redefine the role of farmers?

In an article entitled "Food Security: A Technological Alternative" published in BioScience in 1988, Martin Rogoff and I tried to take a look at the fundamental constraints limiting food availability in the future. We argued that one of the biggest limitations is that the productive capacity of our present system varies dramatically from year to year in response to weather. Our present system is based primarily on the seeds of annual crops. Storage of the perishable products from farms is expensive, so the carrying capacity of the system tends to be controlled more by years of minimum production than by average production. It's pretty much a hand to mouth system. If weather fluctuates even more in the future, the carrying capacity of our present food system could decrease. Furthermore, annual crops are not well adapted to most ecosystems, so fertilizers, pesticides and irrigation are required to create a hospitable environment.

Ruttan — Nature abhors agriculture!

Rawlins — I agree! As we look down the road 100 years or more, the inputs needed to provide the environment needed by annual crops will become limiting. The stark fact is, we do not have a food system that can outlive our fossil fuel and fertilizer supplies. Farmers in developed countries use more calories in the form of inputs from fossil reserves than they produce in the form of food.

As an alternative to producing the whole crop in the field, we considered the possibility of using the field only to capture the sunlight energy and store it as carbohydrates or lignocellulose in perennial crops, including trees. These products would be harvested as needed to produce sugar syrup, from which food products would be produced biotechnological off the farm. The raw food products would be stored as a living reserve of standing biomass. The plants could be chosen on the basis of their adaptation to the ecosystem to reduce inputs. Since nearly all of the energy captured could be converted to food, rather than just the seeds, the capacity of the system could be substantially increased over existing systems. A first step would be to convert lignocellulose to animal feed. This alone would release a large amount of land for other purposes. Other products for direct human consumption would follow as the market demanded.

The point I'm making is that in considering environmental and technical constraints to agricultural production in the future we need to consider possible designs for new production systems as well as resource limitations for our current production system. Certainly we would not want to be accused of considering only the dumb food producers scenario.

Ruttan — You've outlined an alternative agriculture that the adherents or promoters of "alternative agriculture" would not embrace.

Rawlins You are probably right.

Ruttan I notice Bill scowling. Do you have a question?

Clark I want to come back to your statement about USDA and its role in the climate change research.

Munson I think you referred to the amounts of energy that are used in agriculture. In the concern about CO_2, energy is the overriding issue. It seems to me if we're really interested in reducing CO_2 emissions, we should spend money on nuclear fusion research rather than on putting a space station up and going to Mars. They're talking about $400 billion to be spent in the 1990s on that effort.

Abrahamson I've followed the fusion program since I was in graduate school and the story has always been that if we spent more money the problem will be solved in five years. It clearly is decades away from realization in any practical sense. We don't have those decades to wait. Fusion is irrelevant to present concerns. It is an interesting research question, but it has nothing to do with choices that are going to have to be made over the next few decades. The other issue is the matter of biomass as an energy crop. That is where agriculture and forestry both meet. We should be looking very seriously in that direction.

Munson And we put half of our corn crop back into the soil. There's a harvest index of roughly 50 percent. So for every bushel you take off there's an equivalent amount of dry matter produced that's going back into the system that could be harvested and used.

Ruttan When Rogoff first mentioned to me over the phone the work you were doing on biomass, my first reaction was "That's really great. We're going to move agricultural production from the temperate regions to the tropics." His reaction was, "Don't tell anybody at USDA!"

Clark I can't resist a challenge to Dean. He and I will have this fight eventually anyway so why put if off. Dean, you can't have it both ways. Fusion may be a silly place to invest for even more reasons than the space station. Or it may not. But if you were to tell me that an affordable investment regime would indeed give me fusion as a successful acceptable affordable energy source 50 years from now, there is no way that I would not go for it.

Abrahamson Don't misunderstand, I don't argue against R&D money going into fusion. I don't argue against that at all. But, it's not available now and it's not going to be available for the next two or three decades when we've got to make some very tough decisions having to do with energy. I like the fusion program. It keeps a lot of bright people from doing mischief.

Allen — Dean, are you saying that resources are not the constraint in speeding up the time frame for fusion?

Abrahamson — At the moment feasibility has yet to be demonstrated -- that is, the machine that produces as much energy as it takes to run it. Even if that were done this afternoon, it would be decades before it became a commercial reality. It violates no physical principles, but who knows when feasibility will be demonstrated. But the amount of R&D money involved is trivial compared with a lot of other things.

Clark — My point is that 50 years out for many of the issues we're talking about is quite a realistic time horizon. The only thing I was objecting to was the cavalier dismissal of fusion because it has a 50-year time horizon.

Rayner — Let's stop the talk about fusion.

Chen — Steve, you mentioned that USDA is getting into the global change program. I would assume that USDA's interest is primarily on the impacts and policies side? Is USDA going to actually jump in with more research?

Rawlins — Our main new thrust is research in support of the CES Global Change Research Program. We will also be involved in impacts assessment and development of response and policy strategies.

Chen — That's my question. I have watched these things for 10 years. The research on inputs and climate tend to suck up all of the money. There's a lot of lip service to the impacts and policy but in the end no one actually does any work.

Bochniarz — I'd like to get into another question. Fusion is an interesting prospect. But what about other alternative sources of energy? It is possible that if we had kept expenditures for solar energy at the level of the middle '70s we would have, in the middle of the '80s, economically viable sources of solar energy. All big companies have completely cut out the research on solar energy.

Rayner — I'm sorry, but at least as far as the United States is concerned, the question of alternative energy technologies isn't anything near as interesting as the issue of energy conservation through efficiency. The current actual United States emissions averaged about 1-1/2 gigatons for 1988. The Edmunds-Reilly base case projection to the year 2020 suggests an increase to something over two gigatons CO_2 emissions for 2020. The best saving that we can predict at the moment with nuclear, solar, and biomass energy, would still bring us down to something just over 1-1/2 gigatons of carbon emissions for 2020. On the other hand, energy efficiency improvements alone would bring about a real cut from our present emissions level by about one-third, and to a halving of the predicted emissions level from the Edmunds Reilly base case.

If we then add the alternative technologies onto that for the year 2020, we can cut down to about a third of the present emissions levels. It's not really until you're getting into the 50-year time scenario that the availability of improved or non-emitting energy technology really is going to have an important impact on U.S. fossil fuel CO_2 emissions. In the United States as far as getting an immediate big bang for the buck is concerned, we should be talking about efficiency, not talking about alternative energy technologies. Now, that situation is quite different for the developing countries.

Allen — Steve, please give me some examples for the high efficiency scenario.

Rayner — Examples include increased efficiency in electric motors, in commercial and domestic applications, improved generating capacity, and improved transmission.

Waggoner — Are all your assumed increases in efficiency, Steve, within the range of present knowledge or technology that is on the shelf?

Rayner — Absolutely. Those are things we can technically do tomorrow.

Crosson — Who is paying attention to the economics of conservation?

Rayner — The economics are a different problem and the situation in the developing countries is different than in the United States. We expect the developing country emissions to exceed those of the United States by about 2000, and we're expecting that on the assumption that developing countries will use a lot of fossil fuels (Figure 2). This is what I wanted to raise with Steve. You were talking about moving to a perennial cropping system based on lignocellulose for food security. One of the things that we've been considering at Oak Ridge is that if you're going to stop developing countries from moving into fossil fuels, what kind of alternative generation technologies can be provided for them? We are not going to realize the same efficiency benefits in developing countries as in the developed world because those benefits rely on an inelasticity of demand for energy services. In developing countries energy demand is very elastic, particularly in China. We've been very interested in looking at the whole issue of biomass for energy in which the biomass is gasified and the gas is run through a high efficiency turbine. Bob Williams of Princeton[2] has made some estimates which show, in fact, that it is a cost effective technology. From the point of view of CO_2 emissions, it has the benefit of closing the fuel cycle because you are fixing the same amount of carbon in fuel as you're producing. Presumably what we would do is woody biomass; things like fast growing sycamores in plantations. It wouldn't appeal to the environmentalists from an aesthetic perspective -- you wouldn't have nice parks and forest out there to feed this energy system.

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[2]To be completed.

And I suspect that if you were using a similar technology for your lignocellulose production, it also would not really be the parks out that would be producing the biomass.

The question is what is the capacity of the agricultural system really to make a transition towards growing these kind of woody biomass crops. Also, what would be the social acceptance of such an approach?

Allen — Vern, I can add an example to support Steve's point. We estimate that at the University of Minnesota we could decrease energy use by about 30 percent with some very simple changes that relate to high efficiency light bulbs, improved efficiency air conditioners, and others.

Rawlins — I suspect the total annual biomass production rate of perennial plants is about the same as good annual crops. But our scenario would convert a larger fraction of it to food than our present system does. The reason biomass energy production requires high biomass production rates per unit area is hauling cost for the raw input product. This, in turn, is related to the economy of scale of the conversion plant. Energy conversion plants need to be large. I don't know how large plants would have to be to convert lignocellulose to sugar syrup, but hopefully they could be smaller, or even portable so that more extensively grown biomass could be harvested.

Abrahamson — You said something to the effect that the economics are another matter, and I don't want to leave that. I've been involved for 15 years, I guess, with these energy analyses, particularly in Sweden, and it's clear that even though the unit price of energy may go up, the cost for energy services can go down. Reduction of emissions in the range you suggested can be accompanied by net savings in total cost of delivered energy service.

Rayner — Absolutely. And you could even reduce the price of the electricity as well. But the economics are more in terms of the rate of capital turnover. It's not so much what is the cost per kilowatt hour delivered.

Abrahamson — Would the user pay less for energy services under the low emissions scenario?

Rayner — Yes.

Sanchez — This lignocellulose scenario is very exciting to me because I work in the tropics. Obviously the place to produce it is in the tropics.

Rayner — And where labor is relatively inexpensive.

Sanchez — In the tropics we can grow biomass in two to three years that would take 40 years to grow in Minnesota. There are clearly some geopolitical implications here. But I want to make an additional point. Oil palm can produce about

five tons of oil per hectare per year. During the Second World War, the French, using a simple filter, used the oil palm as fuel in their diesel engines. However, oil palm use for food is going to decrease because of the cholesterol issue. We should look at these and other similar tropical plants to produce oil directly.

Forest Response to Climate Changes

Ruttan — Let me turn to Margaret Davis. As we were walking to lunch, Margaret commented that there was an unusual amount of complacency around the table. I expect this reflects the fact that in her research she has been looking backwards over very long periods, whereas in our projections we take 50 or 100 years as the long term.

Davis — It might be a function of the lifespan of the organisms I'm working with. The long life span of trees makes their response to climate very different from agricultural crops. Let me summarize what I think will be the response of forest to climate changes in the future.

We have calculated the shifts in geographical range that you might expect to find in the northern hardwood forests of the northern United States, given two different climate scenarios projected by different General Circulation Models (GCM's) for a doubling of atmospheric greenhouse gases (2x CO_2). The shifts of geographical range for the trees we worked with -- sugar maple, yellow birch, hemlock, and beech -- are very large. The northern limit would move northward between 500 and 1000 kilometers, and the western range limit would retreat eastward. If you use GCM output that projects both rising temperature and an increase in rainfall, the range shift is about 500 km northward. There is a slight retreat from the western range limit, because the temperature increases are large enough to create moisture stress for trees. With a GCM scenario that predicts a large temperature increase and a large deficit of soil moisture in the central part of the continent, the range shift is much more extreme: the new potential range hardly overlaps with the old range except far to the east in northern New England and Nova Scotia.

The conclusion to be drawn from this exercise is that changes in forests will be very near species' range limits. What happens in the center of the species' range depends on the degree of ecotypic specialization in the species. The question is, can a beech tree that grows now in Nova Scotia tolerate the climate of George where beech trees grow today? Or are the beech trees that grow in Nova Scotia specifically adapted to the Nova Scotia climate?

This kind of information is in short supply for many tree species. More is known about trees that are planted in commercial plantations: some species have a broad tolerance range and others do not. But for trees that grow in

unmanaged forests, even valuable forest trees such as sugar maple, which grows so abundantly that nobody ever bothers to plant it, there has been very little research on which to base relevant models.

The long life span of trees creates problems for forestry that differ from agriculture. A forester needs a precise prediction of what's going to happen 50 years from now because the turnover time for many forest plantations is about 50 years. Some trees can be cut after 40 years, but the rotation time for others, such as oak, is in the 90-year range. Who can tell a forester the appropriate tree to plant, given that it will not be harvested for 50 to 90 years?

Pessimism has been expressed about the accuracy of the GCM's. It is my impression that most GCM modelers are trying to give us a general idea about the trajectory that climate might take. They might be rather alarmed to see me taking their data so literally and trying to project a range shift. We need to keep in mind, as well, that doubling of CO_2 is not an equilibrium condition, nor even an upper limit. Greenhouse gases will continue to increase until we run out of fossil fuel. Temperature thresholds will be reached eventually, although the predicted timing varies with the particular model. For these reasons, it is more useful to think in terms of rates of change than to project equilibrium conditions with doubled CO_2. Certainly for trees it is more useful, because the effects on trees are different with a slow change than with a fast change. If there is a slow rate of change, then the trees themselves will not experience a climate change during their lifetimes that is large enough to actually kill them in situ.

Historical experience tells us what to expect. During the droughts of the 1930s, hemlock trees growing near their southwestern range limit in Wisconsin died from drought stress. The first year of drought they lost more than 80 percent of their root capacity, and in the second year of drought they died from insect damage. It is surprising, however, how little hard information there is in the literature about direct physiological stress to trees caused by climatic events. Information on growth response is available from tree-ring studies, but there are few documented cases of trees being killed by a climate extreme. This is why we know so little about climatic thresholds for adult trees. Much more information is available about the sensitivity of seedling stages, although even here the information is sketchy for most species. Flowering, fruiting, and seed germination and establishment appear to be most sensitive to climate. For this reason the first effect one would see in a forest would be the failure of reproduction of canopy species and invasion of the stand by new species from outside the forest. We have seen major turnovers of species composition of forests over the last century because of our own activities in logging the forest. In this part of the country, most of the landscape supports early successional tree species such as birch and aspen. To have another major turnover in species composition

of the forest might not be more surprising. I think humans would cope with it.

If, however, the climate changes very rapidly, then the effects on forests will be different. Trees will experience problems in dispersing into new areas where they can grow. The distances are much larger than trees disperse normally over the course of a few decades or even several centuries. Furthermore, the climatic changes could be so large during the lifetime of a single tree that from the standpoint of a forest manager, it becomes a question whether there is any tree species for which the climate is suitable both at the time the tree is planted and at the time the tree matures and is ready for harvest. This would be true even at rates of change less extreme than those quoted by Dr. Abrahamson. A climate change of, say 5°C over the course of 200 or 300 years would exceed the tolerance of an individual tree.

Now, let me turn to the direct effects of CO_2. It is difficult even to speculate about the direct effects of CO_2 on forest ecosystems, considering soil as well as trees. It is much harder to do field experiments with such a complex system. The fossil record indicates that trees lag behind other organisms in their response to climatic change. The lags were due either to limited dispersal of seeds or to slow development of suitable soils. This is so, even though the climatic changes in the past were at least an order of magnitude slower than the changes we are projecting for the coming century. The generalizations I am making about response to a rapid or slow climatic change, which are based on a conceptual model of what might happen, are supported by results in the fossil record, which show trees lagging behind decades or even centuries in their response to climate, relative to other components of the ecological system.

Waggoner Does that mean the tree is surviving into the unsatisfactory climate?

Davis Most of the rapid climatic changes that we know in detail from the fossil record involve rapid warmings. The lag is seen as a failure of the trees to establish when the climate is warm enough for trees according to other aspects of the climate record. The beginning of the present interglacial shows these effects most strikingly. The original explanation was that seed dispersal was the limiting factor. Now soil development is identified as the fact slowing the establishment of forest. Here I think we should be aware of the fact that the CO_2 concentration in the atmosphere was lower than at present, although rising steeply. There is also evidence for lags in tree establishment later, around 10,000 years ago, when CO_2 was near the preindustrial level. In northern Europe there was a rapid, 1000-year long-cool interval between 11,000 and 10,000 years ago. During this interval subarctic forest was replaced, without a lag, by tundra vegetation. The absence of a lag suggests that trees were killed outright by the change, which must have exceeded a critical threshold for trees.

Waggoner What was on the ground? Something must have been there.

Davis In north America, spruce was replaced by temperate trees 10,000 years ago. These systems have not been studied in enough detail to learn what was competing with the spruce, and whether the trees were dying in situ, being destroyed by fires, or whether they were being replaced gradually through a process akin to biological succession. Past rapid climate changes were often accompanied by natural disturbances that speeded up the response of vegetation. In a model you can show that the lag in response of a forest community to a rapid warming or a rapid cooling might last about a century. But if you simulate disturbances, the resident trees are removed from the simulation and the change occurs much more rapidly.

Waggoner From your knowledge, could you predict what might happen here in Minnesota? Would you get the present trees persisting well into the latter part of the next century while populations of other trees slowly expanded? Would there be a forest or would there be no forest for a while?

Davis It depends on how rapidly the climate changes and what the threshold is to actually kill a tree. Without that knowledge, I couldn't even apply a model to simulate what would happen. If there is a slow climate change, a tree can continue to occupy territory, while its seedlings fail to persist and seedlings of more southern species get established underneath the canopy, assuming that the seeds are available. An alternative scenario is that disturbances (storms or fires) take care of the problem. There is evidence in the fossil record that disturbance rates are very closely tied to climate. So we might expect to see disturbance rates changing. Here in the Midwest you might expect to see a disturbance regime dominated by either wind storms or fire.

Crosson Does anyone know even roughly what percentage of the world's forests today are managed from the standpoint of the economic gain. I'm setting aside deforestation, which is not forest management, but rather cutting of trees in order to do something else. I'm asking about managing the forest in order to maximize the economic gains. Do we know anything about that? Would you guess it to be large or small like 10 percent or 80 percent?

Davis In North America I would think the percentage would be small. In other parts of the world, certainly in Europe, the figure would be quite high.

Crosson The reason I ask is that if people who are interested in managing forests come to accept the implications of climate change for forestry that you have outlined, it seems to me that it would give managers an incentive to start to increase the cutting of old growth and to replace it with shorter, faster growing varieties. It would increase the economic premium on shorter-life species. If a shift of that sort occurred, this could actually improve the CO_2 problem because these faster growing new trees are absorbing CO_2.

Rawlins Depending on what you do with the old growth.

Davis That's right. And replacing the old trees might affect the fertility of the site. Release of CO_2 from the forest floor could be larger than absorption of CO_2 by new regrowth.

The scenario you describe might occur as soon as property owners perceived that the trees were not putting on wood rapidly. They would log the forests and replace them with a different forest species. The question is, what species should they replace them with? And I suppose they would be looking for species that have broad adaptability, like aspen, which grows everywhere. An early successional species such as aspen has well-dispersed seed, as well.

Clark I think it's useful to point out in the trees discussion that a lot of what Margaret says, if I've learned my lesson right, is going to apply primarily to mid-latitude forests. In the tropical forest case, we expect the rates of climate change to be slower and the rate of forest growth to be faster. There would be at least some a priori reason for saying that the impact might be less drastic.

Davis I should agree. But the land use impact might be larger.

Clark Right. And the point I wanted to get to is that one has got to start differentiating places in order to figure out, if one' concern is forests, whether the direct effects of land use transformation such as arable expansion and rangeland expansion, or the second order effects of climate change are going to dominate. Those balances would be radically different depending on which century you took and depending on whether you took northern forests or southern forests. Even for the tropical forests there is some basis for expecting that, should the climate equilibrate, you might not have an increase in the extent of tropical forests, even deducting the amount removed for land use clearing because of the wider climatic zones created. In contrast in the northern ranges, a modest increase of land in agriculture might really put some squeezes on the boreal forests and some of the northern temperate forests.

Davis I agree with what you're saying. You can't discuss it without a time frame. Vast areas of tundra might become climatrically suitable for forests. Whether the substrate would be such that trees could grow is another matter. And whether the trees could establish themselves rapidly over such vast areas is another matter, too.

Sanchez One hears a lot in the press about planting trees to offset the greenhouse effect. Is it correct that we may need to plant an area equal to France or something in that order to offset the CO_2 effects?

Rayner Yes, every year.

Davis In many parts of the world, we're cutting more rapidly than foresters are replanting. Even if we replanted to keep up with the amount we're cutting, I think that would be an improvement. But as Pierre Crosson was pointing out, the incentive to cut and replace would become large if the trees are perceived to be growing slowly because of maladaptation to changed climate. That means many forests would be harvested. The probability that people would continue to cut faster than they would replant would be quite serious unless it is countered by replanting for the purpose of restoring carbon balance.

Rosenberg A France each year might not be enough. Roger Sedjo at RFF did some calculations (Sedjo and Solomon 1989). There are three gigatons of carbon remaining in the atmosphere or incrementing into the atmosphere each year. He calculated how much new plantation would be required to extract that three gigatons of carbon annually. Using fairly conservative annual growth accumulations, something like three-tenths of a kilogram of carbon per square meter per annum, an area about two-thirds the size of the United States would have to be planted to fast-growing trees. And if you could plant all of that at once, it would work for about 40 years. For 40 years you would take out three gigatons a year, but then your trees will stop extracting carbon. They will reach their maturity, and you have to cut the trees and replant.

Waggoner And you have to store the carbon.

Rawlins Or replace fossil fuel.

Clark But there is also recent really disturbing new data out concerning the carbon that has been assumed to be going into the oceans. It doesn't seem to be in the oceans. It seems to be tied up in biosphere. So I think that a lot of bets are off right now regarding what fiddling around with the planet's forest cover and soil will do with this carbon cycle balancing. And at least the folks I talk to right now say that we know less than we thought we knew a year ago.

Rosenberg Okay. But no more, or not much more than three gigatons is accumulating in the atmosphere. If I understand Bill correctly, he is saying that the terrestrial biosphere has probably been soaking up even more carbon than we thought over the years because the oceans apparently have been soaking up less. I think there's a misapprehension that the rate of CO_2 accumulation in the atmosphere is increasing. It did for a couple of years around the last big El Niño event. But it's now down to about the same rate as it has been over the last decade or so.

Abrahamson Between one and two million square kilometers per year of new forest will take out a gigaton a year.

Rayner Is that for normal commercial forest or for high intensity biomass?

Abrahamson That's normal commercial forest. And, of course, as you say, that is on average until it reaches its 40 years or whatever it is before it reaches maturity. But there's something a little disturbing in that. Perhaps some of you know why the CO_2 concentrations in the atmosphere did not respond appropriately to the reductions in fossil fuel use that took place in the late 1970's and continued into the 1980's. Either the sink is being poisoned or there's a source that's not been taken into account. And that source may be increased rate of respiration with the temperature.

Rosenberg I don't know how much you want to explore the carbon cycle, but the one other very interesting item of data bearing on this argument is that the amplitude of the annual carbon dioxide cycle at Mauna Loa has been increasing. This is reasonably well established. There are a number of explanations or contributory mechanisms, but one that cannot be ruled out is an increase in biomass in the temperate regions. This doesn't mean that the tropics are not being deforested, but the tropics exert little control over the annual Northern Hemisphere cycles of photosynthesis and respiration. In the tropics photosynthetic activity varies very little with season. But in the temperate zones, of course, we have the large annual amplitude that gets larger in the high latitudes. This increase in the amplitude of the CO_2 concentration wave must signal an increasing terrestrial biomass -- more photosynthesis, more respiration -- occurring outside of the tropics. This fact, together with some of the other things we've been hearing, tends to suggest that the CO_2 fertilization effect, even though we can't prove it and we can't measure it directly, is, indeed, occurring.

Davis I would emphasize again that in considering forest responses, the rate of change is much more important than how much change would occur at doubling or tripling CO_2. The same kind of reasoning applies to looking at agricultural responses. It's really how fast these changes occur that affect how well we can adapt to them. It seemed to me in looking at forest responses, that even given the uncertainties of the GCM's and the uncertainty about what's going to happen to CO_2 in the atmosphere, there's a lot to be learned by looking at a rapid rate of change and seeing what that would do, and looking at a slow rate of change and seeing what that would do and coming out with some alternative scenarios. I wonder if this is not also a useful way to approach the agricultural scene.

Waggoner I just want to go back to a point that I tried to make and I didn't make very well, I guess, and that is that there's nothing wrong with cutting trees so far as carbon dioxide is concerned, and nothing right about planting trees itself. The important thing is to have rapidly growing forest rather than stagnant mature ones or bare ground. That thing seems to drop out of sight every once in a while. It isn't how many acres we plant, it's how many acres we

have growing rapidly. The second issue is what we do with the wood after it's produced that matters.

Clark — Paul, wait a minute, if you take a hectare of mature forest and cut it down and burn it up, you've just lost a hectare worth of carbon into the atmosphere. Replacing that with trees growing really fast to simply recapture the carbon you just released, doesn't gain you very much.

Waggoner — If you burn those trees and replace fossil fuel, or if you take those trees and build a house, you probably have gained. That's what I want you to understand. Be sure you don't just think that cutting trees is bad or planting them is good. Think through the whole thing. What you want is a rapidly growing forest. And what you want to do is either burn the product to replace fossil fuel or build a house. That's the whole story.

Rosenberg — Just one more point to round out the argument. You also have to think in terms of afforesting areas that are out of forest now. Badlands in many portions of the world, particularly the tropics, may be hospitable to trees. So there appears to be many thousands of hectares into which trees might be planted. This could only be a net benefit in terms of stabilizing CO_2 levels. Afforestation, if promptly initiated, could have some impact in controlling CO_2 accumulation in the atmosphere -- even within the next 20 years.

Waggoner — If they grow rapidly.

Rayner — You would want them to feed the food technology that Steve Rawlins was talking about or to feed the kind of biomass program that is appropriate for the developing countries that I was talking about.

Stipulations, Conventional Wisdom, and Real Issues

Ruttan — We will now turn to Paul, who's been giving thought for a number of years to the issue of impact on global climate change on agriculture.

Waggoner — First, I will make some statements about climate change that I believe deserve to be promoted from hypotheses to stipulation. And then I'll mention some conventional wisdom about climate change that I believe merits demotion to hypotheses. And finally, I want to talk about some issues that I think hang over the whole matter of climate change and agriculture. Stipulations, of course, are the agreements between attorneys before a trial starts that they make in order to get the things that everyone agrees on out of the way.

My first suggestion for a stipulation is both a cooler climate and a warmer climate with the same water resources is unlikely. This allows us to

concentrate on three future situations for any locality; (a) same climate, same water; (b) warmer climate, less water; (c) warmer climate, more water. Now, that doesn't seem like much of an advance given all the calculations that have been made over the past 10 years. But when you think about it, we have eliminated from this list of three, something that preoccupied us tremendously back in the days of the supersonic transport; namely, the possibility of a cooler climate. And I must say that I recently presented these three alternatives, and a contrarian immediately contradicted me. But I think that we could stipulate those as the three possibilities.

The second stipulation I would suggest is that a progressive two centigrade warming and 10 percent drying or wetting during a half century represent reasonable scenarios. Now, a scenario isn't a forecast. It's merely a plausible view of the future that is at least internally consistent.

My third stipulation is that reliable probabilities for these three futures will be slow in coming -- leaving us uncertain for a long time.

In the AAAS study that Norm and I participated in, we made up a table of climate change projections. In the last column is "estimated time for research that leads to consensus." For global temperature it was 5 years. I'm sure Steve Schneider would now lengthen that. For almost everything else, it was 10 to 50 years. The recent halving of the calculated warming by the British modelers was due to some changes of cloud parameters. This has thrown everything into such uncertainty that even 10 to 50 years is probably optimistic. So I've stipulated that reliable probabilities about these three scenarios are going to be a long time coming.

My fourth stipulation is that the hardest blow from climate change on human affairs will be due to changes in water resources. From the Northwestern hills to the shore of my little state of Connecticut, there is a three centigrade degree difference in average temperature. And that doesn't really matter very much. But, they grow lettuce in the desert in California and in the suburbs of Boston, and those are quite different temperatures. It doesn't really matter. But if there's a difference in water, it makes a whale of a difference. Precipitation is the climatic hammer that's going to strike human affairs if climate changes.

Compared to the global scope of climate change, changes in water resources are fairly local. Local actions will be possible, even profitable. There are 21 water resource regions in the U.S. You can act on a regional basis, but even in little Connecticut there are towns that run out of water every time it doesn't rain for two or three weeks. There are other towns that think it's just great -- they can sell water. Localities can do something about water resources, although I can't think of much they can do about climate change.

The diversity of climates where plants, animals and men survive and even prosper, indicates that we can adapt to change in climate given time. I'll go back to my lettuce example. Of course, you can grow lettuce in Boston and you can grow it in suburbs of San Diego. But it took a while to put the infrastructure in place to make it possible and profitable.

The fifth stipulation is that we can adapt to water resource differences, but it takes time. There are parts of the New York City water system in use today that are over a century old. I don't know how long TVA was in conceptualization or preconstruction, but probably it was something like 20 years. Then it took another 20 years to complete the system.

My sixth stipulation is that extremes of frost and drought have more impact on affairs than averages. The amplitude and timing of annual cycles of temperature, moisture and runoff have more severe consequences than differences of annual total precipitation or average temperature. Amenities like recreations, scenery and wildlife, and especially anxiety about health, compete with surprising strength against bread and butter issues. I'm accustomed to limitations on fertilizers and pesticides. Nevertheless I was surprised to hear from a Russian last winter that environmental concerns in Russia were quite capable of stopping development long before they ever had Peristroika. It's really remarkable that in a country like that an environmental issue can stop a large development project. And wonder of wonders, I think the most extraordinary thing I read this week is that the environmentalists have presumed to stop the Israeli Air Force from using a piece of the desert for bombing practice. Now, if that doesn't show the strength of environmental issues, I don't know what could. It's good, but it also justifies a statement that I heard by a person who said he feared more irresponsible acts to prevent climate change than he feared climate change.

My seventh and last stipulation is that an act, in the end, always costs. Think of policy actions as investments -- I have a favorite question that I like to ask. How would you invest your own money to make 10 percent or more per year on your insider's knowledge about climate change?

Well, now, those are some things I would like elevated to stipulations. Now what about conventional wisdom that I think might be reduced to hypotheses? These, like my stipulations, are questions for research. One piece of conventional wisdom is that waiting will only drive up costs. That is true, only if you don't have to pay any interest and if we have dumb farmers. Otherwise it may not be true.

"There are only losers from climate change" is a second bit of conventional wisdom. I don't need to talk about that. We've agreed that piece of conventional wisdom won't stand up.

A third conventional generalization is that the anticipated changes are unprecedented. In fact, during a recent 30 years, the range of annual precipitation in my temperate state of Connecticut was 28 percent below to 38 above the mean. And during the most recent 30 years, annual precipitation fell 29 to 39 percent below the mean in Bozeman, Montana; Columbia, Missouri; Pennsicola, Florida; Rockville, Indiana; and Forks, Washington, which has over a hundred inches a year. It fell 74 to 87 percent below in Childs, Arizona and Indio, California. So changes far greater than the commonly specified 10 percent are regularly encountered. The evidence is not at all clear that the effect of greenhouse warming will be the increase of climatic variability.

A fourth bit of conventional wisdom is that cutting forests always increases the CO_2 in the air. But mature forests fix no net CO_2. Therefore, cutting for lumber or firewood and replacing with a rapidly growing stand or crop will reduce CO_2 concentration. But when it is harvested for lumber or firewood, it will again release CO_2 into the atmosphere.

A fifth bit of conventional wisdom that I have encountered very often is that genetic engineering will save us. It is premature to begin to design crops for anticipated environments. The logical procedure is to continually adapt crops to the climate as it evolves. Depriving conventional agronomy of research support to feed anticipatory research, and betting all our chips on an uncertain future, doesn't seem to be smart to me.

A final conventional generalization is that the poor will suffer most. The proposals for stopping the possible warming may prove costly to the poor. Some very explicit and careful calculation or analysis needs to be made before we accept that statement.

Now, let me turn to some issues that hang over the whole matter of climate change.

The first one is "why have we failed to implement so many well-known and seemingly sensible suggestions?" These include energy efficiency, water efficiency and a very long list of others. Let me read a statement from Helen Ingram, "Just as surely as solutions are sought for problems, solutions go shopping for problems. When an emerging problem lends additional credibility to an already developed policy proposal, the proposal is likely to be attached to the problem." The climate change issue, of course, is attracting all sorts of well-known solutions. It might be helpful to ask why they haven't been implemented. If there are good reasons then let's not fill up our reports with them.

One thing that will increase the possibility of a sustainable agriculture is investment in monitoring and research. We'll surely say to do that. One criterion for investment is the net utility of an investment relative to the

effectiveness of the remedy. But devoting more money to research without any impact on the problem will decrease net utility. Increasing the utility of research is important for agriculture, and it is absolutely crucial for the good name of research.

There are some very severe obstacles to interdisciplinary research. Research in separate disciplines is not wasted, but I don't think it gets directly at solutions. Patrons who want to get results from research on climate change would do well to reward rather than discourage interdisciplinary research.

How does a thoughtful individual factor in climate change? Groups like ours always recommend that the water system managers of American or the seed corn producers of American need to consider the implications of climate change. Well, imagine them trying to do that. What would he or she do? One frequent response is to build in margins of safety. It doesn't take many brains to do that but it does cost money. A real contribution would be to say exactly how to factor in climate change. "If numerous unmanageable alternatives get dumped into the deliberations, participants may decide the subject is too complex, the problems too numerous, and the alternatives too overwhelming and turn to more manageable issues." So I think there is a good tactical reason for us to learn to sort these proposals and get rid of some of them.

A way around the hard job of sorting these things, of course, is to find three or four that are so important that we don't have to think about anything else. The important impacts of climate change are ones that have a highly elastic response -- in the sense that elasticity is used in economics. John Shaake has found, for example, that the elasticity of water supply for a change of precipitation on the east coast of the U.S. is about 2. It rises to 4 and even more in western Texas.

Ruttan What does that mean?

Waggoner That means that if you get a 10 percent change in precipitation in Georgia, you get a 20 percent change in runoff; if you get a 10 percent change of precipitation in Texas, you get a 40 percent change in runoff. So if you have a very high elasticity like this then you're on to something very important in climate change. It's worth concentrating on. The other thing is that the system is very non-linear. Moist weather makes corn grow until a fungus intervenes, and then the plant dies. Cool weather may be good for a crop until it goes below 32, then the crop is killed.

This is what makes the changes in the extremes so important, say the probability of drought (Waggoner 1989) below a certain amount of precipitation. That has a very high elasticity. If the mean changes by, for example 10 percent, the probability of drought in the extreme may change by 40 percent.

Gary Yohe (1990), whom some of you know, has shown how to make good use of these non-linearities or thresholds. Consider the issue of flooding over a levee. The sea level isn't important in itself, therefore, you concentrate on the time when the sea goes over the top of the dam or the levee. So instead of a frequency distribution of sea level depth in let's say 2020, you concentrate on a frequency distribution of the time when the sea goes over the wall. Thinking in that way, you incorporate things about rate, you incorporate things about non-linearity, and I think it is an advance in knowledge for which Yohe is to be praised.

Well, this ends my statement of the stipulations and the convention wisdom as well as my list of these great issues that I think hang over everything.

Ruttan Thanks, there must be a few people who will disagree with you.

Davis Concerning conventional wisdom -- you were challenging the idea that the changes will be unprecedented. And you're challenging them by giving the range of variance. Shouldn't you assume that if the mean annual climate gets warmer, the variance envelope around the mean would stay the same?

Waggoner No, all I meant, Margaret, was that we often encounter changes bigger than the ones that we envision for climate change. Then when we make statements to the effect that we've never seen anything like this before, it discredits the effort.

Davis I don't think it's irrelevant, though, because a severe drought that persists for two years has a much greater effect than if it only persists for one. The frequency of drought years becomes critical for forest systems and, I should think, for economic systems as well. I don't think that we have in our lifetimes experienced climates such as we're visualizing. We have in the geological past. But the natural vegetation in the past contained really very different distributions of species. During the last interglacial, for instance, sea levels and CO_2 concentrations suggest that the climate was warmer than today's. This suggests that we may see really major changes in the natural vegetation given a mean temperature which is higher than what we now experience. I don't think that range of annual variability really suggests that we've seen these things before. I think that range of annual variability fits better with your statement that it is the extremes that are what are important. I certainly agree with that.

Abrahamson Of your stipulations the one I don't much like is the second one; that is, the two degree warming and 10 percent degree in precipitation in 50 years. You have to be awful optimistic. We'll have to be lucky on the scientific end, on the uncertainty of the science, and we will have to be pretty vigorous in terms of our policy response to decrease emissions. Both of those things would have to happen. It's possible but highly unlikely.

Waggoner I said it was a reasonable scenario. But, in fact, my stipulation was that we're not going to know what it is for a long time. Within the possibilities I think it is a reasonable scenario to think about.

Abrahamson I would at least double the assumption about the equilibrium warming to which we are committed.

Clark That's a little high then for the presently published consensual median estimates. But it's close enough.

Chen Can I make one response to Margaret? Jesse Ausubel's point on whether or not this is precedent or unprecedented, was based partly on the CLIMPAX (Climate Impacts, Perception, and Adjustment Experiment) work (Karl and Riebsame 1984), a research project sponsored by NSF, which did at least look back at the historical record and look for large regions to see whether there would have been significant climate changes that had persisted for some length of time. There were examples from the midwest, I forget which states, where there had been as much as a two-degree change in the mean from one decade to the next. And people didn't seem to notice the difference.

Rosenberg I'm sure they noticed the difference.

Chen No, they really didn't. There was nothing in the popular press. There were no expressions of concern about it being warmer this decade than the last.

Rosenberg The really big difference was between the decade of the 1930s and 1940s. And people surely noticed that difference. But CLIMPAX did identify limited areas in which other, less dramatic decadal anomalies in temperature and rainfall occurred. It may be that these weren't large enough changes to cause major impacts on society. They may be why they didn't notice.

Clark I think a way to sort out a lot of the confusion is to note that it is not the rate of change, per se, that's unprecedented -- it is the combination of a high rate of change sustained over a long period. If you plot the paleo records of the last 160,000 years, or paleo records of the last several million years, the combination of rates and durations, you get a red spectrum, which is the standard distribution of climate type noise, showing that the biggest total fluctuations come from very slow, very long duration events. You get a lot of very large changes that only persist a very short time like noon to midnight up at the other end of the spectrum. What is interesting about the climate change from greenhouse scenarios is that the sort of changes forecast up to the present have a fair amount of precedent in the historical record. But if modest rates of change are continued for another 30 or 40 years into the future, much less accelerated, you just get into an area of the rate/duration space where there are no historical observations. So once again, the

statement that it's unprecedented without specifying spatial scale and combination of rates and durations, is a non-argument simply because you're not specifying enough of the dimension to have it something that data could refute.

Waggoner That's exactly right. You have made my point better than I did. I think another useful concept is Yohe's idea of looking at the time when the threshold has passed. One more piece of conventional wisdom -- that should be reduced to hypothesis is that we will know the impact of a future climate on the agriculture by making calculations using present crop varieties. That's the dumb plant breeder's assumption. It should be eliminated from the conventional wisdom.

Abrahamson I just had a question for you and also for you and also for the group. When you said variability will increase, do you mean interannual variability in weather events?

Waggoner We haven't calculated that. We don't know that.

Abrahamson That's my impression. There's no evidence either way.

Waggoner And yet people will say variability will go up, but there's no basis for that statement.

Agricultural Impacts on Climate Change

Ruttan I want to ask Bill Clark about one thing that seems to be falling through the cracks. We have talked quite a bit about the implications of environmental change, both global and local on agriculture. But we haven't put on the table yet very much about agriculture's contribution to either the global or the more location specific environmental problems. Bill has been heading up a committee that is specifically charged with looking at some of those impacts.

Clark Fair enough. I had 32 seconds warning on that one. Vern is referring to a committee of which Margaret Davis is also a member. The National Academy of Science is trying to outline a research plan for the U.S. Global Change Program. A group composed of natural scientists, plus a few of us who once were natural scientists, went through an exercise in which we tried to focus on the intersections between the classic disciplinary areas of research. The climatologists can define what climatologists want to do. Even the ecologists could almost define what ecologists want to do. But the difficulties in research planning have always been at the interfaces. What do the climatologists need from the ecologists to get on with their work? Research that the ecologists might well not do as part of their own internally

driven agenda turns out to be essential for getting on with the climatology or the atmospheric chemistry.

As part of that exercise, one of the questions asked was what do all the science disciplines, climatology, earth system chemistry, ecosystem dynamics, and so on, need to know in terms of the human forcing functions that are pushing perturbations in the global geosphere/biosphere system. As you might expect, they identified a whole set of issues that had to do with industrial and energy emissions, which are not primarily our concern here. But their second big class of categories was things that result from land use change in general and agricultural activity in particular. And I guess what you're asking is that I just run down, as best as I can recall it, what our answers were. There will be a couple of categories. The most obvious is which land use change activities are resulting in emissions of chemicals, primarily gases, that contribute to changes in climate and/or changes in tropospheric chemistry. (Those being two of the dominant global linkages now on the research agenda on global environmental change, which as noted earlier, was heavily dominated by atmospheric chemistry and climatology.)

The first thing one does is to identify the set of greenhouse gases and ask which of those are mediated by land use transformation activities (Figure 3). Carbon dioxide, one of the major greenhouse gases, is certainly affected by land use changes, primarily through direct forest clearing; that is, clearing of high biomass standing stock, the combustion of that material, its release to the atmosphere, the plowing of soils and the oxidation of those soils resulting in the release of carbon dioxide.

A second is methane coming out of agricultural activities in two routes. One of them is anaerobic production within ruminants, the so-called cow fart factor. When I was an undergraduate, I thought it was an interesting choice of words -- the most interesting human contribution to the planet's atmospheric chemistry. And indeed there is an interesting amount. It turns out not to be a big number relative to other numbers in the accounts, but it's certainly been rising of late. There are more ruminants around than there were 150 years ago.

Almost certainly a large agriculturally-related source is any land area that is wet enough for the anaerobic route gives you CH_4 instead of CO_2. This clearly happens in rice cultivation, and in other wetland-like operations. It also happens in seasonally flooded areas and in very damp soils. One of the great difficulties is that the carbon evolution can switch between an aerobic and an anaerobic pathway very rapidly. It means that the emissions patterns are extremely spotty. You can be getting methane out of a system one day and be getting CO_2 out the next day. So it's a very difficult thing to sample or to understand the sources. But it's equally clear that increases in irrigated areas lead to increases in methane evolution unless those systems are simply replacing natural wetlands.

As far as anyone can tell, there is no ozone source out of agriculture except from internal combustion engines. Nitrous oxides, which are a significant greenhouse gas in that they have extremely long life times, come out with great high uncertainties at about 50 percent from fossil fuel combustion and other industrial combustion processes. The other 50 percent comes from biomass burning, soil fertilization, cultivation of natural soils resulting in some rather bizarre chemical pathways that involve N_20. The difficulty is that these numbers are not well known. N_20 has been a very difficult gas to sample. It is well distributed because it has a very low atmospheric lifetime, but it is difficult to detect at the extremely low levels that exist in the troposphere. Only very recently have sufficiently robust sampling technologies been put in place to begin to get a clear picture. But nitrous oxide is certainly going up. The numbers you will see around in most literature are now somewhat suspect because the portion attributed to fossil fuel burning is in doubt. But over the long run those nitrous oxide sources are something that people wonder a lot about in terms of where they're coming from.

That said, the second class of major chemical issues are those that result primarily from biomass burning such as slash and burn or burning the waste materials in a cropland or a forestland after clearing or harvest. These emit a complex set of gases. Some of them I've already mentioned, but some of them are much more complicated -- low molecular weight hydrocarbons, aerosols, small particles, soot particles and the like. There is a fair amount of sulfur in it. You may have seen the recent public reports that some fairly significant acid deposition damages were being measured in what used to be called the Ivory Coast of Africa, far away from any plausible sets of industrial sources. They were apparently traced back to quite extensive burning of vegetation. A combination of the moisture conditions and the sulfur content of vegetation were quite capable of giving you sulfur aerosol rain downwind from it. The point is that sulfur deposition has been appearing in places that nobody was expecting.

Other effects of this very complex chemistry of incomplete biomass combustion have been a whole set of photochemical smog-like phenomenon. This is occurring even in remote areas. You get some very bizarre air chemistry that can stress all sorts of things. There may be impacts on vegetation and conceivably eventually impacts on human health. The next major category is the water budgets of the earth; that is, the land-atmosphere fluxing of water, turns out to be very strongly mediated by the vegetation cover. This has been one of the areas left out of the first generation of global climate models. The radical differences in the ability of the vegetation surface to pipe water from the ground into the atmosphere between bare land, a smooth field and a forest or brushland has been getting a lot more attention and is now being parameterized into the next generation of global climate models. So there's a lot of research now going on in that area that

builds on a long tradition of agrometeorology studies, but have not until recently received much attention to scaling them up to say scales of tens and hundreds of kilometers. Finally, I guess I merged into the last issue -- the surface properties themselves. Obviously land use transformation changes surface properties as they affect the fluxes of water. They also affect the incoming solar radiation budget -- different degrees of reflectivity and different degrees of wind scouring.

The natural science communities have been asking what can you tell us about plausible internally consistent patterns or scenarios of land use transformation as they affect these various transfer agents, chemicals, physical balances, and so on, over the next 50 to 100 years. They're not looking for predictions. They're looking for sets of plausible reference scenarios. What would agriculture look like in terms of its methane emissions, N_20 emissions, surface cover changes and the like. What would radical alternative patterns of agriculture, these appropriate technology or sustainable versions or whatever, look like in terms of those transfer parameters.

Now, that is the agenda that is being pushed. The missing agendas tend to be the ones that are not directly atmosphere and climate related. They have direct implications for the diversity issues I spoke of earlier and for the fluxes of materials and chemicals into the water system. They are acknowledged, in passing, in terms of the phosphorous budget and its involvement especially with carbon sequestering in the deep ocean. How much carbon and how much phosphorous is being flushed down the major world river systems? But they are very much second tier concerns at the moment in the global change program.

As far as our committee's work, we have simply bowed to a lack of demand pull and relegated those waterborne and direct biotic effects to relatively back-burner status simply to get the atmospheric chemistry and surface properties questions answered first.

Allen — I wanted to ask Bill two questions. One that I didn't hear you mention was the role of termites in methane production and whether there is, in fact, a large unaccounted portion of methane generation. The second was a recent article in Science on the contribution of savannah burning to the carbon dioxide budget of the earth. They were both put forward as very significant sources.

Clark — The contribution of savannah burning to the carbon dioxide budget doesn't make sense to me.

Rosenberg — The paper, as I recall, indicated the burning as contributing to smoke and haze.

Allen — Smoke and haze rather than CO_2?

Clark — If you're trying to watch short-scale carbon fluxes, it does matter. And for a whole range of these tropospheric chemistry issues, it matters tremendously. But not the long-term CO_2 budget vis-a-vis climate change.

There is no question that most but not quite all termites and a whole bunch of other creatures do produce methane in their guts. They're doing anaerobic fermentation. They don't have much choice in the matter. There was several years back one of these elegant little exercises where, having measured the evolution of methane from one cubic centimeter of termite land, you then try to figure out the scaling factor of how many such cubic centimeters were there in the universe. There's an error term in that estimation. Depending on which ends of the possible range you pick, you can turn the world into a methane planet or it becomes an insignificant source. The present view is that the methane budget is unbalanced. The atmosphere isn't getting rid of as much of it as it should be. Something is happening at land surface that isn't the termites. The termites are in there as a source term of unknown size. Most recently, some very elegant isotopic analyses have suggested that a larger fraction of the methane is of fossil fuel origin; that is, coal mine surfaces, incomplete combustion, a whole bunch of things. Very old carbon is now being combusted incompletely or there is more methane leakage from old carbon than had been thought to be the case. The atmosphere people said that couldn't possibly be true. But I think right now almost anyone who knows anything about the methane issue can give you a good argument about why it goes one way or another.

In the December issue of Biogeochemical Cycles,[3] Ralph Cicerone has done an absolutely gorgeous review of the topic from the view of laying out the constraints on the global methane budget -- what we know about the isotopic measurements, the known sources, and the known sinks. Instead of taking a central estimate and putting an error term on it, he comes in from the outside and asks what is the space within which the right number has to fall. It's a very clearly and systematically written piece, now somewhat superseded by some of the new isotope analyses, but the structure holds up quite nicely.

Rawlins — Has dust from wind erosion been considered a contribution from agriculture?

Clark — It comes up any time you ask the question of mediators of mesoscale climate over periods of months or years. We clearly get transcontinental movements of significant quantities of dust. I don't think the Reid Bryson notion that there was sufficient mobilization of such dusts or dust-like aerosols to significantly increase the reflectivity of the atmosphere, that is increase the albedo and not let as much sunlight in as expected thus pushing us in a

[3]To be completed.

cooling direction, has borne out. It's not that it couldn't do it, it's just that the masses involved simply aren't there.

But I should say that the whole aerosols and dust issue, as many would say, has been given very short shift in the global and continental scale atmospheric chemistry arguments. If we were around this table in Germany or the Soviet Union right now instead of in the United States, there would be a lot more discussion about this and a lot more argument that a significant fraction of some of the tropospheric chemistry and event the mesoscale climate effects we're seeing are due to such things.

Rawlins Where do you see the research priorities in agriculture? Where do you see the important gaps that need to be filled?

Clark One of the things that the committee has come out with is to say that we face a very odd situation in our ability to talk about internally consistent long-term scenarios of human activity on the planet. The demographers are perfectly willing to give you hundred year scenarios. The energy people are perfectly willing to give you hundred year scenarios. And despite the excesses on either side, I think most people in the environment and development debate would argue that that's a good thing. Both of those fields have matured sufficiently that there is good critical peer review. One can make a distinction between sloppy work and solid work without falling into the trap of believing the numbers. The odd thing is when you come to agricultural change in particular and land use change in general, the long term studies go out to 2000 or 2010. Most of them are static, for example, an FAO carrying capacity study. It has been virtually impossible to stimulate work on the principal driving forces in large scale persistent land transformation that would show up over scales of hundreds of kilometers and tens of decades. I'm not concerned about the high frequency back and forth this year and that between grazing land and cropland, but the larger more persistent changes. What are the varying roles of demographics, or prices, of demand, and so forth? What, if anything, can we say about the constraints and the determinates under which these patterns emerge, especially as they relate to some of the land use transformations that have shown to be most important for the chemistry and climatology issues I've been discussing.

We need to challenge the agricultural economics community, because nobody else seems even remotely placed to do the work. You must have people who are dealing with long-term processes, the kind of thing Vern talks about, long-term technical substitutions, and long-term demographic transitions and what they mean for these land use issues. Try to challenge them by doing the first cut, first draft global model of land use changes for five or ten decades into the future. The nice thing about that is that, of course, that the model isn't the objective. Identify a dozen or so key processes that are the determinates of transformation and explore those using historical and cross sectional data to begin to get a debate going on the decade-to-decade

changes. That's where real research gets done. It's an area in which all sorts of both cross sectional and historical studies have shown good work can happen but hasn't been done. Try to integrate that work then with changes in major cropping zones. That is the kind of task that I think would bring the agricultural development community and the global change natural science community together. It would give them one place of common contact which I think would be very good.

Rayner — As far as identifying the important processes in long-term land use change, my own institution at Oak Ridge National Lab is just starting a three-year program of research in that area. We would welcome any suggestions or inputs.

Rosenberg — If you take the relative size of RFF and the relative size of Oak Ridge, the effort that we are beginning is about on the same scale. We've agreed to do a one-year survey with support from the Japanese Institute for Energy Economics on emissions of non-CO_2 biogenic greenhouse gases (CH_4 and N_20). To do this we will judge the validity of current estimates of land use change. The validity of methane and nitrous oxide flux measurements will also be assessed. We have not yet really started, but we're gearing up now to do it.

Allen — You didn't mention ammonium relative to animal units and the use of anhydrous ammonia as a fertilizer. Are these significant to global climate?

Clark — It isn't a climatically active gas at all. It has a very short atmospheric resident time -- a matter of days. Its transport distances as ammonium are not sufficient to get it involved in global change research. Now, at mesoscale, obviously there are places where it gets quite involved with nitrogen oxide or nitrogen acid deposition patterns through various chemical pathways.

Rayner — It's also important with respect to fertilizer manufacture. One-third of all of the energy use in the U.S. agriculture is in ammonia manufacture. In addition to the energy use in the manufacture you also have natural gas. The carbon from that usually is in some kind of urea form. When that is subsequently released it contributes to atmospheric carbon.

Clark — Let me switch hats and stop talking about what the Academy's global change committee is doing. What I would hope this group would support is research on how we are delivering nitrogen to the crops we want to grow. What's the difference between the amount of nitrogen that the farmer applies and the amount that ends up in a crop. That is a classic systems mass balance study that needs to be done -- not at a global scale, but certainly at a couple of hundred to thousand kilometer-on-edge scale. We should begin by looking at the agricultural nitrogen budgets from a point of view of really what the chemical products are, what's going into the surface water system, what's

going up into the atmosphere, what's going down deep, what's in the plants.

Rayner — Is everybody really familiar with the different potencies of the various greenhouse gases that Bill's been talking about? I assume you were talking there about the weight of gas emitted, right? You're not talking about the relative contribution to force and effect?

Clark — True. They have very different numbers, and CO_2 is the weakest. For what it's worth, an analysis done by World Resources Institute looking at the next 30 to 40 years of forcing of global warming attributes 13 percent of that forcing to agricultural activities. Within that, 3 percent is attributed to carbon dioxide, 8 percent to methane, and 2 percent to nitrous oxide. Those would not be the numbers if we talked about volume or weight emissions.

Rawlins — One of the reasons I asked you what you think agricultural research priorities should be is that the figures for gaseous emissions from agriculture frequently seem to be the residuals left over after the emissions from energy production and industry have been estimated. Do you think agriculture should take the responsibility for assessing these emissions? One of the weakest numbers seems to be the relationship between nitrogen fertilizer use and nitrous oxide emission. Do we know that this is the source?

Clark — No, we know that N_2O comes, among other places, from nitrogen fertilizer. You can do it in the laboratory and pick it up in the field. It happens. It's a matter of how much of it happens, where and when. I think that there is a real opportunity for the agriculturally based research community to get involved in this in improving these numbers. What I think would probably be a real lost opportunity would be if it retreated off and said okay we'll do this within our own community, instead of moving in and playing an active role in the existing cross-disciplinary effort that has been unable, with a very few exceptions, to get good sustained cooperation out of the agricultural community. What it means is they do the best job as they can with the collaboration they've been able to get. And I don't know a single group doing these budgets that would not be delighted to have very substantial interactions with the agricultural research community.

A Food Systems Approach

Ruttan — I would now like to turn to Bob Chen.

Chen — I will use a visual crutch, partly because I'm going to go over some of the points that were already raised. I might as well do it visually.

Ruttan — Be sure and articulate in a way that the people who read this, and may not have your visuals in hand, can follow.

Chen

I'll try. First of all, I was at a meeting at NCAR a couple of weeks ago and where Bob Dickinson, our climatologist, made the following comment: "Climatologists know a lot about the climate, but they also don't know a lot." And that's reflected in the comments about how long it will take to have the answers -- climatologists just need to do more research for 5 to 10 years and we'll have all the answers. Bob argued: "No, we're not. We're going to have as many new uncertainties coming up as we will solve in the next 10 years." My view is that in the impacts area we really know little and, in fact, we know little about how little we know. The extreme positions are based on very little hard knowledge.

If you look at a simple system in which there is an activity that you're worried about, such as climatic change, it helps to think in terms of the principles we learned in basic calculus. There is a term, the total derivative, which is, say, the change in agricultural production that results from the activity you are concerned about. This limited variable system has a total derivative reflecting how the change in the activity affects the climate (Figure 4).

There is also a partial derivative reflecting what climate change, holding all else equal, does to agricultural production. There also is another term which is of interest -- though maybe not to climatologists -- that captures the benefit of fossil fuel use on agricultural production. That makes up the total derivative, so from a societal viewpoint we must also worry about the benefits from fossil fuel use in agriculture.

Certainly one important thing is that significantly large negative effects on agriculture from climate change must be established in order for it to be important from a societal viewpoint. If this function is zero, then since the effects are multiplicative, there's no net effect on agricultural production. So there is a need to establish that this is a large negative effect before you can proceed in saying that this somehow outweighs the benefits of using fossil fuels in agriculture.

In my work at the World Hunger Program, we've kind of come up with two approaches to looking at some of the impacts. One, you might call a "food systems" approach. Most approaches to climate impact assessment in agriculture have not taken a broad food systems approach. They've really only focused on single issues on the production side, such as yield impacts, effects on inputs, some attention to pests, and not much else. Let me illustrate with a diagram that I've been working on for the purpose of rethinking the issue of food waste in the food system (Figure 5).

One of the first things you notice is that most of the things that Bill included in his list are in my input list. Clearly you have to worry about the effects on inputs and not just land use and yields. In Africa, for example, one of the major constraints on land use in agriculture is the occurrence of waterborne

diseases that prevent human occupation. That's something that will be responsive to climate change. It may therefore be a different pathway for affecting eventual food consumption. It doesn't relate to the demand side at all. Energy use is also a big factor in agriculture. Fertilizer is basically an energy use issue. It was mentioned this morning that if you could use cellulose, for example, to feed livestock, that would introduce a new component into the food system. But another issue is the waste that goes into feeding livestock. If one could increase the efficiency of feed conversion, it would probably far outweigh the effects of a 10 or 20 percent difference in corn and soybean yield.

There are lots of points of vulnerability that I won't go into. Certainly one interesting one is the whole issue of waterborne disease. There is also the issue of disruption of the food system itself. In Africa, for example, 2 percent of the population are refugees of some sort or another, and there is some potential for that to increase drastically. That's led to regional and sometimes national level disruption of the social infrastructure that keeps people fed and housed.

A related issue that was mentioned earlier is temperature and precipitation effects. Norm mentioned that people have looked at CO_2 and salinity, CO_2 and drought stress, and CO_2 and other factors. But what people have not looked at in any great detail is the whole set of cumulative system effects. There have been few synergistic studies of what happens to crops or forests when there's ozone, when there's air pollution, when there's a whole range of climatic stress.

At lunch, I asked about insolation effects on yields. Paul Waggoner was saying that there's probably an elasticity of one, that is a 10 percent increase or decrease in solar radiation over the growing season will result in a 10 percent increase or decrease in yield. But you don't see those kinds of estimates worked into agricultural impact studies principally because the modelers are not prepared to release results on insolation effects because the cloud parameterizations are so weak.

A second issue that has not been addressed to any great degree is the possible connections between climate change and some of the other environmental changes. They may, in fact, have synergistic effects. In addition, there are parts of the system that modelers do not normally think of. I put in agricultural research in that category. Agricultural research will have large consequences for the impact of climate change on agricultural production. But climatologists, and others who have traditionally defined this as a climate problem, have generally ignored agricultural research.

Finally, an alternative to a foods systems approach is to think more in terms of existing societal relationships and how things like food shortage, distribution of food and other factors interrelate. This diagram is too

complicated to explain in detail, but it represents our current thinking of how to deal with hunger. Risk relationships vary at different levels of spatial aggregation. Social relationships become important because the issue goes beyond capacity to produce the issue of access to food. Greater food shortage increases the numbers of people who have inadequate access. But it certainly is not a one-to-one relationship. Inadequate access can occur because of other factors in society. Even within the household, individuals have different access to food and requirements.

This kind of framework allows you to think not of flows of calories, but rather of a hierarchy of risk. Changes in climate which may affect food shortage may also have some other spin-off implications as its effects are transmitted through the system. This gets to the issue of whether there are absolute winners or losers. Maybe there are no absolute winners or losers, but certainly within a system in any particular region, there are going to be relative winners or losers. This may be more important to popular views of the problem than the absolute level of risk.

The effects of climatic change may well occur through other pathways, perhaps through changes in economic relationships within society. Policy actions may modify economic relationships within society and change the degree to which, for example, hunger persists in a world subject to climate change and policies to prevent, adapt or mitigate climate change. This is still preliminary, but it does provide an alternative way of thinking about these impacts that is different from the old "let's do a scenario" and add up the costs and benefits.

Waggoner — I would like to ask Steve Rayner and Bob Chen if you people can tell us how we can use some of these techniques to sort through the proposals for either stopping the climate change or adapting to it to see which is or is not reasonable.

Chen — Well, I think one issue is that, in my mind, the impact studies are so limited that even if you think there may be some CO_2 benefits, there is still a risk of catastrophe. That suggests a more conservative strategy in terms of prevention.

Clark — A simpler and stronger answer is that you should never fund a single additional impact study which has the dumb farmer in it. No study that is looking forward 50 years and does not incorporate a mechanism for behavioral and technological response, should ever be funded or considered again, period! It simply creates a set of numbers and pictures of a world which is inconceivable.

Ruttan — And you better go a bit farther and rule out not only the dumb farmer, but also the dumb plant breeder and the dumb animal nutritionist. We should assume that the research system has some capacity to respond to the changes

in the environment. And if any body doesn't believe that, I'll refer them to Hayami and Ruttan on "induced innovation".

Clark — But the point is we do have enough of a tradition in assessment and response studies for multiple decade time horizons. It is not even a useful first approximation to do the study as though those responses didn't happen. And yet 90 plus percent of the studies out there, even the best of them, are systematically biased in such a way as to make the results or the consequences look much worse than they're going to be.

Rayner — I think it's important not to assume that the smart farmer or the smart plant breeder is necessarily going to make things better. They could make them a lot worse.

Rosenberg — I agree with your premise that the "dumb farmer" scenario is nonsense. The no-adaptation assumption is silly. However, the very fact that so many studies have used this assumption virtually requires those of us who want to go beyond that to use it as a starting point. Policy is, after all, being proposed in Congress and in international fora based on the results of studies that have used dumb farmer scenarios.

Crosson — In response to Paul's question, it seems to me that one area badly needing economic research is this question of the gains from conservation. Are these technologies to increase efficiency in energy use economically viable now. If so, then the question economists always ask is why are they not being used. My point is that if these gains in energy efficiency are as large as asserted, and are even potentially economically viable, then we need to know it. We need to answer the questions, why aren't they in use. They would undoubtedly require some institutional changes, but the greater those institutional changes, the greater the cost. Institutional changes don't come cost free. But if they are, in fact, available at low cost, then all the problems of the uncertainty about climate change becomes a non-problem because it's only sufficient to show that there is some cost to not doing something about climate change. If we can deal with that at very low cost, then it doesn't make any difference whether we don't have good estimates of the future costs. I've been arguing that the RFF people in energy ought to be paying more attention to the economics of the conservation strategy and the energy efficiency strategies.

Rayner — I think you can push that even further back to something Steve was talking about which is the question of what is the starting point for doing impact analysis. One of the concerns that I have is the extraordinary degree of technological precision of the analysis in terms of material flows and emission rates combined with very superficial attention to the institutional structure and its implications.

The whole question of the introduction of a dynamic decision maker into impact analysis which makes the comparative static analysis misleading in the way that Steve indicated. We've tended to rely too heavily on late 1960s and early 1970s systems -- theoretical and flow -- modeling approaches and ignore active choice making. Until we can start to really integrate the active choice making into our impact analyses, we're always going to have the problems that Bill just said he would like to see excluded from modeling.

Cheng — I want to go back to the comment on the dumb farmer because it's quite clear that in a modern farming operation anyone who is not adapting to change is not going to be a farmer very long. It is the dumb modeler who makes such simplistic assumptions that worries me. Should we even be using equilibrium models for the problem we're dealing with?

Sonka — Paul, you asked about what tools and techniques that exist to help in prioritization. The tools and techniques used in the studies I will be discussing were useful and they were cheap. I'm struck with the odd choice of words. We distinguish between impact analysis, and science. I don't want to sound defensive, but we don't put that kind of money into studying the science relevant to impact analyses that it deserves. When an issue comes along you pull the old models off the shelf.

Waggoner — Perhaps the reason is that you haven't convinced somebody that you can do better.

Rosenberg — I have the answer, Paul. First of all, there have been any number of studies about the impacts of a climate change on agriculture. The EPA study illustrates the inadequacies of the dumb farmer assumption. The studies show that yields go down. Yields go down because heat units go up. In the plant growth models used, growth rate is determined by the accumulation of heat units. Hence the plant runs out of time. The crop stops dead because it reaches its heat unit limit weeks early so that the time for accumulating photosynthate is curtailed. In real life, farmers perceiving a warming trend and observing that crops are maturing too early would begin to plant earlier or otherwise change their management practices.

Ruttan — The plant breeders would increase the days of maturity from 100 to 110 days.

Jones — They already have the varieties. They would just pick different months to plant.

Modeling the Social and Economics Effects

Ruttan — I'm going to shift now to Steve Sonka. Steve, you've been looking at the climate models. We would like to get your perspective on what you think we can learn from them and what we need to do.

Sonka What I've been looking at is the studies that have been trying to measure the social and economic effects of climate change on agriculture. About six months or so ago, the Organization for Economic Cooperation and Development (OECD) commissioned me to undertake this review. I was asked to look at the methodologies that were being used to assess the potential social and economic effects of climate change on agriculture.

We tried to do three things in the study. One was to just review the empirical studies to find out what has been done. We were able to draw on Martin Parry's work at IIASA quite a bit. The second objective was to critically assess the methodologies used in the studies and the third was to suggest improvements.

In another incarnation, I teach in the area of management. And one of the things that we talk a lot about in management, particularly in the strategy area, is that you should spend some time thinking about whether you are doing the right thing as opposed to spending a lot of time thinking about whether you are doing things right. The bottom line from my review of the studies is that we've been spending a lot of time worrying about the correct way of doing the studies, but we haven't worried very much about whether we are doing the right studies. We are not providing the information that societal decision makers can use to make these very, very difficult choices.

I'd like to take just a few minutes to review what we did, then talk about where we think some of the key deficiencies are and then relate them to our discussions this morning, particularly Bob Chen's presentation.

One of the first things that I tried to do in doing this was to change the mind-set from climate change as the primary issue. From the viewpoint of society, or of societal concerns, climate change is not the primary issue. And I stress that because the studies that have been done have almost all have taken climate change as the central issue. As we thought about the basis for society's concern about climate change, it seemed to us food security was a primary issue. Food security has local, national, and international dimensions. Furthermore, the dynamics of food security are probably the central concern.

Furthermore, society is concerned about the production and consumption of food and the economics of that system. Whether an area is a food-producing area or not, food consumption is a major economic activity. Climate change has the potential for affecting food consumption in ways that may be as important from an economic perspective as its impact on food production.

A third societal issue is that of investment in agricultural infrastructures. Our concern in this meeting about the implications for agricultural research is one

aspect of the issue of agricultural infrastructures. We need to think about the implications for public and private investment in the infrastructure.

In our review, we looked at 19 empirical studies. We looked at 17 different characteristics. I won't try to talk about them all here. But they fit fairly neatly into three categories. The first relates to the source of the climate change and how the climate change process was being modeled. Harking back to some of Norm's comments, almost all were generated by Global Circulation Models. That was the underlying source of the climate change projections.

Probably most troubling to me were two things: one was the instantaneous change approach used in some studies -- that all of a sudden we wake up and the climate is different, nothing else is different, but the climate is different. From a societal or from a policy maker's viewpoint, I think it is very hard to understand such a situation. I don't mean understand it in the intellectual sense, but in the sense of what to do in a bureaucratic and political sense. That's a very nebulous kind of information.

Probably of more concern, or at least as much concern, is the very limited analysis of the uncertainty associated with the climate change process. Every one of the reports goes into great length talking about the uncertainties of climate change. But when it comes time to do the modeling, they essentially ignore uncertainty. The analysis rarely goes beyond a little sensitivity analysis -- typically rather naive and not very meaningful. I don't want to be too critical here. I view the methodologies as evolving. If I were doing these studies I would probably have done the same thing over the last three to five years. Our criticism is directed toward how to conduct the next set of studies.

The second group of characteristics we looked at were the economic modeling issues. The studies did pretty nice jobs in terms of the kinds of models they used and how they generated coefficients. They did what reasonable people could be expected to do given the small amounts of resources available to do the studies.

That was comforting since from the viewpoint of trying to find something wrong, we didn't find very much. But what we did find was what Norm referred to as the dumb farmer mentality. Although I kind of object to that characterization because I know, from growing up on an Iowa farm, that not even the dumbest farmer would agree with the assumption that the climate is going to change significantly but nothing else will change. The reality is that if you're concerned about food security, climate is only one of many things that will change over the next half century. One of the things that we found very troubling was a lack of concern about other resources, about population change, or the many other changes that will impinge on food

security. We should be looking at a world that is somewhat more like the world that will actively exist in the middle of the next century.

The third set of things we looked at were the outcomes that the analysts attempted to quantify. All 19 studies looked at agricultural production. But when we went into some of the other measures such as environmental impacts, regional shifts in production, and agricultural profitability and employment, we found very limited coverage and sometimes inconsistent coverage. I recall one study that looked at environmental impacts using a very micro-type focus -- modeling the impact on one hectare -- and then went on to look at the regional economic impacts using large scale regional models. It may be not too bad to use different models for different questions, but some of the assumptions driving the two were not consistent.

The most important deficiency, in our mind, was that food stocks were just not talked about except for one USDA study that looked at international trade. If food security is, in fact, what the policy maker is concerned about, the possibility that the world may become a very unpleasant place to live in the next 30-40 years as a result of massive levels of hunger should be addressed. But it was not addressed in the studies we reviewed.

We made three recommendations. The first dealt with the geographic scope. The studies that were done had tended to focus on the northern hemisphere mid-latitudes to the exclusion, or almost exclusion, of Asia, Australia, South America, Africa. There's a whole lot of the world out there, that grows lots of food, that was not analyzed. Recommendation 2 dealt with non-climatic demand and supply factors. Even if one is studying Saskatchewan the investigator ought to ask how the changes there relate to changes in the rest of the world. There is a rest of the world out there and a global marketing system is what ties it all together. We can't predict what the world is going to be like 40 years from now. I'm not suggesting that. But I am suggesting that one might consider how population changes, irrigation development, land use changes, and other important supply and demand factors will modify the climate change effects.

A third recommendation then was to shift our impact modeling in order to make the results more useful as decision support systems rather than models. I have in mind decision support systems that can be used in an interactive manner.

In summary, there have been a lot of good technical analyses done and we have done a reasonably good job of answering the wrong question! When you read the studies -- particularly the summaries of the studies -- the authors then go to great detail to tell you why these results probably will not hold -- that things aren't going to happen this way. That is troubling. It goes back to not asking the right question when the analyses were designed.

The good news, I think, is that in the discussion we had at OECD two or three months ago (that Pierre was a part of), we're seeing some of the modeling emphasis starting to change. Some work is now starting to look at transient climate change and the process by which climate change can be incorporated into social and economic models.

One thing I would like to mention because I heard it at OECD two week ago and again this morning is that the climate change is the problem. Therefore, we need to solve it, and let's not worry too much about modeling social and economic interactions because they will be huge -- whatever they are. Therefore, let's just worry about reducing emissions. All we need to do is cut back on CO_2 and the rich developed nations will do what they should be doing anyway -- not using as much fossil fuels -- and they'll adjust their life styles. I think we need to think more carefully about a scenario in which that does not happen. The rich countries, even if there are reductions in CO_2, will fight to maintain their lifestyles and will do that in ways that may not be very socially desirable. If the cost of cutting emissions is increasing the likelihood of World War III, do we want to pay that cost? I think those are the kinds of issues that policy makers have to deal with. And those massive dislocations in the near term aren't just simple economic issues. They're very complex political, social, and economic issues that we don't know how to even think about intelligently.

Let me turn back to the implications of the studies I have reviewed. If you look at the studies critically and just ask, "What are they saying in terms of impact?" The answer almost unanimously is climate change on the magnitude expected over the next 50 years is not a problem for agriculture. It is just not a problem for production agriculture. I disagree with that conclusion, not because of the way the studies were done, but because I don't think they're asking the relevant questions.

Ruttan — I take it that there are two dimensions to the transition problem. One is instability. The second is the fact that it's dynamic in the sense of you're not moving to an equilibrium. Rather, you are moving toward an equilibrium that may itself be very unstable.

Sonka — There are two dimensions. One is that of heightened instability. There seems to be a consensus that global warming will result in greater climatic instability. Instability is hard on agricultural institutions. The marketing system, the credit system, and the government institutions just don't handle instability very well.

Waggoner — Do you mean variability from year to year, is that what you mean by instability?

Sonka — Yes.

Rawlins — But that's never incorporated into the scenarios.

Sonka — You mentioned a second aspect of the dynamics. Realistically we don't know what the equilibrium is toward which we are making a transition. The people involved in policy are going to be making decisions, not about transition to equilibrium, but about the direction of change.

Rosenberg — Even on the subject of equilibrium, there's no reason to assume that it will stabilize at the CO_2 equivalent doubling or at any other particular level.

Chen — You alluded to the fact that some of the 19 studies were very limited in resources. Do you have a sense of the order of magnitude, in money or man years, spent in those climate impact studies? Did it include the Climate Impact Assessment Program (CIAP) study, which is probably the largest, that was conducted in connection with the SST (Supersonic Transport) debate?

Sonka — No, it did not include CIAP.

Chen — Do you have a sense of the order of magnitude of the rest of the studies? I know how much was spent on Martin Parry's study at IIASA (the International Institute for Applied Systems Analysis) because I helped set it up. In two and one-half years, they spent a total of probably $250,000 -- not including some of the contributed time of the individual researchers and individual members of the project. The money that went into it was trivial in comparison to the amount spent on some of the big international meetings that have been held in the last year or two.

Sonka — I was going to say that if a million dollars was spent on the studies I reviewed, I would be amazed.

Rosenberg — I would think that EPA surely spent half a million for their studies.

Waggoner — But you're considering only the agricultural impact studies?

Sonka — And only the social and economic impacts on agriculture.

Chen — It just makes a point that I'll try to make again later. Very little has actually been done in terms of real in-depth research. This leaves a lot of room for hand waving so that people can say "Oh, there are huge negative impacts." And you turn around and someone else is saying, "Oh, the benefits are wonderful." This just reflects the vacuum of in-depth studies that go much beyond the "back-of-the-envelope" types of analysis.

Ruttan — How would you characterize the level of resources that have gone into the physical studies as compared to the studies that deal with social and economic impacts?

Chen — Several order of magnitude in difference. It depends on where you draw the line. But even if you look only at climate models, the resources have been large. I was just at a meeting where Bob Dickinson (of the National Center for Atmospheric Research) was saying, "There are only 40 people who really know the models. We don't have many resources and we don't have our own Cray to run our models." But you're still talking tens of millions of dollars per year. And that's just the climate models. I think there's easily several orders of magnitude difference. If you look at the global change research budget that the administration talks about, it is in the $500 million range.

Rosenberg — Bob raised a very interesting point about the complexity of nature. He said that sunshine and other factors need to be considered. Most of the models used for impact studies have not considered enough of these factors. Generally temperature is increased, say three degrees and stays that way day and night, day after day, week after week. But climate change involves more than temperature. For example, less precipitation means fewer clouds; fewer clouds mean more sunshine; the humidity of the air changes, the windiness changes. The GCM's do not provide reliable information about these phenomena.

I want to point out part of the reason for an apparent "putdown" of impacts research. Many impacts studies have not made good use of available scientific knowledge. For example, in the early impact studies, modelers equated evapotranspiration with a change in temperature. If temperature goes up, evapotranspiration goes up. This is correct, of course, unless other factors such as sunshine, windiness, and humidity also change. Plants will either be bigger or smaller, depending on what the climate change does to them. The effect of CO_2 on stomatal regulation must also be considered. When all of these factors are considered a much broader range of possible evapotranspiration outcomes becomes evident. We are trying to incorporate knowledge of these phenomena in the impact studies that we're now doing.

Ruttan — I have a sense that both economic modeling and physical modeling suffer from a common problem. The problem that strikes me often in our computable general equilibrium models is that they're very resistent to the introduction of new knowledge. This partly because of mathematical convenience and partly because the modelers don't know that much about what new knowledge is available. I get a sense when I hear people talking about the physical modeling that you have some of those same problems -- that we have a lot more micro information than we're able to incorporate in the models.

Rosenberg Yes. I think that's a problem but one that time and patience can help. When studies are commissioned in a hurry, say, to meet a Congressional mandate, models must be taken off the shelf because there is no time to do anything else. But we have good information on the CO_2 direct effects and a rich agrometeorological literature is available to people who want to construct better models. The permutations can reach six orders of magnitude. The trick is to select a limited range of plausible changes.

LOCAL AND REGIONAL RESOURCE AND ENVIRONMENTAL CHANGES

Environmental Change in Eastern Europe

Ruttan I now turn to Zbignew Bochniarz. Zbig has been concerned about environmental policy in Eastern Europe and the USSR, a part of the world where there are rather severe environmental changes underway.

Bochniarz I speak about environmental change in Eastern Europe and the USSR from the perspective of an economist. This is not always easy for me, because I grew up as an economist within the "monoculture" of a Marxist economy that has not dealt well with such issues as economic efficiency or the environment. There are a lot of common misunderstandings when talking about socialist countries. Sometimes these countries are described as planned economies. However, the evidence based on plan fulfillment contradicts this common assumption. It is really true that they have plans and they spend a lot of time on planning activities, but if you consider the implementation of plans and usually their poor fulfillment, you might better call them planning than planned economies.

In one aspect at least, these plans were very successful. That is in reaching the level of industrialization of the Western developed market economies. Unfortunately, this is not the level of industrialization as measured by wealth, but rather, by pollution. In terms of pollution per capital, they are the leaders among the developed countries. Let me give some examples.

According to a recent study by the Battelle Institute,[4] energy related carbon emissions from Eastern Europe and the USSR (called also CMEA or COMECON countries) reached 26 percent of the global emissions in 1988. The contribution of the OECD countries was about 49 percent. What is very interesting is the change of shares of these two blocks. Thirty-five years ago the planning economies contributed only 18 percent while OECD accounted for 71 percent. After the "oil shock" the share of the OECD countries dropped to about 57 percent, but the share of the CMEA countries rose to

[4]To be completed.

24 percent. In other words, the data shows a growing contribution of COMECON to global warming.

What are the major reasons for such developments? I would divide all reasons into two groups: objective and subjective (or man-made). In the first group I should specify two major factors contributing to growing emissions of carbon. The first is the natural resource base. Most of these countries based their industries on coal (hard, soft or lignite), which they have relatively a lot, but which is less efficient than oil. The second is the spatial structure of the majority of the CMEA economies, which usually requires a long distance transport of energy sources for industrial activities.

The second and even more important reason is related to the Stalinist model of industrialization with its priority on heavy industry. There has been underpricing of natural resources, energy, and capital goods as well as a lack of real incentives for economic efficiency both at the macro microeconomic levels.

One of the results of the Stalinist model is inefficient energy production and consumption. According to the Warsaw University study (Krawczyk 1987) the CMEA energy intensity per GDP is presently 2.7 times higher than in Western Europe. In terms of particulate matter pollution (dust and fly ash), the average pollution per $1000 of GDP was, for East European countries, 12.7 times that in the EEC countries. Some cynics in Eastern Europe asked why should we be concerned about global warming since we are increasing the dust and this way decreasing sunshine!

In terms of SO_2 (sulfur dioxide) and NOx (nitrogen oxides), the difference between Eastern and Western Europe is not as dramatic. But it is still 2.5 times higher per $1000 of GDP in Eastern Europe.

The pollution problems are not just a function of industrialization, but most importantly, the very wasteful economic system which was established there along with the authoritarian political system imposed after World War II. This path of development has resulted in three types of crises -- ecological, economic, and political. All of them need to be solved in order to put these countries on a path of sustainable development.

Let me present some data illustrating the seriousness of ecological crises. In Poland we have officially recognized 27 areas called areas of high ecological risk (environmental hazard) inhabited by about 35 percent of the population. Five of them are classified officially as areas of ecological disaster. Due to pollution and degradation of the environment, morbidity, and mortality rates are significantly higher in these regions than in the rest of the country (in the case of respiratory diseases and lung cancer about 30 percent higher). In addition to these areas we have about 50 cities that are environmentally substandard. These include about 50 percent of the Polish population.

Fortunately, we have in Poland quite good environmental statistics with full access for everyone. This is not the case of the most CMEA countries, where either statistics are poor (Rumania) or the environmental data is classified (East Germany). According to dissident sources in East Germany and Czechoslovakia, the share of population living in environmentally hazardous (substandard) areas is about 60-70 percent. In the European part of the Soviet Union it is about 50 percent. When interpreting this data, one should keep in mind that the environmental standards are not, in general, as strict in Eastern Europe as in Western Europe, USA, or Japan.

There is a clear interaction or feedback among several environmental problems. One of them is acid rain, or more appropriately, acidification. This is closely related to energy policy and strategies of industrialization and hence, with global warming. Despite the fact that there are several schools of thought about the metabolism of forest decline (at least six according to the World Resources Institute), none of the top experts neglects the impact of air pollution and acid rain on this phenomenon. This is a very serious issue in North and Central Europe, in the eastern part of North America, and is currently emerging in the southern part of China.

In general, acid rain is associated with emissions of SO_2 and NO_x (sulfur and nitrogen oxides), is a part of a larger problem of acidification. Acid rain is only one of its major manifestations. Acidic compounds can also be deposited in snow, fog and dew. They can also fall as dry particulates. The dry deposition usually takes place nearby the emission sources. Despite the fact that this phenomenon is not recognized as a global problem, the results of these emissions can occur up to a few thousand kilometers from the emission sources (wet deposition). According the WRI about two-thirds of total atmospheric acidity is due to sulfur, and about one-third to nitrogen.

Acid deposition in streams and lakes and in soil and forest, as well as in buildings and technical infrastructure, causes serious damages to ecosystem, national economies, and human health. Agriculture, fishery, and forestry are among the first victims of acid deposition. Corrosion of metal structures and the dissolution of buildings and historical monuments are other examples of the effects of acidification. Let me give some data related to forest damage from a recent study of the UN Economic Commission for Europe. About 35 percent of the European forest area has been damaged. Estimates for individual countries are: Czechoslovakia (71 percent); Greece and United Kingdom (64 percent); West Germany and Estonia (USSR) (52 percent); Norway, Denmark, Poland, Netherlands (50-48 percent).

Lake acidification is also very serious. According to the UN Report there are growing numbers of strongly acidified lakes -- in Canada, Sweden, Finland, and USA. In Norway, fish were depleted completely on about 13,000 square kilometers.

About 70-80 percent of Central and North European farmland is significantly affected by acidification. A meaningful increase in average soil acidification over the last 20-30 years was noted between 0.8-1.5 pH in this region. Soil acidification has had serious consequences. It has caused crop yields to decline in heavily affected areas. An even more serious effect is the release of heavy metals deposited in soil due to its acidification. Released in this way heavy metals such as lead, cadmium, or mercury are moving either to plants or to groundwater and in this way they are coming into the human food chain.

Soil and water acidification depends on its buffering capacity. It is in turn related to the composition of bedrock and surrounding vegetation, forest-soil, hydrology, and land use. In Central Europe the buffering capacity is much higher than in Scandinavian countries. For that reason they are more vulnerable to acidification than Central European countries. In order to increase buffering capacity and to decrease acidification in lakes, forest and soil several technologies have been implemented. The most popular is liming. This is, however, a very costly technology. In the case of Poland, it costs about $5 million per year.

More and more visible deterioration of the environment, as well as health effects of pollution, has led to the emergence of independent environmental organizations in Eastern Europe and in the USSR since the early 1980s. They are bringing environmental issues to the public, lobbying for effective environmental protection policies and educating their societies. The oldest organization in the CMEA is the Polish Ecological Club, which I had the honor to represent at the United Nations annual conference of Non-governmental Organizations on Sustainable Development last September. An interesting question was asked during this conference: how would you rank global warming among the major environmental threats? Only a few representatives from developing countries, including Eastern Europe, ranked it first. It is not viewed as a major issue in that region despite the fact that the fact that the scientific committees are very concerned. In these countries problems such as acid rain, water and air pollution, and other local environmental issues are of more concern.

The dramatic political changes going on this year throughout Eastern Europe, together with deteriorating economies, has produced a complete distrust of any kind of planning. There is somewhat of an overreaction to past failures and the emergence of belief that only the market can save us -- that the market is good for everything. I do not share this opinion. It is obvious that we do not need the kind of planning we inherited from the Soviet Union. We need to rely on market as a principal form of regulation of national economy. It will change the behavior of the principal actors in the market. However, I believe that we cannot leave environmental policy entirely to the market. We need state regulations -- environmental standards and strict

enforcement systems. We also need a kind of indicative environment planning in the area of market failure.

We also need new institutions to respond to the global environmental challenge. East European countries are far behind, in comparison, with their Western counterparts in sound institutional design for the environment. For this reason, last September, I organized (in Poland) an international workshop on market mechanisms for environmental protection. It was attended by representatives from most East European countries as well as by top experts from the U.S. and Japan. We prepared policy recommendations on how to use market-based incentives to protect the environment and to promote sustainable development. There is, however, a basic precondition for this instrument. They cannot propose solutions in emission trading within a "bubble". We are considering introduction of about 100 bubbles in Poland over the next couple of years. Similar approaches are discussed now in the Baltic Republics of the USSR.

Research in Eastern Europe is mostly focused on the scientific aspects of global warming. The social sciences are still far behind. I will organize an international workshop in Poland on institutional design for the global environmental challenge next fall. This workshop will bring together leading environmentalists from both the East and West. So far there are about 20 people working on this project.

We in Eastern Europe need more collaborative research with the West to improve our technologies, especially in the energy industry. We would like to reach the Japanese or Swedish standards of energy efficiency. Opening the economies of Eastern Europe has created new conditions for technology transfer, joint ventures and even direct investment. It should help to change the structure of our economies. There is an urgent need of collaboration in institutional design on a country as well as a regional or European level. There is a lot of transboundary pollution. The solutions will require new transnational institutions. The role of planetary economy in global warming and ozone depletion should make us more aware of the need for successful collaboration. These global problems cannot be resolved without involvement of Eastern Europe and the USSR. It is in our joint interest to develop that kind of effective collaboration.

Ruttan — Are there questions for Zbig? It seems to me that it may be realistic to view the eastern European experience as a model for what we are likely to see in many parts of the developing world over the next decade.

Bochniarz — If you value industrialization over the environment, you end up where we are now. This is the point I tried to make at the United Nations conference.

Crosson — Did you say that the bubble concept is actually being implemented?

Bochniarz We are just beginning. We organized a conference and after the conference we sent recommendations to the government. Now there is a government team working on it in Poland. Probably next year we will have the first simple bubbles. We are also thinking about expansion of the bubble concept. In the Baltic Republics of Estonia, Lithuania and Latvia, there is also movement in that direction. The people who established the first bubbles in the U.S. are involved.

Rawlins What is the bubble concept? I'm not familiar with that term.

Bochniarz The bubble concept is one of the forms of emission trading. The EPA sets an ambient standard for a certain area as a ceiling. This area creates in such a way a kind of bubble. All polluters within this area (under "bubble") have to meet the standard cutting their emissions. For some of them this reduction of emissions is cheaper than for others. They can also reduce emissions more than required by the standard. In this way they can earn "emission credits," which in turn they can sell on the market or save for their own future needs. In order to use this concept, we in Eastern Europe must first introduce and respect ambient standards and appropriate individual emission permits. On this base we can further develop emission trading.

Crosson Are levels of air pollution in some parts of Poland now having measurable effects on public health?

Bochniarz In the southern parts of Poland measurable effects on public health were observed. These include higher rates of respiratory diseases, lead poisoning, lung cancer, circulatory diseases, miscarriages, infant mortality, and others.

Crosson Is there any evidence of the effects on economic productivity in these countries?

Bochniarz There are several estimates. In general the most conservative estimate is that we are losing about 10 percent of our GDP per year from pollution and environmental degradation. Some studies suggest as high as 20 percent. But the most conservative and documented losses were about 10 percent.

Ruttan What about simply a measure like number of lost days of work per year?

Bochniarz We made some estimates in the middle of the 1980s. Compared with the 1970s, air pollution and absence from work caused by respiratory diseases increased two-fold in the 1980s. For this reason, we concluded that there was a strong relationship between those two phenomena. In real terms, we expressed those losses as 28,561,000 days or 188,503,000 working hours lost due to respiratory diseases caused by pollution. That amounts to 4.7 days per person employed in state enterprises.

Sonka — If significant moneys come from western Europe for investments in East Germany and Poland, for example, will the investment and associated economic activity increase the pollution or will the efficiency of the new plants offset the effect of increased economic activity?

Bochniarz — A very good question! First, you probably remember that during last spring we conducted Roundtable talks between the opposition led by Solidarity and the Government. One of the small tables organized at the Roundtable was devoted to environmental problems. Both sides reached an agreement in all but one problem -- nuclear energy -- which is very promising. Both sides agreed to utilize a concept of sustainable development (in Polish eco-development)) as the concept for harmonizing environmental and economic goals. This agreement stressed the need to increase dramatically economic efficiency as a way of reducing pollution as well as to achieve better utilization of natural resources. The marketization of the Polish economy will help to achieve this restructuring which will lead to closing many inefficient and polluting plants. Since the beginning of the 1980s we have closed several plants due, first of all, to a new independent (for the first time in Eastern Europe) Polish Ecological Club and a very militant environmental movement. The best known case was closing the country's largest aluminum plant in Skawina, which contributed about 50 percent of the total production. In reference to the topic of our consultations, I would like to mention that the Club also prepared a concept of "Ecological Agriculture" -- an organic farm belt in the buffer zone for the National Parks in 1983. Since that time the second independent environmental organization was established in Hungary (Danube Circle, 1984). Since the Chernobyl disaster and proclamation of Gorbachev's "glasnost", environmental organizations are mushrooming around the USSR and Central Europe.

Ruttan — From a historical perspective, we are now in the third wave of environmental concern since World War II. The first wave was very much a concern about materials adequacy. You will recall the President's Water Resources and Materials Resources reports. The scarcity issue was largely resolved by a technological response. The second wave of concern the -- the environmental crisis of about 20 years ago -- was largely about micro environmental spillover effects. The prescription that came out of that was to internalize externalities. It was so cheap to pour residuals into the environment that we used up whatever cheap space was available. In this third wave things are much more transnational. It's probably more transnational in the parts of the world where countries are small than where countries are large. But I haven't seen much discussion of the institutional innovations that will be required to deal with these transnational issues. For any one national unit, except perhaps the very largest and even perhaps for them, there will continue to be a tremendous temptation to free ride. I don't see very much discussion about how to design the international regimes that are going to have to be put in place to achieve some compatibility between national and global interests.

Temperate Region Soil Erosion

Ruttan — Unless there's another burning question for Zbig, I think we'll turn to Pierre Crosson for a discussion of the soil erosion issue.

Crosson — When we start thinking about the erosion problem, it's essential that we make a distinction between the problem in the United States and the problems in the developing countries. We now know quite a bit about how much erosion is occurring in the United States, particularly sheet and rill erosion. The estimates for wind erosion are less secure. We now have three different sets of estimates of the long-term yield effects of sheet and rill erosion. Despite what we have often read in the literature on erosion, it wasn't until 1977 that we had any reasonably reliable estimates of how much erosion was actually occurring on non-federal land in the United States. In 1982, a second set of more comprehensive estimates, obtained from a much broader sampling base, became available. Those two surveys, made in 1977 and 1982, constitute the base of data that people in the United States use in assessing how much erosion is occurring and its productive effects.

There are three studies of the productivity effects. One was done by a set of soil scientists here in the University of Minnesota under the direction of Bill Larson (Pierce, Dowdy, Larson and Graham 1984). They developed a Productivity Index model (the PI model) which looks at the effects of erosion on certain critical characteristics of a soil. As erosion occurs, those characteristics which are most critical to crop yields tend to be changed on most soils in ways that are adverse to yield. When it's run over various periods of time, typically 50 and a hundred years, the model shows that on some 98 million acres of cropland in the corn belt where average rates of erosion are in the neighborhood of nine tons per acre per year (which is well in excess of what the SCS says is the maximum tolerable amount), that 100 years of erosion at present rates would reduce yields by about 4 percent.

Another major study in this area was the EPIC model developed by USDA people at ARS, and by economists at the USDA soils facility at Temple, Texas (Crosson 1986). EPIC has been run for crop producing areas across the entire country, not just the midwest. The EPIC results show that, at current rates of erosion, at the end of 100 years cropland yields would be about 3 percent less than they otherwise would be.

The third study was done at RFF (Crosson and Rosenberg 1989). It was an entirely different approach. We did a regression analysis of the relationship between intercounty differences in crop yields (the dependent variable) and erosion, topsoil depth, and number of other independent variables for several hundred counties in the corn belt and the northern plains. We found that

there was no statistically significant effect of erosion on wheat yields, that corn yields would be reduced about 5 percent, and that soybean yields would be reduced 10 percent over a 100-year-period.

The significant thing to me about these three studies is although they come at the issue in quite different ways, they all show that the hundred year effect of present rates of cropland erosion on crop yields is small -- on the order of, say, 3 to 10 percent. That's very small compared to the expected impact of technological change on yields over the next hundred years. Production or productivity losses on that order would, in effect, be lost in the noise.

Ruttan It would be equivalent to about three years of normal productivity growth?

Crosson Yes. Now, I have made some estimates taking the work that I did and also some work that USDA people did with EPIC at Temple and estimated the economic costs of long-term loss of crop yields in the U.S. The effects, as you might expect, are very small.

As far as the United States is concerned, the long-term effects of soil erosion, at present rates, on the capacity to produce agricultural output is trivial. A much more significant erosion-related problem is the off-site, or off-farm damages. These include the effects on water quality, particularly of sediment after it leaves farmers' fields. These turn out to be at least an order of magnitude greater than the economic costs of lost productivity. In research on erosion in the United States, there ought to be much more attention being given to water quality issues relative to the amount of attention being given to productivity issues.

It is not surprising that the on-farm damages should be much less than the off-site damages. Vern made some reference a little while ago to the externalization of costs. The loss of soil productivity is an internal cost for farmers. The farmer bears that cost, and therefore has incentive to do something about it where it significantly affects either his income or the present value of his land. He has no such incentive to deal with the off-site damages. Those are external as far as he is concerned. They are internal, of course, to the total society. And the fact that those external damages are almost surely greater than is socially optimal is a reflection of institutional failure.

I earlier distinguished between the erosion problem in the U.S. and in the developing countries. The contrast in our knowledge is startling. Despite the fact that we read statements about how much erosion is occurring in the developing countries and what the productivity consequences are, the fact is that nobody really knows. A recent article in the Journal of Soil and Water Conservation (Colacicco, Osborne, and Alt 1989) by one of the leading people in this area, emphasized that we really don't have a clear idea of even

how much erosion is occurring in developing countries, let alone what the productivity consequences might be.

There has also been some recent work at the World Bank which carefully examines this twin issue of on-site productivity losses attributable to erosion and the off-site damages in Indonesia. The results are preliminary. But they suggest that the on-site costs are, in fact, higher than the off-site costs. It seems to me that much more of this kind of research is needed in places all around the world where there is reason to believe that erosion is a significant problem. There are areas in the Himalayas, in the mountainous parts of Latin America, and in East Africa where there is a lot of anecdotal information suggesting that, not only is erosion high, but that it may be having long-term consequences for productivity. I'm not arguing that the situation in the United States is typical of what is happening elsewhere in the world. The point I'm making is that we don't know enough about what's happening elsewhere in the world with respect to soil erosion to be able to make well grounded statements about the importance of the problem, and what we ought to do about it. My own hunch is that, when such studies are finally done, they likely will show that, in most areas, the off-site damages are likely to be higher than those on-site damages. It is important to consider that we need to know much more than we presently know about the erosion problem in the developing countries, in order to be able to address issues concerning the sustainability and enhancement of agricultural production capacity.

There was a special issue of Scientific American (Crosson and Rosenberg 1989) in September. Norm Rosenberg and I had an article suggesting strategies for long-term agricultural development. The focus of that article was on the emerging pressures on the natural resource base in response to rising demand for food and fiber over the next several decades -- well into the next century. The question we asked was what can the community of people that are concerned do in order to accommodate the increases in demand and relieve the pressures on the resource base. We particularly focused on land resources, on water resources, and on biological diversity. We concluded that there will have to be a continuation of new technologies which permit farmers to respond to rising demand for food an fiber, in a manner that is consistent with environmental and other social costs. Some of the institutions are now in place for developing the appropriate technologies, and are relatively well established -- the national agricultural research institutions and CGIAR system. The more difficult issue is likely to be the development of the institutions which would correctly signal the emerging stress on environmental resources. The development of the institutions needed to reflect the social scarcity of those resources would be more difficult to develop, primarily because of the difficulties of establishing property rights in water and in biological diversity. As a consequence, we concluded that the institutional challenge or the challenge to develop

appropriate institutions, would be more difficult than meeting the challenge of developing the appropriate technologies.

I was also impressed, as I read through this special issue of Scientific American, how much weight was given in the other chapters to the issue of institutional design. The design of institutions for managing our resources in ways that give proper weight to the various social values we place on those resources, is emerging as a key element in our thinking about development processes and, in particular, about issues of sustainable development, not only in agriculture, but also in the total economy.

Allen — Pierre, each time I go to Africa, I get depressed about the difficulty of bringing about the institutional changes needed to generate the appropriate technology, in getting that technology transferred to the farmer, and in creating the right incentives. I hope that maybe my interpretation of what I'm seeing is totally off base. I'm curious whether you gave any attention to bringing about the needed institutional changes in some of these countries where population is growing at an explosive rate and the land resource base is degrading.

Crosson — My impression is that Africa is a worse case. But there really has been some rather impressive progress in other parts of the developing world. As you know, Africa emerged from colonialism later than these other areas. There was systematic discrimination against agriculture pricing policies, in investment policies, and in rural education and infrastructure.

Ruttan — My sense is that it's not going to be easy to generate rapid growth in agricultural production in Africa. In the European and Asian cultural systems, there is a sufficient similarity in property rights and family structure to give us a good deal of intuitive understanding of how institutions work. My sense is that, for both property rights and family structure, which are closely related to each other, the system in much of Africa is so different that it appears obscure to outsiders. Furthermore, the family structure was often deliberately obscured by the local people during the period of colonial development.

Rayner — Vern, if I can put my anthropological hat on here, I would like to disagree with you. It's not so much that the workings of the traditional African land tenure and kinship systems are obscured. In the ethnographic literature, you can find very good descriptions of them. I think the problem is largely that our institutional arrangements are not directly transferrable. Nor has the expertise on the working of those traditional land tenure and kinship systems from the academic world of anthropologists been transferred to, or accepted by, the development community. Nowhere is this clearer than in the land tenure issue. Economists have gone in with western ethnocentric assumptions, such as: "If you want to get people to plant trees you have to give them tenure of the land." In some of those systems they have well

developed tenure rights to the standing crops. I see that more as our institutional failure. It's not that the information doesn't exist in the West to understand if there is a willingness to use it. It's much more the dominance of the Western neoclassical economics that obscures our understanding of institutional behavior.

Sanchez — Let's backtrack to your question, Gene, on how extensive the erosion problems are in the tropics. Erosion is much more severe in the semi-arid regions, the areas where the land is bare during the dry season and gets torrential rains in the beginning of the rainy season. This includes most of the semi-arid regions of Africa as well as some highlands areas. Parts of Ecuador, in the Andes, are tumbling down visibly and grossly. Erosion is less of a problem where there is ground cover continuously throughout the year, as in much of the humid tropics. That doesn't mean there's no erosion. But it's certainly less of an issue. We need to think in terms of having a ground cover throughout the year. It doesn't matter whether it's weeds or tropical forest. It would make a difference in erosion.

Rawlins — Pierre, have you looked at the positive impacts of sediment delivered to off-site locations? Many major river systems have very productive deltas that are the product of upland erosion. King, in his book, Farmers for Forty Centuries,[5] discusses the husbanding of sediment as a means of enhancing productivity in the orient. I wonder if anyone has taken a systematic approach to assessing the productivity of whole river basins and balanced the decrease in productivity in eroding highland soils, where the climate may be less desirable, with the increase in productivity in deltas and river valleys.

Crosson — As far as I know, it hasn't been done on a river basin scale. There was a little work done with the EPIC model to examine the effects of deposition on productivity on different types of landscape. They found that it makes considerable difference when you take deposition into account. But the model simply assumed that increases in soil depths because of deposition would have had positive effects. That is not necessarily correct if soil depth is not limiting. Bill Larson may know more.

Larson — I have some comments. I know about that study. But let me first comment on your earlier remarks. The 3 to 10 percent loss in productivity due to erosion just doesn't tell the whole story. For about 25 percent of the 400 million acres of cropland -- about a hundred million acres -- the losses would be on upwards of 10 to 15 percent. And if you take the 10 percent most erosive land, the losses would be in excess of 25 percent. Now, it's that 10 percent that we have to concentrate on. If we lose 25 or more percent of productivity, that land's going to go out of crop production. And it should!

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[5]To be completed.

The conservation reserve, and to some extent the cross compliance, should be aimed at the land where sal losses are in the 10-15 percent range.

While I agree with you that the NRI estimates of 1977 and 1982 are the very best data on erosion we've ever had, they still leave a lot to be desired. As you know, the Universal Soil Loss Equation (USLE) gives us point estimates. They don't take into account the landscape effect. They don't take account of deposition. There's a lot of things that are not included. They estimate only sheet and rill erosion, but not gully erosion. There's also a need for more careful definition of what is acceptable or tolerable and what isn't. Much of what we accept is not much more than folklore. It's not based on any real measurements. It's a committee decision that was made 40 years ago. I was probably part of that committee.

Cross compliance is going to become a very big issue. As you know, by 1991 or 1992, farmers who aren't complying with these acceptable limits, whatever they are, won't be eligible for price support or deficiency payments. A recent study looked at the same farms that had been certified for compliance, and with little or no change in practices, the estimated amounts of erosion are far different than had been predicted. You know, there's something odd going on. A lot of it depends on what goes into the soil loss equation. A lot of it depends on the erosion trends that we define as acceptable, and I don't think we know.

I recently reviewed a paper written by Harold Dregne **(YEAR???)** in which he tried to review all of what he considered quantifiable data on erosion from Africa. And he only came up with 8 or 10 small studies. Many of those were for very limited physiographic areas, so the conclusion must be that we don't know. You can go to Africa and you can see erosion everywhere, but there's very little quantitative data.

Crosson

The numbers I gave on erosion induced productivity losses in the U.S. are national average productivity losses. They are meaningful numbers when the question is how the nation's capacity to produce will be affected over the long-term by erosion. I have argued that the USDA programs really ought to be focusing on areas where there's reason to believe those losses might be high, but where farmers may be not aware that over the long-term, they will be losing significant amounts of productivity. Some of the work that you (Larson) did indicates that the relationship between productivity loss and top soil loss is linear over a long stretch of top soil losses and then turns down sharply. Farmers are not likely to know that. They can be moving along having erosion of 20 tons per acre per year, and suffering little or no productivity loss when, in fact, they may be nearing the edge of a cliff. They may have no reason to know that they are approaching a threshold. They judge what the future might be by what their past experience has been. The USDA would be well advised in its soil erosion productivity research to be focusing on those soils where it's believed that relationship is non-linear.

Chen — I have one minor point. There are estimates that some of the flooding problems in the lower Mississippi Delta are precisely because the erosion has been reduced. There is a benefit from sedimentation in terms of keeping existing deltas from suffering from local sea level rise. Bill just related that 10 percent of the land suffers from a 25 percent yield decrease due to erosion. Is that 10 percent the most productive land or the most marginal land?

Larson — The most marginal.

Chen — So in fact the proportional contribution to total agricultural production may be a lot less than that?

Larson — Yes. When you look at a piece of land in terms of the effect of erosion, you've got to look at both its inherent productivity and the rate of damage. The USDA has tended to only look at the amount of erosion. Some very deep soils can erode for a long time without much damage. But it you have only 20 inches of soil over bedrock, you can't erode very long before you're in trouble. We've argued that you want to look at both of those things here in Minnesota in our RIM program. The USDA hasn't seen fit to follow our lead.

Rawlins — We hope the new methodology being developed to replace the universal soil loss equation (USLE) will not be used simply to calculate average annual soil loss from erosion, and that the databases being put together to support it will help move in this direction. The Water Erosion Prediction Program[6] (WEPP) should make it possible to make risk assessments, taking into account weather scenarios, soil and management factors at specific sites. If WEPP is used simply to replace the USLE in calculating annual average soil loss we will have failed to achieve our objective.

Clark — You've just indicated that, for the U.S., there are three different studies that really give us a handle on the impacts of long-term erosion on productivity. Is there written down someplace what the minimal program, in terms of time and resource requirements, would be required to get comparably credible estimates for a useful sampling of situations around the world? I encounter vast piles of material and new sets of equations coming out of FAO, UNEP, and even USDA. I have been involved in extensive efforts to push the international geosphere/biosphere program in the direction of incorporating, a very large coordinated measurement effort, directly relevant to the ability of the world system to support people. But I have yet to see an outline of the minimal requirements. I believe that it is the sort of thing that the IGBP program would be extremely interested in having because they are being

[6]To be completed.

beaten up all around the world for arguing self-indulgent pure science, with no connection to food security, agriculture, human health or anything else. They're not willing to leap all the way out into policy research. But hard physical measurements guided by theory is great.

Ruttan — Bill, what did it take to generate the data that you and Pierre used to analyze the effects of erosion on crop productivity?

Larson — To start with, it would require a generalized soil map of, say, Africa along with a topographic map and some kind of a weather data base.

Crosson — There are two steps. One is the collection of reasonably accurate erosion data and the second is using those data in models that tell you something about the effects on productivity. Those were both very expensive in the U.S. I don't think it would have to be as expensive now. With the EPIC model the USDA can now cover the entire crop production area of the country.

Ruttan — But doesn't that require a lot of sites where you're actually collecting data?

Crosson — There were close to a million points in which data were collected in 1982. The 1977 NRI was much less intensive -- about 300,000 data points, it came to essentially the same conclusions, as the much larger 1982 study of the productivity effects of erosion.

Larson — Pierre, I think you could come up with a first approximation with much less than 10,000 points. But, it would have to be done by soil scientists or engineers. You would have to have the collaboration of someone who really knew the soil and the landscapes in the country. You can't do it in Washington or St. Paul. It could be done -- at a reasonable cost, but with not quite the accuracy of the U.S. analysis.

Clark — I would think that the one very specific notion I would like to see coming out of this meeting, is that there is an effort afoot for the global change agendas doing a next generation of soils and topographic mapping, and climate mapping for the world, with the wrong variables to be of any use, simply because the input from the soils community into that program has been virtually zero. A small, quick and dirty working group which would flesh out the proposal you just made would be very timely. Half the countries of the world are already flying under the sustainable development banner.

Ruttan — What about the big project at the University of Hawaii? Doesn't it have a very large data base that is relevant to this issue?

Sanchez — It's not an erosion data base, it's a crops simulation data base. FAO has done a map of soil degradation in Africa. I personally think it's terrible, but it may be quick and dirty enough for you and Bill.

Larson — My experience in Africa is limited, but erosion is everywhere. You can see it and recognize the seriousness of the problem. But it must be quantified to get any credibility. I do think that a program like Bill Clark was proposing is needed. We could argue about the scale. But some precision is needed to give it credibility. I was shocked when I read the article by Harold Dregne, who is a respected soil scientist. He could only come up with about 8 or 10 examples of reasonably adequate quantitative measurements of erosion in all of Africa.

Bochniarz — We have been told many times that the U.S. Soil Conservation Service program could be used as a model for other countries. What is your opinion, Pierre and Bill, about the U.S. soil conservation program in terms of its impact on soil erosion and soil quality? What is the net result of that program? Is it a model for other countries? My second question is whether there is adequate data about desertification in developing countries. What is the relationship between soil erosion and desertification? To what extent does soil erosion contribute to desertification?

Larson — Let me respond to the question about the value of our research rather than the SCS program. A half a dozen different groups from different countries have tried to extend and use our Minnesota model. Actually, the EPIC model and the work at Temple is even better. So I think the answer to the first question is that the research could be transferred. I don't know much about the desertification. I think that's even more of a no-man's land in terms of reliable numbers.

Crosson — There are two ways of looking at the question, whether the U.S. Soil Conservation Service could be a model. As far as I know, there haven't been any definitive estimates of how much difference the Soil Conservation Service has made over the last 50 years in reducing erosion and protecting soil productivity. It can hardly be anything but positive, however. There is less erosion and less productivity loss than you otherwise would expect, but the question of net economic benefit is less clear.

But the second part of the response is that the effects could have been much better. That there has been a lot of waste of Soil Conservation effort, not because the SCS was indifferent or wanted to do things that way, but they were under constant Congressional pressure to put projects into areas where there was no significant erosion threat. I think it has been a positive difference, but not nearly as much as it could have been.

Cheng — I wanted to share a little observation that I made in the People's Republic of China. Even in the U.S., much of soil conservation policy is inconsistent with the economics of farming. For many years, there was a great effort going into reforestation to prevent soil erosion. But during the last few years, after the household incentive system was introduced, farmers suddenly found that they don't have the time to continue the conservation practices. Erosion

problems have worsened. China had been conducting a nationwide soil survey and had trained people down to the township level. Tens of thousands of villagers and technicians were collecting soil samples and doing analysis. This was the Second General Soil Survey which began in 1983. But up to now, there hasn't been a single soil map generated from those data. And the data that were collected were not very useful for soil management. It's too generalized. So it's not going to be very easy, as Pedro pointed out, to get a generalized map of Africa or a country of comparable size like China. The effort in this country has taken many, many years.

Rawlins — I think we need to follow up on Bill Clark's proposal. The databases are being constructed now. Agriculture needs to have an input into the global change program to answer some of the questions being raised. We have teams developing predictive technology for water and wind erosion composed of representatives of USDA and Interior agencies. These teams are developing cooperative agreements with groups in Brazil, Canada, Australia and Israel to validate these models under their conditions. We would be more than happy to extend this network by cooperating with others to make certain the appropriate data are collected to answer the important questions.

Herdt — I just want to make an observation on the discussion that we've been having about the need for additional research or information gathering. Governments in the Third World, especially in Africa, are under great pressure. I'm not sure how many of you saw 60 Minutes last night. A lot of the shots were from Tanzania. But the program started off with the news that 40,000 children die every day in the Third World from a combination of disease, malnutrition, lack of water, and so many other things. And governments in the Third World are not insensitive to disasters of that magnitude. But they are incapable of addressing it. They're incapable of preventing it. That's just one illustration of the kinds of immediate pressures that these governments face. Many of you have worked in the Third World and you know that in every field there are immediate needs that push back research, especially research that has a payoff in the far distant future. In soils-related research, there is a great scarcity of human resources. H.H. mentioned the training of thousands of people in China. The data was collected, but you can't find the results -- there has been no pay-off.

Ruttan — The number of developing countries with more than 50 people trained in the agricultural sciences is less than 25 countries.

Clark — But we also know that one of the surest ways to increase that number is to build training into an apprenticeship mode around solving very particular problems that bridge the line between immediate relevance and basic science. It is because this issue has a certain amount of substance to it, frankly much more so than in many of the areas I see my natural science colleagues trying to cultivate through developing country collaboration, that I push it a little harder than I might otherwise. It's irresponsible to place demands on that

incredibly scarce resource without designing the effort to expanding the capacity to sustain the food resource base.

Tropical Region Soils Management

Ruttan — This morning we're going to continue with our discussion we began yesterday afternoon on the micro-environmental changes. Our first presentation is by Pedro Sanchez.

Sanchez — I will switch gears a bit and talk about the humid tropics. I want to focus on tropical deforestation and possible solutions. One possibility of abatement of global climate change is to reduce tropical deforestation. A lot of technology is sufficiently developed to be worthwhile testing. This is an issue that is not only related to global change, but also to other important issues such as the preservation of biodiversity. Reducing tropical deforestation is not only relevant in terms of global change, but it's also relevant to many other issues. The process of deforestation is very complex. Most of it is population and economics driven. This is illustrated in Figure 6. The idea here is to try to put together in one figure the causes and effects of tropical deforestation.

Herdt — You call this a Sanchezogram?

Sanchez — Horrendogram. In the Third World, the driving forces, shown on top, are population growth, limited fertility and land tenure inequities. The consequence is a landless rural population that is faced with three choices. One is to stagnate in areas of high demographic concentrations such as the Andean region, northeast Brazil, Java, and others. A second is to migrate to the urban centers. In the case of Latin America, we have the dubious honor of having the largest cities in the world already. A third alternative is migration into the humid tropics. In the Andean highlands and in northeast Brazil, agriculture is being pushed into steeper and steeper areas, causing a lot of erosion, siltation of reservoirs, and smaller and smaller minifundia every generation. Those who migrate burden the urban carrying capacity. This is evident in the large cities in Latin America. When I lived in Lima, a city of six million people, half of them did not have any sewage services, electricity or water.

The ones who migrate to the humid tropics, either spontaneously or sponsored by government colonization projects, end up in a world that they do not understand. The peasant farmers are not familiar with the shifting cultivation systems used by the indigenous inhabitants. They practice shifting cultivation in a non-sustainable manner. The forest fallow periods are shortened and the productivity of the system declines. In some countries, particularly Brazil, a large part of the deforestation is caused by land speculation. Tax breaks and credit incentives from the governments induce

large landowners or companies to clear land, partly for cattle production but mainly for land speculation. There are new laws now that are beginning to slow things down. In either case, the result is an unsustainable agriculture which results in economic failure. Most of the people who migrate to the cities thus exacerbating unemployment. Traditional societies are disrupted. The result is a cycle of further deforestation, soil and land degradation, loss in genetic diversity and an accelerated greenhouse effect.

What can be done? The data show that 80 percent of the tropical deforestation is caused by non-traditional shifting cultivation -- by small farmers who clear and burn a couple of hectares of land a year, mainly to grow food. The other 20 percent is caused by land speculation, by logging, by urban development, road construction and other unit works. But the vast majority of land clearing in the humid tropics is by small farms. Are there alternatives? Many people believe that we can stop deforestation by making it illegal -- by outlawing shifting cultivation. Shifting cultivation is illegal in many countries -- in Indonesia, for example -- but that doesn't stop it. Other policies include producing food outside the humid tropics to reduce the pressure on the humid tropics. Consider, in Brazil, the now very productive Cerrado region south of the Amazon. Brazil should grow its food there rather than in the Amazon. But people are still migrating into the humid tropics. Sometimes migration is even supported by the government, as in the transmigration programs in Indonesia. Other people believe that you should put a fence, so to speak, around the tropical forests, make them into huge national parks, and not touch anything. That is not realistic. The national parks have to be defended. It is not possible to stop people who want to clear forests to grow food.

Rawlins — But shifting cultivation does not leave the abandoned land in a permanently cleared state. Don't the clearings grow up to forests when the cultivators leave?

Sanchez — Traditional shifting of cultivation, with low population densities, allows forest to grow back over 20 or 30 years. Even so, the forest looses much of its genetic diversity during that transition because when it's cut, the second growth is not as diverse. It has also lost a lot of the carbon because the secondary forest will never grow to the size of the primary forest. But it would go back and have no long term detrimental effects on soil quality or soil erosion. But the trouble is that, with high population pressures, farmers cannot afford to wait even 15 or 20 years to reclear. When we got to the area where I work on Peru, in the early 1970s, the fallow period was about 20 years. Now the fallow period is about two to three years. In its pristine stage, shifting cultivation is fine from the ecological point of view, but the cultivator remains in perpetual poverty. Other alternatives are needed. What are these alternatives? Are there alternative technologies that are viable?

There are a lot of myths or misconceptions about the agronomic potential of the humid tropics. The soils are low in fertility. But the statement that it isn't possible to grow crops continuously in those soils is incorrect. It isn't correct that clearing a piece of forest will turn soils into laterite or that they will be so compacted that it becomes useless for agriculture. This may occur in about 3 percent of the soils. Certainly not 97 percent. It is not correct that most of the nutrient cycling that goes on between the forest and the soil bypasses the soil. Those are wrong assertions. What has been found by research is that sustainable agriculture is feasible. The classic form of high input agriculture which feeds the world, including the green revolution areas in the tropics, is technically feasible in many areas in the humid tropics. It may not always be logistically or economically feasible because the roads may not be in place and the marketing infrastructure may be absent.

Therefore, a menu of options is needed and has been developed. I would like to share with you a very simple landscape model. It first shows the heterogeneity of the humid tropical landscape. There are beaches, low flood plains, and high flood plains. There are areas that flood every year, or perhaps once every 10 years. There are high terraces with low fertility soils, but flat and relatively easy to cultivate technically. There are also low fertility soils in hilly areas that are difficult to mechanize. Finally, there are mountains, usually with young soils. A series of options that have been developed for each of these areas that are very sustainable. The most obvious one is to grow paddy rice, as in southeast Asia, in the high flood plains -- in areas water can be diverted from the river or where low lift pumps can be used. Rice is consumed in all of these countries. In Peru, there has been great progress in paddy rice production in the Amazon, based upon very simple technologies transferred from Asia, combined with plant breeding to adapt the varieties of local soil, pest and pathogens and to local tastes (Figure 7).

For the high flood plains that do not flood regularly, or for the high terraces that are flat and easily mechanizable, continuous cropping with lime and fertilizer inputs is feasible. But this requires a good road infrastructure, accessibility to market and a reliable credit system. In general, the physical and institutional infrastructure is underdeveloped except in areas around the large cities of the humid tropics. Indeed, there are some large cities -- Belem has about two million people, Manaos is over a million people, and Iquitos is over a half a million people. Although this system is technically feasible, it is economically viable only where the infrastructure exists. For most areas, it is not economically feasible. In such areas, a low input cropping system is probably the best alternative. The idea is instead of changing the soils to meet the plant requirements to change the plants to produce under conditions of soil acidity and low levels of fertilizer. We have been able to design such systems by finding varieties of key crops, rice and grain legumes, that are productive at low pH levels -- that are perfectly happy at pH_4 or so, which is very acid. By designing an improved slash and burn system, we have

been able to grow about seven crops of rice and cowpeas in rotation over about three years without any fertilizer or lime. And we had pretty decent yields. This has been done by trying to capture and recycle the nutrients. We capture the nutrients from the slash and burn secondary forest, religiously using all the crop residues. This recycles most of the potassium. After a while, the fertility of the soils does go down, simply because we are taking a lot of nutrients out, such as phosphorus, in the form of crop harvest. There's no way we can totally put that back in the form of crop residues. As fertility goes down, weeds increase. It is then time to abandon the field. But instead of letting it grow to a secondary forest fallow, we use acid tolerant legume fallows such as kudzu that cover the ground rapidly. Kudzu smothers the weeds and after a year or so you can slash and burn it and start the circle again. But some fertilizer will be necessary to replace what has been lost by crop removal.

The next stage is a transition to high input agriculture if in the meanwhile the physical and institutional infrastructure has developed. Otherwise the transition may be to agroforestry systems. The agroforestry systems are based on the use of trees that are acid tolerant, that are well adapted to the region, but that can produce food or timber or some other marketable product. There are several of them that are very promising. Most of them you probably have not heard of. But this is part of the beauty of the biodiversity that exists in tropical forests. Let me give one example. The peach palm (Bractis gasipals) is very well adapted to acid soil conditions. Within four years, it starts producing fruits that look and taste like sweet potato. The nice part of it is that it can produce about 10 tons of fruit per hectare per year over a period of 15 or 20 years. You don't have to plow. It's edible. The local people like it. It's also a good feed for monogastrics such as swine and chickens. It could replace corn in feeding systems. This palm is multi-purpose. You can cut off the apical stem and market it as a gourmet food here and in Europe as heart of palm. This particular palm regrows after cutting its stem, so you don't destroy the tree as in some other species that are used to produce heart of palm. Other fast growing trees can be used to produce charcoal or wood. Many are legumes, so they fix nitrogen.

Pastures have a bad reputation in the Amazon. They deserve it because they're poorly managed pastures that have been introduced mainly from temperate Brazil. The producers there use no fertilization, employ poor cattle management, and do not incorporate legumes in the pastures. But well-managed pastures which use acid tolerant grass and legume species, developed mainly by the International Center for Tropical Agricultural (CIAT) in Colombia, have proven to be very productive.

So there are a number of options. Groups of researchers involved in these studies believe that we're probably at the same stage as the Asian green revolution was in the late 1960s. The prototype technology is there. A combination of these alternatives, when applied to areas that are undergoing

intensive deforestation by people who want to settle and produce food perhaps slow the deforestation, given the right policies. It's not going to happen unless the government policies support these more sustainable systems and discourage shifting cultivation, and other forms of destructive land use.

We calculated how many hectares can be saved from deforestation for every hectare put into these different management options, . In the case of flooded rice, farmers are able to grow about 11 tons per hectare per year of grain. That's in two crops averaging about five and a half tons per hectare per crop. Under shifting cultivation, where upland rice yields are one ton, you would need to cut 11 hectares to produce 11 tons of rice. For every hectare in flooded rice, you could save about 11 hectares from additional deforestation. The ratio in low-input cropping systems is less. But for every hectare that's put into even the low input, sustainable systems, you might be able to save from 5 to 10 hectares of forest every year.

There are viable alternatives to shifting cultivation. Farmers don't shift and cut forest because it's fun. Cutting a tropical forest is extremely hard work. It also means moving households, or commuting by foot further and further from their fields. There may be real options that could slow deforestation if policies are developed that would encourage sustainable systems. About eight countries account for over 80 percent of the world's humid tropical deforestation. A program that concentrated in those eight countries would cover most of the problem areas. I am not going to speculate how much this would affect global warming. In the last year, I've seen reports that tropical deforestation may account from as little as 10 or as much as 25 percent of global warming. The point is that something that can be done now.

Crosson — Could you tell us a little bit more, Pedro, about the policy changes that would be necessary in order for these systems to be adopted on a wide scale?

Sanchez — Some of the policy changes are quite simple. The Agrarian Bank in Peru should pay the farmers for their rice at the time it is sold, rather than four months afterwards. With an inflation rate of 40 percent per month, farmers are discouraged from growing rice if they can't get paid for the product when it is marketed. Others are more complex. The transport infrastructure has to be developed to reduce the cost of getting inputs, such as fertilizer, into the communities, and getting the products out. Also, there should be some disincentives against further land clearing.

Crosson — You mentioned that the absence of adequate infrastructure is a primary impediment to adoption of high input systems. Would you expect to see both the high input and the low input systems expand if they provide the necessary infrastructure?

Sanchez — It depends on individual country or regional situations. A country like Brazil that can produce plenty of food in the South probably should not provide incentives for high input systems in their Amazon. It would be more appropriate to focus on some of the low input agroforestry systems. A country like Peru that is deficient in basic food grains may want to encourage rice production. The point is that there really is a wide range of options, depending on the local ecological and economic environment.

Rawlins — I have seen claims that the long term harvest of nuts and other natural products from the natural forest would product a higher return in the long run than could be obtained by opening the land for pasture or crop production. Are there other economically viable but less destructive ways of using the forest?

Sanchez — Very few. Natural rubber is one. But while it may preserve the forest, it provides no way to escape from poverty for the rubber tappers. But if you want farmers or gatherers to stay where they are, that's one way to do it. Selective cutting has been very disruptive. In order to select and harvest the few marketable trees per hectare in humid tropical forests, you destroy a good deal in the process. Forest enrichment, in which you cut swatches two or three meters wide in the forest, and plant improved species, has not worked. There's too much competition from the natural vegetation. Pastures under forests have been tried. The pastures are poor and the forests are partly destroyed. It may be better to leave the forest as it is. If you want to save the forest, don't touch it. Do something else around it. From a forestry point of view, a tropical forest is a mess. It's a horrible tangle of hundreds of different species. A production forester does not want to mess around with a humid tropical forest. He would rather have a nice, well-planted, well-spaced uniform stand of trees. There are a few exceptions like rattan, which is a vine that can be used for baskets and furniture. There are things like the rosy periwinkle, a little flower discovered in Madagascar, that's used as a base for chemotherapy. But, you can't use a tropical forest and keep it as it is.

Chen — I read something about using iguanas and other small animals for food. Could enough of them be raised to get a reasonable income from the meat?

Sanchez — Iguanas are from the semi-arid areas. But there are also a lot of small rodents in the rain forests that are delicious. But, if you're going to produce them commercially, it will probably mean raising them outside of the forest. I think most animal scientists are not optimistic about the possibility of using new animal species on a large scale. At the local level, however, they have a place.

Rawlins — What about biomass power generation? Species mix would not be an obstacle.

Sanchez — No. That could be another option. You could have income from the forest and replace it with fast growing biomass. Inga species produces over 15 tons of dry matter per hectare per year during its first three or four years. The oil palm, as I mentioned yesterday, does produce more oil per hectare per year than any other crop. You can put it directly into diesel engines. There are other species of palm that might be used for oil production in the Amazon. We may be able to harvest the tropical forest for biomass, but I hope we will not. Biomass can be grown better elsewhere. Also, keep in mind that the carbon accumulation in tropical forest may be as large as 200 tons of carbon per hectare. Every time we clear a tropical forest, we're releasing large quantities of CO_2.

Waggoner — Would you repeat that? 200 tons of carbon per hectare in the standing crop per year?

Sanchez — The range is probably between 50 and 250 tons of carbon per hectare. In the standing crop of a virgin tropical forest, there and in equilibrium, it's not growing. It's just sitting there. When it is cut and burned, most of it either goes right into the atmosphere or decomposes and goes later. It cannot be recaptured. Some soil organic carbon also decomposes after land clearing.

Rawlins — If you put the forest biomass through a power generator to replace fossil fuel, you haven't lost it.

Waggoner — Then presumably it could be replaced with fast growing trees that would have a positive accumulation of carbon per year.

Davis — What he's saying is that it would be very hard to regenerate to that very high original level.

Sanchez — It could take 50 to a 100 years.

Rayner — The other problem, if you're looking at this from an energy perspective, is where to locate the generator? You're not going to locate it near a forest that will not be replacing. For biomass energy to be economically feasible, it must be based on high intensity biomass production. There's no other way to do it economically. That means growing closely planted, fast-growing species.

Davis — Can the production systems you're talking about be used on present pastures? Can you reclaim those present pastures?

Sanchez — Yes. There are two or three ways. One of them is to improve the present pastures by planting some of the improved species, especially legumes, in strips. In small pastures, you go in and spread a little bit of rock phosphate and plant legumes. They gradually take over and improve the pasture. When the pasture has been degraded badly, you can burn the degraded

pasture, fertilize, and seed. It depends on the nature of the degraded pastures. A lot of pastures are degraded because they're infested with grasses that animals don't use. Others have been compacted or degraded physically and chemically. They require a different type of renovation than ones that are just degraded in terms of weeds.

Davis — What are the economic and policy issues there? Who owns these degraded pastures? Who controls them, who uses them, and what happens to them?

Sanchez — Well, it varies from country to country, but most of it is owned by individuals. The large scale pastures are often owned by absentee landlords. They often don't manage them well because they're just sitting there speculating on the land price. The farmers are in the 50-100 hectare range, as opposed to thousands of hectares in some parts of Brazil. These small units are interested in improving their income. You can work with them.

Davis — But in Brazil where they've cleared forest and replaced it with pastures, there's no way that a small farmer really has the capital to go in and reclaim a pasture, is there?

Sanchez — The small farmers in Brazil have pastures. In Rondonia, where they may have 50 to a 100 hectares, they are very interested in having those pastures become more productive. There are low cost technologies that can be used to gradually reclaim the pastures. This is in contrast to what happened in eastern Brazil along the Belem-Brasilia Highway, where so much deforestation took place about 10 years ago. Huge pastures were developed in that areas. It's probably going to take some government intervention to make those people change.

Allen — Pedro, you didn't say anything about fish culture or animal culture beyond ruminants on pastures. Are there any other animal systems that would be useful if integrated into the total systems you talked about?

Sanchez — There are other possibilities -- fish like tilapia. Instead of having two crops of rice a year, you could have one rice crop and nine months or so of fish culture. There is also some potential for the water buffalo in this system. The water buffalo eats low quality pastures that no self-respecting cow would touch. It is the ideal draft animal in the humid tropics. They have great potential in the humid tropics of South America.

Ruttan — Pedro, realistically, isn't the problem that, until the infrastructure comes in, you can't get the stuff in and you can't get the stuff out without having to haul it on your shoulders? But even when the infrastructure is developed and the more intensive system becomes economically viable, it will always be a poor system. The producers are not going to get rich, even if they work as hard as a Taiwanese peasant. It seems to me that, given the pressures of people against the resource (and that's not going to stop), you're going to see

continued opening up and destruction of the forest. I find it very difficult to believe that the governments of Brazil, Peru, Venezuela or central Africa are going to be able to stop that process, given their limited administrative capacity and their political structures. As you know, even the Philippine government cannot keep peasants from invading the national park on the mountain right behind the International Rice Research Institute.

Sanchez — That's why I think there will have to be policy intervention to change the incentives. I see very little hope in central Africa at the moment. But in countries like Peru, Brazil and Indonesia, changes may be more feasible.

Rawlins — Reducing population pressure must ultimately be the means to reduce the exploitation of tropical forests.

Clark — It's too late.

Crosson — If systems you are working on are economically more attractive to the small farmers than the slash and burn system, why don't they adopt this system rather than slash and burn?

Ruttan — In the areas I've looked at, infrastructure is a major barrier. Just ask yourself, "How many kilometers do I have to carry a bag of fertilizer or a bag of rice before its value becomes zero?" Not very far. There has to be dense infrastructure to sustain intensive agriculture.

Rayner — Surely in a place like Rondonia, Vern is right. A decade and a half ago there were only four or five paved roads in the whole state. Now if you look at the aerial maps, at least two-thirds of the state is covered by a very regular grid pattern of paved roads. The pattern of deforestation has followed the developments of that road system very closely.

Sanchez — The area in Rondonia affected by roads is still very small -- no more than 5 percent of the state. But you are right that, where the roads are, is where people are. They get a land grant of about a hundred hectares. Then the question is what do they do after they clear and cultivate for a couple of years.

Soil Fertility

Ruttan — Now I would like to turn to Bob Munson. Bob has worried about soil fertility for quite a few years.

Munson — I certainly have had a long-term interest in soil fertility. I started out working on nitrogen soil tests at Iowa State with George Stanford, and then did my Ph.D. work with John Pesek. At that time, we were working on nitrogen soil tests and trying to figure out how to predict, from soil tests,

what you should apply to the soil. In the 1960s nitrogen became so cheap that we proceeded to forget about what we knew. Now in the 1980s, we've come back to some of the same issues. We are making nitrate soil tests and coming up with better prediction as to the nitrogen rates that should be used in terms of both crop response and environmental impact.

There is still a great deal that you can do with a pencil. You don't always need a computer. Several years ago, a dealer asked me, as a consultant, to come up with a prediction equation for the amount of nitrogen that should be used on one of his customer's fields. We had soil samples to three feet and complete soil test information. He asked the question: how much nitrogen do I need to apply to grow 150 bushels of corn? I reviewed the available data from Illinois, Iowa, Minnesota and Wisconsin. The answer was zero. The hand-harvested check on six different hybrids was 162 bushels. On the combine check, it averaged 157.8 for six different hybrids. He then asked me how much nitrogen do I need to apply to get 175 bushels of corn. My estimate was 75 pounds. He pulled 172 bushels off of that check. My point is that we know a lot more than we're using. The other point I would like to make is that we don't get something for nothing. Each crop has an internal nutrient requirement. That requirement will vary some, with the maturity and variety, but it's an almost linear rate from about 60 bushels up to over 300 plus bushels of corn. It takes a certain amount of nutrients to grow a bushel of corn.

If you look at soybeans, it's a different value but the crop has an internal requirement in order to grow and produce a bushel of grain. The same is true for wheat. Phosphorous requirements will tend to be more variable than nitrogen and potassium. The other thing to remember is that every bushel of grain that you take from the farm removes a certain amount of nutrients. The amount that's taken off per bushel of grain is fairly constant once you get up to economic yield levels. In terms of efficiency and the nutrients we apply on different soils, there's much greater variation. On many of our more productive soils, we recover only about 50 percent of what we apply.

In integrating that, it should be remembered that we obtain that recovery by differencing the soil organic matter which will provide a certain amount of nitrogen. In many cases, we tend to forget about that amount of nitrogen that's provided by the soil organic matter. In southwestern Minnesota, the average 24-year yield on the control plots where no nitrogen was applied was about 69 bushels per acre. The yield ranged from zero to 141 bushels on that plot. There were good nitrogen responses over time on those experiments. It takes about 1.12 pounds of nitrogen to produce a bushel of corn. About 77 pounds of nitrogen per acre came from that soil year after year over this 24-year period. Organic matter is about 5 percent nitrogen, so to produce that 69 bushels, it took a little over 1,500 pounds of soil organic matter. If we take into account all of the nitrogen in the system, there's roughly 25 to

30 percent that we cannot account for, even if we measure down all the way to the ground water. My earlier view, based on available research, was that it had been lost to the air and not to ground water. But we know that even under the best conditions on those control plots, there's going to be nitrogen that gets to ground water. The measurements that have been made in southern Minnesota on unfertilized lysimeter plots, show that the water coming out of the tile line is about 13 parts per million nitrate nitrogen. If you put on a hundred pounds of nitrogen and you increase the yield up to about 145 bushels, the water coming out of the tile line had about 41 parts per million of nitrate nitrogen in it. My point is that you cannot produce crops without having some nitrate nitrogen around. If people think that we can grow a legume -- for instance, continuous soybeans -- and not have some nitrate nitrogen coming out of the system, they're just kidding themselves.

There is a cost of growing crops and part of it is having nitrate nitrogen. As soon as we tilled our prairie soils and speeded up the decomposition process and the release of nitrogen from the soil organic matter, we started to release nitrate nitrogen into the environment. And so no matter what we do, we're going to continue to release some nitrate into the environment. The other thing to remember is basically the nitrogen in the system is rate driven. It becomes very important to choose the right rate so that you grow the highest yield you can and have as little nitrogen left in the system at the end of the season as you possibly can. Other things to remember are to use profitable amounts of other nutrients and land use management that will optimize the efficiency of the applied nitrogen.

Information Systems for Soil Management

Larson

My thesis this morning is that many of our environmental and natural resources problems could be eliminated or minimized if we used better geographic information systems. I think we've all seen cases of bad land use in agriculture, forestry, rangeland, urban development, waste disposal sites, and others. Today, of course, we pretty well understand the geology and the macro geographies. But we still don't recognize and take into account what I call the micro spatial variabilities in soils and landscapes. The micro spatial variability is usually captured in our soil surveys. The National Cooperative Soil Survey has the goal of having the cropland in the entire nation mapped by 1992. That's a tremendous job. I don't know what it costs nationally, but in Minnesota, the federal and state governments spend about $4 million a year on soil surveys.

In the past, the county soil surveys were usually reported in a thick document with a hundred pages of maps. Most people just won't use them because they were too complicated and cumbersome. But the modern maps have

been digitized and put on computers. A farmer in Minnesota can walk into our County Extension Offices, and within 30 seconds we can have the map up on the screen and start to tell him about the characteristics of his land and how to make interpretations of the soil survey. In Minnesota, we now have about a third of our counties digitized. Most other states aren't that far along. Some of them are a bit further. It costs money but it makes the soil survey a usable tool. We must also combine the soil surveys with good geographic information systems. We in soils have made the soil surveys but we have not always done the landscape mapping in enough detail to make them as useful as they might be.

Let me give you an example of what can be done. Soils vary a great deal in their chemical and physical characteristics. Even a seemingly uniform landscape often has great differences. The public only sees the surface. There's a lot of variation below the surface.

Let me give you an example of what can be done. We took a 50-acre field in southwest Minnesota that is fairly typical of the glaciated areas of the upper midwest. The published soil survey had seven mapping units in that 50-acre field. Surface texture varied from loam to clay loam. The slopes varied from about 0 to 10 percent. We went to our published crop equivalent rating that indicates the potential for corn yields on each of those seven mapping units. The potential yield varied from 65 to 145 bushels of corn per acre. Any soil scientist knows that you have to match fertilizer inputs to the potential production of that soil. It would seem ridiculous to fertilize that field in a uniform manner. That 65 bushel soil does not have the same response to nutrients as the 145. Our published fertilizer recommendations then would vary on those different mapping units from 40 to 150 pounds of nitrogen per acre per year on corn.

We have recently developed equipment that will apply differential rates of fertilizer as it goes across the field. The equipment carries straight nitrogen, straight phosphorus, straight potassium, and herbicides in separate bins. It can mix them on the go and apply different rates as it passes over the field. These rates can be based on the soil survey, or it could be based on soil tests, or on historical yield records. The computer facilities are in the cab of the machine to vary application rates as the machine goes down the field. These machines are made by a company here in Minneapolis and are commercially available.

If you fertilize the 50-acre field at the 150 pounds of nitrogen rate, which is appropriate for the best soil, which is probably about what a farmer would do, then only about 10 percent of the field would be fertilized at the correct rate. But 77 percent of that field would get 30 pounds more than would be recommended, 7 percent would get 50 pounds more per acre, and 7 percent would get 110 pounds per acre more. Likewise, these seven mapping units have a hydraulic conductivity that varies by about five-fold. The absorption

coefficient for the two pesticides vary about five-fold. This means that on those seven mapping units, some of the herbicide recommendations would be only half what they might be on others.

On this 150 acre field, using the machine that I described, you could save about $8 an acre. At the same time, you would reduce the leaching of the fertilizer into the ground waters. I calculated that you would save about 1,500 pounds of nitrogen on the 50-acre field. And if you assumed that all of that was going to leach into ground waters, then it would account for about 10 parts per million of nitrate in the top foot of the ground water. That may not be perfectly accurate but it does give you an order of magnitude. I also calculate, using our model, that if erosion continued at present rates on that field, at the end of a hundred years some soils would be unchanged. Others would experience about a 12 percent reduction in productive capacity.

My point is that we are now developing the information technology that will help us achieve sustainable agriculture. We've got to do a much better job of matching the soil and the landscape characteristics with the management of our land, including nutrient use, pesticide applications, erosion control, and others. With modern digitized soil surveys and modern equipment, we are making progress. The data isn't available in many places. But it seems to me that's our charge for the future: to develop the data bases, including soil surveys, landscape data, and weather data bases.

I'm often asked if I picked an example that's not typical. I think that field is reasonably typical. When I was out in Idaho in the Paloose area a couple of weeks ago, they were talking about what they called Catina management. It is the same thing we're talking about, but by a different name. Last weekend I was in South Carolina coastal plain, giving this same sort of talk. I asked Pat Hunt how many mapping units he had in a 60-acre field right adjacent to the station. He said 18 different mapping units on this coastal plain land that looked as flat and level as this floor. The variability I described is normal. In the future, we will benefit to take that variability into account in our management systems. We have the technology right now. But the data bases are still underdeveloped.

Clark — Is this $8 an acre or so you thought you could save figured with current market prices of the inputs? Is that a big incentive relative to the investment you have to make? Let's assume the data base exists, so it's just the added investment to be able to utilize the machine. I have no feel for the scale.

Larson — It could represent about 15-20 percent of the fertilizer cost.

Ruttan — Another way of thinking about it is to ask how much would it cost for the precision application.

Larson — The machine is a big machine. It's not very practical for an individual farmer. For custom application, the charges are about $2.50 an acre more if the rate is varied as compared to not varying the rate. The $2.50 is subtracted from the eight already. The $8 is net.

Waggoner — Bob, you started out with the example of what you did on the back of an envelope. I want to ask H.H. and Bill Larson about all this savings that you were going to realize with these elaborate machines. Couldn't the gains be realized without this intermediary of the elaborate machine?

Cheng — I think it's the principle we're trying to get across. The point about soil variability must be understood.

Larson — I told someone at the break, Paul, that when I was a boy in Nebraska my father used to put me on the manure spreader and say take it out and put it on those eroded knobs. That was farming by soil variability. You can do it by hand, you can do it a lot of different ways; it doesn't have to have that elaborate machine.

Waggoner — Yes, but my point is whether the machine really is necessary. By concentrating on the machine we could imply that the principle was only applicable to Europe and North America.

Rawlins — I think it is a very good point. We always need to distinguish between principles and tools. But there are places where you simply must have the machines to apply the principles. Having sufficient nitrogen in the root zone for highly productive crops does not have to result in pollution if the right management is used. In Florida some horticultural crops are grown with a plastic cover to protect the root bed from leaching. This management practice forces the water to infiltrate between the beds, leaving the nitrogen intact. We need to be smart enough to develop other management practices that decouple water and chemical transport. But application of these practices may require specialized tools.

Larson — The company that manufactures this equipment has sold 40 or 50 all over the world.

Clark — So at the moment, if one simply conceives of the data base itself as a public good that should be publicly funded, then one doesn't even have to add that investment cost to the fertilizer and pesticide prices in order to have an incentive that is sizeable.

Larson — The cost of establishing the data base is. But there are the water quality benefits as well as cost reductions.

Crosson — Not for the farmer, though, unless his own well is being contaminated.

Larson — That's frequently what happens. Our farmers are also concerned about the environment.

Clark — I think the key is that if you can make money on the issue and feel good about it to boot rather than having to impose a cost to do good, then it's just all that much more of an incentive.

Crosson — Does this company have a program to develop the yield potential information? It would seem that there would be a market incentive. Is there any evidence that that's happening?

Larson — A third of our counties have the data for the whole county digitized. Farmers can get that from us or from their county. If the county doesn't have the data, the company will digitize the farm for a fee. We charge the counties for digitization because they use it for land tax assessments and lots of other things besides farm management. It costs about $35,000 for a county to do it. That is about $1,200 for a six mile square township -- practically nothing.

Rawlins — I have been working with some commercial companies on the possibility of developing position sensing instrumentation for tractors and harvesters. Experimental harvesters have been developed that can measure yield continuously as they move through the field. Combination of these two technologies would make it possible to develop highly detailed yield maps. Using last year's yield as a surrogate for soil productive capacity throughout the field may be a good first approximation for varying the distribution of fertilizer automatically through computer control.

Position sensing would also provide guidance for machines to follow the same track each time through the field. This would provide the means for implementing Bill Larson's zonal tillage concept. A compact traction zone could provide all-weather access to the field to apply chemicals or harvest in a timely manner. A specifically tilled infiltration zone could provide route infiltration around the root zone, decoupling water and chemical transport. Fertilizer and other chemicals would be applied only to the protected root zone, which is tilled to enhance rooting. All of the components to practice zonal farming exist, at least at the experimental level. Someone needs to take the responsibility for integrating them into an economically viable system. The first customers for these could be experimenters who need to put out yield trials. They could design the yield trials in their computer, program the seeder or fertilizer applicator to half the application rate in some sites and double it in others. Then when the field is harvested the computer could automatically calculate response functions from its numerical yield map.

Ruttan — The one question I have is whether you have a device to protect the farmer against the dumb or the drunk machine operator?

Rawlins — The machine should ideally be operating on auto pilot, but a dumb or drunk operator on board could over ride it and create havoc.

Bill, it seems to me that last year's yield map may actually provide finer structure for applying variable fertilizer rates than the soil map.

Larson — Perhaps. I often like to use the analogy of a dairyman. A dairy farmer would never feed every cow the same grain ration. He feeds the cow depending upon her milk response. Similarly, we've got to feed every soil depending upon its response potential.

Munson — There are soil sampling devices that record exactly where the sample came from. When that is fed into the microchip, it provides the information to change the rates of nutrients applied as the fertilizer spreader moves across the field.

Cheng — You were talking about precision sensoring. Right now it's done by laser, by triangulation, and it's not too accurate. But satellite technology is coming on stream that will let us pin point the application of fertilizer by computer within 10-foot intervals.

Davis — I have recently attended a forest soils conference in which very much the same philosophy was being proposed for managing a national forest to reduce the inputs of herbicides. The USFS was trying to develop soils maps which would tell them the potential of a site and then manage the forest for what would grow there anyway so that they could reduce the cost of herbicides and other forms of management.

Ruttan — My wife would like to make sure they don't spray when she's out picking blueberries. Let me turn now to H.H. Cheng.

Cheng — Bill spoke of a number of the things that I had in mind. But I would like to pick up on a number of things discussed in the last couple of days, and clarify a few points.

Yesterday I mentioned the adaptiveness of farmers. When we were talking about dumb farmer models, I made the comment that the problem is the dumb modelers. Even those of us that grew up on a farm often have an image of farming which is decades out of date. For example, in many of our global models, we tend to treat all crops as the same. But even all corn is not the same. Some producers use as many as 10 different varieties each year.

When I was still in Washington State, we had a very well-known wheat breeding program. There's one breeder who has been quite successful in breeding winter hardiness into wheat. Yet every time I went to wheat

growers meetings, I would find the farmers using varieties from Oregon rather than from Washington. The varieties are less winter hardy, but have other characteristics that are probably more desirable. They were willing to take that risk because they were betting on the weather. We had not had a really hard winter since 1968. They're willing to take these risks. They are much more adaptive than our scientists, who just keep on trying to breed winter hardiness into the wheat. We have the same problem with a plant pathologist. He was always trying to identify varieties resistant to snow mold, but we haven't had snow mold for 20 years. We really need to think about adaptiveness of our science and our scientists.

Let's move on to a few other points. I'd like to clarify something about methane gas. I think we need to be careful in thinking that any time we find waterlogged or saturated soils, that we will automatically produce methane gas. Methane is only reduced at the lowest redox levels. There are a lot of other oxidized species in the soil which must first be reduced, particularly iron, manganese, and nitrate. De-nitrification is far more important. Even in rice fields we find, because of water movement, there is an oxidized zone in the soil. There are certain soils in the rice field that do produce methane. But we have to be very careful about these generalizations. We talked yesterday about the cadmium in fertilizer. We found in California and in Japan that cadmium is not a problem.

So I think these are some of the things, but perhaps one we have not paid enough attention to is the variability of soils. In recent years, I've traveled quite extensively trying to understand about wet soils. They look beautiful under their natural conditions. If they are kept wet, there is good leaching capacity and they generate very nice lush growth. But as soon as they come into cultivation, as soon as they dry, a lot of their characteristics change. You have to be very careful in managing these soils. We have to recognize that each soil has to be managed differently. We may be able to reduce the material inputs by increasing our inputs of knowledge and information. This means not only data intensive, but also analysis intensive systems. The problem with many of the models is that there is no way to verify them. We've worked for years on the water quality models, large landscape watershed type models. EPA has worked for almost 20 years. Finally they gave up because there was no way to verify them because of the variability. So most of our modeling effort must become much more process oriented, rather than just regressing the apparent cause on effect.

But let me just go one point further. What Bill has described is only one application. In the soil survey information system, we have the data base not only for agricultural production, but for water quality. We are including data on pesticides, their leachability, and their adsorption characteristics in each soil. We also have decision making aids for wildlife habitat, for recreation purposes, for building constructions, and for a number of other purposes. There's a whole list of information being gradually built into the system to

make the soil survey information useful, not just for farming, but for total management of our soil resource.

Herdt — I wonder if everybody accepts your last proposition that, by going to a more closely controlled use of inputs, you're going to achieve all the social goals as well as all the private goals.

Cheng — The economists and the sociologists are going to have to work with us to answer that question.

Sanchez — I agree with H.H. I think he is in a win-win situation. If he can increase the efficiency of inputs and decrease pollution, that is a lot to accomplish. Isn't this what sustainable agriculture means in the U.S. context?

Clark — It is at least moving towards sustainable agriculture. I think the point it that if you can substitute information for inputs, that has very positive environmental externalities. The information is less polluting than the pesticide or fertilizer that you displace. You may still end up with too much nitrogen or too much pesticide drifting around your system. But you have made the next stage of the problem easier to address.

Larson — It's a big job to make all these surveys, digitize them, develop all the auxiliary data bases and interpret it. Software development is a big job.

Waggoner — Now you're beginning to say that perhaps it's expensive.

Crosson — My understanding, Bill, is that once the data is available, then it is relatively inexpensive to make that information and related services available to the farmer. But it's still not entirely clear to me how the cost of collecting the information in the first place should be handled.

Larson — The $8 that I quoted didn't cover any of that.

Crosson — When I refer to a win-win situation, I interpret that to mean that the costs to the society of making these practices available at the farm level are less than their social benefits and that the cost to the farmer of adapting the practices is less than the benefits he derives from them.

Chen — But there are gains to society over and above those to the farmer. Thus, society has to make the investment in order to get the returns.

Crosson — The nice thing about win-win is you don't have to do anything other than provide the farmer information about the practices. In his own interest, he will adopt these practices, so he wins and we win. It may still be in society's interest to do something to achieve these practices, even though it would not be in the farmer's economic interest to pay the full cost.

Rayner — In the report that we just completed for DOE on policy options for private sector responses to climate change, we actually looked to the issue of smart machinery, and suggested that two things at least would be important in compressing the market penetration time. One would be some kind of public invention support program to get the right devices developed. An the other was some public expenditure on a demonstration program for the technologies.

Cheng — The Minnesota Legislative Committee on Resources has been funding our accelerated soil survey. The state has just passed a new constitutional change that will create an environmental trust fund which will eventually build up to a billion dollar base so that we'll have somewhere about $50 or $60 million every year to improve resource management.

Pests and Pathogens

Ruttan — Let me now turn to Richard Jones. We've talked about many things that have implications for entomology. Climate change is going to affect the things he's concerned about. And what he does about the things he's concerned with is going to affect the environment.

Jones — Vern asked me to participate in this workshop and discuss constraints in agriculture in the next century as it relates to pests. Although I'm an entomologist, I will try to talk about pests in general -- insects, weeds and diseases -- because these are three significant worldwide constraints to agricultural production. I'll try to talk about the changes that I see coming in the next 15 or 20 years that affect the way we deal with these three pest types.

We do, as most of you know, suffer significant losses in agricultural production due to pests. The latest estimate is about 13 percent of the agricultural production is lost just to insects. When you add weeds and diseases to that, it would be considerably larger. Insects, weeds and diseases are constraints on the types of crops we grow in certain parts of the world and even in certain parts of the United States. And without pesticides, for example, it would be almost impossible to grow potatoes in the Red River Valley or lots of other places in the United States. Cotton is another commodity that it would be very difficult to grow without pesticides. These are commodities that are on the pesticide treadmill.

What changes do we expect? Many of the changes will relate to the costs and benefits from pest control. The farmer does a cost benefit analysis to make the decision whether or not to use a pesticide. Social cost benefit calculations enter into public policy and regulatory decisions. Now issues are being added to the cost calculations. These include greater attention to food

safety and water contamination. The question is how to incorporate the environmental insult from the use of pesticides in a manner that influences farmers decisions. The farmer responds primarily in terms of perceived change in profit. This calculation differs around the world. The cost-benefit relationship in Africa is different than in the United States. The pesticides which we have depended upon heavily for the last 30 or 40 years are under increasing pressure, not only because of increased costs, but also due to increased pest resistance. Many companies are finding their pest control business less profitable and one either considers cutting the R&D budget or even getting out of the pesticide business.

Whether we like it or not, we are going to have to look for more alternatives in dealing with our pest problems. One of the alternatives is biological control. Certain types of biological control can be less expensive, but many will be more expensive. Another is host-plant resistance. A third is the use of biocides-pathogens that perform like an insecticide. Integrated pest management has been a concept that has been around for the last 25 or 30 years. Adoption has been slow because it is information and management intensive. For example, we have developed economic thresholds and recommend that farmers spray only when the populations reach a threshold. But farmers tend to be reluctant to make the counts. In certain parts of the country, and for certain crops like cotton, consulting has become an active business. Consultants do these weekly counts. But it's not very widely adopted. And the reason I mention this is that there are sociological considerations that enter into the farmers' decisions. They like a simple operation.

One of the things we've talked about is global warming and how that will that affect pest problems. It will affect weeds just about like it does other plants. We can expect increases in the range of certain weed species. In terms of insects, two or three degrees centigrade change can affect the range of a pest by several hundred miles. In the case of Minnesota, if that happens, that means that probably we'll have another half of a generation per year of European corn borer, as an example. It will increase the number of generations of an insect pest. This will create an increased demand for pest control.

I don't know that anyone's really examined the effects of an increased CO_2 level. At lower oxygen levels the metabolism is inhibited because insects breathe by diffusion, and there's an oxygen-carbon dioxide ratio that determines their metabolic rate. I would assume that if CO_2 increases and oxygen stays the same, then you expect metabolism to slow somewhat in insects. But this may be more than compensated for by the increased temperature.

The fertilizer effect of increased CO_2 will actually make a more nutritious plant. This will be a plant more desirable to insects. For example, one of

the theories about the spruce budworm outbreak is that it is nutritionally related. So if you do get a fertilizer effect of CO_2, then it could have some impact on insect populations and outbreaks.

Moisture is an important factor also. It's particularly important for pathogens. Increased humidity improves the conditions for pathogen development and there would be more problems with plant diseases. On the other hand, lack of moisture creates a favorable environment for some insect pests like spider mites and grasshoppers. During the last three years in Minnesota, with drought and above average temperatures, both of these problems have increased significantly.

One of the things that influences the severity of pest problems is that our world is shrinking because of modern transportation. We wind up with a lot more exotic pests. The pests that are causing most of our problem in the United States are the exotic pests. This is a problem that probably will get worse instead of better. I don't know how to deal with the problem because it's not possible to effectively regulate movement of people and goods in and out of countries. However, a number of these exotic pests are good candidates for classical biological control. If you go back to the country of origin and collect the natural enemies, there's a good possibility that you can reduce the equilibrium population of the exotic pests. That's worked with a number of exotic weeds and insect pests.

Biotechnology will have an impact on pests, particularly in the area of host plant resistance. We can expect to see great progress in transferring genes that will provide resistance to plant specific pest species or to pathogens. It's not a panacea, however, because once you put that gene in the plant a process of co-evolution of pest and host will ensue. An example is the case of wheat and Hesian fly. It's been going on for 30 years. We have to continually release new varieties of wheat to maintain resistance to the Hesian fly. That type of thing will continue to occur as biotechnology is applied, only the types of resistance will be a little bit more dramatic. Progress has been limited thus far because there's only been a few different suitable genes identified, such as the BT toxins, that are suitable for putting into plants. So far, they aren't tissue specific, so the toxin goes all over the plant. It remains to be seen how acceptable these toxins are gong to be in the food chain. That's a big issue that hasn't been resolved yet. With our increased concern regarding toxic chemicals in our food supply, it's likely to become a significant concern.

Another thing that I have concern about is property rights. Using this type of breeding to develop resistant plants puts the whole ball game into the hands of the seed companies. This could cause the price of seed to become more expensive -- a lot more expensive if one company has a monopoly on a suitable gene. This raises the question of who will develop these materials and who the property rights belong to. In the past, universities have been

very heavily involved in crop breeding. And the whole question of the role of the public sector in developing and maintaining ownership of this genetic material is becoming a significant question.

Another issue affecting the pest problem is chemophobia. That's the current public perception of the danger of chemicals. This is something that's going to be with us for a long time. We can expect to see more attention to how synthetic insecticides or pesticides compare to the natural pesticides which actually may be a lot more carcinogenic than the synthetic pesticides. The issue of the naturally occurring carcinogens that we eat regularly will receive increased attention. This is not just a scientific issue but a question of public perception. We must be conservative in the use of our pesticides, but we need to be realistic. There's a public perception of the danger of some of these chemicals that has little relationship to reality.

How changing agricultural practices will affect pests, particularly things like reduced tillage. Rotations for the most part, reduce pest populations. Reduced tillage will probably result in increased pest populations, particularly insects. Fall surveys of European corn borer in counties in western Illinois indicate over five borers per plant, which is higher than it's been since World War II. And that's in an area of Illinois where there is a lot of reduced tillage. One doesn't want to generalize from such an event combination, but it's an indication of something that needs more investigation.

What are some of the alternatives to pesticides? I've mentioned some of them -- classical biological control; biologicals that behave like insecticides; and host plant resistance. Integrated pest management will be more widely used. There's always talk about big population reduction programs such as the use of sterile males as in the screwworm control program. People are still thinking about ways to pursue such techniques with other pests. There is currently a project going on to eradicate the boll weevil from the southeast. It's making some progress, but it is working against very powerful forces of natural selection. Only a pest that is causing tremendous economic cost can justify such large scale expensive techniques.

I'd like to mention a few more things. One is habitat destruction, such as deforestation. We think it's a big problem, but we don't really know how big it is because we don't know what's there in terms of either insects or plants. A big effort to really inventory what is there is needed. We know a lot more about our solar system than we know about the biology of our planet. And this is a big deficiency. E. L. Wilson says it's more important to be doing a biological inventory of the planet than the human genome project because the genome will still be here 30 years from now but these other genes will not be.[7] But that kind of biology is not glamorous. It involves drudgery

[7]To be completed.

work, like the soil survey work. It's hard to get funds to do it, but until we do it, we won't even know what we're losing.

Another issue is the relationships between pests, health and agricultural production in Third World countries. The battle against insect vector diseases is being lost. There are more people dying of malaria today than there ever have been -- a million a year in Africa. DDT didn't eliminate malaria and it didn't eliminate mosquitoes. But it did eliminate all the people that were working on malaria and mosquito vectors (because of a perceived lack of need). Now we have very few medical entomologists. We don't know what the impact of this million deaths a year on agriculture in Third World countries will be.

Ruttan — In our next consultation, which we have scheduled for June, we will be looking at the relationship between health and agriculture.

Jones — One concern is the declining support for graduate training and research in the pest management disciplines. We need to give greater attention to urban entomology. But in the present budget climate, any increase on urban problems will be at the expense of agricultural efforts. Another thought is how to use these constraints, for example, global warming as an opportunity to make changes that we know need to be made. One change that will make agriculture more sustainable is diversification. In Enterprise, Alabama, there's a statue in the city square with a big boll weevil on top of it. The status is a monument to the boll weevil because the boll weevil mandated the diversification of agriculture in Alabama. They diversified out of cotton and into peanuts, cattle and some other things.

Abrahamson — Have you speculated at all on the insect vectors and human parasitic diseases that might affect Minnesota with a somewhat warmer climate? For example, why don't we have malaria here any more?

Jones — Mostly because we have eradicated the breeding sites of the malaria vector in the United States. We have recently introduced into the United States the Asian tiger mosquito. It's a vector for encephalitis. It has moved as far north as Chicago. If it gets three to four degrees warmer, it could move into Minnesota. Lyme Disease could turn out to be very significant. The Minnesota Department of Health thinks we don't need to worry about it very much, but the Wisconsin Department of Health is more concerned about it. It's a tick borne disease that, in its latter stages, can be very crippling. But it can be controlled with antibiotics if caught early. With warming, we can expect to see additional diffusion of vectors from the south into the upper midwest. For example, right now Heliothis is a problem in sweet corn in southern Minnesota about one year out of five. But if we go a few degrees warmer it could be a problem four years out of five.

Waggoner — IPM is an example of more intensive use of information that has been around for a long time. What can you learn from the experience with IPM?

Jones — Pesticides are used heavily in cotton. IPM has been successful in cotton because the cost of insect control is very high -- up to $150 an acre. When we came along with additional tools, such as fall stalk destruction, host resistance, and economic threshold measurements, it was possible to make significant dollar savings. I think we see less IPM in Minnesota because the cost of insect control is less here than it is in cotton or some other crops in the south. A soybean field in Minnesota is practically sterile, but in Missouri the soybean field is alive with insects and has to be sprayed.

Ruttan — My perception of the slow adoption of integrated pest management is that IPM represented a political compromise between agricultural entomologists and ecologically-oriented entomologists. They papered over their differences with the IPM label, but the technology really wasn't there.

Jones — That's partly correct. It was a concept that was ahead of its time. An important component of pest management is accurate predictive models. We're still working to develop the predictive models for a lot of crops. You have to have the data before you can feed it into the model. The data has been expensive to obtain. The hope of integrated pest management, of integrating all of the pest control practices, has fallen short because of lack of information. For example, we're just now running trials in potatoes to determine the effects of water, verticilim and leaf hoppers to try to find out what's causing something called potato early dying. It's not due to the simple effect of any one of these, but to some combination of events. IPM will require data on the interactions between these different pests.

Rawlins — I think that's an extremely important point. It bears on your comment that we will probably be moving toward more diversification in the future, which will be more management intensive. One reason the farmers have gone to monoculture is that it is less information intensive. You start diversifying, particularly when you bring animals into the picture, and you have to develop a whole new set of talents. One of the challenges to research is to learn how to deal with complexity and to provide the tools to farmers that will help them to deal with that complexity.

Clark — I don't want this five-degree temperature change number to become established by repetition as common knowledge. The current accepted view, to differ somewhat with you, Margaret, is that if we're concerned with summer temperatures, which are the ones most significant for most of the insect and pathogen vectors in this part of the world, we should be talking about smaller increases for the 30 to 60 latitude band.

Davis — I'm thinking of the projections from the Manabe-Wetherald[8] weather model only. But let me return to what I said earlier. Just wait long enough and you will get as much temperature rise as you want.

Clark — All right. But I really think that if you are careful to make clear that if you wait long enough, you can have very large temperature increases. But that isn't a useful contribution in a management and policy orientation discussion. How much by when is important. We should make a mental footnote that when we are discussing this worse case upper bound, whether we are talking about it for the middle of the next century or some time in the indefinite future. Five degrees isn't the relevant number for most of the reference points that have been implicit in the discussion around the table today. It may be a thoroughly defensible number for certain specified times in the distant future.

Davis — The problem is that whenever you make a precise estimate, then you start into this argument about the accuracy of the models. And it seemed to me that we spent about an hour yesterday morning discussing the validity of the models which isn't something we can really deal with in this group.

Clark — But if your number had been a range of one to five degrees I would have no quarrel. But it's locking on a given number and sanctioning it by repetition that is dangerous.

Davis — You have suggested two degrees. I don't think that's helpful either. The range from one to five is okay.

Jones — A range of one to five can be a huge difference in terms of impact on insect populations.

Clark — That's why the strategy that scientists are now struggling to put into place should be one of dealing with uncertainty.

Davis — From a policy point of view, it's really useful to know that there is that degree of uncertainty. What the argument is about is how expensive the warming is going to be relative to how much it will cost to do anything about it. It's really useful to know that a two-degree warming would cause some changes but nothing drastic. A warming more than that, as far as insects are concerned, can be really serious. That's a very important distinction to make.

Clark — Absolutely. I mean, if somebody could estimate the form of the relationship between pest virulence and temperature, and decide that the curve has a large kink in it, that's the information the policy debate is madly looking for. I don't think that science is going to support that sort of thing. But certainly,

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[8]To be completed.

any subfield that can come up with such a relationship will be doing an incredible service in focusing the debate on a relevant issue.

Ruttan — It seems to me that an important generalization comes out of the discussion in this section. Beginning about 25 years ago, certain materials became so cheap, fertilizer, for example, that we used the materials as substitutes for knowledge. People were expensive, and we let the materials substitute for them. This took place in both crop nutrition and animal nutrition. It seems to me that what we're saying now is that, whether you think of it as knowledge intensive, information intensive, or management intensive, we're in a situation where materials again become expensive, either to the individual farmer or to society. This is telling us that we should substitute knowledge for resources in some sense. This is the general principle.

Rawlins — I agree.

Ruttan — The second question is, how do we get that knowledge on the ground where it can be used. And it seems to me in a society where people are very expensive, it becomes economical to use machines to get the knowledge used. In a society where people are less expensive, or even cheap, you're going to have to make a much stronger effort to get that knowledge into the hands of people. If everybody is going to do it on the back of an envelope, they are going to have to understand the principles. Extension programs in developing countries will have to go beyond teaching practices to teaching principles. Unless you can teach the principles, then people are not going to be able to do the calculations.

Rawlins — And that might be more costly.

Ruttan — That kind of extension is very manpower intensive. In's the kind that the World Bank is trying to do with its Training and Visit system. But extension workers in developing countries are very cheap.

Waggoner — The approach you're talking about is such a good idea -- why isn't it done? What is the experience? Is it getting done or do we just keep saying we ought to do it?

Ruttan — It's very controversial. The World Bank T & V system is very manpower intensive. Many people are worried about whether the costs will be sustainable when external support is no longer there. It seems to me we are talking about a world in which we're going to have to be information intensive or farmers just aren't going to be able to get the productivity out of the technology that should be available to them. Unless they have the schooling or the informal education that will enable them to understand the principles involved, the level of rural schooling in a wide range of countries -- from Brazil to Pakistan -- is inexcusably poor. Until they do something

about under investment in the schooling of rural people, the productivity inherent in the technology will be unrealized.

Cheng — I don't think we need to accuse others, because our own approach to teaching farmers is often too simplistic. For instance, just last week I heard a very disturbing thing in a neighboring state about nitrogen recommendations. Instead of teaching principles, they are coming out with a very simplistic guideline, such as if you have less than, say, 2 percent organic matter, you can apply fertilizer up to 200 pounds per acre. If it's 2 to 4 percent, apply 160 pounds. This totally ignores the environmental impact.

Waggoner — But why are they doing such a thing?

Cheng — I'm asking our extension people if we are doing the same thing. Are we falling in the same trap? We need to raise these questions about our own programs.

Rawlins — I agree that our society is going to have to be more knowledge and information intensive but all of the knowledge and all of the information does not need to be in the farmer's head.

Ruttan — Some of it he can buy.

RESPONSES TO CLIMATE CHANGE

Nature Myths and Policy Design

Ruttan — I have asked Steve Rayner to think about the implications of the kinds of uncertainty we face in the environmental and resource area for agricultural research. But I don't really know what he is going to talk about.

Rayner — In a way I feel that I'm a little bit of an anomaly at this meeting. I don't have the background in agriculture and some of the appropriate allied disciplines that are represented among most of the participants here. In fact, my initial training, before anthropology, was in philosophy and theology. It may be quite appropriate, however, since philosophy and theology are concerned with the problems of faith and reason. I have faith that we could see a 4-degree temperature rise sometime in the next 100 years. But reason tells me that the climate models aren't sufficiently good to let us know if the 4 degrees are Centigrade or Fahrenheit at the moment.

This kind of variation reminds me of the question that Vern asked yesterday about the optimal climate. It reminded me of a story I heard back when I was a philosophy student about a young man who was charged to go home

over the weekend and write an essay on the topic, "How Do I Know I Exist". He returned on Monday looking very haggard, unshaven and worried, and said to his professor, "Professor, you've got to help me, I haven't slept all weekend. I really worried about it. Do I exist?" And the professor said, "Well, who wants to know?"

That's the question that we haven't really asked yet. Is climate optimal for what? And resources for whom? So I want to introduce the question of who wants to know at this stage, because in a sense, what I'm proposing is that, having started with a topic entitled Resource and Environmental Constraints, we're really adopting a nature-centered view of the problem. We could equally have developed an anthropocentric view of the problem. We could have started out asking what the institutions are, what are their resources, and how are they threatened by change. Resources are recognized, or not recognized, according to a whole variety of societal and institutional variables. One man's hazardous waste or noxious waste could be another person's valued resource, depending on whether it's piling up in a stable or whether it's spread out over the fields. There's clearly some locational implications involved. There's also a question of activities and interests. Where I dwell at the moment in east Tennessee, strip mining is an important economic activity. What you have been talking about in the past two days as "top soil" is called "overburden" by the mining industry. The terminology puts a different complexion on the nature of the resource.

One of the things that emerged over the last two days as the most important resource constraints are the human resources of institutional information and capacity, which are defined very differently. Climate change, in fact, can be viewed as a resource rather than as something that only impacts on resources. Certainly if you're in the tourist industry, climate is a very important resource.

Anthropologists like to tell stories. I'm going to tell you about the Lele and the Bushong, two tribes who live in what in now Zaire. They live on either side of the Kasai River in Zaire. The Bushong say that their summers are terribly hot and difficult. The Lele describe their summers as being very leisurely and pleasant. The standard climatological data gathered by the ethnographers of these two tribes, doing their research simultaneously in the 1950s, indicates that such measures as temperature and rainfall were identical on both sides of the river. There was no difference. So what caused them to perceive climate differently? The most important resource in both societies (forgive me the sexist construction here) is women. In anthropology, kinship is commonly discussed in terms of the exchange or competition for women. The other two relevant resources were raffia cloth and cattle. The Lele pay their bride wealth in raffia cloth, which is gathered by women and woven by men. The Bushong pay bride wealth in cattle. To get access to the resource of women, you must possess either raffia cloth or cattle. Now, the other twist is that the Lele are polygamous -- one man, many wives. The

raffia is woven by the old men so the old men have a monopoly on the resource of women. So there's not really much young men can do to get a wife except wait until they're older. So, in the summer, they sit around under the palm trees drinking palm wine and enjoying the pleasant climate. The Bushong, on the other hand are monogamous. They pay their bride wealth in cattle. So a young man who wants to get a woman works very hard through the summer trying to increase his herd size so that he can afford a wife.

Ruttan — My knowledge of cattle breeding is somewhat limited, but I do wonder about what activities the young men engaged in to increase the cattle numbers?

Rayner — I wouldn't touch that with a ten-foot pole! But you can see how the incentive structure and the functional activities cause the two societies to have different views about what is an optimal climate. I've used an exotic example here. But there are more familiar examples. Energy efficiency was not viewed as a resource by utilities until very recently because of the emphases of utilities on demand expansion. Now that attention has shifted to the supply side, utilities are now actually paying energy service companies for the avoided costs of having to build new plants to generate more electricity. Efficiency is now seen as a resource. We've had a transition there in the perception of what is recognized as a resource.

There are at least three distinctive policy responses that can be made to climatic change. Each has a moral component. Each is supported by a distinctive myth about the nature of resources. The first policy response is the preventivist approach. Just say no to climate change. And this view is supported by a naturalistic philosophical perspective that holds that it is morally wrong to mess with nature. The myth holds that nature is fragile and that natural resources are scarce. Any slight perturbation will irretrievably upset the balance of nature.

There are some fascinating parallels here, with the religious right on the issue of sex education and with the political left on the issue of civil defense. The religious right, at least in my part of the Bible belt, insists that we shouldn't teach kids about sex because they'll be encouraged to experiment with it. Similarly, we find that certain groups on the political left argue that we shouldn't even talk about civil defense because this will encourage people to accept the dangerous myth that nuclear war is survivable. We are told by hard line preventivists that we shouldn't be talking about adaptation because this will encourage people in the notion that we can adapt to climate change. We should be concentrating on prevention.

The second approach is an adaptivist approach. This approach is illustrated very well by the people who erected the statue to the boll weevil. It may be no coincidence the town is known as Enterprise, Alabama. They saw change as an opportunity. And just as the boll weevil presented an opportunity for

the people of Enterprise to change their farming system, climate change may well present us with opportunities to recognize new resources and to use them in different ways. Related to this position is the moral judgment that it's wrong to curtail development. For example, the position that a preventivist strategy will condemn the poor peoples and the poor countries of the world to a state of continued poverty or underdevelopment is seen as morally wrong. The underlying nature myth perceives nature as robust. It does not become unbalanced easily.

These two myths go very far back in American society. It was represented in the arguments over the management of national forests at the turn of the century. More recently, though, we've had the sustainable development response. This is a sort of a Hegalian synthesis of the classic dialectic. The notion is that growth should be controlled. The moral imperative is to preserve choice for future generations. There is an image that nature is robust within limits. A certain amount of perturbation can be tolerated, but one has to be careful not to exceed the limits -- even though we don't know what the limits are. These myths are of particular importance when we're dealing with issues that are attended by extraordinarily high uncertainty, and where the stakes are both high and long term. Three types of uncertainty have been identified by people looking at these issues. *Technical* uncertainty is what we are talking about when we look at the uncertainty bands around an estimate or a measurement. And that very image gives the notion that uncertainty is always reducible. As one moves from bench science more into the broader environmental realm, we frequently encounter *methodological* uncertainty. Do we even have the appropriate tools for modeling and dealing with a problem? Finally, there is *epistemological* uncertainty. Epistemology is the study of whether or not you have appropriate conceptions for dealing with a problem. And clearly that's an issue which affects us in the kinds of debates we've been having about the extent and nature of climate change.

There are three kinds of stakes involved -- local, societal and global. Different tools are appropriate for dealing with them. When you have low stakes and merely technical uncertainty, you pretty much know what the probabilities are. However, when you move to methodological uncertainty and a medium decision stakes, you're moving into much more uncertainty. The probabilities are less tractable. And here decisions must be more in a clinical mode. However, when we then get up into the area of high stakes and epistemological uncertainty, we're really in a realm of indeterminacy. Very often, as in the climate area, we don't even know what the signs of changes will be. For example, there is still considerable debate about whether cloud cover is going to provide a positive or a negative feedback for the climate system.

If you can't increase precision, what do you do? You try to have a prudent response, analogous in some respects to insurance. The catch here is that the advocates of the different nature myths that I talked about earlier have a

different approach to the issue of prudence. The preventivists focus on avoiding the worst case costs. They are willing to spend a lot of money in insurance that may not be needed. This can create considerable societal discord.

I want to now try to distinguish between two types of resource impact that we might want to consider in further research. We have a project at Oak Ridge where we're doing a review of the programs that U.S./AID has in place as to whether they ameliorate or exacerbate the issue of climate change. What we have tried to do in a first cut was to distinguish two kinds of resource impacts. The long-term secular changes and the sort of short-term emergencies that are likely to come along before we get to whatever temperature changes may be occurring in the middle of the next century. The interesting thing is that we're already seeing the cumulative impacts of urbanization, transmigration, and others. Our view is that it makes perfectly good sense to discuss these as if they were problems of decision under uncertainty and possibly under risk. We already have the tools to deal with these problems.

The longer term issues are likely to fall in two areas. One is the industrial metabolism, particularly energy use. The other will be land-use change on a global scale.

We spoke yesterday about the importance of energy conservation in the United States. Biomass is considered by researchers at Oak Ridge at least, a serious contributor to the very long-term reduction of greenhouse gas emission. By the year 2,000, the developing countries and newly industrialized countries will contribute more to CO_2 emissions than the industrial world (Figure 2). We feel that biomass technology is going to be very, very important for these developing countries if they are going to avoid more intensive use of coal -- the energy equivalent of heroin. And it may also be worth our while to consider whether the United States would be getting a bigger bang for its buck in terms of CO2 reduction by developing and transferring biomass technologies to developing countries. We can try to reduce our own emissions through accelerating replacement of the existing plant generating stock in the United States. But we really need to be thinking about the interaction of agricultural and energy systems on a global scale. Unless we get a serious handle on the global emissions problems, it won't make much difference whether we close down our coal fired power stations in 10 or the next 40 years.

Implementation of a biomass program raises the whole question of market failure. We've had a lot of research on market failure in energy efficiency research. Pierre raised the issue yesterday when he asked why, if energy efficiency technologies are available, they aren't being introduced. We've identified several reasons. One is the high first cost problem. Highly efficient compact fluorescent bulbs are available that can replace

incandescent lights, and considerable amounts of money and energy over the life of the bulb. They cost $25. When you stop at the hardware store on Saturday morning to replace a light bulb, you may not feel like splashing out $25.

The other problem is the split incentive problem. The people who, in particular, occupy commercial and industrial buildings are generally not the owners, and certainly were not the builders. Owners and builders have an incentive to install the lowest first cost appliances into buildings, not the ones that are most efficient to run over the life of the building.

Let me now turn to the issue of land use transformation. At Oak Ridge we are trying to bring together a variety of people from the social sciences and from the biophysical sciences to work out integrated models of how resources are perceived, used and transformed. At the moment, we're simply trying to develop simple algebraic models of the various parts of the system. We're not at the point yet where we've developed any computer simulations. The time has come to move away from seeing land use change in traditional social science terms, or in traditional biophysical terms.

In closing I want to address the broader issue of information flows. Yesterday Vern suggested that I talk about international policy. The traditional model of international relations was relationships among governments. Nation states would make their own decisions according to their own national political cultures and agendas. They would then come together at the governmental level, formulate some kind of consensus, and embody it in a treaty, which they would then be individually responsible for enforcing within whatever framework of international law applied. This was very much the model that was followed in the attempt to ban CFCs in aerosols. The aerosol ban, one of the precursors to the Montreal protocol, failed. It was also much the model for the negotiations around the U.N. convention on the Law of the Sea, to which the U.S. eventually did not become a signatory. In this model, it's assumed that the decision makers know what the national self-interest is when they go into those negotiations. The assumption is that the science is already pretty clear.

Now, there was a dispute between the E.C. countries, U.S., Canada and the Scandinavian countries, over the science of CFC's and aerosols. When this dispute is described in the United States it's usually described in rather cynical terms to the effect that the Europeans were simply interested in stepping into the market niche that the Americans might vacate through decreasing CFC production. However, if one looks at the way science is incorporated into governmental decision making in different countries, one can see that, in fact, a lot of the disagreement was associated with the problems of how the different societies dealt with uncertainty in science. The United States and the Scandinavian countries were moving towards avoiding the worst-case scenarios whereas the European Economic

Community countries were concentrating much more on avoiding the opportunity costs. Given the failure of the aerosol ban, there was an explosion of direct networking among non-governmental organizations such as scientific, technical and industrial groups across national boundaries. We had things like the development of the Council for Responsible CFC Use. American environmentalists went to talk to West Germans and West Germans talked to the United Kingdom. There was a proliferation of information flows directly across national boundaries. By the time of the Montreal meeting, a consensus on a course of action had already been agreed on. It was only necessary to go through the process of symbolic confirmation -- which is what the Montreal protocol amounts to. It's not the means by which we're going to reduce CFC emissions. As an anthropologist, of course, I think symbols are very important. But if we were serious that the Montreal protocol was going to have the effect of reducing CFC emissions, we couldn't have allowed the Soviet Union to become signatories and open new CFC factories -- which in fact we agreed to do. But the people who were involved were smart enough to recognize that, in the long run, it is much more important to have the Soviets involved, even symbolically, than to quibble over the details. I have described this use of specific kinds of expertise to deal with global problems as "thinking globally and acting locally". My colleague, Luther Gerlach, who is in the Anthropology Department here at Minnesota, has pointed out that the ability to think globally is itself a very specific kind of local knowledge that is restricted to really quite a small community in the world.

Let me now turn to climate change. The U.S. initially opposed participation in the Intergovernmental Panel on Climate Change (IPCC), until the Bellagio meetings, at which the SCOPE project, which is one of those international scientific organizations, first turned its attention to policy issues. The U.S. and other governments sensed that the lead was being taken by the World Meteorological Organization rather than being led by governments. The Bellagio reports didn't have government fingerprints on them. They were policy documents without government fingerprints. Governments felt they had to deal themselves back in. An Intergovernmental Panel on Climate Change was formed that involved much of the expertise that was previously involved in direct interactions across national boundaries. That expertise is now being redirected back into the more traditional model of intergovernmental decision making. We have a hybrid between the traditional model that I first described and the polycentric model.

Now, the reason why I discussed this example is because in the agricultural area, we have a whole series of cross national institutions -- the Consultative Group on International Agricultural Research (CGIAR), and others -- which are capable of collaboration across national boundaries without having to go through government processes. These organizations may be one way to intervene in countries where the governments itself is very often a very large part of the problem. Part of the solution is the development of non-

governmental organizations in developing countries with which direct interaction can occur with our non-governmental organizations to transfer knowledge and transfer technology and to conceptualize the issues in a manner that induces changes in policy.

Waggoner What's the value of attempting to narrow the probabilities with respect to future climates?

Rayner One thing I didn't talk about was Coase and Rawls (1971). Their problem is, "How do you seek a fair solution to a problem, such as the intergenerational problem, where there are both winners and losers?" Coase, who is an economist, says that the way you get a fair solution is that you reduce the uncertainties to an absolute minimum so you know exactly who's going to win by how much, and who's going to lose by how much. You then allow the participants to negotiate a redistribution in which either the losers bribe the winners not to win, or the winners compensate the losers for the loss. Rawls, on the other hand, argues that won't work for a variety of reasons, including the fact that you never have equal market power on both sides. Rawls suggests that one way to get a fair solution, particularly when you can't know who the winners or losers are going to be, is to ask what solution each player would chose in the absence of knowledge about which side he or she will be on. That gets you a fair outcome.

Waggoner Does that mean shut down all the sources of CFC?

Rayner It suggests that we don't pursue greater precision in scientific knowledge until we figure out how it relates to the equity issues. On the other hand, Coase is saying that the scientific knowledge must be very precise in order to have an equitable solution. The problem is that neither of these courses of action are achievable.

Waggoner But we are always faced with a choice of where we're going to put our chips in allocating our science resources.

Rayner I would pursue the Coasean solution to the short-term emergency issues where we do have enough reasonably good information. For the long-term problems in determining issues, put the money into increasing institutional and societal resiliency so that we can better respond to great certainty as more knowledge becomes available. I suggest pursuing the Rawlsian strategy for the latter category.

Chen It seems to me that the CFC case is one where there is enough information for most climatologists to agree that the change is coming. This provides the motivation to want to negotiate. But there is not agreement on the regional distribution. There is, therefore, uncertainty about winners and losers. Do you think that the disagreements are about the science or because of biases

about winners and losers? You don't have any cynical view of why some people are claiming uncertainties, do you?

Rayner — I don't think that people are deliberately and cynically manipulating uncertainties, giving their own views an advantage. But I do think that we have these underlying myths about the nature of nature that introduce ideological considerations into policy preferences.

Research Resource Allocation

Ruttan — I now want to turn to Steve Rawlins and ask what we've learned about how we should be using our research resources.

Rawlins — I've been stimulated by Steve's discussion, particularly the point that before we decide what to do, we ought to think about who needs to have the answers. One problem agriculture faces is that it does not have a single customer. We had a very useful discussion yesterday by Steve Sonka on food security. It that the central issue agriculture should address? If it is, it is the consumers of food that we should be concerned about. Or is it the producer and the profitability of his enterprise? Or should we be concerned about the environment and the health of rural communities?

Ruttan — I would think that the decisions that we're thinking about that this discussion would be more relevant for research decision making at the CGIAR, the USDA, the state experience stations and the granting agencies. I guess one way I would ask the question is, given what we think we know about the next 20-40 years, and having some sense about the uncertainties, how should we change our research portfolio. Part of that research portfolio might include research to improve our knowledge about the future. It might also include greater effort to monitor the changes so that we know what is happening, and in what direction the changes are taking us.

Rawlins — So I guess maybe my cynical response would be that you are suggesting that we should be primarily concerned about ourselves.

Ruttan — No, we're concerned about the producers and consumers because they put the money in our pay check

Waggoner — The word portfolio is important.

Rawlins — Certainly that is true. I suppose we could divide our multiple concerns into two broad categories: (a) the impacts of the environment on agriculture; and (b) the impact of agriculture on the environment. By environment I mean everything external to the agricultural system, including political and social as well as physical, chemical and biological elements. The framework

developed by the IPCC provides a useful division of research responsibilities -- science understanding, impacts assessment and response strategies. One thing is clear. Agricultural research needs to interact with the rest of the scientific community.

Looking specifically at research related to global environmental change agriculture has contributions to make in all three IPCC categories. To develop a more complete understanding of the system agriculture can make better measurements of biogeochemicial fluxes of greenhouse gases from agriculture, contribute to a better understanding of the biosphere component of the carbon cycle and bring our understanding of soil and hydrology to bear on the inputs needed to improve GCMs. In the area of impacts assessment I was intrigued with Steve's suggestion for linking the biophysical land use models with models of the socio-economic system. Population is an important driver in this system that can not be ignored. If we deal only with physics, chemistry and biology we'll fall short of coming up with answers that are needed. Only after we understand the system and its interactions, and the social and economic impacts of environmental changes on the system can we develop rational response strategies and policies. Unfortunately, much of what we are doing now is not directed toward the ultimate development of policy. We need to create these linkages. Making an attempt to outline policies now will help reveal the specific knowledge gaps that need to be filled. Response strategies should include both strategies to help prevent negative environmental changes as well as strategies adapt to changes by increasing the resiliency of agricultural production systems.

Finally, we need be aware of the critical relationship between water and agricultural production. Water is the lifeblood, and most frequently limiting factor for agricultural production. Not only is agriculture the largest user of water, if you include forests and rangeland, it is one of the major sources of water. How these resources are managed can have a substantial impact on the nation's water supply.

Ruttan — The water issue came up very strongly in our previous consultation. It came up again in this one. And in the consultation or health issues, it's going to come up again. It's going to be a central issue.

Rawlins — It is rapidly becoming the most limiting environmental variable as far as agricultural production is concerned.

A third research priority should involve the design of response strategies. They should include both prevention and adaptation. We ought to be very seriously concerned about developing greater resiliency within our food system. As information is becoming more intensive, the system should become more resilient. Agricultural research also needs to be involved in the design of strategies to help prevent global warming. A first step is to more carefully assess the impact of agricultural systems on the radioactive gases

that are being emitted from agriculture. After we need to assess it and to measure it, we need to develop practices that will minimize emissions, particularly methane and carbon. I think agriculture has an opportunity to be on the positive side of carbon flux by sequestering carbon. I think there are opportunities through reduced tillage to increase organic matter in the soil. We must be involved because agriculture occupies such a large part of the land area.

Ruttan Let me now turn to Gene Allen.

Allen This conference is a good example of driving home concerns about agriculture and the environment that have got to come closer together on both the input and the output side.

The concept of sustainable agriculture will become increasingly important in the decades ahead. But it is not as widely accepted at this point as it should be. I've used the example of holistic medicine as an analogy. Holistic medicine is a very appropriate concept in thinking about health. But it is not an acceptable term in the health professions, because in the past, it was associated with quackery. The concept of sustainable agriculture is not yet that contaminated. But it was promoted originally as only organic or chemically free, when this is only one aspect of it. Other terms such as alternative or low input agriculture have been used, but sustainability captures more of the concept at the intuitive level. An agriculture that is sustainable must also be profitable. If we can accept the concept of sustainability, it can be used to provide a philosophical foundation for our research priorities.

I think the other thing that is important for our research programs to recognize is that there's not just one kind of land use in Minnesota, the United States, or in the world. In Minnesota, for example, we devote approximately 20 million acres to cropland, 18 million acres to forestry, and 5 million acres to recreation uses. There are 7 million acres of peatlands. About 5 million acres are in multiple use -- forestry and recreation. Agricultural land uses have undergone significant change. Land used for crop production has declined in the Northeast. But maize and soybeans have moved north in the West and Northwest parts of the state. The structure of agriculture is increasingly bimodal. We have both small farmers and large commercial farmers whose needs must be addressed. The distribution is more bimodal than it was 20 or 25 years ago.

When one also considers the need to bring together the agriculture, environmental, food safety, water quality, profitability, and trade dimensions, the system becomes exceedingly complex. We need good disciplinary sciences. But we have also got to go beyond the reductionist mode and learn how to integrate our knowledge and our technology. One of the things I am very excited about in the initiative for agriculture research proposed by the

NAS/NRC Board of Agriculture, is that 40 percent of the new funding is proposed to go to interdisciplinary teams. We believe this is not only needed for applied agricultural research, but also in many areas that have been funded primarily by single investigator disciplinary grants.

Another point that I want to make is about my concern that politicians are making decisions about science without the needed scientific input. A problem that we have in this country, at least in my view, is that we're thinking more locally and acting more locally. We must bring to the general populace a greater understanding of some of the scenarios that we're discussing if we expect the politicians to change. And just as an example, too few of our undergraduates today are coming out of universities without any general sense of the issues that relate to food and hunger, natural resources or the environment.

Ruttan — Thanks, Gene. I will now go around the table and see what other people would like to put on the agenda in terms of research priorities, or what they think should be highlighted out of this day and a half.

Waggoner — We must learn how to choose amongst the possible abatements and adaptions Steve Sonka has spoken more clearly to than anyone else here. Then we must find the obstacles that are stopping us from doing the things that we know how to do. We must continuously develop and test and adapt crops and systems outdoors. We must quantify the effect of land use on the parameters of carbon and water exchange. This is not only important as an input to global circulation models, but it will also determine the limits that can be put on agriculture by those attempting to slow the climate change.

Rosenberg — In the article that Pierre and I did for Scientific American (1989), we tried to get a handle on the kinds of environmental deterioration that are caused by agriculture -- desertification, salinization, and erosion, for example. We were both extremely frustrated by the poor quality of the data on which we could draw. The reliability of the knowledge base on land use and land degradation is woefully inadequate. It seems to me that we have to find a way to improve the way we characterize and document the magnitude of environmental problems.

Coming at it from another side is the International Geosphere-Biosphere Program. I served on the first IGBP committee. One of the ideas that I thought most useful at the time came to be called the Geosphere Biosphere Observatory -- a network of stations where important observations of land change process could be made systematically and over long periods of time. Scientists in the developing countries could be enlisted to work on monitoring of natural resource problems, such as erosion, salinity, and desertification. These are immediate problems that should be able to maintain the interest of LDC governments.

Chen — I want to follow up on the interdisciplinary research issue. It seems to me that there are three areas of concern. One is the problem of working at the natural and social science boundary. The second is the interface between climatology and agriculture. I organized a meeting in February at IIASA on the issue of using climate scenarios in impact studies. There is a whole range of issues here that really need a lot more technical work. The third area is the food security-hunger nexus. A systems view will be very important for determining the constraints on sustainable agriculture.

Allen — Do undergraduates at your university have the option of taking a course in world hunger as part of their general education requirements?

Chen — We now offer an introductory course and one or two follow-up courses. I've been teaching a course on environmental policy in the developing world that relates to a lot of the issues here.

Rayner — I'm still not quite sure why it is that, in an institution like Oak Ridge, which is predominately engineering and natural sciences, the social sciences also seem to thrive. But one of the things that I would like to emphasize about interdisciplinary research is that it is very difficult. We have found, for example, in our land-use project that you can talk with colleagues from other disciplines, thinking you understand each other for several hours or days, then suddenly discover that you've been talking past each other. A lot of patience is required. It is going to be a real challenge to the way in which we do science, both in our laboratories and our universities.

So as far as a research agenda is concerned, the issue of biomass for energy would be high up on my agenda. And, as I've learned at this meeting from Steve Rawlins, the issue of biomass for lignocellulose food sources could be very important. It may be particularly important for developing countries; even in this country as a source of cattle feed. Something like a hundred million tons a year of grain in this country is used feeding livestock.

In the institutional area, though, which is really the one in which I feel that I have the most competence, I think I would like to see a focus on resource management. Attention to the issue of market failure and institutional design are also important. We know, for example, how price support systems distort markets. We have seen in recent years a very strong emphasis on the private sector in developing countries. Sometimes this has been productive, sometimes it has been counterproductive. There has been failure to recognize that common property systems that are capable of effectively managing resources do indeed exit in different parts of the world. We are, in fact, in danger of perpetrating a loss of institutional diversity. In other words, we're losing a lot of the small-scale institutions that we could learn from to understand how to handle the big-scale problems better. The second in the three models of international decision I referred to earlier was actually

derived by Luther Gerlach and myself by looking at decision making in African tribal societies.

Finally, I think that it makes perfectly good sense to develop policies that are capable of responding to the short-term local impacts of climate change. I am referring to issues like flooding, refugees, epidemics, and others.

Jones — I think we should concentrate efforts on pesticide alternatives. This is a simplistic approach to the water quality issue. If you could just eliminate the pesticides, then outside of nitrogen you've solved water quality problems. Of course, we can't do that overnight. But I think we have to be careful with the water quality problem not to make another acid rain case where you know what needs to be done, but don't do it.

We have to emphasize integrated management approaches, not only integrated pest management, but crop management programs. There's a lot going on in biology in the high tech area, but there's really been a decline in the nuts and bolts stuff. Since 1971, the number of entomologists employed by the state and federal level has decreased by 30 percent. And that same thing is happening in the other biological fields.

Another area I would like to make some comment about is the assumption that Third World countries should implement environmental programs using the same criteria we use in the United States. I'd like to quote something written by an entomologist, B.D. Walsh, in 1866. "Let a man profess to have discovered some new patent medicine and people will listen to him with attention and respect. But tell them of any simple common sense plan based upon scientific principles and they will laugh you to scorn."[9] Not a lot has changed since 1866. We are imposing our risk-benefit parameters on Third World countries when it is likely to be very difficult.

Bochniarz — We now need social science research to be more concerned about understanding institutional diversity, particularly political institutions. On the question of regulation and deregulation, we need to introduce an international perspective that draws on more diverse experience. The problem of internalizing externalities is perhaps largely unimportant.

Munson — One of the things that we need to do is figure out better ways to increase efficiencies in input use. Water is becoming one of our most limiting factors in our production system. We need to take a much closer look at the water use efficiency of our various crops and how that interacts with other input use.

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[9]To be completed.

Larson — And I agree with a lot that's already been said. We need to inventory our natural resources so that they can be identified on a spatially accurate basis and then develop data bases that characterize these natural resource units. We need to bring these data bases together for use in development, management and impact assessment. This is in contrast with the trial and error method of research often used in agriculture.

Cheng — I think one of the things we need to do is achieve closer articulation of the sciences with the social sciences and the humanities. I was recently speaking with someone in the humanities, and I asked him if he ever thought that agriculture is part of a culture. Agriculture is different in different countries because culture is different. And agriculture in turn has affected the culture. His first reaction was quite negative, but after we talked a bit, he became interested enough to want to incorporate the idea into a world culture course.

Steve's comment about the decreasing institutional diversity reminds me of the experience a friend of mine, Jim Cook, had in China. He went to China in 1978 with the first plant pathology delegation. When he came back he said, "You know, the Chinese are practicing integrated pest management!" That technology, perhaps suited to that particular agricultural system, may not be suited to our system. During the 10 years I've been going to China, I am worried that increased use of pesticides has almost totally eliminated the traditional concept of integrated pest management. Another area of technical knowledge that was almost lost was crop rotation in this country. With the introduction of chemical inputs, we went to continuous corn and continuous wheat. When we started looking back, we found that we have been misled by ourselves because the yield increases have masked the deterioration in soil quality.

Davis — There are two new sub-disciplines that are developing within the field of ecology that are relevant to a lot of the discussions we've had here. One is landscape ecology. The other is conservation biology. The emergence of these fields have resulted in the formation of new scientific societies and new journals. There are new courses and new graduate curricula. Certainly ecologists are concerned with natural landscapes, but they recognize that landscape is very much shaped by human activity. Many of the problems we've been discussing here really fall within the purview of landscape ecology. Similarly, human impacts are creating many of the problems in conservation biology; there are very interesting basic scientific issues that have to be addressed in developing strategies for conservation of species.

The need for basic ecological research on the interface between human impacts and natural impacts on the landscape has resulted in the formation of a new journal called Ecological Applications,[10] which is trying to deal with

[10]To be completed.

the literature that falls in the area between applied biology and basic biology. Much of what we've been discussing here is really systems or ecosystems research. These new developing fields of landscape ecology and conservation biology are evidence that ecologists are moving in your direction. But are you moving in our direction? For instance, I teach a course in ecosystem ecology. Faculty from Agriculture come in as guest lecturers to present about 10 percent of the lectures in the course. I've had students from forestry, wildlife, and fisheries, but I don't believe I have ever had a student from any of the agriculture disciplines. It seems to me that training in ecological research is essential for students in agriculture. Most students in ecology are very much interested in problems such as those we've been discussing here. Some of my students, for instance, have taken a course in tropical agriculture. I think we can easily establish better communication than we have now.

Abrahamson First, I want to thank Vern for the meeting. At least for me it's been very valuable. I've gotten a big kick out of it, in fact. I agree with Steve Rawlins on his opening comments, that agriculture has not been very sensitive to environmental concerns. I was pleased to hear that there is some sensitivity that's developing, at least if this group is representative. On the other hand, I've been very uneasy here. I grew up on a Minnesota farm. I remember when the first tractors were bought and I helped bring home the first bag of fertilizer. Then I spent nearly 20 years working as an applied physicist. I enjoy machines and technology, but when I sit here and hear this kind of high tech agriculture talk, I get real nervous. I just don't like management. And what we're talking about here is turning the whole world into a zoo. Conservation biology is coming along just in time to study natural systems as they go down the tube.

I clearly have a great deal of the preventivist theology that Steve described. But the choice is not between adapting and limiting. If we're going to avoid what I think will be really catastrophic changes down the line, we have to limit emissions of these gases and we have to do it vigorously. That means limiting fossil fuels consumption and ending deforestation. Fossil fuels account for about 60 percent of the greenhouse gases. We heard today that deforestation accounts for someplace between 10 and 25. But also we've got to adapt to or cope with those very large changes which are unavoidable. Now, the costs of coping are very high. Even though you can go a long way with technical fixes, it will not be enough. It's necessary but it's not sufficient. The required changes will demand true grass roots political support and public understanding to marshall these resources. Norm, that's why I'm an advocate. I do advocacy because I just don't see any way to marshall the resources and political support to deal with these issues unless there is a public that understands the implications of inaction and not providing those resources.

Sanchez I thoroughly enjoy this meeting, particularly the broad philosophical perspective provided by Steve Rayner. By all means we should get away

from the extremes of being too catastrophic or too utopian. We need more emphasis on the abatement technologies. But abatement technologies have been around for some time. The question, that Paul Waggoner and Pierre Crosson kept raising is how come technologies are not utilized, has not been answered. We should focus more on the technologies that have a win-win potential, that both increase production and have positive environmental gains.

My second point is that I'm just fascinated by the efforts to put some realistic economic values on environmental costs. The problem of internalizing externalities calls for some institutional innovations.

There were several very important observations made in the last several days. H.H. Cheng observed that methane emission from paddy rice is likely to occur only at very low redox potentials. Most of the rice fields will not have those low redox potentials. What is going on? The people who work in methane certainly should look at the chemistry more carefully. Bill Larson comments that desertification is reversible is very important.

Agronomists and other agricultural scientists are turning to ecology in a serious way. At my own institution, our soil scientists, entomologists and foresters are taking courses in ecosystems. Conservation biologists are learning about soils, plant and animal science. They are also learning.

Ruttan

I want to apologize for keeping people so long from their lunch. But I do appreciate people coming here for two days and engaging in this very intense dialogue. I have learned a great deal. I also want to let Bob Herdt know that we appreciate the support the Rockefeller Foundation has given to support this effort. It's been nice having you here.

ISSUES AND PRIORITIES FOR THE 21ST CENTURY

Ruttan

As we look even further into the next century, there is a growing concern, as noted earlier, about the impact of a series of resource and environmental constraints that may seriously impinge on our capacity to sustain growth in agricultural production. One set of concerns centers on the environmental impacts of agricultural intensification. These include groundwater contamination from plant nutrients and pesticides, soil erosion and salinization, the growing resistance of insect pests and pathogens and weeds to present methods of control, and the contribution of agricultural production and land use changes to global climate change. The second set of concerns stems from the effects of industrial intensification on global climate change. It will be useful, before presenting some of the findings of the second consultation, to briefly characterize our state of knowledge about global climate change.

There can no longer be any question that the accumulation of carbon dioxide (CO_2) and other greenhouse gasses -- principally methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFC's) -- will set in motion a process that will result in some rise in global average surface temperatures over the next 30-60 years. There is substantial disagreement about whether warming due to greenhouse gasses has already been detected. And there continues to be great uncertainty about the increases in temperature that can be expected to occur at any particular date or location in the future.

The bulk of carbon dioxide emissions come from fossil fuel consumption. Carbon dioxide accounts for roughly half of radiative forcing (Figure 3). Biomass burning, cultivated soils, natural soils, and fertilizers account for close to half of nitrous oxide emissions. Most of the known sources of methane are a product of agricultural activities -- principally enteric fermentation in ruminant animals, release of methane from rice production and other cultivated wetlands, and biomass burning. Estimates of nitrous oxide and methane sources have a very fragile empirical base. Nevertheless, it appears that agriculture and related land use could account for somewhere in the neighborhood of 25 percent of radiative forcing. On a regional basis the United States contributes about 20 percent and western and easter Europe and the USSR about 30 percent of radiative forcing by all greenhouse gasses. In the near future contributions to radiative forcing from the Third World will exceed that of the OECD and what used to be called the centrally planned economies.

During the consultation, Steve Rayner, as well as several others, characterized the alternative policy approaches to the threat of global warming as preventivist and adaptionist. It seems clear that a preventivist approach could involve about five policy options. They include reduction in fossil fuel use, or capture of CO_2 emissions at the point of fossil fuel combustion, reduction in the intensity of agricultural production, reduction of biomass burning, expansion of biomass production, and energy conservation.

The simple enumeration of these policy options should be enough to introduce considerable caution about assuming that radiative forcing will be limited to anywhere near present levels. Let me be more specific. Fossil fuel use will be driven, on the demand side, largely by the rate of economic growth in the Third World and by improvements in energy efficiency in the developed and the centrally planned economies. On the supply side it will be constrained by the rate at which alternative energy sources will be substituted for fossil fuels. Of these only energy efficiency and conservation are likely to make any significant contribution over the next generation. And the speed with which it will occur will be limited by the pace of capital replacement. Significant reversal of agricultural intensification, reduction in biomass burning, or increase in biomass absorption is unlikely to be realized within the next generation. The institutional infrastructure or institutional

resources that would be required do not exist and will not be put in place rapidly enough to make a significant difference.

This recapitulation forces me, although reluctantly, into adopting an adaptionist approach in attempting to assess the implications of global climate change for future agricultural research agendas. It also forces me to agree, as Dean Abrahamson insisted during the consultation, that we will not be able to rely solely on a technological fix to the global warming problem. The fixes, whether driven by preventivist or adaptionist strategies, must be both technological and institutional.

In this context, an adaptionist strategy implies moving as rapidly as possible to design and put in place the institutions needed to remove the constraints that intensification of agricultural production are currently imposing on sustainable increases in agricultural production. Examples would include (a) the policies and institutions needed to rationalize water use in western United States and the Indus Basin in Pakistan; (b) to manage the use and development of coastal wetlands and shorelands to limit contemporary losses to property and human life; (c) or to deal with groundwater management, including the effect of pollution resulting from agricultural intensification, in both developed and developing countries. If we are successful in designing the institutions and implementing the policies needed to confront these and other contemporary problems, we will be in a better position to respond to the more uncertain changes that will emerge as a result of future global climate change.

Let me now turn to some of the research implications that emerged from the consultation.

1.0 A major research program on incentive compatible institutional design should be initiated. The first research priority is to initiate a large-scale program of research on the design of institutions capable of implementing incentive compatible resource management policies and programs. By incentive compatible institutions I mean institutions capable of achieving compatibility between individual, organizational, and social objectives. A major source of the global warming and environmental pollution problem is the direct result of the operation of institutions which induce behavior by individuals, and public agencies that are not compatible with societal development -- some might say survival -- goals. In the absence of more efficient incentive compatible institutional design, the transaction costs involved in ad hoc approaches are likely to be enormous.

2.0 A serious effort to develop alternative land use, farming systems, and food systems scenarios for the 21st century should be initiated. A clearer picture of the demands that are likely to be placed on agriculture over the next century and of the ways in which agricultural systems might be able to meet such demands has yet to be produced. World population could rise from the

present 5 billion level to the 10-20 billion range. The demands that will be placed on agriculture will also depend on the rate of growth of income -- particularly in the poor countries where consumers spend a relatively large share of income growth on subsistence -- food, clothing, and housing. The resources and technology that will be used to increase agricultural production by a multiple of 3-6 will depend on both the constraints on resource availability that are likely to emerge and the rate of advance in knowledge. Advances in knowledge can permit the substitution of more abundance for increasingly scarce resources and reduce the resource constraints on commodity production. Past studies of potential climate change effects on agriculture have given insufficient attention to adoptive change in non-climate parameters. But application of advances in biological and chemical technology, which substitute knowledge for land, and advances in mechanical and engineering technology, which substitute knowledge for labor, have in the past been driven by increasingly favorable access to energy resources -- by declining prices of energy. It is not unreasonable to anticipate that there will be strong incentive, by the early decades of the next century, to improve energy efficiency in agricultural production and utilization. Particular attention should be given to alternative and competing uses of land. Land use transformation, from forest to agriculture, is presently contributing to radiative forcing through release of CO_2 and methane into the atmosphere. Conversion of low intensity agricultural systems to forest has been proposed as a method of absorbing CO_2. There will also be increasing demands on land use for watershed protection, and biomass energy production.

3.0 The capacity to monitor the agricultural sources and impacts of environmental change should be strengthened. It is a matter of serious concern that only in the last decade and a half has it been possible to estimate the magnitude and productivity effects of soil loss in the United States. Even rudimentary data on soil loss is almost completely unavailable in most developing countries. The same point holds, with even greater force, for groundwater pollution, salinization, species loss and others. It is time to design the elements of a comprehensive agriculturally related resource monitoring system and to establish priorities for implementation. Data on the effects of environmental change on the health of individuals and communities is even less adequate. The monitoring effort should include a major focus on the effects of environmental change on human populations. Lack of firm knowledge about the contribution of agricultural practices to the methane and nitrous oxide sources of greenhouse forcing was mentioned several times during the consultation. Much closer collaboration between production-oriented agricultural scientists, ecological trained biological scientists, and the physical scientists that have been traditionally concerned with global climate change is essential. This effort should be explicitly linked with the monitoring efforts currently being pursued under the auspices of the International Geosphere-Biosphere Programs (IGBP).

4.0 The design of technologies and institutions to achieve more efficient management of surface and groundwater resources will become increasingly important. During the 21st Century water resources will become an increasingly serious constraint on agricultural production. Agricultural production is a major source of decline in the quality of both ground and surface water. Limited access to clean and uncontaminated water supply is a major source of disease and poor health in many parts of the developing world and in the centrally planned economies. Global climate change can be expected to have a major differential impact on the water availability, water demand, erosion, salinization, and flooding. The development and introduction of technologies and management systems that enhance water use efficiency represents a high priority both because of short and intermediate run constraints on water availability and the longer run possibility of seasonal and geographical shifts in water availability. The identification, breeding, and introduction of water efficient crops for dryland and saline environments is potentially an important aspect of achieving greater water use efficiency.

5.0 The modeling of the sources and impacts of climate change must become more sophisticated. One of the problems with both the physical and economic modeling efforts is that they have tended to be excessively resistant to advances in micro-level knowledge including failure to take into consideration climate change response possibilities from agricultural research and the response behavior of decision making units such as governments, agricultural producers, and consumers.

6.0 Research on environmentally compatible farming systems should be intensified. In agriculture, as in the energy field, there are a number of technical and institutional innovations that could have both economic and environmental benefits. Among the technical possibilities is the design of new "third" or "fourth" generation chemical, biorational, and biological pest management technologies. Another is the design of land use technologies and institutes that will contribute to reduction of erosion, salinization, and groundwater pollution.

7.0 Intermediate efforts should be made to reform agricultural commodity and income support policies. In both developed and developing countries producers decisions on land management, farming systems, and use of technical inputs (such as fertilizers and pesticides) are influenced by government interventions such as price supports and subsidies, programs to promote or limit production, and tax incentive and penalties. It is increasingly important that such interventions be designed to take into account the environmental consequences of decisions by land owners and producers induced by the interventions.

8.0 Alternative food systems will have to be developed. A food-system perspective should become an organizing principle for improvements in the performance of existing systems and for the design of new systems. The

agricultural science community should be prepared, by the second quarter of the next century, to contribute to the design of alternative food systems. Many of these alternatives will include the use of plants other than the grain crops that now account for a major share of world feed and food production. Some of these alternatives will involve radical changes in food sources. Rogoff and Rawlins have described one such system based on lignocellulose -- both for animal production and human consumption.

APPENDIX

Tables

Table 1. Increases in annual average temperature for the region including Minnesota. Temperature in degrees Celsius above the present.

	Temperature Increase by Year Degrees Celsius		
	2000	2030	2050-2070
Low scenario	0.6	1.4	1.9 - 2.4
Medium scenario	1.0	3.0	4.7 - 6.5
High scenario	1.3	4.8	7.5 - 10.4

Table 2. Base case values of various climatic parameters.

Parameter	Year 2000	Year 2030	Year 2050
Average annual temperature: degrees C above present average	1	3	4-7
Additional frost-free days/year		20-30	45-55
Decline in heating degree days		1300-2000	2000-3500
Increase in cooling degree days		250-400	500-1000
Weeks earlier for spring snow melt		2-3	3-4
Number of additional July days over 90°F		10-20	25-35
Twin Cities average July temperature, degrees F		88	91
Average summer soil moisture, percent change from present		-25	
Annual minus summer precipitation, change from present		+10	
Summer precipitation, percent change from present		-15	
Drought frequency		Increasing	
Runoff		Decreasing	

Table 3. Regional scenarios for climatic change.

Region	Temperature Change (as a multiple of global average)		Precipitation Change
	Summer	Winter	
High latitudes (60-90°)	0.5x to 0.7x	2.0x to 2.4x	Enhanced in winter
Mid latitudes (30-60°)	0.8x to 1.0x	1.2x to 1.4x	Possibly reduced in summer
Low latitudes (0-30°)	0.9x to 0.7x	0.9x to 0.7x	Enhanced in places with heavy rainfall today

Figures

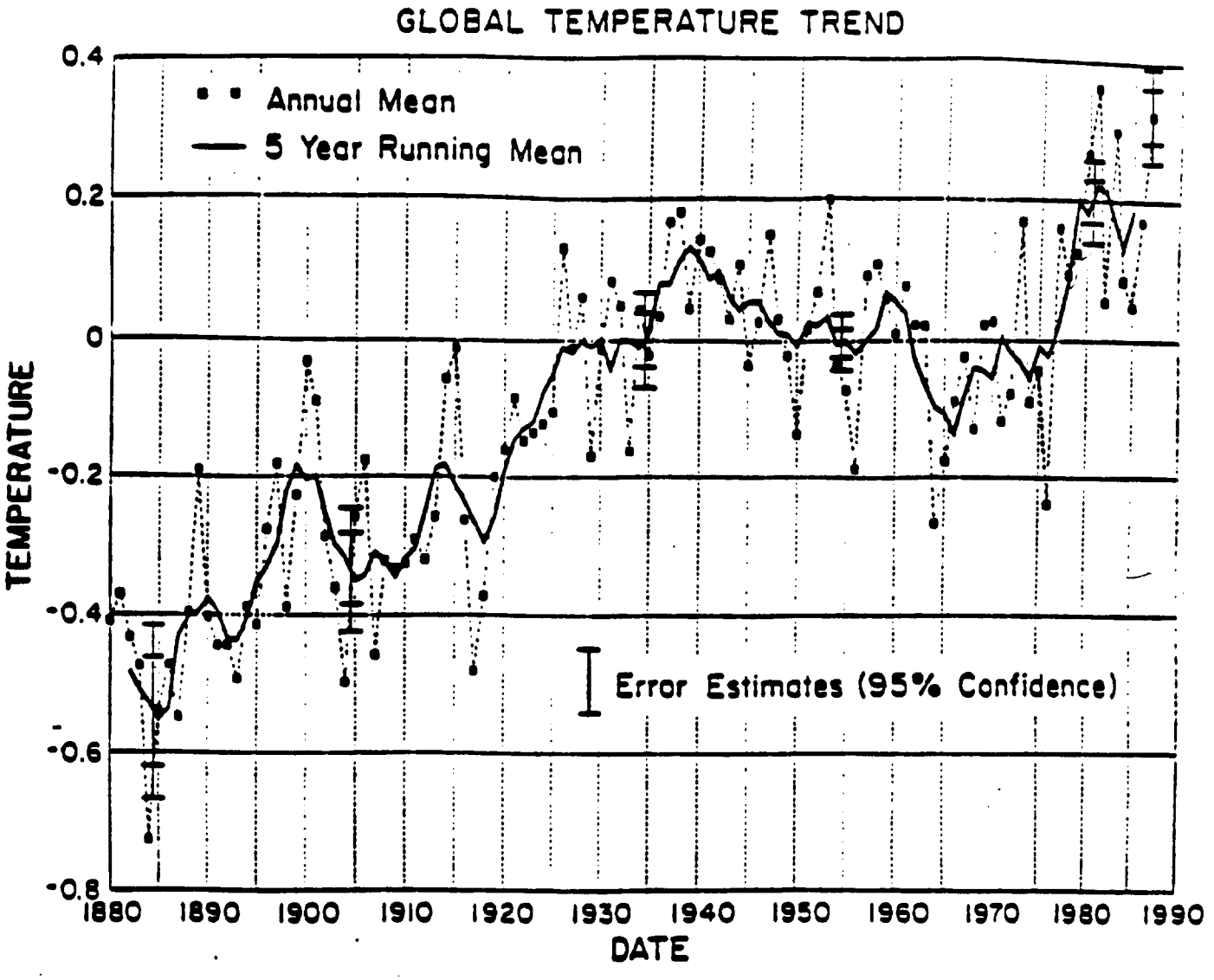


Figure 1. Global temperature trend for the past century.

Source: J. I. Hanson, A. Furg, S. Lebedeff, D. Rind, R. Ruedz, G. Russell. Prediction of near term climates evolution: What can we tell decision-makers now? In J. Topping (ed.) Proceedings of the first North American conference on preparing for climate change (Washington, DC: Climate Institute, 1987).

Figure 2.

Extrapolating Growth Of Past Decade Shows Importance of Developing Nations

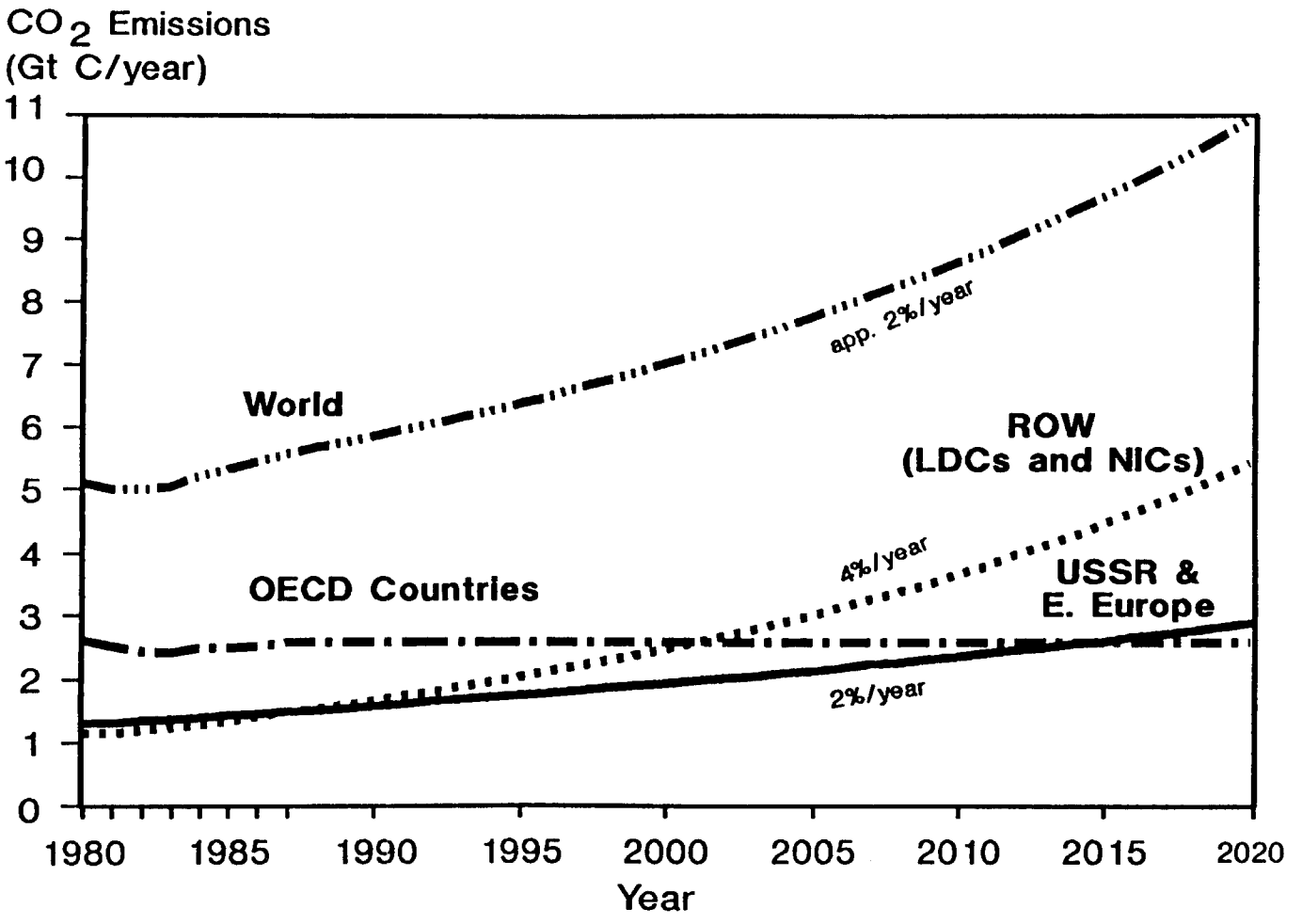
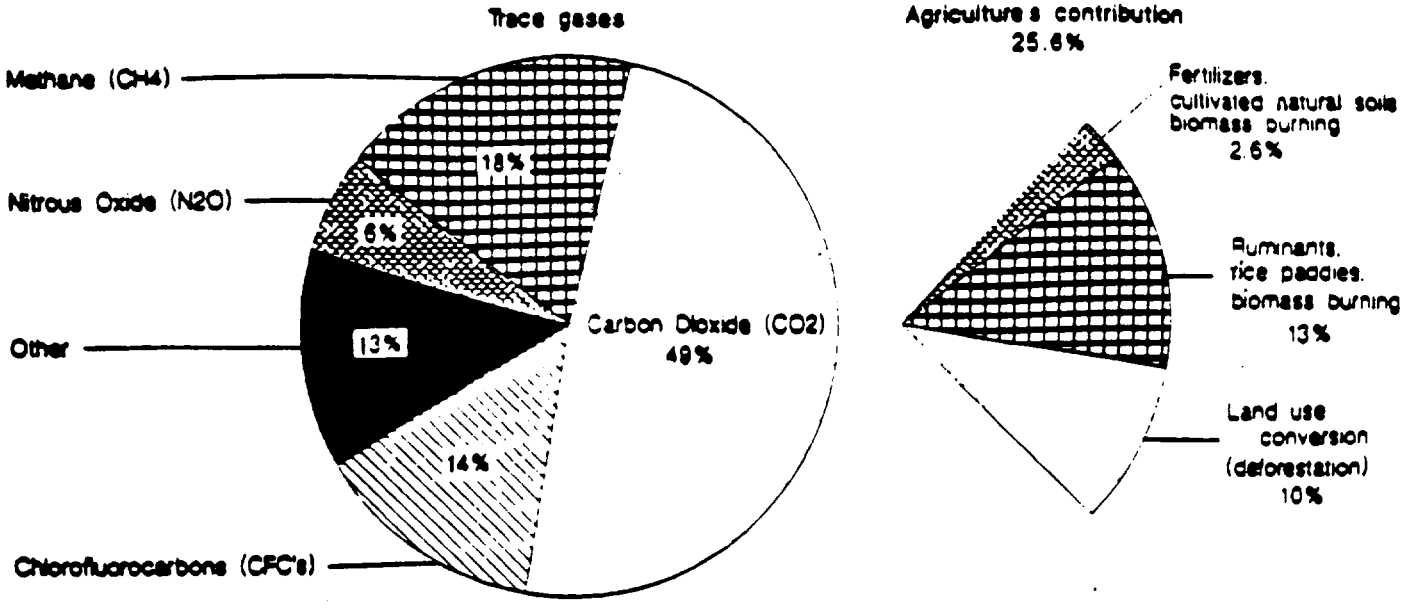
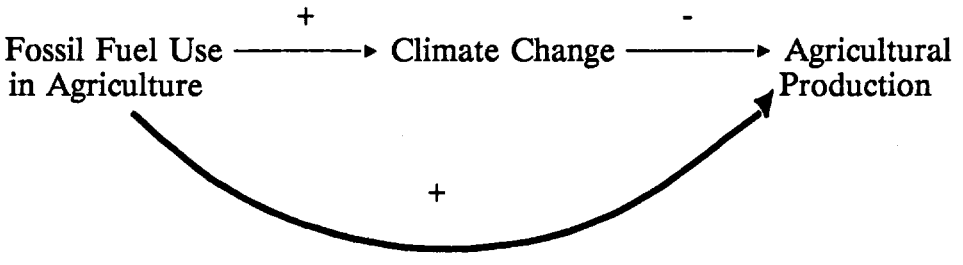


Figure 3. Contributions to Increases in Radiative Forcing in the 1990s



Source: John Reilly and Rhonda Bucklin, "Climate Change and Agriculture," World Agriculture Situation and Outlook Report (Washington, DC: USDA/ERS, WAS-55, June 1989).

Figure 4. Linking fossil fuel use and agricultural production.

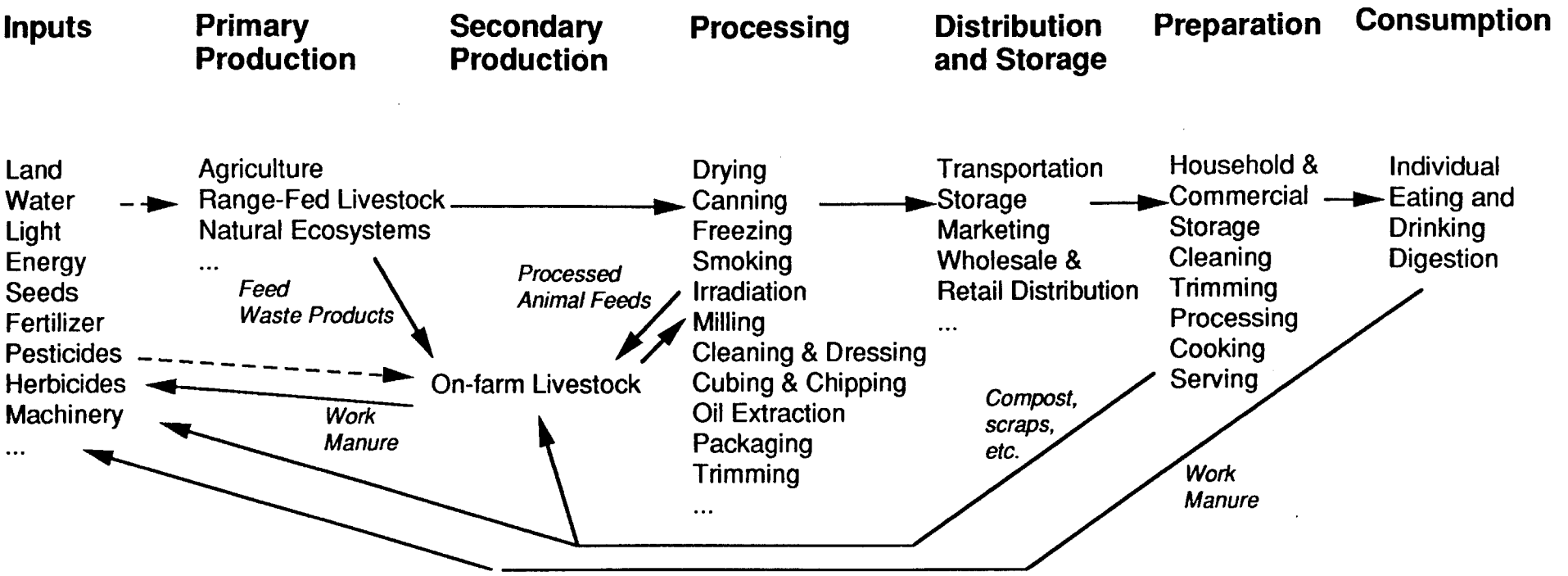


Example of one activity (X), one environmental variable (Y), and one impact (Z). The total derivative $\frac{dZ}{dX}$ represents the net effect of a change in the activity X on the impact Z. Through the chain rule, this total derivative is equal to the partial derivative $\frac{\partial Z}{\partial X}$ -- the direct effect of a change in X on the impact Z, holding all else constant -- plus the product of the total derivative $\frac{dY}{dX}$ -- the net effect of a change in the activity X on the environmental variable Y -- and the partial derivative $\frac{\partial Z}{\partial Y}$ -- the effect of changes in Y on Z, holding all else constant. In other words, $\frac{dZ}{dX} = \frac{\partial Z}{\partial X} + \frac{\partial Z}{\partial Y}\frac{dY}{dX}$.

Figure 5.

Flows and Losses of Food Calories in the Global Food System

Solid arrows represent flows or expenditures of food calories
Dashed arrows denote flows of energy or materials



Potential Losses

Inefficient application, use, etc.	On-farm losses: pests, diseases, storm damage, incomplete harvesting, harvesting damage, etc.	Inefficient calorie conversion Non-food livestock products Animal diseases, parasites, etc.	Waste, storage losses, inefficient conversion	Waste, spoilage, pest and storage losses	Waste, cooking losses, spoilage, non-food uses of food, pet foods, etc.	Malabsorption, disease, parasites, incomplete digestion

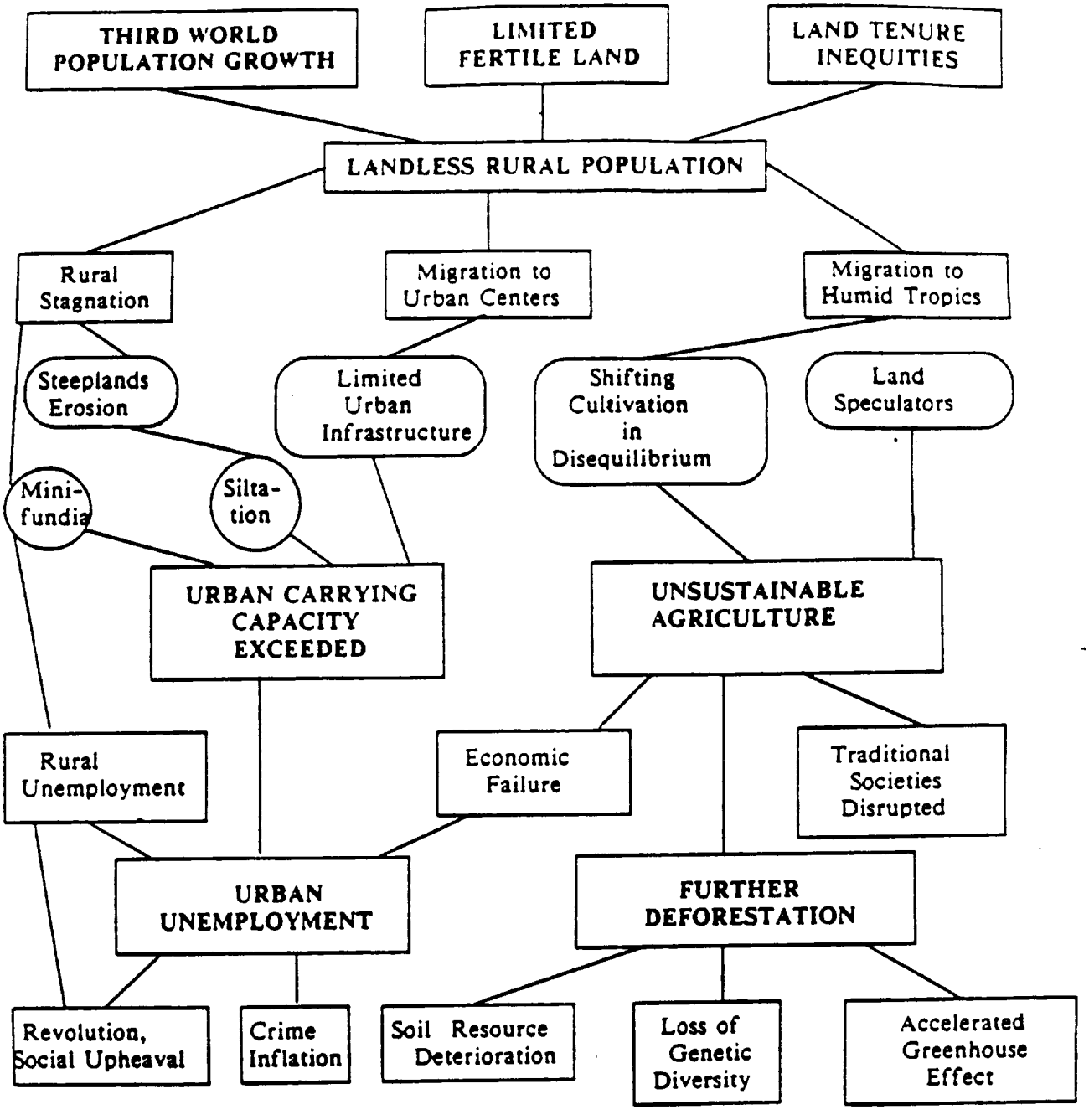


Figure 6. **Cause-effect relationships related to tropical deforestaton in developing countries.**

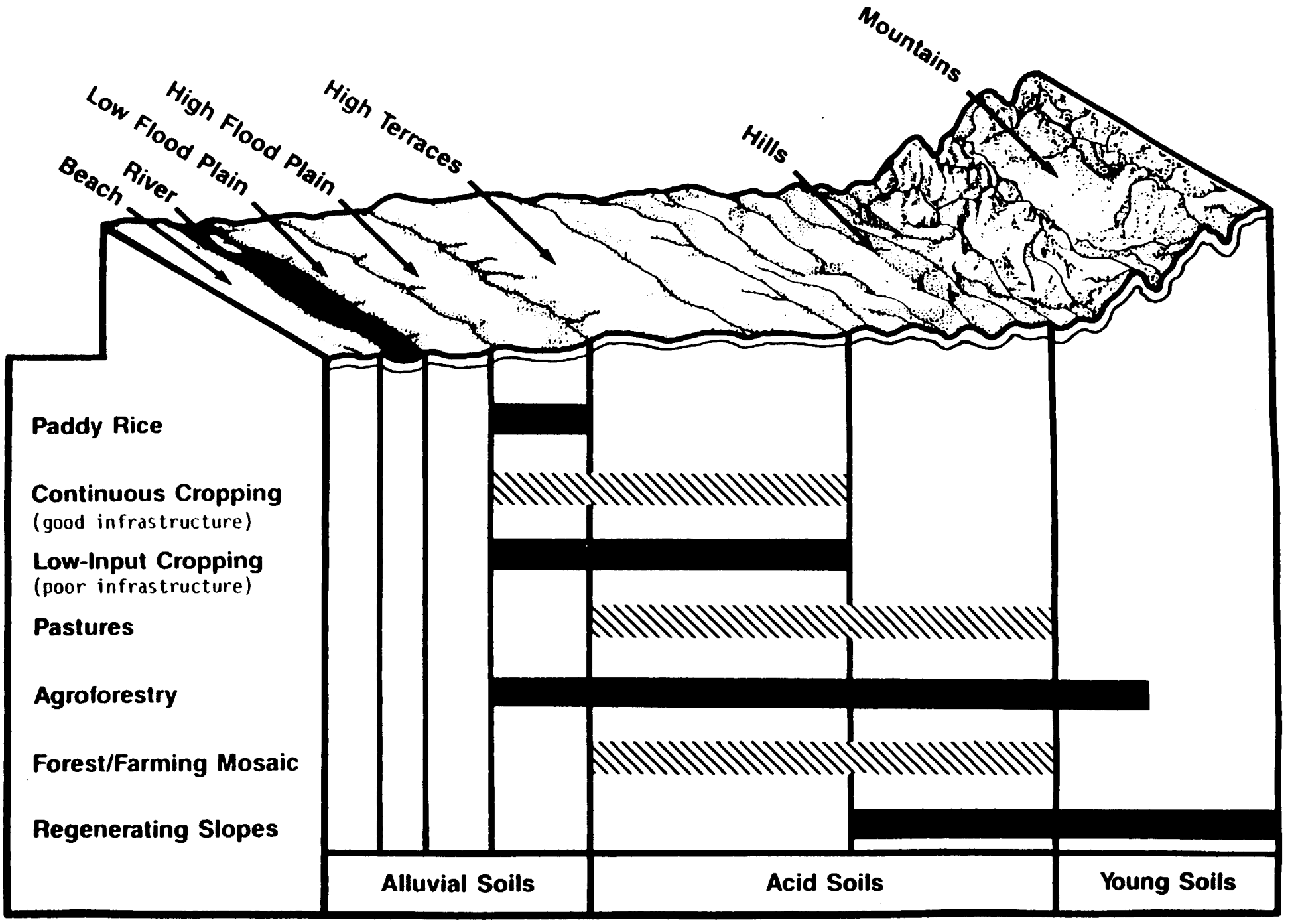


Figure 7. Some soil management options for humid tropical landscapes dominated by Oxisols and Ultisols (3).

Lists of Participants

CONSULTATION ON RESOURCE AND ENVIRONMENTAL CONSTRAINTS ON SUSTAINABLE GROWTH IN AGRICULTURAL PRODUCTION

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Invitation Letter

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August 18, 1989

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Dear Pedro,

The purpose of this letter is to invite your participation in a small "consultation" to discuss the question of "Resource and Environmental Constraints on Sustainable Growth in Agricultural Production."

Let me provide you with a brief background on the consultation. During the last year, Robert Herdt of the Rockefeller Foundation and I have held several conversations on the leading issues for agriculture and rural development as we move into the 21st century. We have decided to organize a series of informal consultations with a limited number of knowledgeable individuals about several issues that we believe will be important.

The first of these consultations was held in mid-July on "Biological and Technical Constraints on Crop and Animal Productivity." The second consultation will be on the issue of "Resource and Environmental Constraints on Sustainable Growth in Agricultural Production." The meeting will be held here at the University of Minnesota on November 27-28.

In most developing countries, it will be necessary to achieve sustained growth in agricultural production in the 3-5 percent range at least to the first quarter of the next century. There is growing concern about the impact of the series of resource and environmental constraints that may seriously impinge on the capacity to sustain growth in agricultural production in this range.

One concern is with a set of changes largely associated with increasingly intensive agricultural production practices. This includes (a) waterlogging and salinization in irrigated areas; (b) contamination from plant nutrients and pesticides; and (c) growing resistance of insects, pests, and pathogens to present methods of control. A second set of concerns relates to the extension of agriculture into more fragile environments. These include soil erosion, desertification, and the potential climate change resulting from deforestation in humid and sub-humid tropics. The third set of concerns stems from the impact of

industrialization on environmental changes resulting from the impact of the intensification of industrialization on climate change. These include the effects of atmospheric contaminants such as acid rain, global warming, destruction of the ozone layer, and others.

The objective of the consultation will be to explore with a small group of knowledgeable people the implications of the micro-level and macro-level environmental changes referred to above for resource allocation in agricultural research. One of the results of the consultation will be to identify the priorities among the several issues referred to above and sketch out an agenda for a conference that might explore the issues in greater depth.

We hope very much that you will be able to accept this invitation. Those who have been invited include:

Dean Abrahamson	University of Minnesota
Zbigniew Bochniarz	University of Minnesota (Visiting Professor)
William Clark	John F. Kennedy School of Public Affairs, Harvard University
Pierre Crosson	Resources for the Future
Suzanna B. Hecht	University of California
Robert Herdt	Rockefeller Foundation
William Larson	University of Minnesota
Martin Parry	IIASA and University of Birmingham
Steve Rayner	Oak Ridge National Laboratory
Norman Rosenberg	Resources for the Future

The project will be able to take care of your airline ticket and other expenses incurred in your participation in the consultation. It would be helpful if I could have your response within the next few weeks. Please give me a call either at my office (612-625-4701) or at my home (612-644-9570) if you have any questions.

Sincerely yours,

Vernon W. Ruttan
Regents Professor

VWR:rrl

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