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BIOLOGICAL AND TECHNICAL CONSTRAINTS ON CROP AND ANIMAL PRODUCTIVITY: Report on a Dialogue

July 10-11, 1989

Edited by
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The Twenty-First Century Project

Center for International Food and Agricultural Policy
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TABLE OF CONTENTS

BIOLOGICAL AND TECHNICAL CONSTRAINTS ON CROP AND ANIMAL PRODUCTIVITY: Report on a Dialogue

July 10-11, 1989

Ruttan Good morning. I am Vern Ruttan. I am very pleased to welcome you to the University of Minnesota. I have asked Dean G. Edward Schuh, our host here at the Hubert H. Humphrey Institute, to extend an official welcome. I don't think I really need to say very much about Ed Schuh. He has worked in Latin America a good deal of his life. He was head of the Department of Agricultural Economics here in the early 1970s; has been Head of the Agricultural Program Office at the World Bank; and is currently Dean of the Hubert H. Humphrey Institute of Public Affairs.

I also want to introduce Shenggen Fan, the young man monitoring the tape recorder. He has recently completed a Ph.D. thesis on sources of productivity growth among regions in China. He is here to help us keep the conference going. He has assembled a big book that shows trends in crop yields and land use for a large number of countries. You may want to refer to the data at some point in our discussion.

Schuh Thank you. I am always impressed with how well organized Vern is. You notice that he counted the number of chairs around the table and invited just that number of people. I will make a couple remarks on the nature and the importance of what you are doing today and tomorrow.

I was never a subscriber to the 1970s Mathusian scare because I thought we had a lot of capacity to produce new agricultural technology; we had the new rices and new wheats. Their contribution to production was only beginning to be realized. I have a different view of the world today. My concern is that we are slipping at the switch.

There are a couple of things that impress me when I look around the world. The first is that I see some of the national research systems that were coming along very well and developing very strong capacities being decimated as a consequence of the international debt problem. The Brazilian EMBRAPA system is an example where budget support has declined dramatically. A lot of the best people have left. It has fallen into bad leadership. It was a very significant institution. It was coming along very well. There are other examples like that around the world of emerging national research systems that have really fallen into a bad way.

An even more serious concern in many countries is that the capacity to train agricultural scientists have also fallen on hard times. Again, Brazil is an example. The same thing is happening in many other countries. So when I look at that and look at the fact that we may have exhausted the easy productivity gain in rice, wheat, and maize, I can't help but conclude that what you're up to these next two days is very important. I wish you well. I wish I had the time to be here and I may still come sit in once in awhile. I'll bring my own chair.

Ruttan Thanks, Ed. Let me say a little bit more about the background on why we are here and how we got here. A little over a year ago, Bob Herdt and I

were talking on the telephone. Bob raised the question, "Don't you think it's time to begin a process to think about what the needs of agriculture are going to be as we move into the first decade of the next century?" We talked about some of the people that might be involved. At that time we were thinking about a conference. We met again at the Agricultural Economics meetings in mid-summer. We decided that a conference would be premature. What we really needed to do was get a group of knowledgeable people together and outline significant issues, talk about what issues needed further investigation, and then decide whether there was a basis for a conference. This is the first of a series of what we decided to call "consultations."

It may seem a bit strange to be thinking about the constraints on crop and animal productivity at this time. If it had not been for last year's drought, the United States would still be swamped by surpluses. Western Europe has been dumping its surpluses on the world market for some time. There continues to be a great deal of optimism among some quarters.

It is worth remembering the kind of cycles we have gone through in our thinking about these issues. As late as 1980, if anybody had said that by the mid-1980s there would be depressed farm prices and surpluses, they would have said, "Where have you been since the energy crisis of the mid-1970s? You're out of touch with reality!" If in 1984 or 1985 you had started talking about shortages again, the response would have been: "But surpluses are here to stay."

When we shift our attention to the developing world, there are a number of things we need to be concerned about. The promise of the Green Revolution is still just a promise in large parts of the world, particularly in Africa. In those areas where the Green Revolution has been most successful, there is the question of what do you do for an encore? Twenty-five years ago, if I had been asked, "Where is the production going to come from in South and Southeast Asia to meet the food needs of the late 1980s and 1990s?" I would have identified three things: water, fertilizer, and new varieties. The question is not as easy to answer today. The biotechnology revolution seems (at least to me) almost as far as off as it did a decade ago. If you take Burt Sundquist's projections in the package of material I handed out, my guess is that you could shift his 1990 projections forward to the year 2000.

We are going to be increasingly confronted with a series of micro and macro environmental changes that impinge on agriculture. The micro things I have in mind are groundwater pollution, salinization, and other consequences of intensification of agricultural production. The macro changes are the consequences of intensification of industrial production. We're going to have a separate consultation on those issues, and on the implications of those issues for agriculture research. If you knew what was going to happen in the next 20 years, how would it change your research portfolio?

But today, we will be concerned with the constraints and opportunities in crop and animal production. My sense of the way to proceed--to put a

little structure in this unstructured session--is to start out with the crops people and get their perspective on how they see the issues. Then we'll move from the crops people to the livestock people. Then we will go to the resource and economics people. That will occupy most of the day. Nothing is ruled out in terms of what people want to put on the table. Tomorrow morning, we will come back and focus on the issues that need more careful thought.

Gains from Conventional Plant Breeding

Ruttan Don Duvick is Senior Vice President for Research at Pioneer Hi-Bred International. I've asked him to lead off. Don watches crop production and crop production research in a great many countries of the world.

Duvick Thanks. Since I am one of two representatives of industry here at this consultation, it might be worthwhile for me to give just a little background on our company, Pioneer Hi-Bred International. We are one of these organizations known as a trans-national corporation. We are a seed company. Our original business was built on selling hybrid seed corn in the United States. Over the last 20 years, we've spread around to other parts of the world and have enlarged the number of crops we work on. We now work on seven or eight of the major crops--such things as soybean, sorghum, wheat, sunflowers, alfalfa, and a few others. We are just starting on rapeseed. In addition to that, we also select and sell strains of organisms that are used to improve silage quality and other strains are given to animals. But seeds are primarily our interest. We work both in open pollinated and hybrid seeds in the United States. We did not get into self-pollinated seeds until the Plant Variety Protection Act was passed because, of course, we thought to invest in producing self-pollinating seeds and then turn them loose for anyone else to go into business on was not exactly in line with our goal to be a profitable company. We still work only in hybrid seeds in almost all other parts of the world because there is little protection in most parts of the world for self-pollinated seeds. Europe is the exception. But up to this point, we felt we couldn't really get into the mature and highly competitive self-pollinated seed market in Europe--at least we haven't up to this point.

This gives you some idea then with regard to the kind of crops that we work on in Third World countries. They are primarily three: hybrid maize, hybrid sorghum, hybrid sunflower. We also do hybrid pearl millet in India. A major constraint to productivity from the point of view of a seed company is protectability of the seeds. This is a biological constraint--it is also an economic and legal constraint. But this does have a lot to do with what kind of assistance Third World countries can expect to get from industry. In some quarters, as you know, the private seed industry is looked upon as a potential source of help rather than a threat.

What are the biological and technical constraints to crop productivity that we see? Anywhere in the world where we operate as plant breeders, we see a continuing possibility to make improvements in achievable yield of all of the crops we work on--even in the United States in hybrid corn where

immensely concentrated work has been going on for 50-60 years. Improvements in yield--this means in yield in the presence of various disease, insect, and weather problems--continue to be achieved. Unfortunately, from our point of view they are achieved by our competitors as much as by us--which means that there is a lot of competition going on. All breeders are raising yields everywhere.

In most of the Third World countries there are much easier gains to be made in yield primarily by selecting for stress resistance, resistance to heat and drought, and resistance or tolerance to the major disease problems and to some extent tolerance to insects--although this always seems to be more difficult in the crops that we work on. So you could say there are no biological constraints to increasing productivity by breeding.

But the costs of breeding get more and more expensive anywhere in the world, particularly in the developed countries--the U.S./Western Europe and also Eastern Europe every year. It costs more and more for each unit of gain.

I personally have made some comparisons of rates of gain in hybrid corn yields in the midwestern U.S. over the years and find that we have made a straight-line gain ever since 1930. I just completed a recent series of tests and it was still a straight-line gain as of about four or five years ago. I think the gain is still straight line. However, I also put together some figures for the number of plant breeders, corn breeders, and support breeders. That has not increased as a straight line--that has gone up in a curvilinear fashion. So you can see that the cost per unit of gain is increasing. That may well be eventually an important constraint on productivity.

We have added a biotechnology group within the last 7-8 years. We find that a biotechnology researcher is no more expensive to maintain than a field corn breeder. But when you add that on to the cost of field corn breeding, you have considerable extra cost. And, we also have a lot more emphasis now on plant pathology and on entomology and on computer science. All of these things are adding to the cost of research. They are all necessary. But they are all adding to it. So these are our constraints. They're aids to progress, but they're also constraints in that they cost money.

I've talked around the subject pretty well, Vern. Is there any other point you would be interested in having me touch on, or should I stop here?

Ruttan You mentioned to me earlier that you were more concerned about some of the economic or institutional constraints than you were the technical constraints. Do you want to say anything more?

Duvick Yes, I could, particularly in the Third World countries. In the past in many Third World countries, there has been active discouragement of private industry in the seed trade. We've had resourceful people at work in our overseas operations and we have managed one way or another to find a niche in many countries where we can operate.

But there are still problems which have to do with regulations, bureaucracy, importation of seeds--what to us seem (in some cases) to be excessive concerns with plant quarantine, for example. All of these things make it very difficult to operate in many Third World countries.

In addition, there is the weakness of the infrastructure itself. In Brazil, for example, we cannot get our data on our worldwide computer system adequately because of absolute restrictions on importation of certain kinds of computers. In the Sudan, a computer turned up for our sorghum breeder. The only problem was there was no electricity. The infrastructure there, of course, is extremely limiting. So these are problems. The problem of inflation in Argentina makes it difficult to do business. So there are these constraints, particularly in Third World countries. I should also mention the constraints with regard to protection of our proprietary breeding materials. This is an important problem anywhere in the world. But there are fewer means of protection in Third World countries than in the First World.

Ruttan Are there additional questions you'd like to ask Don?

Goodrich In the international market, do you work exclusively on hybrid seeds? I ask that question because it appears that frequently that imposes an added external cost on the country?

Duvick We work only on hybrid seed, yes, because only through physical possession of the inbred parents can we maintain ownership of the seed that we sell. And of course, it is our intention to sell the seed every year or if it is a perennial crop like alfalfa, sell it every time it is reseeded. That is our business, that is the way we make a profit on our investment in R & D.

Goodrich There is a bit of conflict, if you will, when one looks at that issue from an animal science point of the view. If we would spend adequate amount of effort in developing non-hybrid varieties that could be self-generated within those countries that are very short of capital to buy external goods, there would be greater benefits for the country. Let me refer to poultry rather than a seed-corn. Many of the countries of the world that have increased their poultry production have done so at the cost of buying all the inputs. They buy feed, they buy the young chicks, they buy the equipment. Sometimes I really wonder if they're much better off than when they started. The improved non-hybrid chicken might be a lot better for that country rather than this bird that has relegated them to reliance of the technology of another country.

Duvick That gets to the heart of what I think is a real problem for Third World countries. To what extent can they withdraw from the world and be successful in entering the world? There may well be crops in which it's better to withdraw from the world and rely on themselves. But sooner or later, if they intend to take their place as equal partners among the nations of the world, they're going to have to learn to take part in international trade as well. Let me back up just a little bit more and

speak particularly about crops. Our opinion as a company has been that there are only certain areas in which there is any reason for us to be operating in Third World countries. We're in hybrid crops because that way we can maintain ownership. But look at it from the Third World country's point of view. There are some farming systems with some crops where it really pays to buy the expensive seed (expensive compared to farm grown seed) year after year because of the added productivity to be gained from that seed. We as a rule of thumb, say that if the farmer cannot get an extra gain in income from our seed equivalent to three to five times the extra cost, the seed is not worth buying--and he usually won't buy it, in our experience.

Goodrich Is that because plant geneticists have not spent an adequate amount of effort in improving genetically those non-hybrid seeds. Also, have we spent the appropriate amount of effort on other kinds of varieties.

Duvick Actually, in wheat in this country, very good progress in non-hybrid seed has been made. So good, in fact, that it has not yet been profitable to produce hybrid wheat--and it may never be for that matter. In crops like sorghum and corn and sunflower, it has been debated, and probably will always be debated, as to whether or not the equivalent effort put into the development of open-pollinated varieties might not have given things just as good as hybrids. I went back into real comparisons back in the 30s in the Midwest when our company was first introducing hybrids and found that the average hybrid in our yield trials as compared to the local farmers open pollination had a yield advantage of only about 15 percent. Now that's a lot, but it's not quite what you might think, from today's perspective, the advantage was. This was fifteen percent of a much lower yield. We now know that with some of the breeding methods that have been developed since then, improved open pollinates also could probably have given a 15 percent improvement in yield. But they weren't developed because the know-how was not then available. It is probable that the best hybrid is always going to better than the best open pollinated, according to theory and experience. There are well-based theoretical reasons why the hybrid crops probably will always have a performance advantage.

I think maybe the most important thing is because the first hybrids were so easy to do, there was more breeding effort put into hybrid improvement. It's sort of a "which comes first" type of argument, but this seems to have had something to do with it; that is, the east of finding and fixing hybrid vigor resulted in great stimulation of practical breeding plus theoretical studies.

Byerlee I think, on this point Don is re-emphasizing, that hybrid technology creates a condition that allows society to get more investment in crop breeding through the private sector. You have a mechanism there that we haven't quite been able to mobilize for a number of other crops because there is no way for private entrepreneurs to get hold of some of the benefits. And whether society should have made the equivalent kind of investment in open-pollinated improved maize, for example, can be debated, but the evidence suggests that the public sector underinvests.

Plucknet One of the poorest countries in the world has the most advanced system for hybrid rice. Nobody else has been able to make hybrid rice work other than China. So it's a question of what countries want to do, decide to do, and have the ability to do. There are countries that are actually taking up hybrid technology and are handling it fairly well. It isn't as closed a door for many countries as it may appear.

There is also an evolution of responsibility of who does this work. Hybrids allowed private industry to move into corn breeding and universities and other public agencies to the other crops. And as far as whether it is more vulnerable or whether we could have made better progress in other approaches, some people will say if you buy private seed, you'll pay twice as much as public seed, but you have got to recognize that public seed also has a hidden cost--the cost of all the public breeding facilities have to be counted. When private industry takes over this responsibility the universities have a responsibility to reduce their effort. I don't think that's left us more vulnerable--it's left us with greater investment in plant breeding.

Fitzhugh This is really a difficult argument. It becomes even more difficult when you move to livestock. All agree that research needs to be done in order to improve the genetic potential of crops and livestock. But where is that research going to be done? In the very poor countries the national systems themselves, as H.K. Jain will probably tell us later, are poorly developed. Public resources aren't going to be adequate. Ed Schuh mentioned that even EMBRAPA, which has been one of the shining examples of the development of the national program in a developing country, is now deteriorating. We could look at a lot of other cases--Peru, Mexico, Colombia. If we agree that research is really critical to developing genetic resources and genetic potential, then where is it going to be done in developing countries. I hate to exclude the private sector, but the only reason the private sector is going to do it is if there is a profit. So I think we have to be realistic. Developing countries will benefit from better quality seed. They will utilize the seed if they pay for it. They will only pay for it if the gains are several times the cost. That sounds like a pretty good deal. That's the way I argue in favor of support for the private sector research.

Plucknet I would like Don to assume for a minute that the Plant Variety Protection Act has just been blown apart and it does not exist in the United States. What would Pioneer Hybrid do?

Duvick I'll back into that by noting that there is no Plant Variety Protection Act in Canada at this time. But we have been selling soybean varieties in Canada for about 10 years. Now it's a little mystery to me sometimes as to why we are able to do that. But we are using Canadian variety registration laws. Maybe there is a certain amount of hesitation, in addition, in Canada for people to pirate our material and go into business with it. Maybe it is happening more than we realize. If in the U.S. the PVP Act were repealed by Congress, what would we do with our soybean breeding and wheat breeding--those are the two chief crops protected by PVP? We probably would try to go on as though we still had protection. If pirating

got to be too serious we would drop out as we did with cotton seed about five years ago. We were breeding cotton seed, mostly in Texas, starting about 15 years ago. In spite of the theoretical protection of the Plant Variety Protection Act, pirating was so serious that we quit. The better varieties that we had, the more widely they were sold--but not by us. In this particular case, there was a socio-economic system in which cotton ginners had always saved seed of the best varieties and sold it to the farmers. They adapted very well to our protected materials. It was like swatting mosquitoes in northern Minnesota. You could kill as many as you wanted to but there were millions more and so we gave up.

Goodrich I'd like to follow up on a question. I think if I heard correctly, you identified yield as the main breeding objective. There are obviously other characteristics of crops that would be highly desirable, more so in some developing countries than in this country. If the hybrid companies tend to be located in those countries that have better fertility and rainfall, are we putting enough focus on developing characteristics in those crops such as drought resistance, specific disease resistance, and nutritional quality. Are those issues being addressed with the crop genetic improvement systems that are now in place?

Duvick I'd like to talk about that--in fact, it is something that I meant to bring up. I (and most plant breeders) will typically talk about yield, but what they really mean (and what I really mean) is achievable yield. If you're trying to grow corn in C te d'Ivoire where a particular virus is the limiting factor, the way to get yield is to have virus resistance. That's what makes yield. Or if you're planting dryland corn in northeastern Nebraska, especially last year and this year, the way to get yield is to have heat and drought resistance. So we automatically mean tolerance or resistance to the primary biological constraints when we refer to yield.

It so happens that any measurements that have been made in any crop anywhere in the world that I know about, show that the newer "higher yielding varieties" as they're called almost always are better at meeting these various biological constraints to yield than the older varieties they have replaced. They are not weaker--they are actually stronger. Take higher yielding rices, for example. They may be particularly adapted to a particular set of cultural, flood, or irrigation environments. They're not an upland rice. But for those particular constraints, I think you will find they are always better at meeting whatever the disease or other problems are. There is one other thing, however, that I should point out. That is the widespread success of so many of the varieties. This means that they get spread very widely. Then you introduce genetic vulnerability problems and things that were not a constraint before become constraints all too quickly.

Goodrich You need minimum of environmental genetic interaction then in crops--is that what I heard?

Duvick Yes, in fact, that's the only way to succeed. You make the plant resistent to the yield-depressing things that nature does and responsive to the yield-enhancing things that man can do.

Byerlee Just one more question for clarification. You talked about straight line increases and gains in terms of kilograms per year. That implies a decreasing rate of gain per year. I think we need to put that in context. The other question was if there are increasing costs of making gains, that should be reflected in increased costs of hybrid seed. I understand that is what has been happening in the U.S.

Duvick Well, I see complaints from our marketing people that we haven't raised our prices enough to cover the increasing costs. However, I should point out that the cost of research in our company is not one of the really large costs in operating the company. A lot of the other overhead costs are as important and probably the most important cost actually is the cost of seed production.

Ruttan One of the things that I was hoping Don Plucknet would raise is the maintenance costs or the maintenance breeding issue, but we'll leave that for his presentation.

Organizing Science for New Genetic Technology

The next person I have asked to speak is Dr. H. K. Jain. Dr. Jain is Deputy Director General at the International Service for National Agricultural Research (ISNAR). He was formerly Director of the Indian Agricultural Research Institute (IARI).

Jain I must say that when I began to think about yield increases in the present century and in the prospects for the next century, I had two very different kinds of impressions. First, like many of us here, I am, of course, very impressed, especially after listening to Dr. Duvick about how much has been done using the technology which we have at present--the genetic technology and its applications--especially in the last 25 years. This technology has served us well. Coming from South Asia, I can say that if we had not had this technology in the last 25 years, millions of people would have died of starvation. So it has been a good technology. It has been a wonderful technology. We must really recognize the work of those people like Dr. Borlaug, who made all this possible for many of us. One obvious answer is to use this technology more widely. That's what Don Duvick was suggesting--diversifying the hybrid research program because we still don't have hybrid or high yielding varieties in some other crops like oil seeds, grain legumes, some of the fiber crops, certainly not many of the horticulture crops. There is an enormous scope to extend the present technology to a wider group of crops.

Secondly, of course, there is a tremendous potential to develop a new kind of technology for the stress environments. Dr. Duvick did make the point that even as we breed for yield, we always stress resistance to stress environments. Of course, we do, but my feeling is that we, as geneticists, probably have over-emphasized the role of genetic improvement in these stress environments. I have a very strong feeling that if we had not taken up this very strong commodity approach, which is virtually

synonymous with plant breeding, and had paid greater attention to soil management, water management, and other environmental factors, progress would have been even greater.

One of the key problems of both national and international agriculture research today, is that all solutions are sought through plant breeding. Of course, plant breeding does make a tremendous contribution. But do we, as students of genetics, recognize the importance of environment? I will say that there are environments, stress environments, such as those in sub-Saharan Africa, where you do need to address the environment itself as much as the genetic improvement. The leadership in these environments should rest with soil scientists, with water scientists--soil and moisture conservationists. Possibly you have even got others. All that I'm saying is that we have this technology. There is a tremendous potential to use it well and it will continue to serve us at least throughout the closing years of this century. Because to be very realistic, I don't see that in the next 10-15 years, certainly not by the end of the century, much of the world's agricultural production will come from any other kind of technology. We do have this tremendous promise of biotechnology, but I personally do not believe that in practical terms, the harvests which farmers across the world will achieve by the year 2000 will come from technologies which are not essentially similar to what we are using today. There will be an increasing component of biotechnology, but most increases will come from application of the classical technology.

That is my tribute to the modern technology. I purposely paid this tribute because when it comes to the next century, I want to stress something totally different. I want to plead for a totally different kind of technology. I want to make the point that the scientific basis of present production technology is very, very narrow. This is my main point. I will stress this point by saying that most of the scientific advances which we have achieved in this century have been based on the by-products of advances in basic sciences. Rather than organizing basic research specifically for the purpose of producing some very precisely defined agricultural objectives. It's not as if we had in mind some very well-defined agricultural objectives which we wanted to achieve and then organized basic research to accomplish these objectives. It wasn't anything like the Manhattan approach, for example. It was more the spill-over effect of basic research. It was being done, nevertheless, irrespective of any agricultural considerations.

Now let me take just two examples to make this point. A great deal of scientific research has contributed to present technology. But more important than almost everything else, there are two discoveries which are at the very center of our present technology. In the last century (19th Century), the German chemist, Liebig, was working on the mineral nutrition of plants. He was not an agriculture scientist--not in the sense which we define agriculture scientists today. He was a good chemist and was working on the mineral nutrition of plants and, at least initially, was unconcerned with the implications of his work for agriculture. Now we know that, in the last 30 years, his work was directly responsible for the world-wide growth of this tremendous chemical fertilizer industry.

At the beginning of this century, my second example, we had the rediscovery of the work of the Austrian monk, Mendel. He was even less concerned with agriculture. His research was a hobby. He was a student of basic science, or natural sciences as they called it. It is only in the last 30 years that these two very far-reaching advances in basic science, unrelated to agriculture, were brought together in a highly synergistic manner to create very high yield potentials. We in plant breeding today have a "central dogma." The central dogma is that the geneticists assemble the genes to create the potential to take advantage of modern farming practices, like use of chemical fertilizers, to achieve very high yields. And of course, it works very well. My point is that, while there is absolutely nothing wrong with making use of spill-over benefits, there are limits to which we can continue to improve yields in this manner. I noted, Dr. Duvick, your point about almost linear increases, but I will show you in a moment that these just can't be sustained because all that we have been doing in the last 80 years since Mendelian plant breeding started was to recover more and more of the dry matter in the form of grains. We are simply redistributing dry matter in the plants. In fact, if I were to be slightly cynical, I would say that in the last 30 years, in a true scientific sense--in a biological sense and in a physiological sense--we have not increased crop yields at all. The yield was all there. The dry matter was all there. The "land races" were often more efficient in producing dry matter than improved crop varieties. And I will give you some evidence.

What we have done (for which we must recognize the work by the geneticists and breeders) has been very ingenious. I myself belong in a very minor way to that fraternity. But nevertheless, all that we have done is to redistribute that dry matter--improve the harvest index. That's improved the grain/straw ratio and recovered more and more of the nutrient intake in the form of grains. Now, it is obvious that there is a limit to improvement in the harvest index--the grain/straw ratio. In many crops that limit has already been reached: in wheat and rice, certainly, I don't see dramatic increases in yield coming by the end of the century. In most of the crops--sorghum, millet, maize, rice, wheat--if very aggressive plant breeding programs are maintained, then probably as much as 50 percent of the total dry matter will be recovered in the form of economic products, grains, or whatever. And then there is nothing because if you go on increasing the harvest index you will virtually leave the plant with no leaves. There is a limit to which you can redistribute and I suggest that those limits are beginning to be reached. In wheat and rice I don't clearly see that in the next century we will be increasing yields; it is arithmetic--we will be reaching the limits of harvest index improvement.

So what are the opportunities open to plant breeders in the next century? I think we must begin to ask that question, because in the next century, human populations are certainly not going to begin to decline fast enough. They will continue to build up. It is a very difficult question. The answer must be photosynthesis. If you really want to keep on increasing crop yields and you can't keep on doing that simply by increasing the harvest index, you must address the problem of photosynthetic rates. And it's very depressing that there are hardly any differences in rates of photosynthesis.

Millions of years of natural selection seems to have fixed crop plants for given rates of photosynthesis. I suppose one of the most fundamental challenges in agriculture in the next century, especially in the context of recent advances in molecular biology will be to do something about these enzymes. That really is the way to get yield in the next century. But if you don't do that, I don't believe we will be able to keep on these linear trends in yield improvements. Some of those, in any case, are coming from other sources than genetic manipulation--but they certainly will come to a stop pretty soon as they are beginning to do in some crops.

My first point, again is that we are continuing to live on the by-products of advances in basic science. A good example of a different kind of approach will be to organize basic research to attack the photosynthesis problem. If we now recognize that photosynthesis is the key to future yield increases, can we bring some of the brightest molecular biogists and physiologists over the next 10-15 years, this should be the greatest area of concentration. That will be a different approach--that will be different from what we did in most of the 19th century when we really were just waiting for something to turn up. Fortunately it did! It took a long time. But that was not what agriculture needs today. It needs a much more focused effort.

My second point is that if in this century the oil fields of the Middle East had not been discovered and, more than that, if they had not been dominated by the Western countries, the motivation for development of an improved crop production technology would have been very different. Once you have oil, it became very easy. I said earlier that the yield, in terms of dry matter, was already there. All we did was to recover more of it in the form most useful to man. The cow doesn't make distinction whether it eats the whole plant or if it eats a few seeds. For the cow, the whole plant is yield. But we are interested only in a small part as economic yield. My other point is that if we didn't have this enormous resource in the form of cheap energy, we probably would have worked for a different kind of technology which would not be so highly dependent on fertilizer and other petro-chemical based inputs. Now, of course, we must use these because that's all that we have at present. But we must replace these enormous non-renewable resources of energy with the renewable kind. I say this because while the developed countries obviously can afford to use energy intensive inputs, either because they have it or because they can afford to import. The developing countries, because they have no other option, must also use these inputs because there is nothing else. But today they are finding it hard. Let me say that there are countries today in the developing world--countries like Pakistan, the Philippines, even Bangladesh, and India--where technology in many crops is as good as any in the Western countries. Those countries have made large gains in their agricultural production. But even then there is a large yield gap. Their yields are still one-half those in the developed countries. The reason for that is not technology. The reason simply is how much subsidy the government can offer for these inputs--how far the government can keep on providing subsidies which here, in the developed countries, you do it because you can afford it. They can't afford it. So this tremendous dependence on non-renewable resources of energy is a major constraint on

crop yield improvement. Nevertheless, there is nothing else which we can do. But in the next century we may be able to use a whole range of microbes as the fertilizer producing factories for the agriculture of that generation. Can we have more efficient biological nitrogen fixation from symbiotic and nonsymbiotic bacteria? Can we genetically reconstruct bacterium to do a much better job than they do in legumes? Now that will be basically a different kind of agriculture. In the 21st century we will need a very different kind of agriculture.

Now let me summarize this by making three points: I should not be misunderstood. My first point still remains that the present production technology is extremely good. It's all that we have and we must use it fully. It will be a mistake to give an impression to developing countries that something is around the corner in biotechnology, which will solve all their problems. For the next 15-20 years, this is all that we have and we must keep using it even if it means subsidized inputs--do it! But that's it! Unfortunately, you hear a call these days from parts of the First World which urges a return to low-input technology. Now that to my mind is the worst advice that can be given to farmers in Third World countries. With the kind of population pressures they have, they can't really afford to go back to low input technology. That's what they had for thousands of years. And look where it got them. I have a great deal of respect for the modern technology--let's keep using it--that's all we're going to have in the next 15-20 years. We cannot afford to go back to low-input technology. In fact, if anything, farmers in developing countries need even more sophisticated technologies than the ones which they are using today. That's my first point.

My second point is that when we are talking of the next century, we must make this break from the past tradition where we were sort of carried along a current generated by Mendel and Lebig and the spin-off effects of basic science. Let's organize basic science research in pursuit of very well-defined objectives such as improved rates of photosynthesis and development of renewable resources of energy. That will be a truly scientific agriculture. Today the scientific basis, as I said earlier, is very narrow. We did very well to use these spin-off effects, but that's not what agriculture deserves. It deserves much more.

In conclusion, let me again emphasize that modern agriculture is nothing more than a human attempt to convert fossil fuels into food using biological technology. It's a mechanism to convert one form of energy into another. And if you don't have the fossil fuels, you are stuck. In the next century, that's why we need a very different kind of technology. Let science be mobilized directly and not let science be something which is developing independently of agriculture.

Rubenstein I agree with you that we need more basic research in plant biology. But I am reminded of something that happened in this country about 10-15 years ago when the so-called "war" on cancer was announced. Some individuals at the time made the comment that "it's like announcing the project to go to the moon without knowing the laws of Newton." And when you gave examples of how discoveries in basic science have helped in this century,

you made the point, which I would also like to make, is that you don't know where the answers are going to come from because basic science, by its nature, means you're asking questions whose answers you don't know. So if you have in mind using basic knowledge, I think you fail in suggesting that we should focus on "photosynthesis" or "nitrogen fixation" or "whatever else," rather than to say, "Yes, we need more basic understanding of how plants grow and interact with the environment." Let the most interesting projects go forward in terms of addressing problems. I think a lot of agricultural research in this country is supported on the basis of what you just advocated: "We're going to work on stress; we're going to work on nitrogen fixation; or photosynthesis." I think that's an inefficient way of doing basic research. If you're really talking about basic research, you must take the best minds and let them "discover what they want to do". Then you will get the Mendels, and the Lebigs. We must get more basic research because 30-40 years from now the knowledge will be needed, and if we don't start it now, we won't have it 30-40 years from now. But I would not agree with you at all that we need to focus it on photosynthesis or on nitrogen fixation.

Jain — I would generally agree with you. I was not suggesting that you only have one kind of basic research. In fact, my view is that basic research will and should go on as it has. By its very nature, inquiring minds seek knowledge. They're not particularly worried about consequences. That must go on. I was not suggesting for a moment that you divert all the resources from these very talented people in pursuit of these specific objectives. Nevertheless, even as this is being done, I would like to see some key groups being organized around very defined objectives. I gave a few examples. So I don't see a conflict between doing both. Let me say that I have met some very, very brilliant people, people working in the Rockefeller Institute who are totally isolated from agriculture. They pointed out that: "No one comes to us and poses some of these problems. We would be delighted to at least consider some of these possibilities even as we explore basic knowledge." So I would say that we need both.

Faras — I agree on the caveat which you have just made that we do need both. The war on cancer clearly helped facilitate our understanding of cancer. It may not have contributed directly to a cure. But it certainly facilitated a great amount of basic research in biological sciences. I think what we are really talking about here is the level of support for biological research. Clearly we need more basic research. There is no question about it. On the other hand, I believe strongly, as you have indicated, that our fossil fuel dependence is a real problem, and that if nothing else, we should have some commitment to really putting an effort into developing ways and means which we can develop technologies that would not rely on fossil fuels in the next century.

Sanchez — As a soil scientist, I was very pleased to hear your remarks on the limitation of plant breeding. I think one problem one sees with increasing yields or increasing efficiencies is the increases in the nutrient requirements of those plants. Perhaps more research needs to be done on biological sources of plant nutrition.

Jain We should work on the task of manipulating and harnessing microorganisms.

Heichel Given your comments that many of the dry matter yield traditional varieties is about the same as the improved variety, and that basically what we have done is shift the grain to crop residue balance, I wonder if we are looking hard enough at total food production gain including the animal component that is produced from the crop residue. We may not maximize food production by simply focusing on grain yield. Some data suggests that the straw becomes less digestible as you increase the grain/straw ratio.

Jain Let me comment on this slight misunderstanding. The effects of higher total dry matter production with modern varieties is that even while reducing the ratio of straw to grain, there is more total dry matter being produced.

Burnside You mentioned that we've gone quite a ways in improving the harvest index. How far have we gone in improving the nutritional value of the crop? Is the reason we haven't moved further because we sell our products on the basis of pounds produced. If we could sell our products on the nutritional value of what we've produced, there would be an incentive for a number of changes. Look at the high lysine corn and the increased food value of that corn when fed to pigs. We can do this over and over again if the market would provide appropriate incentives.

Jain Yes, I generally agree with you. But let me stress one point--that the major grain yield improvements have not been at the cost of nutritional value. The plant breeders have managed to maintain the protein content--the lysine content. They have maintained nutritional value. I know that people are trying to breed specifically for nutritional improvement. But it is a complex undertaking. Whether the need exists or incentives can be provided is not clear to me.

Sundquist You may not want to talk about economic issues, but you did bring up a couple of topics. One is the extent to which a part of the agriculture production in the developed countries is based on subsidization of the agricultural sector. If one were going to move to a non-subsidized system, it's probably the case that, in total, agriculture production would decline somewhat from its current level. In the developing countries if one were going to adopt policies that did not penalize the production of agricultural commodities, there might be gains in production. It seems to me that given those situations, and given the fact that the current production system is based heavily on use of fossil source fuels, if those energy sources decline in the future (which seems reasonable) we might very well be looking at a situation in which we not only need to look for increased production to meet the needs of increased population. But we may need to find ways to offset the loss of some of that production capability that is currently based upon high energy.

Jain I see your viewpoint very easily. In some of my recent writings, I have been addressing the same point. Basically what I say is that the present production technology is very efficient in terms of gains of production. It

is productive--it is highly productive. It is very impressive in that sense. But it is inefficient--I use the word inefficient because the total input/output ratio is not very high. It uses enormous amounts of fossil energies to obtain those high yields. The challenge for the next century is to maintain and indeed, enhance the production of food. The reason we adopted the energy intensive path was that there was all this oil. It was there! It was cheap! It was $6 or $7 a barrel. But now that is changing. We must take what you have said into very serious consideration. As energy prices rise, it can no longer play the role of a driving force or a focusing device for the next generation of technology as it has in the past.

Heichel Dr. Jain, a lot of what you said struck a very responsive chord with me. I have dabbled in some of the areas that you discussed over the years including photosynthesis and nitrogen fixation. One alarming situation that I see in both of these areas of research is the widening gap between fundamental understanding--call that basic knowledge--of the process and the extent to which we can translate that knowledge to some practical use. If one looks at the international symposium and international congresses of these various fields over the past decade, you divide the proceedings up between field-oriented knowledge and lab-oriented knowledge. The proportion that comes from laboratories is increasing and the proportion that is devoted to field understanding is decreasing. I see this as a problem of connecting our already-burgeoning understanding of the basic biology of these processes with solutions to our problems. So, I come back to a comment that you made about mobilizing science to resolve some of these major problems. That's what I see as the real need--to find innovative ways to put together a development and a delivery system that links scientists together to somehow implement some of this understanding of the solution of problems. Now, in the United States, we've had a big emphasis on nitrogen and photosynthesis research for a number of years. I feel that it is peaking and it's going to end with little technology development to show for the effort. Part of the reason is that the clientele has not observed that it's made any difference. I would hate for us to increase or effort on biological research, in the next century, without looking at the lessons to be learned from where we have already been, especially in these highly-developed nations where we have not yet adequately solved the problem of how to effectively articulate advances in scientific knowledge with technology development. I have not worked at the international level for a long time, so I have to admit to a relatively narrow vision. But I sense that, in this country, we have not done a good job of coupling science together with solutions to problems. At least for those of us in Federal research, perhaps that's because the political system gets in the way. Research priorities get redirected too frequently.

Qualset Gary and I are not sitting together and have not conspired to ask the same questions. But I was really going to touch upon the same thing. I would only add that I think what I hear is a plea for thinking about our research needs in a continuum rather than in separate packages labeled "basic" and "applied." Foreign bodies don't come together well except under pressure. What we need, I believe, is a way for people on both sides to recognize that if they come together, they will probably have greater synergy, and

that what they are doing will be more interesting than if they stayed by themselves. We in this country have not done a very good job of that. There are a variety of reasons, ranging in the way we support research, the way educate our scientists, the way our professional societies are organized, and the way we publish. I think that this is an institutional constraint that I think this country needs to address. We must begin to think of research in this continuum rather than as two packages that don't come together.

Jain — Maybe the affluent industrial societies do not have the same compulsion as the developing countries have for closer articulation between basic and applied science. You still can afford to live with an inefficient technology as long as it is productive. The developing countries cannot afford this luxury.

Sundquist — But take oil away from us and we will not be able to afford it either. Your assumption is that in the next century all of us will be more equal--is that right?

Jain — Well, many of you probably have cold fusion in mind!

First — In part, I think the answer to what you are discussing must be found in the education of the next generation of scientists. If we construct education and their research projects in such a way that they have opportunities to work at this interface, this will become the means by which you can achieve that communication. It is much more difficult, it seems to me, to pick older scientists and teach them new tricks. On the other hand, I think if we make a point of structuring our education in such a way that new people are raised in that tradition, I think that, in the long run, we will be able to make the transition to a more efficient system of organizing our research.

Duvick — I want to interject a dissent on one point. The view that yield gains in the past have been due simply to change in harvest index and that whether yield gains in the future will require enhanced photosynthetic capacity is too simple. I think that each statement represents only a part of changes that have occurred in the past or that might occur in the future.

Changes in harvest index are a consequence of other changes in protective physiology, which have allowed the plants to devote more energy to producing desired components such as grain, and less energy to producing excess fodder for insects and diseases. Examples of protective physiology would be whatever biochemical reactions give insect and disease resistance, or tolerance to short sharp periods of environmental stress such as excessive heat, water logging, or high winds.

In the future, particularly in the small grains, increases in total dry matter production will be needed for increases in grain yield (with this is the goal). However, I think these would come largely from breeding plants that can withstand the stress and strain of making more grain heads per hectare, more specifically more kernels per hectare. To do this will, I believe, be largely a matter of making more efficient use of the

photosynthetic capacity already on hand. As was noted by one of the other participants, only a small fraction of present photosynthetic capacity is used. There just is no particular need to increase the present rate of photosynthesis, rather the need is to make more effective sinks for the products of photosynthesis, and (to be repetitive) effective sinks are those which can be formed and will stay alive and active, during the whole bumpy road from planting to harvest.

The biological basis for continuing advance in yields has been established already; we know how to do it, at least empirically. Our challenge for the next 15-20 years is to simultaneously identify the individual bumps in the road (the physiological weak points) and learn how to correct them both individually and in a coordinated whole organism (or indeed whole population) fashion. The tools of biotechnology and statistics, aided by computers, will let tomorrow's plant scientists reach many of these goals.

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COFFEE BREAK

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International Agricultural Research

Ruttan I am going to try to move the discussion a little faster now. We have put a lot of ideas on the table. I think that it may be feasible to go around the conference table by noon. Let me now turn to Don Plucknet.

Plucknet Thank you very much. I come to this discussion from a somewhat special vantage point. In my official capacity my role is to work with the Consultative Group on International Agricultural Research (CGIAR) sponsored international agricultural research centers. I watch what they do, try to keep up with general trends in science, and also try to understand what is going on in agriculture research in developing countries. One of the things that Vern said in the outset was that the intensification of agricultural production in many parts of the world is a fact of life today. There really isn't very much new land that can be used. The increases in production we are going to need will have to be gained mostly on existing land.

It seems to me that any country is wise to use its best lands first. That means irrigation development; it means a whole lot more use of fertilizer. Most of the developing Third World is desperately under-utilizing fertilizer. Higher fertilizer use is not an option. The use of more productive crop varieties and good agronomy are complements to higher levels of fertilizer use. If you intensify use of all your best lands, there are several things that will happen. Concerns about the environment and sustainability are flooding in on us now. If we really do a good job of enhancing productivity on our better lands, then we will have a better chance of protecting some of the marginal lands. By reducing the pressure on marginal lands, using marginal lands less intensively, we may be able to use them less disruptively.

Above all, there is the need for better agronomy, better crops, and better soil/water management. I want to leave no doubt about the need to use better crop production techniques--crop management techniques--in order to realize as much of the genetic potential that's possible. For many crops, at least today, we have better genetic potential than we have crop management. Part of this is due to the fact that there has been quiet a bit of effort on collecting and preserving genetic resources. This is an area that has developed very rapidly in the last 15-20 years. It is much more systematic than it ever was. But there is a great need for more effort in the genetic resource area--including evaluation of some of the collection materials that have been brought in.

The question of yield potential is clearly of great interest. I think the question of yield potential in rice is more important right now than yield potential in wheat. It appears that wheat still has unrealized genetic potential and there are still gains being made. In tropical rice, yield potential has to be a concern. And it's a question that must be answered soon because there are so many people that depend upon rice as a major crop and as a major food. If we are nearing the biological yield potential, then that is an important matter to be made known to the Asian governments, because there are a lot of other adjustments and strategies that must be developed if growth in rice yields should slow down. If there is still substantial potential to enhance yields, we also need to know that.

There is a lot of work underway on insect resistance and disease resistance. There is also a lot of effort now in many crops on drought tolerance, and researching for drought tolerance for crops. Something like 20 percent of rice breeding projects in Asia today are looking for drought tolerance. But how much drought tolerance do we really expect to find in a hydroponic crop? How realistic is it for us to keep pushing crops into the areas that they were not originally adapted to? I have been questioning the whole area of upland rice for a long time. And I sometimes rather facetiously, say that the best upland rice is sorghum. I think that there is a real question as to how far we do continue to push, for example, the potato into the humid lowland areas, or wheat into lowland tropics. There are lots of efforts to push crops into areas where they were not originally adapted. There are valid questions of how far we should go on doing that. There is increasing use of wild relatives in breeding, which has been very important and there are many examples now of how useful those can be.

We are seeing some examples of biological control of certain organisms, and where that's not possible alone, why, the use of integrated pest management that has shown some benefits. There are some people that are committed to integrated pest management, as if that's the only way to go. I don't agree with that, but I think where it can be used it does make sense.

I would like to close with two comments. One is that we have major diseases and major insects and other problems that are of world-wide or, at least, continental importance. These need special study, and in many cases, they need international efforts. There is no way you can attack these on a

country-by-country basis. The International Centers have been doing some of this, but I think we need to be much more systematic than we have been on some of these major diseases and insects, particularly those that are evolving quickly and developing lots of biotactics. You cannot keep on top of these problems where biotypes are emerging constantly unless you have an international effort.

Vern mentioned earlier that I might say something about maintenance research. If you consider maintenance research, or yield protecting research, that research which is necessary once you've gotten yield levels up, to maintain yields, at least to sustain those yields and hold them up there, then that is what we might call maintenance research. You'll find, I think, that for those commodities where there have been significant yield gains, as much as 80 percent of the total research effort may have to be devoted just to sustaining yields. In order to sustain the yield gains, sometimes as much as 80 percent of the total research effort may have to be devoted just to sustaining yield gains.

I think that this is an area which we need to spend much more time educating those who allocate funding. When a funding agency asks what kind of research you are doing, it is not very exciting to tell them, "I am working on stem rust of wheat." They will probably respond, "I thought stem rust of wheat was no longer a problem." Stem rust of wheat isn't a problem any longer--as long as you have varieties that are resistant to it. But drop the stem rust breeding program and stem rust will come around again. There are aspects of maintenance research that are relevant not only to breeding, not only to maintaining resistance to insects and diseases and things like that, but also in the area of crop management. I am pleased to see more and more economists who are beginning to look at maintenance research as a useful area of research.

Ruttan I would hypothesize a functional relationship--the higher the yield the higher the percentage of any constant research budget that must be devoted to maintenance research.

Herdt Do the international centers have enough flexibility to respond if there was something of a consensus that certain issues were going to be important during the first or even the second decade of the next century? It seems to me that they're pretty much focused on the next five years. The donors want to see short-run pay offs. Do you see them having enough flexibility in their portfolio to devote a percentage of their budget to longer-term research?

Plucknet I think there is enough flexibility. But I believe that it's going to take some selling to the donors--but the donors can be sold. We've asked the Centers to do long-term strategic planning. In many cases, I think that perhaps they responded too timidly. I think that maybe they should have been bolder. But they aren't very likely to do very much basic research. They are likely to do some strategic research in carefully selected areas. If I were going to suggest some strategic research they might do, some of the major insect disease problems clearly need attention. But there are others that could be taken up, too.

Sundquist Is the current interest in adaptive research an example of centers recognizing the need to put more funding into maintenance research, or is that something else? If I heard you correctly, you said you felt the genetic potential for crop improvement was, perhaps, greater than from agronomic improvements. How do you look at the potential for soil management and at human capital improvement as sources of productivity gains.

Plucknet I believe that there is more genetic potential than there is good agronomy around. One of the problems at international centers, at least from their standpoint, is that it is difficult to know how far to go in agronomy because so much agronomy is location-specific. Unless you can work on certain principles or over-arching problems that reach a lot of different countries, it's pretty difficult for an international center to justify using international funds to work on local agronomic problems. I think there is a need for something that one might term strategic agronomy. There are areas that are really strategic. That might include nitrogen use; it might be phosphorous use; it might be water management. I also think we need a whole lot better characterization of some of our production environments, so that we can find some analogues with other areas and see how effectively we can transfer information.

Goodrich With respect to your example of rice and yield potential, is a country like Indonesia running up against yield potentials.

Plucknet Indonesia is an example of a country that has very effectively exploited the yield potential from traditional breeding. They have a national average yield exceeding four tons per hectare. Java, in particular rice, is well irrigated, heavily fertilized, and high yielding. The question for Indonesia is, where do they go next? How do they increase production? In Jain's terminology, it may be both highly productive and inefficient, because it is using a lot of fertilizer. Per capita demand is trailing off a little bit, but population is still growing.

Jain I am very much interested in Dr. Plucknet's comments on plant genetic resources. That certainly is one area where substantial progress has been made. We all know that ten years ago after the modern varieties had appeared there was tremendous concern that all the "land races" would be lost. But IBPGR and national systems are working well. Materials are available in gene banks around the world. That's a tremendous response to a major problem in world agriculture. But the other side of the story is that despite the availability of this tremendous diversity, agriculture keeps becoming genetically more uniform. Very large areas are still saturated with single genotypes whether it is rice or coffee. So, Don, I'm sure you recognize that the challenge now is to take out some of this diversity from the gene banks and put it in the farmers' fields. The only way to do that, of course, is through decentralized breeding. That is the opposite of the strategy which we had 15 years back of having a centralized facility to breed and send out materials. Probably this should change with more and more decentralized breeding. If we had a very large number of small private companies rather than one very large company, probably the same

thing would happen. My question then is how do we build in a great deal of decentralization so that much of this very valuable diversity collected such at large costs is available where it should be; i.e., in farmers' fields to erect barriers against disease and pests?

Ruttan Don, you've done a good deal of thinking about this, haven't you? You want to comment?

Duvick A couple thoughts come to mind. One is that no matter what system seems to be developed to allow a diversity to be used and exploited, there seems to be an almost irresistible tendency towards a very low amount of diversity on the farm at any one time. Certain varieties become enormously popular almost in spite of any effort to encourage greater diversity. As I look on it from my experience, and that is within the seed trade in developed countries as in the United States, where you have the freedom to breed with each other's materials--everybody still breeds with the same materials. With hard red or soft winter wheats, for example, everyone breeds with the two or three most successful varieties. Although you may have many different companies selling many different names of a soft red winter wheat, you look at the pedigrees and they're all very related. It's very difficult for people not to follow the leader.

However, there is another concept which we must remember and that is something I've taken to calling genetic diversity in time. This means breeders have the ability to rapidly replace the genotypes that are out there as the needs arise. Breeders have within their breeding pools a great deal of diversity that's not on the farm, that they could be put on the farm rapidly if it is needed.

Perhaps more important is the rapid turnover of varieties. Now this is viewed somewhat cynically by some observers of the seed trade. It's a mysterious thing, some people say, that the minute a variety gets into trouble, the seed companies come up with something to replace it. Well, that's exactly right and the reason is that there is a need for new genotypes. If the seed companies don't come up with something to keep their sales up, they'll lose business. But the same principle is valid for public breeding. If in those cases where public breeding is required, if there are not the provisions for continuing successful introduction of new varieties, agriculture is going to be in trouble.

This is an area where I, looking more or less on from the outside, am concerned about the Third World countries. Dr. Jain could speak to this better than I. Is sufficient capital being invested in plant breeding in those areas where the international agricultural research centers have led the way. Can the international agricultural research centers continue to make the turnover, provide the genetic diversity in time, or should the national systems be prepared to do so, and most importantly: are they able to do so? We've heard some rather discouraging comments about Brazil's ability, for example, to continue to do so in those areas where private industry is not yet (or may never be) in place. Is there sufficient capital being invested publically and privately to provide sufficient genetic diversity in time? That's something I am very much concerned about.

Burnside Don, you mentioned that in the future the main sources of growth will be from intensification of agriculture and not from new lands. I'm sure that's true, but I wanted to give you a few examples of new lands that we shouldn't overlook. I was at the Gordon Conference and there was a barley breeder who had developed a cultivar that could be irrigated with sea water. He was postulating all the marginal areas where this variety could be grown. In Brazil right now they will give farmers free land if they'll develop it for soybean production. I don't know what the extent of that resource is, but there is obviously a lot of land that could be developed. Environmentalists may slow that down, however. In a state like Minnesota, we could either grow cattails in marshes or we could grow wild rice in those marginal, aquatic areas. In the Sandhills of Nebraska, there are 15-20 million acres with almost an unlimited water resource beneath these soils. When corn was selling at $3.50 a bushel, I could take a picture and show in excess of 250 center pivots in one snapshot from a low-flying airplane. Now when corn drops to $2.25 a bushel, or something like that, those center pivots disappear--they're white elephants. But if the price is right, the production potential is there. Lake Superior has essentially 10 percent of the fresh water of the world in that one lake. If you divert that water into the Great Plains, crop production potential in that area is almost unlimited. So there are a lot of opportunities even in new lands as well as intensification of agriculture.

Duvick That's true. One of the most interesting sights is to fly over Saudi Arabia and see the center pivots irrigation systems used for growing wheat. It costs over $6.00 a bushel to produce. There is a lot of land that can be used. But I consider much of the land to be marginal for agriculture. Those lands which only with difficulty can be developed for agriculture are, even after development, going to have a lot of problems. But there are certainly a lot of areas in the world where we could produce a lot more food, but at a very high cost.

Qualitative Considerations in Plant Breeding

Ruttan We're going to come back to the resource issues this afternoon. I'm going to move on now to Calvin Qualset, who is from the University of California, Davis. He is a crop scientist working in plant genetics, plant breeding, and part-time in genetic resource conservation.

Qualset My remarks will be made as a plant breeder. I will discuss factors that I think will impact on plant breeders and crop production in the future. One is the increased human population and the concentration of the population into urban areas. That means that a lot of high quality farmland is being lost to urban development. But probably more importantly is the transportation of products from the production areas into urban areas. Transportation of dried cereal grains, is not a serious problem. But for the fresh fruits and vegetables, it is a problem. Food habits are changing.

Second, we will have to look at the pesticide situation very carefully. I think within the 15-20 years time frame we're talking about here, there is

certainly going to be more restrictions on the use of pesticides. We're seeing that the environmental movement is very strong. There os growing concern about using pesticides that would affect endangered species.

We will also have to think more seriously about global climate change. From a plant breeding point of view, we need the genetic resources to deal with that situation. If we're actually going to change cropping patterns in areas, then there will be a need for variety development programs that will have about a 20-year lead time. As far as the constraints to production, I place stability pretty high on my list. A lot of that is related to climate and annual variations in moisture and temperature plus the small things that happen--such as when it rains for two weeks and you can't plant the crop on time and that puts it in a whole different set of climatic conditions whereby it becomes susceptible to frost or other environmental stresses. From the breeding point of view, there's quite a bit that can be done to stabilize production--to minimize some of the effects of the environment variations.

The salinity situation is one which probably deserves some comment. There have been people saying that salt resistant varieties can be grown and you can irrigate with sea water. But frankly I've never heard a plant breeder say that. I think plant breeders have been a little more cautious. It would be a little bit foolish to breed varieties resistant to salt, such that the farmers didn't have to take care of salt management, so the salt level increased and you give the plant breeders another problem so there would be no way of catching up if we ever let up on the soil and water management problems. The toxic situation is somewhat different. There are genetic systems to work with such as boron and aluminum toxicity. I'd like to see a little more stabilization, with a little better understanding of water management in the areas where water can be used and in fertilizer management in relation to the amount of water you have available. For example, Ken Cassman at Davis has been working on monitoring water use on wheat. He can reduce the amount of nitrogen a great deal by just applying it with water at the proper time in the season. Well, that's fine where we have complete control on water.

I guess I'm the only closet plant pathologist in this group. Pest resistance is going to be a very, very important area to emphasize. We're always dealing with dynamic pathogens. We are using many expensive chemicals which are both costly and are going to create problems in the environment. The pest resistance area is very exciting in terms of host-plant resistance and bio-control agents. I think this is one area where the biotechnology will offer some very substantial help.

In the future we should devote more attention to crop diversity. There has been a real pressure on mono-culture systems. We should go back to a little more diversity in crops, do a little bit in nutrient requirements, and change the pest relationships in crops. I'd like to see that considered as a way of alleviating some of the constraints.

Let me add one point that occurred to me a little bit ago. There is always a lot of concern about short-term research dictated by NSF and USDA's

competitive grant program. Get a three-year grant if you can, but you'll probably get it for two years, but almost never for five years. This is a very serious problem in genetics. Plant breeding in the public sector (and private sector) involves a very long-term effort. The project I worked on in the wheat breeding in California started in 1910. You can see how much we've done in 70 years--even if I wasn't there all that time! These programs involve long-term commitments. The University of Minnesota has stayed up front by making long-term commitments.

Ruttan I think of Gene Lambert spending his whole life moving soybeans north.

Fitzhugh That provides an opening to go back to an earlier question. There was a pause when someone asked the question, "Why is AID giving increasing emphasis to adaptive research?" I said to myself, "AID giving increasing emphasis to ANY research?" It's going the other way. I think our major concern is not only the type of research, whether short-term or long-term, but that there is real lack of enthusiasm among the traditional funding sources. There is less feeling that research is really the way to solve these problems facing agriculture. I believe that has to be a real concern.

Ruttan Could you comment why, in your opinion, that is happening?

Fitzhugh There are all sorts of things. Here in the U.S. the financial problems that the agricultural sector has had over the last few years meant that politically it wasn't a good idea to talk about increasing funding for international research. I think most people feel like the success has lead a lot of politicians to believe that "the problem's solved." The success of research, the gains that were made in rice and wheat breeding, have led a lot of the political supporters of research to believe that, "Okay, we've done that; now we'll move on to health or other things." There is a concern that we're running faster and faster, but we're not staying ahead of the population problem. When H. K. Jain said that if it hadn't been for increasing food production, millions and millions of people would have died, I found myself asking what's going to happen 100 years from now?

Faras The answer from Paul Erlich's point of view is yes. You're not going to be able to keep up and you're going to have major famines that are going to control populations that cannot be controlled by governments and various societies themselves.

Herdt I think there is a less pessimistic perspective. I was a reviewer of the book, Famine 1975. Increasing food production is not the direct route to solve the problem of population growth. It's the indirect route--increasing food production leading to increased economic growth leading to increased income levels is the way to solve the population problem. It's the only way.

Faras No, there are countries that haven't grown quickly that have used other measures. It's not the only way.

Herdt — But it has been done. I don't think we need to be as pessimistic. Just look at the cycles of optimism and pessimism over the last 40 years. I think we could largely chuck that scenario.

Ruttan — I don't know how many people the world can support, but I certainly think it will be easier if we approach that limit slowly. I want to ask Cal one question. You've probably gone farther in California than in many other states in responding to concerns about the environmental impacts of intensive agricultural production. You have major supermarket chains that sell only organic foods. What can we learn from California. California is always first, but those concerns are also bothering Gene Allen here in Minnesota.

Qualset — Well certainly the movement toward a pest-free environment is very strong. There is a perception of serious problems in fruits and vegetables. Probably the most damaging thing to human life out there is air quality and you can't attack that because you have to get at the cars. But people insist they've got to drive their cars. But they worry about alar saying it is a pesticide when it is not. I guess it's a matter of what value people place on things and I think part of it is getting the truth to them. If crops can be produced without using pesticides, it's an advantage to the grower and also a less-costly solution. What has happened--perhaps a more serious answer--is that they had a fairly strong program in the University of California which created extension positions dedicated to integrated pest management (IPM). Those programs have been pretty effective. The field crop management consultants are finding that with improved scouting in fields that they can reduce the number of applications of pesticides. Farmers understand that this also reduces costs. Before that, they knew it was expensive, but it was also an insurance policy to spray every seven days. Now they do it less frequently. Groundwater issues on the use of herbicides on rice are also serious problems.

Faras — I was sort of facetious about the Paul Erlich issue. But in all seriousness, I would like at least some idea of how groups like the Rockefeller Foundation and others are thinking about population growth, fossil fuel consumption, and crop productivity. Is their thinking based upon predictions or assessments of whether we will run into real problems in the next century. If that's the case, maybe a tremendous effort ought to be placed on some of the things that we heard from H. K. Jain with regard to utilizing these other renewable resources for productivity.

Ruttan — That's why the Rockefeller Foundation has asked us to come together on these issues. I'm going to turn to Orvin Burnside now who is Head of the Agronomy and Plant Genetics Department here at the University of Minnesota. His background is in agronomy and weed science.

Reducing the Cost of Pest Management

Burnside — The area of pest control has been alluded to a number of times. When I think of pest control, I think of not only insects but also diseases, nematodes, weeds, etc. If you look at pesticide use in the United States, it

is about 65 percent herbicides. If you look at Minnesota, about 91 percent of pesticides used are herbicides. When you talk about a chemical treadmill, certainly the weed scientist is the one that's on the biggest chemical treadmill. That's because we're depending heavily on herbicides to control weeds rather than doing accelerated research on other methods of weed management. Somewhere along the line, we've got to get off this chemical treadmill as the entomologists have already done.

There are a lot of management opportunities in the area of weed science, but the research hasn't been done to the extent it has in other pest control fields. For example, some of the older varieties of cucumbers will grow in the presence of weeds. They actually have a chemical within the plant that will kill surrounding weeds. But we have bred that out of the cucumbers by ignoring allelopathy while trying to get higher yields. We have not selected cucumbers for their ability to control or tolerate weeds. The same thing could be said of other crops. I've looked at wheat, sorghum, soybeans. If you will take the common varieties grown, there is a lot of opportunity for host resistance as far as weed control. You can subject the common varieties to a 50 percent growth reduction (GR-50) weed pressure and you can have yield losses that range from 20-50 percent. In other words, some varieties have tremendous abilities to compete with or tolerate weeds. It isn't the entire answer, but if you can eliminate one-third of the weed competition, you go a long way to reducing the herbicide required to profitably manage weeds.

The thing I have noticed over the years is when you look at variety improvement in developing countries, weed control is mentioned, but it has never been given the emphasis that has been given to fertilizers or plant breeding. Yet it must be important because the seed safener that CIBA-GEIGY introduced that allowed Dual to be used on sorghum was a marketing success. By introducing this one technological change, they went from 5 to 15 percent of the sorghum seed market in the United States. Other companies looked at that marketing potential and the major chemical companies have since bought most of the seed companies in the United States. The main one they haven't gotten yet is Pioneer. Why is it that a pesticide company can come along and receive the lion's share of the profit from the sale of agriculture inputs, and established seed companies are being bought out just so that they can sell their products? Now what worries me is what personnel from a major chemical company told the wheat breeders in Nebraska: "Don't worry about a wheat variety that's susceptible to leaf and stem rust because we have a fungicide that will control those. Don't worry about weed competitiveness in your varieties, we have plenty of herbicides that take care of weeds." But what about the profitability and competitiveness of the production of these crops if we continue to go in that direction? If you look at pesticide use in Europe, it is about two times what it is in the United States. The reason is that they subsidize their wheat and other grains at a much higher level than we do in the United States. Therefore, they can afford to spray a number of times with fungicides, insecticides, herbicides on a routine basis. But if they had to compete with the U.S. farmer in an open economic environment, we would drive them out of business compete very successfully.

The ecofallow or reduced tillage trials in the Great Plains, and other dry areas, have shown that you can almost double crop production on some of these dry areas if you don't have to till every time that you need to control weeds. The reason is that every time you till you dry out the soil to the depth you till. Without tillage you get better infiltration and retention of the rain that falls. This has been a factor in sorghum production and corn production moving farther west in the Great Plains. It's just like a leap-frog arrangement when you go into these semi-arid regions with reduced tillage systems. But there, of course, you're going to depend on higher amounts of herbicides for weed management as you have reduced or eliminated the tillage option.

The other thing that has been alluded to a few times is sustainable agriculture. There is quite an effort right now to talk about going back to low input or sustainable agriculture--or to combine the best of the old and the best of the new. Dr. Jain mentioned that as soon as we start advocating this, we are moving in the wrong direction. But in a state like Minnesota, we almost have to think of sustainable agriculture because 40 percent of our farmers are commercial producers and produce about 80-90 percent of the food and the other 60 percent are part-time farmers and as a university, we can't ignore that 60 percent. So we will be giving more attention to sustainable agriculture. I do not know where we will come out in the area of sustainable agriculture, but it's certainly going to be a factor in crop production in the future.

Ruttan Are there questions for Dr. Burnside?

Qualset I guess we're all talking about sustainable agriculture--that's the whole idea, isn't it, that we're going to have to be here 100 years from now.

Burnside The problem that is worrisome is that much of the thrust for development of sustainable agriculture use the term LISA or low-input sustainable agriculture. Many companies take LISA as a personal affront--they produce and sell those industrial inputs.

Heichel I am fascinated by the concept that we may be able to breed allopathic genes back into crops. How much do we know about this?

Burnside At the present time our knowledge is limited in this particular area. But there are tremendous opportunities for advances. The studies I mentioned are just using the normal varieties available to the farmer right now. Some of them are quite competitive to weeds and others are very non-competitive to weeds. We know right now that if you're going to use a "nurse" crop to establish alfalfa, you generally use oats; you do not use barley. Barley is too competitive and within oats there are some lines that are better "nurse" crops than others because some are less competitive. So what we want to do is interest the plant breeders in breeding for weed competitiveness just like they breed for host resistance to plant diseases. There are tremendous opportunities here for advances.

Duvick I'd like to follow up on this same thought. It occurred to me while listening to you that I don't know how much oil is used per year to make herbicides worldwide. I don't know what the trend is and the amount of oil. First, of course, the newest herbicides are safer (non-carcinogenic and so forth) and second, they require a much, much lower poundage per acres--only grams per hectare. But I don't know if it takes much more energy to make those concentrated products, or if it takes less energy and how does that compare to the energy needs for mechanical weed controls? It would seem to me that to pull together information on this matter would be very important. Maybe it has already been done but it hasn't come to my attention. Then going on from there, I would like to look at that in comparison to the relative amount of effort and the time it would take for breeders to get the same thing done. Then I might be able to think for myself--should it be all one, all the other, should you do a little of both, or what proportions would be important? I just don't have the background to do that thinking.

Burnside I think you have a very interesting question here, Don. If we look at mechanical weed control where you cultivate 2-3 times in the cornfield or if you spray it with Atrasine and Lasso, the energy requirements are a wash--about the same in either case. But now, if we talk about a corn hybrid that will compete with certain weeds, and the corn breeder has done a considerable amount of that already, then it's not a wash. It's much more beneficial and economical to manage weeds with a competitive corn hybrid. If we could reduce a third of our mechanical or chemical requirements by breeding allopathic potential into the crops, there is a tremendous energy savings to be realized. Just like host resistance in plant pathology, we can either stack genes for resistance in wheat varieties and not worry about stem rust and leaf rust, or we can let that lapse and go into 3-5 fungicide sprayings at $15.00 per spraying and you can figure out real quickly which is the most economical. So plant breeders, if you can introduce weed resistance into your varieties, you will increase profitability and competability of our crops tremendously.

Larson How much could we reduce our herbicide bill if we really applied only the amount that is necessary? Aren't we tremendously over-applying herbicides?

Burnside That's an excellent question, Bill. It is also true in many instances. The first thing we could do is cut our herbicide use in row crops by one-half or two-thirds immediately by "band applying" rather than broadcast spraying. We are still cultivating one or two times out there anyhow so why broadcast spray the entire field? But the herbicide companies are driven by sales. At one time we were having the farmer spray band applications. Then they said if they would spray broadcast, they could forget the cultivation. The reason they did that is that it increased their sales 50-60 percent. Take Lasso, for example. For years we used a pound and on-half per acre for grass control in many crops. All of a sudden they said there is no label clearance for less than two pounds per acre and we generally recommend three. Why? Because they said in these marginal situations, you're still going to get good control. But in reality, it increased their sales 30-50 percent. Now with water quality concerns with

pesticide contamination coming into the forefront, there's going to have to be some changes in the future.

Goodrich Who is running whom here? I'm not sure that what universities and international research centers are recommending should necessarily be determined because some company wants to increase their sales 50 percent.

Burnside It's difficult when you go out in the field and the farmer get one recommendation from the company who is supplying and standing behind that product and the other one comes out of an extension bulletin. What really happens out there is largely controlled by companies that must make a profit.

Goodrich How strongly, though, have we collectively stood up and tried to continually tell our story and how much have we worried about the grants? I think it is a serious question. I mean it as a serious question.

Burnside There are a number of University of Minnesota faculty that are not very popular because they have opposed company recommendations. Let me tell you what they do. If our weed scientists would go out and say farmers can reduce herbicide rates--they can reduce the rates less than what is on the label. The company will turn around and say, "Oh, we have a performance concern here. You used less than the label rate. Why don't you check with that university extension specialist and ask him to make up the loss in yield?" That's a very effective argument and I don't think Dean Allen is willing to have every extension agent get out there and become a target for litigation.

Larson Maybe we need a law like our fertilizer law. There is a law in Minnesota that says that any soil testing concern that makes a recommendation to the farmer must also give the University of Minnesota's recommendation. If he recommends 150 pounds of nitrogen, they must say the university recommends only 100 pounds. You could do the same thing to herbicides.

Ruttan Now I keep hearing about this new generation of herbicides--the ones that use ounces per acre. Are we approaching a period where this problem is more severe now than it will be in the future?

Burnside I think there is no question that we have found pesticides that are more phytotoxic. Companies have progressed from big amounts per acre to using small amounts. The same thing is happening with herbicides where a few ounces per acre is effective. Now as far as water quality is concerned, there is still largely the same problem--the biological activity in groundwater will be the same because it will be effective or phytotoxic at a lower rate. If you use irrigation water that is contaminated with herbicide, whether you're dealing in parts per trillion or parts per million, it depends on the biological activity of the product involved. Some of these pesticides used at grams per acre rates are also very persistent.

Qualset I was just going to say that I don't know where this analysis will go or what you're going to do about it. But the Russian wheat aphid situation

would be a good example to work on right now because it came into this country in 1986 and it has gone all the way through to Texas, Kansas, and Colorado. there are measurable losses and it is requiring systemic insecticides for control. There are lots of problems. It is a current example that calls upon all the techniques we can find. There is searching for bio-control. But there are some pretty good numbers now that the current losses due to that one pest, and there's at least one of those every 4-5 years, that are important.

Biological Science and Agriculture

Ruttan I'm going to turn to Gary Heichel now and get his perspectives. He is a plant physiologist with USDA/ARS, located in the Department of Agronomy and Plant Genetics on the St. Paul campus.

Heichel A number of very important issues have already been mentioned. The ones I'll focus on are the ones I know the least about. Perhaps you'll forgive me for that later on. For developing countries in the future, I am concerned about the extent to which producers will be able to adopt the technologies that might be most appropriate for the needs of society. What am I saying? With the current debt situation in developing countries, I wonder if there will be enough capital around to adopt the technologies that might be most useful, or secondly, whether lending institutions will allow those technologies to be adopted. I wonder if we'll get to the situation we sometimes face in the United States where lenders only provide operating capital if the producer is willing to follow a certain prescription of management practices.

I should speak about biology since that's where I have the strongest credentials. I'll go back and speak about photosynthesis because Dr. Jain was kind enough to introduce that earlier. I think it would be very useful for us to have a current assessment of just how much sunlight we can capture in agriculture. Now it is worth reminding you that the thermodynamic efficiency of photosynthesis is about 12 percent. I don't think that is going to change much, but what that means on a practical basis is if you had a continuous green leaf cover over the soil surface throughout the year, you would capture no more than 12 percent of the incident radiation in a certain spectrum. The best we do in farmers' fields in the U.S. is about 3 percent. The average is about .5 percent.

So when we talk about increasing photosynthesis, we can talk about increasing photosynthesis rates which has a connotation of changing that enzyme which biotechnologically is very appealing. Or we can try to think of ways to keep leaves out there for more times during the year to capture what was already there. I don't know the extent to which we have thought much about developing cropping systems using plants with today's thermodynamic efficiency, but keeping those solar collectors out there in different combinations and different groupings at different times of the year. Of course, there are some parts of the world where there is no water or there's lots of ice and that precludes keeping your solar collector out there.

But to what extent can we improve on the collection of solar energy by changing crops or combinations of species. You might call that multiple cropping or inter-cropping. Whenever the discussion of photosynthesis arises, we're thinking of accumulating carbon. The carbon accumulation never occurs more than 12 hours per days, sometimes as little as 8 hours per day. But the process of carbon dissipation goes on 24 hours per day. One lesson that was learned (I think a very useful lesson) was that the process of carbon dissipation throughout the 24 hours of the day is just as important in determining yield as the process of carbon accumulation. I'm talking about respiration.

While there has been a lot of activity in trying to improve photosynthesis rates in plants, I believe that the real interesting success story was what happened with the rye grass in the Welsh Plant Breeding Station several years ago where rates of respiration of the plants were modified genetically and this did actually translate to differences in growth rates and dry matter accumulation in the field. This was reported by a scientist whose name escapes me, but he was at one of the plant symposia at Iowa State. So I raise that cautionary flag. Don't think of carbon accumulation--think of the net balance over a 24-hour period.

I think I'll return and re-emphasize what I said previously about organizing research to solve particular problems. I think there is a real opportunity in developing countries for institutional leadership in targeting a specific problem and developing the cadre of people to deliver the technology. I fear that is a constraint that we can't cope with here in the U.S. We change our priorities in every farm bill or every granting cycle. But if we have a priority to increase the capture of solar energy on a land area basis, and to achieve this by any means open to us, we can do this with plant breeding. We can do it with crop management. We can do it with the nutrient use efficient techniques and with genetic manipulations. And in the end it is going to cost us less fossil fuel. I think it is visions like that. I don't like to use the term "Manhattan Project" because it has some undesirable communications that lend themselves to long-term programs with assured support.

Finally, I think that progress in developing countries is going to be hampered by the same problems that are hampering the progress of science in the United States. We're a world-wide economy. We are also experiencing changes world-wide of how society perceives scientists. We sit in our groups as agriculturalists and speak with sadness about the amount of funding or the fact that our grants are short-term, or that priorities are often changed. But in reality, society has lost some of the trust in scientists that it once had. I'm talking about all science--not just agriculture. We've had a few Three Mile Islands and Chernobyl's and Buhpal's which have now led society to view scientists as part of the problem rather than part of the solution. Agriculturalists are subject to that criticism just as much as anybody else. So I think that's a burden we share with society. It's going to be just as important in developing nations in the next 25 years just as it is in the United States today.

Rubenstein Recently, Gary, as you are aware, I have been trying to assess what has been going on in the way of biotechnology and other related research on photosynthetic enhancement and use of PGR plant growth regulators. It is rather clear that research investment in those areas has declined significantly. I suppose partly as a result of not having had major breakthroughs in those areas, but also because of a very pronounced feeling on the part of a lot of people, including funding agencies, that "we're going to be able to deal with these problems by genetic manipulation and therefore let's wait until the state of the art for genetic engineering gets to the point where it can deal with these problems." It seems to me that perspective is doing something to penalize some important areas of research.

Animal Production

Ruttan We will now shift from crop to animal productivity. Our first discussant will be H. A. Fitzhugh. Hank is Director for Africa/Middle East Division at the Winrock International Institute for Agricultural Development.

Fitzhugh Thank you, Vern. My orientation will probably be more toward the developing countries. Let me say just a little bit about our organization. When we started Winrock International in 1975, it was completely oriented to livestock. It was Winrock International Livestock Research and Training Center. Then 10 years later we merged with the International Agriculture Development Service and with the Agriculture Development Council. We hired Bob Havener as president. Now Winrock International Institute for Agriculture Development is working with agriculture across a very broad spectrum. Our activities involve crops resource management and policy studies as well as livestock activities.

The reason why I tell you is that I am an animal scientist. I couldn't have survived through this sort of transition in the organization if it weren't for my own views about the role of livestock in agriculture. My view is that livestock have a role only as a component of a balanced agriculture system. When we deal with livestock, we can't deal with them separately from the rest of the agricultural system. Livestock are and will increasingly be viewed as a source of cash income in developing countries. Livestock provide opportunity for small producers to generate income as they move from a subsistence to a cash-based economy. And livestock, just as in Europe, North America, and other developed countries, do offer a significant opportunity for income generation.

The second view I feel strongly is that as we try to increase the productivity of livestock, it will always be in the context of a low-cost production environment. Certainly that's true in the United States. Whenever livestock producers forget about cost of the operation, they start getting in trouble because of the market cycles and other things. Successful livestock producers are always trying to keep costs just as low as they can. And that's particularly useful for livestock when their role in a balanced agriculture system is to convert relatively low-cost or low-value crop resources into animal products. The point was made this morning that

we need to value both the grain and the stover. Livestock will always be produced under economic stress. Let me emphasize this point by talking about dairy cows because it doesn't make any difference whether you're talking about the dairy cow in Minnesota producing 12,000 liters or the dairy cow in the highlands of Kenya producing 1,200 liters. They are both producing under stress. Now it's a different sort of stress. But whenever we are trying to increase productivity, we have to think about the limiting resources. It may be labor, it may be feed, or it may be something else. That imposes economic constraints on livestock production and on the opportunities we have for increasing production.

Let me talk about genetic resources. The particular concern I have is our access to the global pool of genetic resources. I think that we have a real opportunity with livestock to follow along the path of plant breeding with hybrid poultry, hybrid swine, and finally hybrid cattle. In plant breeding, access to the global genetic pool has been exceedingly important for the genetic improvements that we have been able to realize recently. One of the concerns that I have is that just as we're beginning to have the technologies that free us from some of the concerns about disease transmission and other problems (I am thinking particularly of embryo washing techniques) we're finding that we're running into a political constraint in use of the pooling of genetic resources. I'm from south Texas. We always used to say when walking through mesquite pastures, the first person woke the rattlesnake up, the second person made him mad, and it was the third person that got bitten. Well, on the animal genetic side a lot of the plant collections that have been done in maize, wheat, and rice managed to wake up some political sensitivities. Now whenever we start talking about a global animal gene pool program, political barriers are being put up.

I chair the Committee on Animal Genetic Resources for the National Research Council studies on genetic resources. What seems to be a real concern now is that where we would like to make recommendations on putting U.S. resources into Africa or into Latin America, or into Asia to help the conservation of indigenous genetic resources, our efforts are being looked at with great suspicion. Why is the U.S. assisting with a program? Are we trying to get our hands on their resources! If a country like the United States, where we have the resources to invest, is excluded, it's not going to be done at all. Developing countries, like Zaire, will not invest in maintaining these really valuable or unique genetic resources. I see it as a real problem--excuse me for preaching--but I see this as a serious constraint to future growth of animal productivity.

Fortunately, on the animal health side, biotechnology has brought us to the threshold of some real opportunities of both propolactics and therapeutics that will impact on the serious health problems limiting livestock productivity. The difficulty is whether the farmers can and will afford these costly inputs. They are going to have to buy them. ILRAD and the Rockefeller Foundation are funding the study on socioeconomic aspects of health. My own feeling is that farmers are not going to make those investments unless there is a high return. Don, I liked your point. Three to five times the cost. They have to see that sort of return to cost

coming back. It's going to require at least that before they're willing pay for vaccines and other prophylactics. I think that we have a real challenge here which takes us outside the technical and more into the need for market mechanisms that will reflect the extra quality in these livestock products and that will then pay the farmer who is willing to make that investment in producing a better quality product.

Feed supply is the greatest limiting constraint and, perhaps, the greatest research opportunity. I don't think that the limiting constraint is animal nutrition. It's feed supply! All of the issues that we talked about on sustainable agriculture become relevant. Our opportunity here is to make better, more comprehensive utilization of the plant materials being produced--to take full advantage of this 12 percent plateau that we might have on solar transformation. But to do that, we'll have to put a lot of roughage through livestock. I think that research has to be done so that the potentials will be recognized. This will require multi-disciplinary approaches. It's going to take major inputs on the plant side and major inputs from the social and economic side in order to gain these increases to livestock productivity.

Goodrich Does the current trend of importing black and white cows (Holsteins) into a lot of tropical developing countries bother you?

Fitzhugh No, because I think we have learned a good deal from the experience. In many places it's been a very heavily subsidized activity. I suspect that the U.S. government has put the greatest single share of their investment in livestock on the international scene into the export of black and white cows.

I've got a quick anecdote. I had a call about five years ago from a person in AID. He was not a livestock person. He was asking my opinion about how well Holstein cows would do in the Sahel. After I picked myself up off the floor, I said, "What are you talking about?" He said, "We just read that there have been large number of cattle that have died from the drought and we have all these surplus dairy cows here." They were seriously proposing shipping these cows over to the Sahel.

Goodrich Thank you. If your comment is that the role of livestock is to utilize crop residues, do you need a Holstein cow?

Fitzhugh No, but that's the reason that I'm not worried about it. I think that it will be self-correcting.

Ruttan But if you're advising the Indonesian government, you wouldn't advise them to put their own money in it, would you?

Fitzhugh No. But if I worked for Land O'Lakes, I might answer differently. We wouldn't advise importing cattle, and certainly we wouldn't advise using World Bank loans to bring U.S. dairy cows into a troubled economy.

Jain I have just one small question. An important problem in the developing countries is poor animal nutrition. Most of the animal population is very

poorly fed--subsisting on crop residues. Yet no matter what we do in crop breeding, at least 50-60 percent of the total crop production will always be available in the form of crop residues. I see an important challenge for biotechnology to try to improve the nutritional quality of this residue through some form of bioconversion, not some of the diagnostics or the vaccines which, of course, are very important. But in relative terms, conversion of residues would make a tremendous contribution to nutrition if these very low quality crop residues could be made more useful for animal nutrition.

Fitzhugh I agree. I think that there are also some related ways of producing very low cost protein supplements that could be done through biotechnology. You could use these in conjunction with low quality straw. There's a lot that could be done. One is just to make sure that straw goes into a mature cow and not the young animal, which is not as capable of utilizing poor quality resources. It has worked very well here in the U.S. The basis for most of our meat production is to utilize a stratified production system. But in most places the level of management that would be needed doesn't exist.

Faras I recently spent two weeks in Indonesia with the National Research Council (NRC), on a committee for biotechnology in agriculture in southeast Asia. One of the things that we noticed is that malnutrition and disease go hand in hand. Our conference set forth a number of recommendations. They were fairly simple, traditional kinds of things that needed to be dealt with. Yet the government, in its dichotomous mentality, would subsidize the government-supported dairy herd. They wanted to play catch up quickly, and they were getting into the embryo transfer and even talking about cloned growth hormone genes. How do you get around this? You have this mentality that says we want to be developed, so therefore we want to use the highest technology. Yet they were not dealing with the simples issues of nutrition and disease control to improve milk production.

Fitzhugh My quick response is that when the producer really benefits from the change--the producer responsible for the management, not a parastatal or whatever--then you will see the appropriate changes. As an example, let me refer to an experience in Szechuan Province in the People's Republic of China. Szechuan has a large number of government funded farms. Expensive Holstein or Simmental cows are brought in. Many government farms had one-quarter of the cows still producing milk. Yet in 1982 you could go into the farms where the farmers have been able to buy cross-bred cows from the state farms and they were taking good care of those cows. A lot of those cows had had mastitis so bad that they had moved them out of the state farms. But these farmers had gradually taken care of the mastitis. They were well-managed, well-cared for cows.

First But there may also be different sectors of that livestock industry that really should develop along more intensive lines. If you are going to provide meat and milk to the people in a large city, for obvious nutrition reasons, then I think you must look at rather intensive management and improve those animals as much as you can to get as much milk above maintenance as possible. And I don't think those animals should be

maintained on the same kind of feeding regimes that the animals out in the village are going to be maintained on. The other reason for some of those techniques coming in is that you can have relatively few herds of intensively managed operations that provide outstanding breeding stock for distribution within the country for cross-breeding programs.

Larson The questions that Dr. Jain asked has some real major implications as we move from crops to livestock to resources and then to economics. Your answer was that the animals are there to eat the crop residue. It is something from the soil resource point of view I abhor because those residues should go back and recycle the nutrients into the soil. So we have a dichotomy. When we recycle through the grazing animal, using the rice straw, it's less inefficient than in a cornfield where the nutrients go directly back. In substantial parts of the tropics there have been some real major advances in pasture production, in poor environments, in acid soils where animals do not need to compete with crops. That offers another option. Of course, in a situation like India, land is too limited to permit a significant amount of pasture so you go to continuous cropping.

Fitzhugh I agree in principle with your concern particularly if the waste doesn't get back to the soil because it's burned or something else. It is good for soil fertility to have livestock process the straw as long as manure goes back on the land. But, of course, if you remove the straw and even the manure doesn't come back, then you've got problems maintaining fertility.

Duvick What is the status of animal genetic resources preservation, Hank? Have there been many gains in gathering and conserving animal genetic resources?

Fitzhugh There have been real efforts to get programs started because there are technologies, cryogenic methods and others, that are available. There are two things limiting the success rate. One is the political issue of control over genetic resources.

Duvick What you're essentially saying is that the plant genetic resources people have scared up the snakes and gotten them angry and you guys are coming along and getting bit. Is that right?

Fitzhugh That's right. (Laughter) I'd probably be even blunter about it. But just to go in and do a collection is tough. It's tough to get permission to do it. I think the other concern among the animal geneticists is that there has been so little characterization of the genetic resources. When you try to put together a cost effective plan for collections, you don't know enough about the variability out there to come up with the right strategy. If you're going to go to west Africa and collect for the trypanosomalisis resistance, you can't go in and collect semen from the first five bulls you meet.

Qualset I was just going to ask Hank about the feed supply situation. Overpopulation and overgrazing must be a big concern.

Fitzhugh Again the solution is better management. Whenever livestock are produced for the market rather than for subsistence or as a stock of wealth, it is easier to improve management. There must be pricing policies and other things to provide the right sort of incentives. In Morocco and throughout the Sahel, trying to develop a policy that would discourage overgrazing is very difficult. I think that the best chance is to provide alternative sources of income so that the population pressure on the land resource can be reduced.

Ruttan I want to get a question in. I want you to tell me why improving livestock productivity seems to be so different than improving crop productivity. If I look back at crop improvement, we weren't successful in getting farmers to use fertilizers until we were able to breed crops that were responsive to fertilizers. Then the gain from the incremental fertilizer made it profitable. In the livestock area I keep hearing people say, "Genetic improvements are not important. The shortage of high quality feed supply is the major constraint." That sounds to me a little bit like telling cultivators, "You just need to get fertilizer out there!" I'm just wondering if you are really sure? I have a sense that when you move from self-supporting animals to animals where you have to put in the equivalent of fertilizer, which is protein feed, you have to go to substantially higher prices to make it profitable. Somehow I have the sense that maybe you're never going to get across that bridge until you change the animals' capacity to respond to those inputs. Is that too much of an analogy?

Fitzhugh I think that most of the livestock in the world are very responsive now to better quality feed. You can double output from indigenous livestock populations by improving the quantity of feed and making sure that it's there on a continuous basis. The serious problems you often run into is that you have good quality feed for only part of the year. When I started working in Venezuela in 1962, the problem was that our animals might gain a couple hundred kilos toward the end of the rainy season, but then they would lose all of that during the dry season. As a geneticist, I would never say genetic resources aren't important, and that they don't need to be improved, but I don't believe that most producers now have any incentive to achieve high productivity in meat production. On the milk side that's not true. On the milk side you get that quick payoff. That's really the closest analogy to the crop side--you get the quick payoff to higher genetic potential. In western Kenya you can see people going to the market to buy feed to put in their cow because they know that two days later they can see an appreciable increase in milk production. If they get the right amount of feed, particularly a better quality legume into that cow, then they can see a 20-30 percent increase in the milk supply. So they do it because they know what the value of that milk is. With meat, the payoff comes so long after the input is made it is often hard to see the payoff.

Animal Biotechnology

Ruttan We will now move on to Neil First's presentation.

First I think you have set the stage for my beginning remarks. First, I want to address some constraints and opportunities relative to the biotechnology area. The constraints and opportunities relative to animal biotechnology depend on what it is we really want to do with animals. What would we like those animals to do in the place we want them to do it? I would suggest that what we would like to do is build animal systems that are adapted to or fit alternative environments. That includes disease resistance and nutrition. It also includes the fact that we may want to make browsing animals out of what once was a grazing animal. Then we want them to produce a product that is acceptable to the people who are going to eat it in that area, or in a market. We want them to do this as efficiently as possible. And we also want to propagate them as quickly and efficiently as possible.

Within that perspective there are three levels of constraints. One level pertains to the basic science that underlies the biotechnology. Do we know enough in basic science to accomplish these sorts of things in all aspects? The second set of constraints really pertain to building the animal and the production system. That is the applied science. Are there constraints there that need addressing such that if we did not solve certain problems we couldn't modify animals to be adapted to a particular environments. Third is the constraint of applying the technology to production. For example, in the developed countries we're dealing with issues such as the consuming public's perception of wholesomeness in the product. What are contaminants in the product? Is the product drug treated? If it's going to the European market how do we replace those drugs with something we can genetically engineer into the animal? Is the animal healthy? Did it grow and develop well? Was it healthy in terms of the consuming public's perception. Is it healthy also in terms of what it does to the humans; i.e., is it going to contribute to reducing or elevating cholesterol, etc.?

We have the constraint, in the developed parts of the world, of animal welfare. If we were in the Scandinavian countries, we would face constraints on the way birds are housed that would make broiler production non-competitive on the world market. We'd simply give up and buy the birds elsewhere. If we were dealing with an underdeveloped nation, I think Hank has discussed most of those aspects, we would have bigger constraints of environmental adaptation to the feed and the disease load in that environment. There may be much less concern about animal welfare or about cholesterol. Cholesterol may be beneficial in high quantities because it's contributing to caloric intake. We have some of the same constraints, however--should the animals be healthy. We have the same constraints with the production efficiency--although the set of circumstances associated with efficiency may be different.

We have the ability to genetically engineer animals to fit consumer demands. We have the ability to produce disease resistant animals. And some of that work is just reaching the beginning stages with mice. For example, we have the ability now to make mice that are totally resistant to the whole herpes and pseudo-rabies family, because we have altered a glyco-protein (GP4) in their plasma membrane. This principle was borrowed from plant genetics. It was first applied in poultry at Michigan State.

Now it's being moved into the other animals. There are at least six modifications that can now be made in the cells of animals that suggest that we have at least six ways of altering their resistance, not just to a single disease, but whole broad classes.

These possibilities may have significant economic implications. Let's suppose, for example, that we move animals into Brazil that are totally resistant to hoof and mouth disease. Brazil could very well replace the U.S on the world market in terms of meat production. Those are institutional and economic considerations we haven't even discussed.

We have the ability to engineer animals that require no drugs, simply because the organism that the drug was there to treat won't be an organism that affects that animal anymore. I'm speaking down the road a ways on this, but the models are available. For poultry we have the ability to set up test and screening systems to assure wholesomeness of the product. We need to develop these further. But there is quite a bit that can be done now, particularly as we now can do DNA fingerprinting in a very efficient way with PCR amplification. We probably could identify almost any microbe. We have the ability to engineer more efficient animals. Certainly in the future we will do this more effectively. Some of these same things will apply for the underdeveloped nations. We also have the possibility of developing ruminants that are browsing rather than grazing animals. The common cow may browse instead of graze. Now, I looked around the room and saw everybody shaking his head saying yes, that would be a good idea. But is it? Turn to some questions you raised about the soil a moment ago. Let's suppose that in the Sahel where there has been grazing by cattle, we make cattle browsing animals. What happens to the browse? The browse goes away. What does the Sahel become? It becomes desert! So, we have to think about those things as well. We have to be sharp enough to know what we're doing in the modeling because our tools have gotten so good that we can really destroy things in the process of trying to be beneficial. We also have for the developed nations, the ability to engineer animals for survival, for more efficient production, and for less food intake per unit of product.

The constraints in developing this technology, from a genetic engineering perspective, are four. One constraint is how to more efficiently do the gene transfers in genetic engineering. That's a pretty straightforward thing that a number of scientists are addressing. The second constraint becomes how to make these tools more useful. That is how to be site specific in where the gene is inserted in the tissue and how to turn that gene on and off at the time that man decides. That's not so far-fetched. We can target about ten different tissues in the body now. For example, we can target the mammary gland very efficiently. We can target skeletal muscle very efficiently. And we have at least some control--not the precision we'd like--but some control over the time of turn-on and turn-off of these genes. We have synthetic glucocorticoi promoter sequences that are responsive to an exogenous glucocorticoi signal. We have growth hormone releasing hormone being driven by prolactin sequences that are episodic in their response along with prolactin release. But the important part is that we can use prolactin antagonists now to turn what is an ineffective

episodic release into a constant one which is very effective. So we have the beginning of tools that give us turn-off and turn-on signals.

Perhaps one of our biggest constraints, looking toward the future, is the constraint of understanding the genome of the domestic animal sufficiently that we can relate a group of genes to a trait and say that if we wanted to change this, these are the genes that we could manipulate to change it. Within a couple years, we are going to be at the point where that's our deficit in understanding. I think Irwin has implied that the plant world is really at that point right now.

And what do we do about it? So far, we've buried our head in the sand with respect to animals. We've got a human genome mapping program and probably will learn enough from that to be able to make a start. But we have no animal genome mapping program. We have commodity groups interested. The best genome map in domestic animals right now is cattle--all the efforts of one man in Texas, Jim Womack. We have a small cadre working in that area. The basic science developing the tools is not coming out of investment in agriculture. It's coming out of investment in the human genome. And thank God for that because we'll probably be able to use it. But we have a real constraint in this respect.

Rubenstein One question on the basic science side. What kind of basic science do you need to develop further?

First That's a hard question for plant and animal science alike. The basic science information that will probably have some impact on animal agriculture in the more distant future will be those things that come out of yeast studies on cell cycle regulation and a little Drosophila work perhaps, but most heavily out of the yeast area where suddenly we've discovered that genes control the cell cycle--not just a few which control cell cycle stages, but about 50 genes known in yeast that not only regulate important cell cycle functions, but also have influence on the cell cycle or on yeast growth. Those genes are rapidly being shown to hybridize with mammolian cells and antibodies from the proteins of those genes that interfere with functions in cells of higher animals such as amphibian, mouse and man. So it turns out that the yeast is giving man the route to understand cell biology of man and domestic animals because the genes and the proteins seem to be very much the same. It makes sense that if cells are going to function in certain basic ways throughout the animal kingdom that they be controlled by common genes. Out of these understandings, will come the cell events and genes that we will manipulate in the future that might affect growth and efficiency in animals.

Faras With respect to your latter comment, I should just mention that based upon these homologies between various species, as we identify more markers in the human genome, we're going to be able to directly adapt those to some animal species. We know that for many of the sequences that we've been looking at, under certain conditions, can be identified in lower species.

First There is a small group of researchers that have been trying to get a proposal this year (right now, actually) into the USDA competitive grants

program for a small initiative in mapping the genome of domestic animals. Not the whole genome, but at least those parts that might relate to one or more RFLP to linkages that relate to production traits and are really modeled after and use the tools of the human genome. We've run into huge resistance within USDA on this initiative.

Ruttan What is the source of the resistance?

First The resistance is that it's not basic science so it doesn't belong in competitive grants. But on the hand, it's not an initiative that the ARS or CSRS considers important. ARS doesn't really feel that it's got anybody in this area to take it on or that it is the right time to build a program.

Faras It would seem to me that with the political momentum that helped initiate and develop the human genome project would carry over to both plants and animals.

First Agriculture needs this initiative. At a couple of gene transfer scientific meetings, for example, the one at Cornell, we outlined a program for the USDA and the state experiment stations. Everybody was excited--including people from commodity groups that very seldom get excited. But the system has become too rigid and too structured.

Allen The other fear is that there is not going to be any new money.

First Well, there isn't any money if you ask for it in the same category. But there is an initiative coming from the USDA in the plant genome area. So far, it looks like it's on a pretty low-budget basis.

Allen I have trouble with Paul Stump's position that mapping the animal genome is not basic science.

First I didn't mention the fish because Faras is going to talk about that, but fish sort of fit inbetween because you've got high numbers and you can do things quickly. And probably those genes are going to be somewhat in common between the yeast, fish, animals, and man.

Herdt I am confused. You said something about the lack of useful genes and then you made a comment about useful genes coming out of yeast.

First I probably should clarify that. What we're beginning to learn is that the mechanisms at the cellular level that we want to understand in mammals seem to be regulated by genes and proteins that are in common with yeast. In part, those understandings will help us in production traits. But we don't have any understanding of the production traits. And so we don't know what they do. In the yeast, we can say that yeast do certain things in response to temperature. They do certain things in response to changes in nutrition. We don't have that fine tuning in terms of what elevation of environmental temperature does to animal systems and whether the genes are the same. We'll get some help out of the yeast systems. But somehow we've got to understand the animal in order to put this into application. And even beyond that, Gene Allen and his friends in Food Science have got

to tell us what tenderness is in the meat before we can give you any help in terms of how to change the genes and affect the tenderness.

Advancing Gene Transfer Technology: The Case of Fish

Ruttan We should go on to the fish now. The fish story is very interesting. When I called Neil about coming to this meeting, he asked, "Do you have the fish people?" I said, "What do you mean?" Neil said, "Tony Faras is right on your campus." I should have known that--Tony talked to my class about his work last winter. Tony, I appreciate your coming on short notice.

Faras I am not a fish expert, but I am involved in a fish project here at the University which involves three other colleagues in the animal health sciences in the College of Biological Sciences and in Fisheries and Wildlife. Actually they are the experts. I became involved in the collaborative study several years ago based upon our interest in gene transfer in humans. Our interests in human genetics were not only directed at identifying diseases using gene probes which we do now routinely in the clinic, but ultimately curing genetic diseases by doing gene therapy. And the same technology that Neil and Irwin alluded to are applicable to fish research as well.

To make a long story short, we decided to start looking at whether or not we could facilitate several properties of fish productivity. We started with sports fish in Minnesota. The two we started with were walleyes and northerns. We did that for political reasons as well as scientific reasons--which brought us a substantive local grant and allowed us to begin our collaborative studies.

What we found after 18 months (we have just completed our second year of those studies) is that we can increase growth rate and size by transferring growth hormone genes to fish by micro-injecting fertilized fish eggs. Initially what we used were a number of systems which would probably never be acceptable or approvable by any regulatory agencies. We used a retro-virus (a tumor virus) genetic sequence (vector) to transfer the growth hormone gene into fish and promote the expression of those genes. We moved in the first growth hormone gene we had our hands on--bovine growth hormone.

Interestingly enough, what we have been able to find out with this project is that after a year we have northern pike that are growing at best about 100 percent and on average approximately 40 percent over their genetically controlled siblings. Probably as important here was a research project which was really applied research, in the sense that it was directed towards the production of faster-growing fish. Yet as a result, we have been able to develop a system which may have tremendous application to more basic research. That is to say, the interesting thing with respect to the fish, in contrast to a number of the species including mice that Neil alluded to, is that we can micro-inject by hand a lot of fertilized fish eggs per day. In this last round we were working exclusively with walleyes. We did 120,000 fertilized walleye eggs in just about a month. We could average 2,000 per

hour which means that you have a system where you can move in a number of different genes to study a number of basic concepts--including how those genes are regulated shortly after fertilization and how they're expressed. One interesting outcome of these studies has been a maternal influence versus a fetal influence on the expression of the transferred genes that we move into these fish species. So there are several advantages of fish from the point of view of basic research including the fact that you can do large numbers and you can start analyzing these species and those trans-genes very soon after fertilization.

Now along with these kinds of studies, we obviously have been interested in, and have focused on, the opportunities down the line to utilize the technologies that we've developed to enhance growth for commercially produced fish. As I said, we started with bovine growth hormone and viral genes and we moved from these that I consider "heterologous" genes to "homologous" gene sequences. We're now cloning out the walleye and northern growth hormone genes to be able to insert the correct fish growth hormone gene in the appropriate species. We're setting up vector systems to transfer and express these genes with appropriate regulatory genes from these species. Fish appear to be a species that have not been selected for faster growth by traditional breeding, so therefore neither the number of growth hormone receptors or the amount of expression of growth hormone genes in fish have been improved upon by traditional techniques. By genetic engineering, we are increasing the amount of the fish growth hormone gene by contemporary rather than traditional techniques.

So much for the background. Now I'd like to get into what we believe are some of the major issues and constraints in terms of fish productivity. There are really three that we believe are the most important. First, we believe that gene transfer technologies that I have described clearly have the potential of removing the major economical constraints of net-pen farming or fish farming by aquaculture procedures by facilitating the growth of fish in cold water. Of course, as we remove these economic constraints, we will also facilitate cheaper production in warmer climates in developing countries. I will say more about that in a moment.

There is a second reason that we believe increasing the productivity of fish is important. As the fishing fleets have become more sophisticated, harvesting from the sea is eliminating brood stock, slowly but surely. We are seeing an overall increase in consumption of fish worldwide combined with a decrease in the ability to maintain production from natural stocks. If you add in other factors such as pollution and oil spills, we believe, as the Norwegians have for some time now, that fish farming (or net-pen farming or aquaculture) will probably be one of the major ways in which to accommodate the growing demand for fish.

A third issue relates to environmental concerns about fish farming. I am involved in a small fish-farming operation in northern Minnesota directed at growing salmon. If some of you recall, northern Minnesota for several decades in the 1930s, 40s, and 50s was a major producer of high grade iron ore in this country--if not the world. As a result of that, there were a number of large holes or pits in northern Minnesota. When they stopped

mining iron ore, those pits filled with fresh water because they were below the water tables--some of them 600-700 feet deep. There are over 75 such water-filled mine pits in northern Minnesota which could grow fish quite well because of their high quality water. Thus far we have successfully maintained salmon in these mine-pit lakes for over a year, albeit we have experienced slower growth in winter months compared to summer months. But there are individuals who do not want these mine-pit lakes fish or fish by-products, and so we've run into some environmental issues. In the Pacific Northwest, some of the fish farming industries have had problems because of environmental issues. Residents that live along the sea coast regard fish farming operations as an eyesore. Some believe the by-products could be contaminating. Many operations have moved out into the Sound where they're not as readily visible. This location, however, has increased cost of production. These environmental issues which we need to deal with are being accommodated more effectively by developing countries.

When we try to think about the future of the aquaculture industries, we see a great deal of competition. The Norwegians are very competitive because they're government subsidized operations. You have countries that are the world low-cost producers of certain species of fish such as salmon. One such country is Chile. They're the low-cost producer because of cheap labor, no problems with environmental issues, and they have warmer water that expedites the growth of fish. In this particular case, you have an example of a developing country that is doing quite well with respect to competition with the United States and other developed countries. Gene transfer technologies that will enable us to lower the cost of production of salmon in cold water will keep the United States competitively positioned.

My perspective is that if you're concerned about the limiting factors in aquaculture, you're looking at two things: growth rate and food conversion efficiencies. We believe that the introduction of growth hormone genes into various species will obviate those two limiting factors. Clearly there are other factors that need to be dealt with. You've heard about it today from a number of other speakers. We're looking at disease resistance as well as other genes that facilitate growth in very cold water such as the "anti-freeze" genes that have been discovered.

Ruttan Are there questions for Tony? One of the things that strikes me is the contrast between what we're saying about big animals and what we're saying about fish. The people worrying about big animals are worrying about how can they afford to feed those animals anything worthwhile (high quality feeds). I take it that in your enterprise there are going to be very few self-supporting fish. You are going to be using high protein feeds.

Faras Right. I said the two limiting factors are growth rate and food conversion efficiency. Fish food will be the largest operating cost. But the interesting thing is that the profit margins are such that the Chileans and others can afford to purchase the feed and, at least at this point, produce fish at a competitive cost.

Ruttan How do feed conversion rates compare say to poultry, pork, or beef?

Faras I don't know the figure well, but with poultry, it is slightly over 2.0.

Rubenstein Do you have to perform the growth hormone gene transfers to each generation as in the case of large animals?

Faras No. We wait until they become sexually mature and test the F-1 or second generation to make sure the transferred gene will actually pass to the subsequent embryos during fertilization. The capacity for rapid growth without increasing substantially the amount of feed used to produce them is currently being tested.

There are other related applications. We believe that distribution of these growth-enhanced fish genetic traits could occur similar to seed corn. For example, you could conceivably add sterility factors to fish eggs that have been genetically enhanced for either growth production or disease resistance. In this case you could distribute those genetically enhanced sterile fish eggs to any aquaculture operation which could only go out and sell these growth-enhanced fish but not reproduce them. Thus they would always be required to obtain an ongoing supply of these growth-enhanced salmon eggs from our hatchery.

Allen You indicated that the growth rate of the salmon increased up to 60 percent. What about the total size?

Faras The initial studies were done on northern pike. What generally happens is early on during their development they increase in length, then the controls catch up, and they increase in mass. The northern pike after about a year is just under a pound. The largest one we have is 100 percent larger than the controls. In contrast to mammals, fish grow until they die. That's why mature lake trout are 70 lbs. because they do not stop growing. That's a fish that is probably 50-60 years old.

Duvick If I understand you correctly, you apparently already have some characteristics in the fish that you want to enhance genetically. You add more genes for that same trait so you get around the problem of regulatory controls. Do you have evidence that you actually increase the level of fish growth hormone expression?

Faras Yes. What we're looking at is simply the amount of growth hormone being expressed. We can monitor that. We're looking at the expression of those genes and the amount of growth hormone that is produced. There may be additional problems with respect to the introduced genes. But one thing we do know for sure is that when you introduce these genes, and you look at them during development, there are various times when expression has peaks and various times when it goes down and then again you'll see another outburst of activity. So what might be happening is that you might get larger outbursts or greater amounts of growth hormone produced early on in life or in various organs.

Ruttan If I were the Minister of Fisheries in Indonesia, I would want to know how soon we could take advantage of this technology. What would be your answer?

Faras I would say probably a decade. Even if what we're seeing in the laboratory is real, we need to make sure it's a stable gene and to do this, we need to move it through several generations. I'm promoting the technology as something we're going to use tomorrow. We are involved in a good ten-year study. If we're lucky, we might have something going in five years. But I'll be fairly conservative and would prefer to say we're looking at ten years before we know enough about the stability--about the physiology--which we don't know enough about now and whether we can meet the regulatory hurdles which we will need to face.

Fitzhugh The answer in this country may be different that it will be in some others. Even though we may be six months away from the bovine growth hormone being released in this country, it is now being used in at least three other countries of the world. Not in the United States, but in some areas.

Faras My ten-year prediction is for use in the United States.

Ruttan It seems to me that this could have more impact for developing countries within the next decade than anything else we've talked about.

Faras It could have an effect in an extremely short time because the bovine product is active when given in feed to fish.

Fitzhugh So you don't have to catch those fish every day and inject them. You can just put the hormone in feed and that makes the technology applicable tomorrow if you can find a company who will supply the bovine growth hormone. You could be in business almost immediately.

Faras If it becomes available and becomes cheaper--there is a cost issue--then I believe, based upon studies that were done in other aqua-species, that it could occur very rapidly.

Ruttan Does anybody know whether ICLARM or any of these people are doing anything?

Plucknet ICLARM is not doing any work like this. They're working more on breeding.

Faras The interesting thing with fish is that for most species, other than rainbow trout, there has not been a lot of traditional breeding. I think that's another reason why we're seeing the growth in aquaculture.

Technology Transfer: A Skeptical View

Goodrich I was just going to say that soybean producers are very interested in this because they will provide the protein supplement for them. (Laughter)

The Chinese are also doing some work in this area. But in terms of constraints, I'm going to cross out a few of the topics that have been covered. The first constraint I listed was water. If we look very far down

the road, from an animal agriculture standpoint, the availability of water is going to have an impact on whether we use feed or crop residues. In those countries with an adequate supply of water, I would assume that we may feed those animals very much like we do in this country. We may grow special forage crops for them and emerge, over time, with production systems that would not be too different from here.

The second one I listed was energy. We haven't heard too much about that today, but we must look at alternatives. I don't know what kind of a time frame we're looking at, but the constraints on food production are going to be dramatic if we don't have alternative energy supplies. This will be true in livestock production as well as for crops.

A third constraint I would list would be rate of technology adoption. That is more true in this country than most of us think. It is true in Minnesota particularly with respect to livestock operations. It's not very complimentary that less than half of the dairy herds in the state of Minnesota use DHI record systems. Many of the developing countries that we're talking about do not even have a milk production recording system in place, let alone a system of determining which are the outstanding sires. So the rate of technology adoption is both one of the constraints and an opportunity. I think, frankly, that we don't do enough work with anthropologists and sociologists to study how people learn. Why do they change? How do they adopt new technologies? From working in Africa, it appears to me that adoption of proven technologies is still going to be tremendously slow. It may be that the productivity of poultry is in plateauing, but only under those production systems where state of the art technologies are being applied. I think if you would go to a lot of countries, one could not make the argument that the existing technologies are being used effectively. So I think there is still room for growth in animal production from more effective application of known technology.

Another constraint that I would list is the rate of muscle (protein) turnover. I'm going to come back to this as an opportunity. I think I am approximately right--the skeletal muscle, whether we're talking about humans or a meat producing animal, has a half-life of something between 7-10 days. It is terribly costly to deposit all of that muscle and in 7-10 days break half of it down and build it up again. So in terms of improving the basic efficiency of a meat producing animal, that turnover of muscle protein is a major constraint. It's going to be an opportunity.

I'm going to list as another constraint, declining support for agricultural research in the United States. That is going to the development of new technologies, not only in this country, but worldwide. We are in a period where agricultural research is not very glamorous because the politicians are so concerned about our ability to produce surpluses that they don't see the need to advance either knowledge or technology so they're cutting back on agricultural research. This will become a major constraint to our ability to feed this world. We're going to pay for the lack of support of agricultural research in a relatively near future. If you will permit a little editorializing, I spent some time in Ruwanda, a country with about 20 times the population density of Minnesota. A country that farms from the top of

the hills to the bottom. A country where there are no miracles left. I have no doubt that there will be massive starvation or revolution or massacres over food in our lifetimes in that country.

Let me make one more comment about constraints. This is going to be personal. As I travel in developing countries, and as I listen to people who have traveled in places other than those I have been, I have noted that they all have balance of payment problems. Many are importing feed for livestock and food for humans. It is easy for us to say we will produce some high-tech vaccines, and it is easy for us to say we'll hatch the chickens so they can feed them, and then we're going to ship the feed over, too, and then we're going to sell them buildings and mechanize the equipment to feed those chickens. I'm not sure they're better off, when this is all done, than before we got there. That's why I raised the question about chickens, so I don't have to get too far out of my field. But it would appear to me that if we would spend a significant effort working on a dual purpose chicken that laid 175-200 eggs a year instead of approach 300 eggs a year and was fairly respectable in meat production--not as good as our broiler--but they might be a lot better off in the long run, both in terms of feeding their own people and in terms of balanced payments. And I think when we work with developing countries, we need to be sure that we are not letting our American values about science and industrialization dominate our thinking.

One of the other constraints I'm going to list is that research agendas are more and more being set by politicians. There is probably not a researcher in this room that would like to admit that. We all stand up and talk about academic freedom, but we are kidding ourselves. The granting agencies are setting more and more research agendas and research priorities. Even at the state level the amount of funding that has come in the last several years to support what we were talking about this morning as maintenance research, is about non-existent. If you want to get turned down in the Legislature, go down there and start talking about "give us more money to fertilize the corn better or we need more research on how to feed the cows and pigs" and they'll just start yawning. But if you start talking about some new initiatives and so on, you're much more likely to get funding. Our state legislators are setting our research agendas. They are moving us more and more away from that maintenance research. If we don't watch it, it won't be very long until productivity of the crops and livestock that we have in this country may start declining simply because we are not keeping the level of maintenance research that is necessary.

Finally, a couple comments and opportunities: I would list one as technology transfer. I think it is an opportunity. I personally am not sure how well we have looked at it or studied it and I think it is very cultural. I think it is probably different from country to country. I think it is different from northern Minnesota to southern Minnesota and I think we have a lot of people who may not understand that. Those of you that think that we can feed the world on corn and soybeans are really wrong. We need to be concerned about getting some animal products so that we might get the methiamine and lycine levels in those human diets up to adequate points. I think we should all be more concerned about the

nutritional value of the foods we produce than we are. We have been interested in producing greater and greater yields of corn, greater and greater yields of wheat, more pounds of milk per cow, and faster growing pigs. And we didn't give a darn about its nutritional composition. It's about time we did.

Let me turn to regulation of genes. Regulation of genes might be too broad. But regulation of the composition of the animal is possible today. There will be a class of compounds called beta-agonists that will probably be approved for pigs within one year. Those compounds when given to sheep will increase muscling 40 percent--35 percent easily. They will increase muscling in pigs 15 percent. This may not be gene regulation, but it is regulation of the partitioning of feed or the energy that the animal consumes between fat or muscle. Growth hormones will do the same thing. They will shift the energy that is consumed from fat into muscle. You can see some very dramatic examples. There is some Penn State work on pigs that produce pork chops approaching the size of a rib-eye beef steak.

Ruttan I was wondering: why not go the next step and instead of feeding me that nice pork chop, just give me a shot of the stuff.

Goodrich Just give you the growth hormone? (Laughter) You might not like the results. But let me try to convince you that the answer is not the same world over. Depositing a calorie of protein is much less efficient than depositing a calorie of fat. When you deposit protein, about 85 percent water goes with it and about 10 pounds of protein and about 5 pounds of fat. Fat is calorically dense and it is low in moisture content. For a population that needs to consume more fat, it is a terrible mistake to import some great big breed of cattle that are hard to fatten. They grow forever--they get up to 2,000-3,000 pounds and aren't fat at all yet. They really ought to have cattle that are easily fattened--cattle that will convert the grass as it comes into bulk muscle and fat. They will get more calories for human consumption if the animal is easily fattened than if it is one of these lean kinds of animals. So don't assume that this regulation of body composition and regulation of fat and muscle depositions should be the same the world over. It shouldn't be and we shouldn't be thinking about the same gene pool in every country.

This last one and I'll stop. Animal waste management is an area in which, in this country, research has almost entirely stopped. In developing countries it is absolutely critical that the animal waste be used back on the fields to maintain fertility.

Ruttan I'm going to ask the resource and economics people to talk about some of these regional issues when we come back. Given the time, I'm going to hold you off and move on to Gene Allen and then we'll take our coffee break.

Research Organization

Allen — Thanks Vern. I would like to preface my comments with one thing that I would like to make sure we don't forget and that is that we frequently think of animals only in terms of food production. We forget about the other uses of animals around the world. But we need to think of animals not only for food, but also for draft, fiber, fertilizer, fuel, credit, and also a variety of things including the value that is attached to tusks and hoofs. I mention this because Dick made a statement earlier this morning, responding to a question about meat and milk being very different, that is a very important thing for all of us to understand about animals because there is a whole variety of constraints that come in to place for meat that are not the same for milk. One of these concerns the harvest: some are daily and others only once each year. In many countries they're faced with the preservation or the distribution of that harvest over time and to large numbers of people. One of the reasons why in many countries we find a weekly market is that is a way to deal with the perishability of food.

A first constraint, therefore, is that animal products that are consumed for food are all perishable. While that is a constraint, it is also an opportunity for biotechnology to find ways to extend the preservation of those perishable products for people to use over a more extended period of time. Cheese was one step in that direction. We need to keep in mind the perishability of horticultural products and animal products. That's one thing these two plant and animal products share that is different than for agronomic crops.

The second constraint I want to list is that of the human resources need to conduct animal research, this has come home more clearly to me since I became an administrator. To maintain an animal research herd, it is not enough to just keep the animals alive. Those animals have got to be reproducing. You need a high management level. You need very long term research. When Neil talks about the milk production of a cow, that's not something you create today and find out about in a year or so. I suppose an extreme example is what happened to us in Uganda a couple years ago when the cattle herd was wiped out during one of the civil wars. We lost 290 of our 300 cattle. That's a very expensive loss compared to losing a crop of wheat.

Ruttan — The Syrian Army ate the Ford Foundation sheep project in the Bekkaa Valley when they invaded Lebanon (I visited this project a few months before the Syrians got there).

Allen — The third constraint (also an opportunity) is at the interface between plants and animals. We have many feedstuffs throughout the world whose value is not fully realized simply because of our inability to improve the digestability and availability of the nutrients. I think this is an opportunity for biotechnology to develop systems that allow us to not only improve the digestability of these products and in many countries to carry these crop residues over from one season to another.

The next constraint I would list, which is very real for the United States and certain other countries, is animal well being. It really comes back to ethical and social considerations involving the bond between man and animal. We're going to encounter serious problems in this area. There is also an additional constraint involving the environmental consequences of bringing animal production units into populated areas. We have a very serious problem on the St. Paul campus of how to deal with animal waste. I think biotechnology has an opportunity to also address the animal waste issue including the production of useful products from the animal waste as well as eliminating odors.

If you think of plants as preceding animals and animals being in need of some plant sources, the animals are in a sense recipients of what is given to them. And man is a recipient of what comes from our plants and animals. In this regard, we need to think for the future much more systematically than we've thought in many cases in the past in research planning. I think our opportunity in the animal area, both in traditional methods as well as application of biotechnology is to further improve the nutritional quality of products either through preservation or through the improvement of these products. Animals can serve as a processor to upgrade the quality of some products.

The final thing I want to say is that in the United States we need much more cooperation among researchers working on the different species groups. We also need more cooperation between the animal science and the veterinary science programs. I believe that will become an increasing constraint to organize research along commodity lines. We may be losing major opportunities for progress if we do not bring about closer cooperation between the animal science and veterinary medicine units.

Sundquist I would agree, but I would distinguish between appropriate cooperation and competition among commodity groups. It is almost a fact of life that you're going to have competition. There may be some areas in common, but when all is said and done, it is going to be hard to get pork producers to be promoters of beef products or of broilers. We will have to live with a high degree of competition, but it doesn't necessarily have to be destructive. On the research side you can certainly encourage cooperation, but I think we have so many examples of commodity competition out there that I wouldn't be very optimistic about overcoming it.

Allen Burt, it puzzles me why soybean producers and corn producers do not form an alliance with animal producers. Animal feed is their market and will be for a long time regardless how long they look for new alternative uses of soybeans and corn. the fact of the matter is animals will be their major market. I think it is less likely for the poultry producers and swine producers to come together in an alliance. But I think as soon as you start to break up this defensive mentality, there will be some alliances formed and when they do form, we'll be better able to address some of our current challenges.

Burnside We would certainly expect our corn and soybean producers to support feeding experiments in animal science. They recognize the amount that

goes through the animal. But when I try to get the soybean producers to support lupine research, I run into a brick wall.

Byerlee Vern, I'd like to raise one question that pertains to much of what we have been talking about. My perception is that in a number of countries private sector research has not developed. It seems to me there are opportunities for it to develop. And I don't mean by the U.S. private sector going into a country. I mean the private sector within that country.

Ruttan I'll pass on that comment, too. My own impression is this is changing fairly fast. We came out of the post-colonial era with a perception that the private sector was an instrument of exploitation and that we could make the public sector work in areas where it has not proven to be effective. In the last decade many countries are becoming more sophisticated about which part of the spectrum from basic research to seed distribution should be carried out by the public and private sectors. Almost every country in the long run will continue to do a large share of its agriculture research in the public sector. But the public sector is usually very poor at marketing new technology. We are seeing more sophistication. How do you see it in the areas you work in?

Duvick I think you about said it all. I think we detect a real strong shift of opinion in many developing countries around the world. they are now looking toward the private sector to provide capital as well as to more efficiently do the job of marketing seed products, for example. I'm not so familiar with the animal side. I sometimes think that there may be more optimism about what the private sector can do than there should be. It's going to take a lot of trial and error to learn how much the private sector really can efficiently handle and how much mst still be done with public support. Even more important is going to be the development of a sense of partnership--of an actual partnership between private and public. This is going to be a very tricky thing to do. We're still working on it in the U.S. and Europe, for example. It certainly is not a "done" thing. This sense of partnership has never existed in many other countries of the world.

Ruttan Derek, CIMMYT has some studies going on in this area.

Byerlee I agree with you. Private sector plant breeding is emerging very rapidly in Latin America and Asia. I would expect that in the next decade the private sector is going to have more invested in seed research than the public sector. It has already happened in countries like the Phillipines and Mexico where the private sector already has significantly more investment than the public sector. In Africa I don't see it happening quite so fast, partly because of the size of the countries.

Ruttan I'm going to declare a break for lunch now. We've run somewhat overtime. But I wanted to finish this particular section. When we return we will start out with Bill Larson.

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LUNCH BREAK

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Advances in Soil: The Technology of Management

Larson I took the approach that I was going to bring up one rather specific item and go into it in a little more detail than perhaps some of the rest of you. And the item that I have is probably most applicable to the development world--Australia, North America, Europe. But I think the principles apply the world over. Here in the U.S., probably two of the major concerns crop producers have today are lower cost of production and concern about environmental effects. Under environmental I include water quality, erosion, and sediment deposition. My thesis today is that one of the things that we've got to do is be much more site specific in the application of our management practices to soils and landscape in order to respond to both of those concerns.

To illustrate let me use a very specific example. I took a 54-acre field in Jackson County, Minnesota and analyzed it in some depth. I looked at some other fields also, but we'll just talk about this one. The field is typical of the glaciated soils--agricultural soils--of North America. The kind of variability that we found in that 54-acre field would be pretty representative of much of the cropland of the U.S., Europe, Australia, and many other temperate areas.

On this 54-acre field we started with a basic soil map--a published soil surveying map. Then we went to the literature--to our crop-equivalent rating studies. These give us an estimated productive potential--a corn-yield potential--for each of these soils. On the 54 acres there were seven mapping units. The potential yield varied from 112 to 162 bushels per acre. Our standard fertilizer recommendation bulletin indicates that the nitrogen fertilizer needs for continuous corn--corn after corn--would vary from about 100 to about 150kg per hectare per year. In other words, some soils in that 54-acre piece would require, to realize their yield potential, about 50kg more nitrogen than others. Farmers, I think, usually fertilize for the better soils. If you use that assumption, then, some soils are going to get 25 to 50 pounds more nitrogen than they really need. And that 25 pounds or 50 pounds then is available for leaching. That's one source of our groundwater problems. The phosphorous need, based on soil tests for these seven mapping units ranged from 10 to 35 pounds of P_2O_5 per year. Again, a sizeable difference. And this is not an extreme case. This is, I think, a common case for southern Minnesota and northern Iowa.

If you look at the absorption coefficient tor pesticides, these same soils vary about four-fold. That is, some of them have an absorption coefficient about four times as high as some of the others. This immediately suggests that those herbicides are not all going to be equally effective. If applied at the same rate on all soils, there will be a big potential for leaching on some soils. We also estimated the hydraulic conductivity of these soils and we came to the conclusion that some of them have about a 65 percent

higher hydraulic conductivity than others. That is the rate of transmission of water through those profiles which could be about 65 percent greater on some soils than others. You should expect that coarser textured soils need the least nitrogen. Farmers are more likely to apply excessive nitrogen on the ones that are going to leach first. The most readily leached soils are also the ones that have the lower absorption coefficient for herbicides. Now, with those kinds of differences, I think we can expect that there's going to be some real important differences in the efficiency of fertilizer and pesticide use and some real differences in the susceptibility of those chemicals getting into groundwater.

We also looked at the erosion potential of those soils. Using standard management practices the erosion potential is about one order of magnitude greater on some soils than others as determined by texture of the soil and landscape position. If you look at the vulnerability, or the susceptibility to damage of those soils, using a model that we developed, it's about three times. In other words, the soils that are most easily eroded are three times more fragile, to put it in layman's language, than the other soils. And if you project out over 100 years, assuming the erosion is going to continue at the same rate, the damage or the loss in productive potential is about two orders of magnitude. A hundred years from now, some of those soils are going to be out of production and some are going to be not changed much.

I'm giving you these examples just to illustrate there is a lot of variability in the landscape. These are natural variabilities. Many people don't recognize this variability because they've never really looked below what they can scuff with their foot. Now, we can do something about it with modern technology. Most states have modern soil surveys. Most of the more developed states have these soil surveys digitalized for easy recall. If you come into our office, within 30 seconds we can put a map of Redwood County on the computer screen.

Now I talked about the variability in the soil and the need for fine-tuning our recommendation to be sure we get the practices on the land that each landscape unit needs. We now have that technology. We have the soil surveys. We have modern equipment. You can slip that soil survey into the microprocessor of a fertilizer spreader and program it so that it will put on 50 pounds of nitrogen on one soil, 100 on the next, and 200 on the next, or whatever you want, and it will do it. It will do it automatically as you go across the field, without stopping. You can put on different amount of nitrogen, phosphorous, potassium, and herbicide. That technology is here. It's not something that's in the future--it's here. I used fertilizer or pesticides or herbicides as an example, but we could do it for other practices. We could vary the plant population, for example. If we don't want to use potential yield calculations in our grid map of the field, we can use historic yields. We can put a microprocessor on a combine and get a running yield for that field as the combine progresses up and down the rows. And the next spring we can use that same map if we want and put on a certain amount of fertilizer for the 150 bushel yield potential and another amount for the 100 bushel yield potential. That technology is here. Now I know at present time, these are big, expensive machines. There is a

company here in town that makes them. They've sold about 50 of these over the world main in Europe, California, and Australia. They charge you something like $3.50-$4.00/acre to put on the fertilizer. If you want to put it on in a site-specific basis, farming-by-soil basis as we call it, then it's another $1.50 an acre. They do it on a custom basis. This is a big, expensive machine, but the machines are being developed on a much smaller scale. So I think in times ahead we'll see it on even a more practical standard scale.

Sundquist Can you say something about the returns for that $1.50?

Larson Our standard line is that it will save you $5-15 an acre if you put on fertilizer as we prescribe it as compared to a uniform rate. I don't think those numbers are out of line. I think I might have a hard time demonstrating it because the data is still premature. But, as Gene Allen knows, we're rapidly collecting that kind of information. But my point is not to emphasize this machine, or farming by soil analysis, but to emphasize that soils and landscape positions vary greatly. And by being more specific in our management systems, for each landscape position, we can cut costs, and we can protect the environment. And I think this is the major breakthrough we've had in soil management in the last decade. We now have the technology to be able to really be site-specific. The greatest application, at least immediately, is in North America and Western Europe and Australia. But I think the same principles hold all over the world. Soils and landscapes do vary and we have to pay more attention to looking at variability and the specific needs of the soil and landscape position. We have to feed our soils depending upon the productive potential and the dangers of environmental contamination.

Ruttan Questions for Bill?

Burnside This isn't a question, but I think you could save that amount on the herbicide alone with soil specific herbicides for corn and soybeans. With some of the herbicides we use on soybeans, you get poor weed control in some areas of the field and good control in the others if you apply them uniformly over the field. It's exciting to see computerized application of fertilizer and pesticides.

Heichel You may no longer have the technology constraint, but you still may have a knowledge constraint. You still have a constraint that needs to be dealt with.

Larson My point is that we now have the technology to make this feasible. We don't yet have all the databases and all the background information to do it. Our job now is to develop those databases including better soil surveys, and other auxiliary data. A soil survey, for example, wouldn't tell you the hydraulic conductivity of these soils. We have to find that out by laboratory or field-type measurement. Those kinds of databases have to be built up. But I'm saying it's technically feasible--I think we've shown that. It's going to be a very large job to fine tune all this.

At the field day at Lamberton, one of our branch station field days a year ago, we had farmers come over to see this big machine and see what we were doing. I really expected somebody to lambaste us and say this isn't practical, this isn't feasible, this is a bunch of monkey business. But we had about 400 farmers come by and not a one of them argued with us. They were all interested, they didn't say it wasn't feasible. So I think sometimes we underestimate our farmers. They'll pick up things pretty fast if you can show a real economic benefit.

Allen We have comparable equipment for herbicide application.

Larson We could map a field for weeds just like we map it for soils. If we have certain infestations of Canada thistle in a soybean field, then we would only have to spray in those specific areas. We have greatly improved our tillage equipment. But progress has been slower on application equipment. There is a comparable machine for dry herbicides, but I don't know of any that will do it with liquid. But I think it could be developed.

Jain I'm interested in this emphasis on cutting costs and achieving greater efficiency in the production process. My impression is that in Western European agriculture, cost reduction has not been a major concern. I know, for example, that the best farmers use 300kg per hectare of nitrogen on wheat--more than anywhere else in the world. The EEC gives very heavy subsidies and they still make a lot of profit. So I'm really interested that you stress these small cost savings.

Sanders Are cost savings or environmental concerns the primary motivation?

Larson I think it's both. My point is if you make progress in one, you've made a contribution toward the other.

Plucknet I'd like to support this approach very much. In other countries, it hasn't been applied so much on smaller single family farms, but this sort of approach has been applied in the plantation sector for a long time. It has not been as sophisticated as Bill is describing, but certainly it has been done with each field being managed quite differently--irrigated differently, fertilized differently, different weed control practices, depending on what's there.

Ruttan I was thinking as Bill was talking of the areas I know in Southeast Asia. We're thinking of the farms that may be 2-1/2 acres to 5 acres. This means that each of those soil areas may be in a different farm. But it has rather strong implications for the kind of recommendations the T and V extension system makes--where you send out an extensionist to the village to tell everybody to do the same thing.

Burnside Another important thing to remember here is the targeting of pesticides. Upwards of 98 or 99 percent of the pesticide does not reach the target. We have tremendous opportunities to improve the efficiency of pesticide use.

Byerlee Vern, another point, along with yours, is that we're very short, in terms of the talent needed to identify what those differential treatments should be. Just imagine the kind of database you would need to apply this kind of concept in southeast Asia, and the limited number of people who can generate the information to do the calibration. They don't have the basic information necessary to say "Well, on this kind of a soil, we treat it this way and on this kind of soil, we treat it that way."

Ruttan This means that we have to move beyond teaching "practice" in our extension work to teaching "principles". Then the farmer who knows his own land can begin to make more sophisticated judgments about input use.

Tropical Soils Management

Ruttan Let's move to Pedro Sanchez. Pedro's going to talk about tropical soils.

Sanchez My comments will be more on the issues related to tropical soils. Also a comment that now that soil scientists are branded as natural resource people, we not only have to worry about food production, but we have to worry about environmental degradation as well. We welcome that challenge.

Most of our attention during the last several decades has been focused on the better soils of the tropics. Those are the soils in which the "green revolution" in wheat and rice occurred. We're pretty much reaching the maximum potential of technology in the areas where the green revolution has been successful. Now we're looking at the other side of the coin, at the marginal soils that represent the majority of the land in the tropics. They're marginal either because they're acid or low fertility, or because they're dry, or because they're steep--and sometimes all of the above. What can we do now with these difficult soils? The work on the better soils to a large extent is in pretty good shape. We still need maintenance research and perhaps even the level of the site-specific practices that Bill Larson just mentioned.

When we start looking at the marginal soils or ecosystems, we can subdivide into about four or five groups. I would subdivide them into the humid tropics, the sub-humid tropics or the savannah regions, the semi-arid tropics such as the Sahel, the steeplands, and the wetlands. Each one has a different set of constraints. I'm going to focus on the first two--the humid tropics and the sub-humid areas--because they happen to be my particular areas of interest. We should recognize, however, that in the semi-arid tropics, the set of constraints are different and the set of solutions are very different

I'm going to concentrate on areas of naturally acid, low fertility soils. There is a fairly heavy mythology as to what can and can't be done with them. One is that they really have no potential for production because they're old, highly weathered and leached. These soils represent a good chunk of the areas of the world that still have potential for agricultural expansion. It is part of the myth that there are no large areas of potentially new agricultural land in the world. If you have any questions

whether this is a myth or reality, think about soybean production in the Campos Cerrado of Brazil. This savannah area, with supposedly terrible hopeless soils has shaken the foundation of the American soybean growing industry in the last 10 years. About 50 million acres of new land has come into production simply by using fairly simple soil management technology and better infrastructure and government policies. These acid soils have, in the long run, perhaps an even greater potential for food production than many of the soils that we are cultivating in glaciated temperate regions simply because their physical properties are favorable. Their chemical properties are poor, but they can be managed. Most farmers would agree that they would rather deal with a nutrient deficiency than with a serious compaction problem or a waterlogging problem or problems that relate to physical properties. There are still areas in the world, particularly in the savannah regions of Latin America, but also in Africa, that have huge potentials for greater production. When a country like Brazil strengthens its research capacity and reforms its policies, it shows what can be done. There are similar areas in Africa, which do not receive much attention, in northern Zambia, for example, that resembles Brazil, except perhaps the soils are a little bit higher in fertility. The maps are quite clear, but there may be in Zambia alone about 20 million hectares of such lands and no one known how many in neighboring countries. They have limited immediate potential because food prices in that particular country are far too low. There's very little incentive for agricultural production. When we worry about soil resource utilization, of course, we have to have the right political and economic environment. Agricultural research will not pay-off unless there are some possibilities of changing some of the policies and constraints. But the physical base for expanded production is there.

There are all sorts of myths about the soils. For example, if you clear them, particularly in the rain forest areas, they quickly turn into laterite--into brick, and they're useless. That almost never happens. It is simply not true. There are myths about their fragility--that they are very susceptible to erosion. Much of that is based, and quite often deliberately, on pictures in magazines of road cuts and gullies caused by civil engineering projects. It's very, very hard to have major erosion in the humid tropics, because for that you need to have your land fairly bare. It does happen, but it doesn't commonly happen because a green cover, be it of weeds or forest, is a main factor in controlling erosion. I was very pleased to read in the assigned reading that Vern sent out some of the data on the realities of erosion. It's not as you might expect from reading Lester Brown's The State of the World. Quite frankly, it doesn't mean that we shouldn't pay attention to the problem, but it's certainly not a complete doom and gloom situation.

Another area where we hear an excess of doom and gloom is the excessive preoccupation about leaching and erosion as nutrient-loss pathways. We are all concerned, and we see a lot of evidence in the decline of soil fertility with time, if fertilizers are not used, or if they're used improperly. But we must realize that the main crop nutrient loss, the nutrient loss, from soils in agriculture, is simply by crop harvests. Crop harvest removal accounts in global numbers for at least 80 percent or so of the nutrient losses from the soil. If we think in terms of sustainability, then you'd better replace

what you take out. And since we cannot easily put back the nutrients that we take off the soil with crop residue or manures, we must do it with fertilizers sooner or later in all soils. But we must put back what we take out. The main point is that the main nutrient-loss pathway for almost all soils in agricultural systems is the crop harvest. There is leaching, and there are other losses, but they are not as important.

Since we have to accept that fertilizers are going to be absolutely necessary for long-term sustainable crop production, when talking to some of the ecological-oriented audiences, some participants jump right through the ceiling when I make this point, but it has to be accepted. What comes out, must come back in--even in the good soils. As Bill Larson was just saying, they're adding more fertilizer on the better soils than the poor soils. Why? Because you have a better chance of enhancing production because water-holding capacity and other physical characteristics are better. We must accept the fact that fertilizers have to be used, sooner or later, in all farming systems. The challenge is in how can we make their use more efficient? How can we make the nutrients cycling in an agricultural system more efficient? It can be done in several ways. One is to recycle crop residues. Sometimes it's socially or economically unacceptable.

We know very little in practical agronomic terms about how to manage the biological side of soils. We can model the inorganic chemical side quantitatively. Soil physicists are also able to model water movements and the physical side of soils. We hardly know anything about how to manage the biological side of soils.

Now I'd like to turn to the problem of soils in the humid tropics. It's very much in the forefront of the whole issue of protection, preservation, and production. Even though by any stretch of the imagination the humid tropics are not likely to be the bread basket of the world, it's interesting to see how things fit together. We start with the variables that we all know about, rapid population growth, limited fertile land, land tenure inequities. The result is landless rural populations. In Latin America or Indonesia, farmers can move up the hills, they can migrate to the urban centers, or they can migrate to the frontier areas. If they move up in the hills and clear it off, it will enhance erosion because with the seed plants, crop cover is very limited. Farm size declines as the children take over part of the land of their parents with the result that there is even more erosion, siltation, and eventually rural unemployment. A lot of people from this large, landless rural population migrate to the urban centers. In Latin America this is getting to be of catastrophic proportions. The limited urban infrastructure pretty much collapses, urban carrying capacity is exceeded. When I lived in Lima, a city of 6 million people, half of them did not have electricity, running water, or sewage systems. The carrying capacity was definitely exceeded. The classic pattern is pioneer settlement in the humid tropics involves practicing some sort of shifting cultivation or slash and burn agriculture. The new settlers don't have the knowledge of the natives. You may have an important element of land speculation as in Brazil, but then you end up with all sorts of unsustainable agriculture. Some settlers move on to urban unemployment. Traditional societies are disrupted. Further deforestation results in soil resource degeneration, loss

of plant/animal genetic diversity, and an accelerated greenhouse effect. About 20 percent of the greenhouse effect is apparently due to tropical deforestation.

Can this process be stopped or turned back? There is an appropriate technology. There is quite a bit of variability. You must tailor management practices to different soils and landscape positions. I have listed here, in addition to different kinds of landscape positions in a humid tropical environment, different kinds of soils--fertile alluvial soils, acid soils, and young soils--and a series of viable technological options. Wherever you have flood plains, that is wherever you have a possibility of irrigation water from the river, you can do continuous cropping. Two or three crops a year using lime and fertilizer are possible if there is good infrastructure including a marketing system. An alternative is a low-input cropping system using only acid soil tolerant crops such as rice and cowpeas. Another alternative is to fallow, but using a legume fallow instead of a tree fallow. Such a system is not sustainable in the long run. It works for a while, then you can shift either to grass and legume pasture that can produce fairly decent levels of beef or milk or to one of a series of agri-forestry systems, many of them including food-producing trees and export crops.

In the research that we have been doing on this subject, we have attempted to determine for every hectare that can be put into this sustainable management option how many hectares would it save from deforestation to produce the same amount of food annually. The numbers are on the order of about 5 to 10 hectares saved for each hectare devoted to food production. I feel it's a very important system because it increases and stabilizes food production for the people who are migrating to those areas. You can't stop them, but it is possible to develop a sustainable food production system.

In the savannah areas with acid soils, what's needed right now is more appropriate government policies that go with the technology. There is a very good possibility as we move into the 21st century, that maybe some of this key problem of producing food could be done in the tropical forest zones and the tropical savannas.

Sanders What levels of production are you talking about?

Sanchez In our research in the Amazon of Peru, farmers can harvest two rice crops a year averaging 5-1/2 tons per hectare per crop. Farmers who slash and burn one hectare of upland rice harvest one ton per hectare. It's an 11-1 ratio. In order to produce those 11 tons of rice per year, you can use one hectare in paddy rice or you can use 11 hectares under upland rice. I'm sure we could get somebody to make it a lot more complicated, but this looks at it just from the perspective of food production equivalency.

Sanders What about costs? Would costs be tremendously different?

Sanchez Whenever we have calculated production costs, they come out to be very attractive. All the systems with which we work (except continuous

cropping) use fairly low levels of purchased inputs. The production of the rice is virtually all done by hand. They just pump water from the river with a small 4-inch hose pump. That is enough capacity for about two or three hectares.

Byerlee What about the upland rice?

Sanchez It's a lot less costly to grow upland rice. We can grow about four of five crops of upland rice in rotation with cowpeas. Compared to shifting cultivation, it's about 2-1/2 times more productive. The hang-up is whether you have an infrastructure that can take care of getting the inputs in and getting the crops out. In the case of low-input systems, you need a lot less infrastructure.

Ruttan You said you could run 4 or 5 continuous crops of upland rice. Is it the weed problem that is the constraint?

Sanchez Weeds are first; fertility is second. Depletion is the other one. The weed issue is certainly more important than the fertility issue.

Larson You mentioned that 80 percent of nutrient loss is from removal of plant material. Is that figuring both the inherent fertility as well as the added fertilizer. Are you talking about the total nutrient content in the soil?

Sanchez No. What I'm talking about is the nutrients taken out by the plant--the portion that is removed as grain from the field. There is additional nutrient loss by leaching or erosion. But most of it is really lost by what we take for our use.

Larson But it would be quite different for different nutrients?

Sanchez Potassium is the easiest nutrient to retain if you can keep your crop residues on the field or return them as manures.

Goodrich Suppose I live in a country that doesn't have limestone deposits and the country has decided that it's economically very expensive to import fertilizer. What are my options?

Sanchez You should start working with some of the cropping, pasture, and agri-forestry systems that are based on very acid-tolerant plants.

Goodrich But suppose the acid soils tie up the phosphorous.

Sanchez The interaction between lime and phosphorous has been exaggerated. If you have a phosphorous deficiency, you'll have to apply phosphorous. Let me add one comment. I've rarely been in an area of acid soils where there isn't any lime around.

Ruttan But you do need some local infrastructure. You need a road system that enables you to obtain the lime at a reasonable cost.

Sanchez That's right. In many areas that infrastructure is probably more of a constraint than weeds or soil fertility.

Ruttan That's been the important factor in expanding crop production in the Compos Cerrado. Once you've learned what the micro-nutrients are and you've identified the lime, then the infrastructure becomes very important.

Sanchez Lime deposits are sort of odd intrusions geologically. They are found in very old rocks in the Cerrado, Brazil. The Amazon sometimes has river oyster deposits. Very few countries import lime. In Indonesia, people say, "Oh, we don't have any lime over here." But where does that cement factory down the road get its lime?

Ruttan Bill, do you want to argue with him a little bit?

Larson No, I wanted to ask him a question. Let's see if he'll agree with me. In these real acid areas, we North Americans go down there and tell them to lime heavily up to a pH of 6 or 6.5. That's overdoing it, isn't it?

Sanchez Absolutely.

Larson The lime needs aren't nearly as large as a lot of people would lead you to believe. In fact, there are some deleterious effects from over-liming--like destroying soil structure by making it more erosive. Isn't that right?

Sanchez Absolutely correct. We lime when we want to grow things like soybeans and corn that are acid sensitive. In our work when we lime, we don't ask them to lime to bring the soil above pH 5.5. For most soils the lime will last for about 3-5 years. But for most crops we're not even recommending lime because we are using acid tolerant strains. We've reduced lime requirements. We might need a little bit of lime for calcium/magnesium fertilizer.

Ruttan And you're using a legume in the rotation for nitrogen?

Sanchez We're using a legume. And there are a lot of legumes that fix nitrogen like crazy that are very happy at a low pH. You can grow a lot of crops at pH 4.5, thanks to good plant breeding.

Ruttan And what about phosphorous, Pedro?

Sanchez This is the real problem. All of those soils are low in phosphorous. You get a little bit of phosphorous input with the ash when you clear and burn the forest. Some of the phosphorous is released and will become available with time. Most countries don't have high quality rock phosphate deposits. Our phosphorous supplies, according to the International Fertilizer Development Center, are supposed to last for about 200 years. The supplies of other fertilizers or ways to produce nutrients, are virtually endless. Phosphorous is the real concern.

Ruttan What are we going to do in 200 years when we run out of phosphorous?

Sanchez I don't know. I hope by that time there will be other techniques.

Faras Our lakes and streams are already overloaded with phosphate. What if the phosphorus is fixed? It stays.

Sanchez If it stays then it's good. It's sort of like a low-interest savings account.

After the Green Revolution in South Asia

Ruttan I'm going to shift now to Derek Byerlee.

Byerlee I'm going to talk about what I call the post-green revolution stage in Asia. We have to remember that in terms of the world food situation, Asia is what makes or breaks it. Half the world's population lives in south, southeast, and east Asia. And over the last 20 years we've seen extraordinary rapid growth in food production in Asia. Wheat yields averaged a growth rate of 4-5 percent per year since 1965 in Asia. That compares with a rate of growth of less than 1 percent before that period. So I think we're looking back, in the recent past, on a very unusual period of growth in wheat yields and also in rice yields. From 1948 to the early 1960s yield increase accounted for about 50 percent of production increases--area increase accounted for about half of the increase in production. From the early 1970s to the present, yield increases have accounted for nearly 90 percent of the total production increases in cereals. That's really a remarkable transition from production increases based on area expansion to production increases based on yield expansion. If we look towards the future around 90 percent of increases will have to come from yields in most of the developing world.

I am handing out a one-page table to give you a summary of how I see the situation in Asia for the two principle crops--wheat and rice. The situation in wheat and rice is not too different. There are three main issues: biological yield potential, farmers yields in relation to that potential, and long-term sustainability. I consider three different environments.

One is the favored environments--largely irrigated with good infrastructure. These are areas like the Indian Punjab, and northwest Mexico. It also includes the irrigated rice areas of the Philippines, much of the eastern irrigated plains of China, and parts of Java. In the case of wheat, we're talking about 3-1/2 to 4 ton yields in these most advanced areas. Rice yields would be similar. The second area is relatively favored as well. It is mostly irrigated, but for various reasons has lower yields. This covers a lot of the Indian wheat area outside of the northwest and much of Pakistan. The third is the more marginal areas. I'm primarily talking here about moisture-stressed areas.

Now if you look at the biological yield potential in the favored environments, in the case of wheat since the semi-dwarf varieties were released, we've averaged about 1 percent per year growth in yield. We have seen a steady but slow increase in yield potential. But the yield

potential for tropical rice is now experiencing very little gain. We've already talked about the question of having to maintain those high yields. In the case of wheat, we are probably talking about 75 percent of our research resources are going into maintenance research.

In the marginal areas--in dry areas--rates of breeding gains turn out to be less than half the rate in the favored areas. These are very small gains in kilograms per year.

The second column shows farmers' yields in relation to potential. In the best areas, in the top group of countries or the top group of regions, there really isn't that much of a yield gap anymore between economically recoverable yield--that means using our best technology and being economically profitable--there isn't much of a yield gap between the farmer's yield and what we observe on experiment stations. In fact, if you take the best farmers in any given area, you'll probably find there's no difference. There is, however, considerable variation among farmers in yields and in cost of production. (We have to be concerned about cost as well.) And there are potential gains to be made from narrowing that gap among farmers in both yields and cost. Much of the solution revolves around a better farm information system, better location-specific adaptive research, extension, and more skilled farmers--many of the things that Bill Larson was talking about here in Minnesota.

There is a good deal of quite disturbing evidence as to what's happening to sustainability of yields in these areas--particularly these very intensively cropped areas. There is evidence from IRRI's experiment station and from other experiment stations, that yields under experimental conditions are declining. I've just been looking at some of the data from the on-farm fertilizer trials conducted in Pakistan over 10 years that indicates that wheat yield, even at high fertilizer levels, have been going down by about 1-2 percent per year. This is quite disturbing. Furthermore, I don't think we really know why it is happening. But what is clear is that in these relatively advanced areas, we're not getting much yield growth--the yield growth is slowing down. We already have 100 percent adoption of improved varieties. The investment in irrigation has really slowed in the 1980s compared with the 1960s and 1970s. Fertilizer levels are quite high--close to 200 kilograms of nutrients per hectare. The marginal gains from fertilizer use are fairly low.

These three sources of yield increases over the last two decades (variety, fertilizer, and irrigation) have, in these areas, largely been exploited. And on top of that we have the possibility--the real possibility--that there may be some negative influences on yields that we don't quite understand.

Let me now turn to the somewhat less favored areas where there still is a significant economically achievable yield gap. This includes a fairly wide area of Asia. These areas have achieved close to 100 percent adoption of improved varieties and they're mostly irrigated. Their fertilizer use tends to be relatively high as well, about 100-150 kilograms of nutrients per hectare. There is a lot of scope in these areas to bring yields up in an economically viable fashion. There are many factors, including pest

management and a whole lot of other management factors that may contribute to improving yields in these areas. We need a much better farm information system because we are working with a much more complex agriculture. It's just a lot more difficult to introduce and sustain these relatively small incremental changes as compared to the larger gains of the past.

Finally, in the marginal areas, particularly the dry areas, gains have been relatively modest. The big breakthroughs are going to come more through crop management and resource management than through plant breeding.

From an overall perspective, the situation is quite worrying. I doubt that we are going to maintain the growth rates that we've seen over the last two decades. I think we can be fairly sure about that. We may not need those very rapid growth rates because (1) the demand for food (cereals in particular) is not growing as rapidly as in the past partly because population growth is slowing and partly because the income elasticity of demand for cereals is falling. But even so, to be able to maintain the growth rate we need into the future, into the next 10-15 years, there is serious concern based on the sort of information we have reviewed. As Dr. Jain was mentioning this morning, we're still exploiting the same sources of technology, which is the improved semi-dwarf varieties, fertilizers, and water. We're still exploiting that and that's all we will have for the next 10-15 years. We have to learn to be able to exploit it more efficiently, not only in terms of increasing yields, but also in terms of cost reduction as well.

Allen Derek, I heard what you said, but I'm not sure I understand a minor statement about the importance of management versus breeding in this marginal area.

Byerlee Well, I think if you take wheat in marginal areas, for example, a lot of the issues revolve around things like moisture conservation. I think John Sanders will be picking that up a little later so perhaps we should refer that to him. But it's using moisture more efficiently through better tillage, weed control, and fertility management.

Allen We have some control over the things you're talking about through management. But if we don't have the right varieties, we don't have a chance, do we?

Byerlee Well, I think in many cases you can use the improved varieties we already have. It's not the critical limiting factor.

Duvick Do you think the right strategies are being used for breeding varieties for marginal areas. What about the varieties? Putting disease resistance into a land race might be a much better strategy than trying to introduce a whole different kind of variety.

Byerlee You still have the question whether there is any chance for a big breakthrough in management practices. For example, diseases in wheat in most dry areas are not a big problem.

Myths About the Sahel

Ruttan Why don't we turn to John Sanders. John has worked in West Africa after long periods in South America. Then we'll direct questions to both John and Derek.

Sanders I want to talk about the Sahelian countries. They are at the opposite end of the scale as compared with the countries Derek was talking about. There are only about 35 million people in the eight countries on the border between the Sahara desert and the tropics in West Africa. Since the 1968-1973 drought, the development community has put a lot of money into the Sahelian countries. I think the things that we can say about the Sahelian countries are very similar to many other semi-arid tropical areas. The Sahelian countries are among the lowest income countries in the world. They are basket cases. The question that I think is interesting to ask is the puzzle of the Sahel: "With so much money (per capita) put into these countries to develop agriculture, why hasn't there been more success?" Most indicators have shown regression in agricultural production per capita.

There are several relevant observations. First, little or no purchased inputs are used in much of the area, except in the higher rainfall regions. When we talk about sustainability or development, it's very different from Asia where many areas are using very high levels of purchased inputs. But there are a lot of myths about this area that are not valid.

It's a very well-kept secret that there has been very rapid development in some areas of the Sahel. One is the southwest corner of Burkina Faso, a higher-rainfall region with above 800 millimeters of rainfall per year (90 percent probability). The French research and marketing work resulting in substantially increased cotton yields over the last 20 years--the sources of the yield increase were new cultivars, fertilizer, and better agronomic practices.

Another myth is that farmers in the Sahel, or in the less developed countries in general, will use fertilizer on cash crops or crops with a guaranteed price only. French village-level studies in this higher-rainfall region show that more than 50 percent of the chemical fertilizer is being used on the domestic cereal crops--corn and sorghum, principally. The successes in these higher-rainfall regions of the Sahel have not been recognized. Many people want to write off most of the Sahel as just marginal and argue that these countries should be importing foods. The basis for the yield increases is the traditional model that we've seen in other areas.

The second point is that there is substantial potential in the region that receives from 600 to 800 mm rainfall (90 percent probability). One of the main failings in technology development has been an overemphasis on genetic solutions rather than crop management or improved agronomic technology. I'm very glad that Dr. Jain made the point because I think it's

much more acceptable than to have an economist make it. Breeding has been talked about in the Sahel for a long time as a solution for everything--drought resistance, aluminum toxicity, low soil fertility.

It has been documented that with water-conservation techniques of various types, the whole picture regarding returns to fertilization is changing. The combination of these two technologies, as demonstrated in farm-level trials, has both a very high economic return and a reduction of risk. Furthermore, introduction of a moderately improved agronomic environment can make breeders' lives much less difficult. If we can reduce site-specific variation, we can then start breeding for a moderately improved agronomic environment over a wider area and focus on the things that breeders have demonstrated themselves to be good at, such as insect and disease resistance, nutritional characteristics, higher yields. Research on drought tolerance and soil-fertility stress may be scientifically interesting, but in the next decade I think we should differentiate between interesting long-run research and short-run development objectives. One consequence of much of the discussion about what we're going to do with breeding is that researchers have given the Sahelian governmental people the impression of a magic solution without increasing input purchases. The government hopes that it can just wait a little bit for a breeding solution. Then it won't need to face the two essential problems: (1) the foreign-exchange cost of importing chemical fertilizer, and (2) getting low-income farmers to purchase higher levels of inputs.

This brings me to the question of chemical-fertilizer imports. For the last decade, people have been hunting for substitutes for chemical fertilizer. They are looking for all sorts of solutions--organic fertilizer, inoculation, rotation, mulches, local phosphates. So far there has been very little impact from any of this technology. An eight-year Purdue program in Burkina Faso tested most of these alternatives to chemical fertilizers at the farm level and there are either technical or economic problems with all of the alternatives. Alternatives to chemical fertilizers in these Sahelian countries are a complement and not a substitute for inorganic fertilizers. The chemical fertilizers are absolutely essential! They will have to be used at moderate levels in the semi-arid tropics. The Sub-Saharan countries will need to develop fertilizer policies and plan on importing substantial chemical fertilizer over the next decade. And they'll have to set aside the foreign exchange to do it.

You may ask why these techniques that we're talking about--water retention of various types, tied ridges, the diking--that are being introduced in Burkina Faso haven't diffused more rapidly. There are a lot of water-conservation techniques that have been around for a long time. If this is so easy and the technology is already available, why haven't farmers used it? I think the essential point is that in these very harsh environments, they're going to have to use a combination of water-retention techniques and soil-fertility improvement. Moreover, most of the water-retention techniques will require overcoming a seasonal labor shortage, often with animal traction.

Finally, there is the policy problem of governments letting the product price collapse when the rainfall is good. In 1984 there was a terrible drought. Cereals production fell by about 50 percent in Niger and other regions of the Sahel. Two years later, after two reasonably good years and continuing food aid, the post-harvest prices collapsed for sorghum and millet. The price went from over 100 CFA per kilo to as low as 20-25 CFA per kilo. (The exchange rate is 300 CFA per U.S. dollar now.)

A coordinated program is needed to attack all four of these things at the same time--water availability, soil fertility, seasonal-labor constraints during the crop season, and cereal-price collapses in good rainfall years; that's difficult. Agronomists generally utilize a reductionist approach to research. They want to isolate just one thing at a time. We've shown the importance of introducing three different improvements of technology at the same time. For farmers there are difficult management problems and financial requirements. And the public sector may not be strong enough to support the price of these commodities. But as in the Northeast of Brazil, they might be able to have public-works program on shelf for years of drought. A feeding program is needed for years in which the foodgrains become feedgrains. In 1987 some of the farmers, reacting to the extremely low prices of sorghum and millet, were fattening sheep with these grains.

One main point is that we not write these areas off as hopelessly marginal. For some regions there is substantial potential. The French have shown the possibility of getting cotton yields up in the high-rainfall years. Fertilizer consumption has been substantially increased. In the more marginal rainfall region, with substantial field data we showed the economic potential of increasing cereal yields with combination of agronomic practices. When you get a better agronomic environment, you can breed efficiently for better cultivars.

Plucknet A little history may be useful. I worked on the Sahel task force for AID in 1973 so this sound like deja vu to me. John, you have made the most sensible presentation on the Sahel I've heard in a long time. One of the things that's always worried me about a place like the Sahel is that one of the things that we as agricultural scientists have been reluctant to do is to tell people that there are some things we can't do anything about. We can offer something in agricultural research for the good years. I came from a dryland farm in Nebraska, so I can tell you how it was there. We talked about good years and bad years. In the good years, agricultural research could help you some--it could help you quite a bit--but during the bad years there wasn't very much anybody could do. I think that we ought to be very honest about this. I agree that we're putting way too much money into drought tolerance. I think we're really wasting a lot of money in drought tolerance research and I'm really worried about it because it implies that there is something there. Everybody's waiting for that silver bullet. The gun may never fire that particular bullet. I don't mind searching for drought tolerance, but I think we have to be careful what we promise.

Byerlee Better water management is a stimulus for farmers to use fertilizer. But I think the general evidence is that farmers don't adopt packages. I think

the evidence is very clear that the farmers have adopted new technology incrementally. In India you don't have to irrigate to get some gains from using the best variety. You don't have to use the fertilizer. But you do get a greater stimulus with more water and more fertilizer. You don't have to introduce it as a package. Look at the Indian experience. In the best areas fertilizer and irrigation were already being used. When the semi-dwarf wheats came in, farmers intensified the use of these inputs. And I think John makes the same point for the Sahel. Farmers recognize the value of fertilizer, even on food crops that they don't market.

Burnside I think that what Dick was saying has some application as part of our weed control strategy when they brought in the sort-statute wheats. They sometimes forgot that these short-statute wheats were not as competitive with weeds. In order to make them succeed they had to spray them with herbicide to control the weeds. In many cases they came up with better weed control than they had with the tall-growing wheats. But the tall-growing wheats would yield reasonably well without herbicides. In many fields where they grew the modern varieties and didn't do anything about the weeds, they either had to pull them or spray them or they suffered substantial yield losses.

Byerlee That's a good example. In the Pakistan Punjab, herbicides are just coming in 25 years after the introduction of semi-dwarf varieties. I agree that they have a big weed problem. I am not trying to argue that you wouldn't have a more rapid adoption if you didn't have new varieties coming in at the same time as moderate levels of chemical fertilizer and water retention technologies.

Burnside Can I assume, based on this figure and others that have been bouncing around, that the farmers were getting a 3-5 fold return on their investment in inputs?

Byerlee It is hard to double yields even with water and moderate levels of fertilizer.

Fitzhugh I want to come back to your point that the slower increase in yields in Asia isn't so much a problem because the demand elasticities are going down. Most developing countries have a very skewed income distribution. Would you see the same trend in elasticity if you used median rather than average income?

Byerlee It doesn't make much difference. We're facing a very serious situation regardless whether the demand for rice is increasing 2-1/2 percent or 3 percent per year. That's the difference we're talking about. We don't know where that increased production is going to come from. We've seen a little bit better performance in wheat than in rice. But we don't know where that increased production is going to come from in terms of land area, or yield increases.

Ruttan You haven't talked about water very much.

Byerlee If we think about water, it's even more serious because it's becoming even more expensive. We're running up against very high marginal cost.

Herdt I think that your point about the changing composition of demand means that in all likelihood people will shift toward consumption of livestock and fruits and vegetables as their income increases. The resource requirements for agriculture are going to increase rather than decrease. They're shifting out of cereal-based diets to high-input diets. While it looks like the demand for grains might be easing off, the demand for agricultural output will be increasing.

More Realism About Biotechnology

Ruttan I was intending to move to Burt Sundquist before Bob Herdt. But somehow as the conversation developed, the sequence got reversed.

Sundquist The hour is late and I think most of what needs to be said has probably been said. There are a couple of things that come to mind. We spend a lot of time talking about biotechnology, but it seems to me that when all is said and done, when you look at output gains, you're going to get from biotechnology over the near term, they're going to be mainly in animal production. The achievements in crop production aren't going to do much for crop yields. They're going to be mainly things like the substitution of bio-pesticides for chemical pesticides. To achieve major yield gains, you're going to have to be able to transfer multiple genes. That's not right around the corner with respect to crop production. I am reminded, as Vern pointed out, of the projections we came out with in 1982. We were projecting some yield gains for maize starting about 1990. By and large those aren't going to happen anywhere near as rapidly. The experience taught me one thing about statistics. That is when you start averaging zeros and real numbers to come up with something, you'd better pay quite a bit of attention to those zeros. There were quite a few scientists who said we're not going to get any gains through biotechnology by the early 1990s. Others were much more positive. We didn't put high enough weight on the zeros or low enough weights on the optimistic projections.

One thing that hasn't been discussed very much are the constraints resulting from limited human resources to work in agricultural research. During my stay at ISNAR last winter, this came up over and over again in our discussions about Africa.

Ruttan When you get down to the number of agricultural scientists in most African countries, you get numbers in the range of 50 and downward.

Jain One major problem is that in sub-Saharan Africa only 38 percent of the scientists in the national agricultural research systems had post-graduate degrees in the early 1980s.

Qualset I think we should be more optimistic about the biotechnology impact. I think it will start making substantial contributions in the 1990s to rates of increase of output. It will allow breeders to make improvements at a faster

rate. I don't know what percentage or what numbers to put on it. In the diagnostic tool area there will also be important contributions.

Ruttan I would like to comment that it seems to me important to go through the kind of exercise that Burt went through 10 years ago. It is important to try to go through the numbers because some of the very dramatic events happen in areas that aren't very important. But even a major advance in something that occupies a very large weight in the system can add a lot to production. Until you go through the numbers it's awfully easy to be either overly pessimistic or overly optimistic. I personally would like to see some similar studies conducted for major crops in some of the major developing countries.

Heichel I was just going to make a couple remarks, one having to do with the contributions of biotechnology. There isn't a lot of point about talking about biotechnology as compared to or as opposed to traditional or conventional breeding. I agree that some things are already coming into use. If you want to stretch a bit and talk about immunological techniques using clones for virus identification, it is out in the field all around the world now. Is that biotechnology in use? Maybe it is or maybe it isn't depending on your definition.

The other thing I would like people to think about a bit more is yield ceilings and raising yield. My personal belief is that the biological yield potential in none of our field crops has been raised by breeding. But achievable yield has been raised continually and will continue to be raised continually and I think--even though I don't know anything about it--that it will be raised in irrigated rice in the tropics and irrigated wheat. The reason is that there are innumerable constraints that limit levels. What breeders have done with crops is to increasingly put in the ability to overcome these constraints so that the average yields on achievable yield have been increasing.

Ruttan I see three hands up and then I'm going to say let's quit.

Sundquist I don't want my comment to be misinterpreted. I think there have been some real achievements in biotechnology. I just want to limit my comment to the fact that when we start talking about yield gains in the near term, I think most of the biotechnology induced gains are going to show up in the animal agriculture side and not on the crop production side. There will be some cases in specialty crops and vegetables where there will be some impact fairly soon. Some are already starting to show up. I'm just saying that when it comes to feed grains and food grains and oilseeds and cotton, we're going to have to wait a few years before we see the results of the emerging biotechnologies.

Allen I was just going to say that I think all of us, as scientists responsible for physical and biological research, have to keep in mind that we didn't comprehend a decade ago the difficulties of moving some of these biologically engineered products through the process of social acceptance. I think there are some things that will drive acceptance. One is need. Therefore I think some of these technologies will be used in other countries

before they're used here. Another is environmental concerns. That is something that is shared around the world. I think we will have some very difficult times moving some of our technology in actual use in this country even when they become readily available. I hope we can improve upon where we are right now in educating the public. But I'm not as optimistic on that as I am about the contributions that the tools of biotechnology can make.

Ruttan It implies that we think about the institutional constraints as well. Tomorrow, what I would like to do is begin to put up on the board some of the things we think that we know and what are the implications. It is amazing that we got people here at 8:15 this morning and we're still here at 6:00 tonight. I appreciate the energy people have put into today. Thanks very much. We'll have dinner at the hotel at 6:30 p.m.

Population and Agriculture

Faras Bob, I assume that the Rockefeller Foundation is continuously thinking about how to make a decision about where to put their money. Should they put it into population control or agriculture. How do you make that decision?

Herdt The Foundation is putting roughly two-thirds of its resources into international activities. It is about equally divided between agriculture, population, and health. There is no decline in the emphasis on agriculture or populations or health. These proportions have been relatively constant for the last 20-30 years. The other point I want to make is that you're looking at 20 percent of the agricultural science staff in the Rockefeller Foundation. You have more people in this room today than the Foundation has total scientists around the world.

Faras That wasn't the answer I was looking for. (Laughter)

Herdt I want to pursue this point because we heard a lot this morning about the international agricultural research institutes (IARCs). They have very high visibility--you have Plucknet here and you have Derek here from the system. Does anybody here have on the tip of their tongue the research budget for agriculture in Minnesota?

Ruttan About $35 million in the University of Minnesota state experiment station/College of Agriculture system. I don't know about the private sector because Don Duvick's headquarters are in Des Moines. (Laughter)

Herdt Okay, that's one state and that's roughly equal to the budget of one of the five larger IARCs.

Ruttan That's about 230 man years in Minnesota.

Herdt The biggest international center would have about 100 man years of comparable level scientific talent. We're talking about incredibly few resources available for tackling world wide problems. It's true that those

people are all focused on the developing countries. But we just heard about the diversity on a 56-acre field in Minnesota. Just think of the diversity of agriculture problems out there in "the tropics." There are big problems out there and relatively few resources. There is not question, therefore, that even to begin to solve these problems, there has to be a three-way partnership. There are people who are inventing science who are leading the way--who are doing what we talked about as "basic" research--who are discovering new concepts. Those people are mostly in North America and in Europe. They're not in the international centers. The people in the international centers are using some of that most advanced science, buy they're also using that science to try and bridge the gap between the technology in the advanced world and the capabilities of national systems in LDCs. There are some national systems that are quite capable: Brazil and India have a lot of good scientists. A few of those countries are able to meet many of their own needs. But by and large in the developing countries, the national agricultural research systems are very weak. But those agricultural research systems are the ones which are ultimately going to have to deliver technology that's appropriate and applicable to their own conditions. The people in the international centers serve as bridges. It's a very crucial role. But they're still more in the nature of bridges than in the nature of developing location-specific technology that farmers will apply. They can't be anything but that given where they're located and the size of their staffs.

Faras — I understand that and the reason I asked the question directed at the Rockefeller Foundation is because of their involvement in population issues. They're focused on developing countries and they are working on two of the issues that I feel are incredibly important--population and crop production. A third is fossil fuel availability. As you indicated there could be a problem of maintaining adequate growth in rice production in Asia. I am interested in trying to figure out how successful we are at dealing with population and agriculture relative to the constraints that we have discussed today.

Herdt — I think there is another issue and that is what kinds of things can be transferred and what kinds of things can't be transferred. I think we've been less successful in the population area than we've been in the agricultural area. It's not a lack of technology--there are effective technologies. It's a lack of understanding how people think. People who are concerned about population growth in Africa often make the statement that "In Africa, the factors that influence population growth are different." They're not the same factors as in other parts of the world. We don't know how to slow the rate of growth in population in Africa. Another factor here is that we are all somewhat uncomfortable in imposing our values about population growth on other people. Or about how they ought to organize their societies and what kinds of incentives or controls they should have in their societies. It is a lot easier for us to justify sharing technology. One of the points made earlier is that in the poultry industry where we are transferring a set of technologies that makes other countries dependent on us. It is our view of development involves people becoming less dependent and more independent. that involves both education and

self-determination. Then, when appropriate, they will want to trade or borrow or use technology from another part of the world.

Goodrich But if there was not a population problem in the world, we would not have a food problem. Being an agriculturalist I would have a hard time arguing against major programs to help address population growth around the world.

Herdt I guess part of the answer is we don't know what major programs are politically acceptable. Our Congress has, under pressure from groups in this country, restricted funding for population programs.

Ruttan I think it is worth putting a couple numbers on the board. In our own case, between 1880-1980 agricultural output grew at 1.6 percent per year. We've had a few short periods where it grew at close to 2.0 percent per year. Initially the increases came entirely from increasing land area cultivated. More recently increases in production have come entirely from higher yields. The population growth rate is running close to 2 percent in the higher income developing countries (Mexico, for example) and up to 4 percent in a few countries (like Kenya) where birth rates are near the biological maxim of over 8 children per woman. In spite of rapid population growth, quite a few countries are having increases in per capita income in the 2-4 percent range. Korea is achieving per capita income growth in the 8 percent range and India, which has been doing very well recently, in the 4 percent range. They spend at least half of the increase for food. That adds another 1-2 percent to demand. Thus the demand for agricultural commodities is growing at 3-6 percent per year. We are asking the poorest and least endowed farmers in the world to generate rates of growth in food production that we've never asked our own farmers to achieve.

Rubenstein With a population growth of 3.8 percent per year you double that country's population in about 18 years.

Ruttan In 40-50 years from now population growth rates are going to be much lower in most parts of the world. We have a really big problem over the next two generations. There's no problem in North America and Western Europe and Japan and Australia and New Zealand in achieving sustainable agricultural growth because one percent per year is enough.

Goodrich But we don't have two generations to allow the population growth which is going to occur because we will either have massive starvation or revolution in that period of time.

Ruttan Before one gets too nervous, it is worth remembering that in 1950, China's population was a little bit over 500 million. Nobody would have believed they could support 1.1 billion by the mid-1980s.

Dialogue About Priorities

Ruttan I suggest that we have a rather free ranging dialogue on what we see as the issues and priorities for the 21st century during the first part of the morning. We will then attempt to develop some priority recommendations. I will not reproduce everything we say here. Rather, I will try to pull out of the discussion the items that seem the most relevant. If enough of us think something is an important enough issue, we may end up commissioning a paper that would examine the issue in enough depth to push toward a broader consensus.

Rubenstein If we had some vision or definition of what we thought the situation in an ideal state would be, we could then come up with lists of things that might help us get there--lists of things that might hinder us from getting there, and lists of ideas that might help us along the way. Out of these you might start assembling goals. I'm just trying to figure out a systematic way of trying to set forth a series of specific goals that then move us toward this ideal.

Statement of Issues and Priorities

Yield Ceiling

Jain Can I come back to this broad question of biological constraints? Don Duvick said that yields have been continuously increasing in maize and in other crops. And so they have. But the point some of us were trying to make yesterday was that all of this improvement is through partitioning, not through increased dry-matter production. But what are the possibilities of increasing total dry matter production? Do we have some limits? There is very well-documented work on yield limits with the present known efficiency of the photosynthetic process. So we know how much rice, wheat, maize, or sorghum could be produced under ideal conditions. And we know there is a gap between the farmer's yields and potential yields. But it is not always possible to restructure the crop canopy in such a perfect way that you capture each and every bit of solar energy. But people are beginning to ask the question whether photosynthetic efficiency could be changed. For example, there was some discussion yesterday whether photo-respiration losses--losses of carbon due to photo-respiration could be reduced--or whether greater amounts of carbon could be fixed. That really takes you to the issue of the photosynthetic enzymes--restructuring them to make them more efficient. Those are very long-term issues, but they are the kinds of things we need to talk about.

Alternatives to Slash and Burn

Sanchez I'd like to discuss alternatives to slash and burn agriculture. This issue impinges both on food production as well as rain forest conservation in the humid tropics.

Ruttan Are you concerned about how to move from long rotations to short rotations?

Sanchez It's more than that. Right now shifting cultivation is collapsing. Population pressure is doing away with the long rotations.

Ruttan We haven't yet designed short rotations that are sustainable. The long rotation is collapsing but sustainable short rotations have not been designed.

Sanchez That's part of the solution. But there are some possibilities that do not involve rotation.

Ruttan It took about 800 years in Denmark to move from slash and burn to sustainable agriculture. We don't have that much time today. We have somewhere between 30-40 years.

Sustainability

Heichel I think we all understand what's meant by sustainable. But we haven't bothered to define it. We've been using the term implicitly. Can we get very far without having an agreement about what we mean by sustainability? Is it an ethical issue, or an economic issue, or a technical issue? Is it zero net soil loss--a rate of erosion no greater than rate of soil formation. Dr. Jain was talking about energy output/input ratios. Does it imply low energy input?

Ruttan In the article I wrote on "Sustainability is Not Enough," I criticized what seemed to me to be an excessively static view of sustainability. We need to think about both enhancing and sustaining productivity.

Post-Harvest Technology

Qualset I have a list that includes a number of post-harvest technologies--post-harvest or post-slaughter food quality. I don't think we do enough on transportation and storage. We need to think of a world in which a sustainable and adequate food supply will be available to all people in a healthy environment.

Ruttan One thing that we probably wouldn't have listed 20 years ago was the "healthy." We would have stressed the amount and the food. But we would have been less concerned about quality--including the impacts on health.

International Centers and National Research

Jain There is a very fundamental question with regard to relationship between national research systems and the international centers. The international centers should work for the national institutions to take on their own responsibility. Do we still recognize that concept to be highly valid?

There really is no substitute for strong national institutions--even in sub-Saharan Africa.

Animal Improvement

Ruttan What about the point Neil First emphasized yesterday about modifying the animal to fit the feed or the environments?

Faras When he talked about making the cow a browser, I wanted to ask, "What are you going to do with the goat?" We already have a domesticated ruminant that is a good browser. In Africa when drought occurs, the numbers of cattle drop off very sharply, while the goat population expands. I think that nature's done a fairly good job of providing a browsing ruminant. Now, if Neil had been talking about manipulating the digestive flora, there are some real opportunities there. What we need, instead of having cows that browse, is to have digestive flora transferred from the termite so they can make better use of wood.

Fitzhugh Let me add a few animal-specific constraints now. They include disease resistance, reproduction rates, ability to use low-quality forage, integrated animal-crop production systems--and regulation of growth. We also need to preserve that genetic material to be sure we don't lose resistance or other qualities.

Goodrich Is there a need to domesticate new species of animals?

Fitzhugh No--primarily because of the time that's required. It is a concern that we have so few species of animals that man domesticated. Whenever the plant people start talking about conservation, they often are talking about conserving species. We're talking about conserving breeds. Probably the opportunities through genetic engineering are more promising even if they're 20 or 30 years away.

Qualset Noel Vietmeyer is writing a book on small meat animals. He's got nearly 100 species of small animals that are used and have been used as potential genetic sources.

Fitzhugh Some of the non-traditional minor species can have a real impact on the nutrition and income at the local level. We should come out strongly in support of conservation and preservation of unusual genetic resources. But to know what is unique requires characterization. But our feeling is that we can't afford the investment in preservation unless there's some reasonable probability that you're dealing with an unusual genetic resource. That could be because it's been isolated, or because it's been evolved under unusual environmental conditions, or it is a minor domesticated species that is useful in a particular area.

Duvick It seems to me that we need to have a better understanding of the proper mix of small scale peasant farming and large scale or factory farming in developing countries. The kind of crops we

breed and sell often aren't designed specifically for peasant farming--they are aimed more at factory farming. What does theory or experience have to offer this problem?

Ruttan — I disagree with you. When you look around the world there is not a single so-called plantation crop that is not grown efficiently by peasant producers somewhere.

Byerlee — My experience is that poor infrastructure is what keeps peasants--small farmers with very limited resources--from doing what they know how to do and would do. Poor infrastructure is the major constraint.

Ruttan — I sense that understanding, particularly at the policy level, is very weak. Is that your response?

Byerlee — The whole basis for relatively successful agriculture in Asia has been peasant farmers. Those peasant farmers are the ones who are growing the same crops that Pioneer is producing seeds for.

Duvick — On the other hand, in Brazil the marginal farmers simply can't handle our products; they don't get their full yield potential because of low planting rates or poor weed control and other factors.

Ruttan — My observation is that when you have a dual structure--when you have a large farm sector and a small farm sector--it's very hard to devise an institutional structure that will serve both. Where you have a large farm sector coexisting with a small farm sector, the large farm sector has the political resources to bias the system in its favor. As a result, you don't get the kind of performance that you get in small farms in East Asia or South Asia.

Animal Nutrition

Faras — From what I understand it's far easier to transport the bacteria to hydrolyze cellulose and lignite and things like this than it is to do it and have that bacteria colonize the rumin and stay there. The same problem exists, I think, in tricking soil-borne bacteria in to doing something you want them to do, and having it survive in the face of the competition of a natural set of predators.

Institutional Development

Allen — I would like to see a bit more discussion of the role of the US/AID and U.S. universities. I sense a decline in our support of research and training abroad.

Ruttan — If you want to get a little broader we could pick up the issue of what we have to do to strengthen the institutional capacity of developing countries. There are some excellent success stories--Cornell in Los Banos, Purdue in Vicosa, or Minnesota in Morocco. But institution building is not in style among the aid agencies today. There is an attempt in the Congress and the administration to start rethinking what the AID agency should look like in the future. My own feeling is that it should move away from the "aid" view and establish an agency for international economic, scientific, and technical cooperation. And it should not limit itself to countries below $800 per capita income. It should embrace the poorest countries, the intermediate countries, and the centrally planned economies. It seems to me that we might still want to have a traditional aid program for sub-saharan Africa. It's time for a movement to the kind of structure that is focused on mutual benefits--for us and for the countries that we cooperate with.

Duvick — Argentina has some plant variety protection laws on the books. Exactly how much they mean, we're not sure, but the potential is there. That's about the only one I can think of.

Ruttan — My sense is that it's time for the international community to think about establishment of a series of basic biology institutes in tropical countries. I don't see the CGIAR institutes evolving into basic needs institutes, yet there are applied problems that will not be resolved unless the basic science is being done in the environment in which the problem exists. It's not because it couldn't be done at Rockefeller University. But what we think about is influenced by the environment in which we work. There ought, for example, to be a major basic biological research institute doing research related to parasitic diseases in the tropics.

Plucknet — I like this idea. Something like this has been done in the past through AID.

Rubenstein — I am skeptical. If you look at parasitology research in the United States, and the money going into it, there is just no way some groups in the tropics are going to be able to compete.

Jain — You would like to see these linked up with adaptive research in the international systems?

Ruttan — In contrast to most CGIAR institutes, they should be located within a university or in some associated relationship to a university. Doctoral and post-doctoral research is going to be important.

Fitzhugh — I think all of us agree with the idea. The reality is how to get funding or stability because for any research to be effective, there has to be some stability of resources coming into the work environment in which the scientists are involved. The developed

nation donors can see their own vested interests being served by providing continuing support through the CG for applied research in agriculture. But the University of Ibadan, which was arguably the best educational institution in the tropical world at one time, has been allowed to gradually decay. I can see how to argue the need for institutes that are doing applied research. But I don't see the external support for basic research.

Ruttan — There are a couple--the Diarrheal Disease Center--it used to be the Cholera Disease Center--in Bangladesh is one that's maintained pretty good support and scientific capacity. The insect Ecology and Physiology Research Institute in Kenya is a case where African scientific entrepreneurship led the development.

Plucknet — The biotech institutions that have been started are doomed because they were organized as intergovernmental institutions. They have a governance structure that is intergovernmental rather than as in the CGIAR system where board members are serving in their individual capacities and not representatives of governments. The CGIAR has one center that's like what Vern talked about--the International Laboratory of Research and Animal Diseases. The donors support ILRAD at a reasonably good level--about $14 million a year now, and they've not shown any indication of pulling back.

Duvick — What's the next step in your plan, Vern?

Ruttan — I will start out with a transcript of these tapes and try to pound the transcript into some sort of shape that says what we talked about and where we came out. If I can't decipher where we're going to come out, I'll decide. (Laughter) Anyway, I think it would be very helpful if I could come back to people with drafts and have people look at them. Bob Herdt and I will be talking about whether we've established the basis for commissioning some more in-depth papers or for organizing a more formal conference. I've enjoyed this informal session the last day-and-a-half a great deal. It's very rare that I get a chance to ask people what they mean by what they say and have enough time to dialogue about it. I appreciate the people who have stayed the day-and-a-half and the people who have come from afar. From my perspective, it's been very good.

Issues and Priorities for the Twenty-First Century

The second half of the second morning of the consultation was devoted to an attempt to sift out the conclusions and inferences that should be considered in formulating agricultural research strategies and in allocating research resources in the future. The discussion was not reported in detail. Rather an attempt has been made to extract from the discussion a series of statements about which there was substantial agreement.

1.0 Advances in conventional technology will remain the primary source of growth in crop and animal production over the next quarter century.

Almost all increases in agricultural production in the future must come from further intensification of agricultural production on land that is presently devoted to crop and livestock production. Until well into the second decade of the next century the necessary gains in crop and animal productivity will continue to be generated by improvements resulting from conventional plant and animal breeding and from more intensive and efficient use of technical inputs including chemical fertilizers, pest control chemicals, and higher quality animal feeds. The productivity gains from conventional sources are likely to come in smaller increments than in the past. If they are to be realized, higher plant populations per unit area, new tillage practices, improved pest and disease control, more precise application of plant nutrients, and advances in soil and water management will be required. Gains from these sources will be crop, animal and location specific. They will require closer articulation between the suppliers and users of new knowledge and new technology. These sources of productivity gains will be extremely knowledge and information intensive. If they are to be realized, research and technology transfer efforts in the areas of information and management technology must become increasingly important sources of growth in crop and animal productivity. In the short run, taken here to mean the next several decades, no other sources of growth in production will become available that will be adequate to meet the demands, arising from growth in population and income, that will be placed on agricultural production in either the developed or developing countries. This conclusion is that both national and international agricultural research systems will find it productive to increase the proportion of research resources devoted to improvement of agronomic practice relative to plant breeding.

2.0 Advances in conventional technology will be inadequate to sustain the demands that will be placed on agriculture as we move into the second decade of the next century and beyond.

Advances in crop yields have come about primarily by increasing the ratio of grain to straw rather than by increasing total dry matter production. Advances in animal feed efficiency have come by decreasing the proportion of feed consumed that is devoted to animal maintenance and increasing the proportion used to produce usable animal products. There are severe physiological constraints to continued improvement along these conventional paths. These constraints are most severe in those areas that have already achieved the highest levels of productivity--as in Western Europe, North America, and parts of East Asia.

The impact of these constraints can be measured in terms of declining incremental response to energy inputs--both in the form of a reduction in the incremental yield increases from higher levels of fertilizer application, and a reduction in the incremental savings in labor inputs from the use of larger and more powerful mechanical equipment. One consequence is that in these countries that have achieved the highest levels of output per

hectare or output per animal unit, an increasing share of both public and private sector research budgets are being devoted to maintenance research--the research needed to sustain existing productivity levels. If the incremental returns to agricultural research should decline, it will impose a higher priority on efficiency in the organization of research and on the allocation of research resources.

3.0 A re-orientation of the way we organize agricultural research will be necessary in order to realize the opportunities for technical change being opened up by advances in microbiology and biochemistry.

Advances in basic science, particularly in molecular biology and biochemistry, have and are continuing to open up new possibilities for supplementing traditional sources of plant and animal productivity growth. A wide range of possibilities were discussed at the consultation--ranging from the transfer of growth hormones into fish to conversion of lignocellulose into edible plant and animal products.

The realization of these possibilities will require a reorganization in the performance of agricultural research. An increasing share of the new knowledge generated by research will reach producers in the form of proprietary products or services. This means that the incentives exist to draw substantially more private sector resources into agricultural research. Within the public sector research organization will have to increasingly move from a "little science" to a "big science" mode of organization. Examples include the Rockefeller Foundation sponsored collaborative research program on the biotechnology of rice and the University of Minnesota program on the biotechnology of maize. In the absence of more focused research efforts, it seems likely that the promised gains in agricultural productivity from biotechnology will continue to recede.

4.0 Efforts to institutionalize agricultural research capacity in developing countries must be intensified.

Crop and animal productivity levels in most developing countries remain well below the levels that are potentially feasible. Access to the conventional sources of productivity growth--from advances in plant breeding, agronomy, and soil and water management will require the institutionalization of substantial agricultural research capacity. In a large number of developing countries this capacity is just beginning to be put in place. A number of countries that experienced substantial growth in capacity during the 1960s and 1970s have experienced an erosion of capacity in the 1980s. Even a relatively small country, producing a limited range of commodities under a limited range of agro-climatic conditions, will require a cadre of agricultural scientists of 250-300. Countries that do not acquire adequate agricultural research capacity will not be able to meet the demands placed on their farmers as a result of growth in population and income. Research systems that do not generate resource and productivity enhancing capacity will fail to sustain public support.

5.0 There are substantial possibilities for developing sustainable agricultural production systems in a number of fragile resource areas.

Research underway in the tropical rain forest areas of Latin America and in the semi-arid tropics of Africa suggest the possibility of developing sustainable agricultural systems with substantially enhanced productivity. It is unlikely, and perhaps undesirable, that these areas become important components of the global food supply system. But enhanced productivity is important to those who reside in these areas--now and in the future. It is important that the research investment in the areas of soil and water management and in farming systems be intensified in these areas.

6.0 Over the very long-run energy and mineral nutrition can be expected to emerge as increasingly serious constraints on agricultural production.

During the last century technical change has been directed along alternative paths by relative resource endowments. Countries where land was relatively scarce or expensive such as Japan, placed a major emphasis on biological technology--in effect, inventing around the land resource constraint. Countries where labor was relatively scarce or expensive, such as the United States, placed greater emphasis on advancing mechanical technology--in effect inventing around the labor constraint. Over the next half century energy derived from liquid fuels is likely to become a serious constraint. It is also possible that the reserves of phosphate raw material will decline to levels that will result in much higher relative prices for phosphate fertilizer. It is likely that it will be necessary to allocate substantial research resources to invent around these two constraints.

7.0 The rationalization of regulatory regimes will become an increasingly important factor in determining the profitability of research investments and international competitiveness in agricultural production.

Incentives for private sector agricultural research appear to be quite sensitive to uncertainty about changes in regulatory regimes and the administration of regulations. Incentives for research and the potential gains from research investment is dampened when use of technology is restricted for reasons other than the assurance of health and safety. Consumers may press for regulation in the interests of aesthetic concerns. Producers may press for regulation to protect themselves from domestic or international competition. Pressure to achieve greater consistency among national regulatory regimes is likely to become an increasingly important factor in international trade negotiations. It will be necessary to devote substantial research efforts to identifying and quantifying the scientific, technical, economic, and psychological information needed to rationalize regulatory regimes in the future.

8.0 A major effort to assemble and characterize the plant and animal genetic resources that are available is essential in order to make the transition from the now conventional biological technology of the 20th Century to a biotechnology based agriculture for the 21st Century.

A major constraint in the development of a cost effective strategy for collection and preservation of genetic resources is an adequate characterization of the materials in in situ locations and in ex situ collections. A crop plant genome mapping program is essential if we are going to make effective use of the genetic engineering techniques that are available now and that will become available in the future. (Should I make the same statement about animals? I could use some help on this topic--VWR).

9.0 Research on alternative crops and animals that can be introduced into production systems can become a useful source of growth in some areas. On a local or regional basis, the development and incorporation of minor cultivars and species could make important nutritional and economic contributions.

It is unlikely that alternative crops or animals will emerge to substantially replace existing crop cultivars or animal species in production systems. It would be wishful thinking to expect any new developments as significant as the expansion of soybean production during the last half century.

10.0 There is a need for the establishment of substantial basic biological research and training capacity in the tropical developing countries.

There are a series of basic biological research agendas that are important for applied research and technology development in health and agriculture in the tropics that receive, and are likely to continue to receive, inadequate attention in the temperate region developed countries. There is also a need for closer articulation between training in applied science and technology and training in basic biology. When such institutes are established, they should be more closely linked with existing universities than the series of agricultural research institutes established by the Consultative Group on International Agricultural Research (CGIAR).

APPENDIX

UNIVERSITY OF MINNESOTA
TWIN CITIES

Department of Agricultural and Applied Economics
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March 6, 1989

Mr. Donald N. Duvick
Senior Vice President, Research
Pioneer Hi-Bred International, Inc.
700 Capitol Square
400 Locust Street
Des Moines, IA 50309

Dear Mr. Duvick,

The purpose of this letter is to invite your participation in a small "consultation" to discuss the question of "Technical Constraints on Crop Yield Increases."

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 will be on the issue of "Technical Constraints on Crop Yield Increases." The meeting will be held here at the University of Minnesota on July 10 and 11.

In spite of the considerable optimism about the impact of advances in molecular genetics and genetic engineering, there are a number of reasons why advances in crop and animal production may be more difficult to realize in the future than in the recent past. For example, 25 years ago it was quite clear that in South Asia increases would come from new crop varieties, increased fertilizer use and expansion of irrigated area. It is not as easy to specify the sources of increased production during the first decades of the next century.

The objective of the consultation will be to explore with a small group of knowledgeable people whether technical constraints on crop and animal productivity can be expected to emerge as a serious limitation on rates of growth in agricultural production during the early decades of the next century. The sources of yield constraints might include (a) physiological or other biological constraints; (b) resource, economic or institutional

constraints; and (c) constraints arising from micro-level or macro-level environmental changes.

One result of the consultation would be to sketch out an agenda for a conference which would explore the issues in greater depth that emerge from the consultation.

We hope very much you will be able to accept this invitation. Among others to be invited are:

Carl K. Eicher	-	Michigan State University
Donald Plucknet	-	CGIAR Secretariat
H. K. Jain	-	ISNAR
Derek Byerlee	-	Cimmyt
David Seckler	-	Winrock International

The project will be able to take care of your air ticket and other expenses involved with your participation in the consultation.

It would be helpful if I could have your response within the next few weeks.

Sincerely yours,

Vernon W. Ruttan
Regents Professor

VWR:rrl

CONSULTATION ON BIOLOGICAL AND TECHNICAL CONSTRAINTS ON CROP AND ANIMAL PRODUCTIVITY

Stassen Room (170 HHH Center)
Hubert H. Humphrey Institute of Public Affairs
University of Minnesota
Minneapolis, Minnesota
July 10-11, 1989

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