Innovation in Resource Management

Proceedings of the Ninth Agriculture Sector Symposium

L. Richard Meyers, editor
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# TABLE OF CONTENTS

**PREFACE** v

**OPENING REMARKS...Barber B. Conable** 1

**SESSION I: ISSUES AFFECTING THE POTENTIAL FOR IMPROVED RESOURCE MANAGEMENT** 7

- Summary 9
- A Prognosis on World Agriculture in the Late 1980s...Patrick O'Brien 11
- Management of Common Property Natural Resources: Overview of Bank Experience...Daniel W. Bromley and Michael Cernea 29

**SESSION II: INNOVATION IN RESOURCE MANAGEMENT -- FIVE MAJOR AREAS** 47

- Summary 49
- Issues and Options in Irrigation Finance...Gerald T. O'Mara 53
- Water Resources Management...Brian Albinson and D. Jeremy W. Berkoff 71
- A Review of Existing Soil Conservation Technologies and a Proposed Method of Soil Conservation Using Contour Farming Practices Backed by Vetiver Grass Hedge Barriers...Richard G. Grimshaw 81
- The Use of Ground Water -- Experience in Sub-Saharan Africa...Stephen J. Carr 99
- Land Tenure Security and Agricultural Production in Sub-Saharan Africa...Shem Migot-Adholla, Peter Hazell, Benoit Blarel and Frank Place 105
- The Implications of Land Registration and Titling in Thailand...Gershon Feder 121
- Containing Tropical Deforestation: A Review of Priority Areas for Technological and Policy Research...John Spears 135
SESSION III: BIOTECHNOLOGY -- A REVIEW OF THE STATE OF THE ART 151

- Summary 153
- Biotechnology for Plant Production: Summary Paper...Peter Dart 157
- Biotechnology in Livestock Production...E.P. Cunningham 161
- Modern Biotechnology: Its Prospective Production and Socioeconomic Impacts...Frederick H. Buttel 171
- Biotechnology -- The Role of the Private Sector...W.R. Scowcroft 187

SESSION IV: LIVESTOCK AND CROPPING SYSTEMS -- RESULTS FROM THE INTERNATIONAL RESEARCH CENTERS 203

- Summary 205
- A Summary of Crop Livestock Interactions in Sub-Saharan Africa: Technologies and Research Priorities...John McIntire, Daniel Bourzat and Prabhu Pingali 209
- Forage Legume Interventions for West African Subhumid Zone Crop-Livestock Systems...R. von Kaufmann 233
- Pasture-Crop Technologies for Acid Soil Savannas and Rain Forests of Tropical America...J.M. Toledo, C. Sere and W. Loker 247

CLOSING SESSION: AGENDA FOR THE FUTURE 275

- Closing Remarks...Michel J. Petit 277
These proceedings are the ninth in a series of records of Agriculture Symposia presented at the World Bank beginning in 1980.

This year's symposium was held on January 10-11, 1989. The theme, "Innovation in Resource Management", directed attention to the importance of technological and institutional innovation with which to conserve as well as increase the productivity of the natural resource base on which agricultural development depends. In a period when many areas of the world are under pressure to increase agricultural production and/or are subject to increased ecological stress, innovation is urgently required to respond to these challenges.

The symposium was opened by Barber B. Conable, President of the World Bank. He singled out three challenges that confront contemporary agricultural development: the need for trade policies that lead to a liberalized trading regime in agriculture; the need for more effective promotion of productive farming technologies in the developing world; and the need to ensure the protection of the environment while at the same time increasing the agricultural output of the world's poor.

In the first formal presentation of the symposium, Patrick O'Brien, Director, Commodity Economics Division, USDA, analyzed the health of current world agriculture and examined the implications of several trends for the 1990s. He suggested that the health of world agriculture has seldom been better but the sector has also seldom been more at risk. This was followed by a paper by D. Bromley (University of Wisconsin-Madison) and M. Cernea (World Bank) on the management of common property natural resources. The authors sought to introduce greater conceptual clarity to discussions of this topic by carefully defining the characteristics of common property regimes and by indicating how development projects can better build upon these characteristics.

The afternoon of the first day was devoted to five simultaneous discussion groups each on a different major natural resource management topic. Each began with the presentation of a paper(s) by World Bank staff. Topics examined included: 1) Water Resource Management -- Meeting the Demands for Irrigation and Other Competing Sectors (B. Albinson and J. Berkoff/G. O'Mara); 2) Watershed Management and Soil Conservation (R. Grimshaw); 3) The Use of Ground Water -- Experience in Sub-Saharan Africa (S. Carr); 4) Land Issues -- Tenure and Productivity (S. Migot-Adholla, et al./G. Feder); 5) Forestry Research (J. Spears).

Biotechnology has been portrayed as holding the promise of major gains in productivity in world agriculture. In an effort to acquaint Bank staff with the rudiments of developments in this field and to give them some perspective on these developments, the entire morning of the second day was given over to the topic of biotechnology. P. Dart of the University of Queensland, Australia, summarized the major technologies that
currently constitute the state of the art in using biotechnology in plant production. E. P. Cunningham of Trinity College, Dublin University, reviewed the range of techniques currently employed in livestock production. F. Buttel of Cornell University examined the potential production impacts of biotechnology worldwide, including sectors other than agriculture, and suggested a number of reasons why he feels the promise of biotechnology may be more limited than is sometimes claimed by its more enthusiastic proponents. W. Scowcroft of Biotechnica Canada spoke on the role of the private sector in the development of biotechnology, using as an illustration the private sector's contribution to the development of canola (rapeseed). He argued for the need for private public collaboration in the development of biotechnology for application in developing countries.

The final afternoon of the symposium was taken up with an examination of the general theme of livestock and cropping system interactions. Three discussion groups were held, each focusing on presentations by staff of one of the CGIAR centers. The topics and their respective presenters were: 1) Integration of Livestock and Cropping Systems -- The Experience in Sub-Saharan Africa (ILCA) (J. McIntire, R. von Kaufmann); 2) The Experience of Integrated Farming Systems in Arid Zones of the Middle East and North Africa (ICARDA) (P. Cooper and P. Cocks); 3) Livestock and Cropping Systems in Tropical Areas -- The Experience in Latin America (CIAT) (J. Toledo).

M. Petit, Director of the Agriculture and Rural Development Department (AGR), addressed the final session. He summarized what in his opinion were the more important substantive conclusions emerging from the symposium and then suggested some implications of these conclusions for the work of AGR and agriculturalists in the World Bank in general.

The planning of the symposium was the responsibility of a Working Group composed of departments of the Bank dealing with agriculture. This Working Group was responsible for not only the theme of the symposium but also the development of the main subjects within the theme and the choice of speakers to develop the papers and presentations.

1/ S. Carr, D. Pickering
   S. Barghouti, P. Brumby, M. Cernea, G. Feder, P. Hazel
   R. G. Grimshaw
   W. Fairchild
   J. Wijnand

Africa Region Technical Department
Agriculture and Rural Development Department
Asia Region Technical Department
Europe, Middle East and North Africa Region Technical Department
Latin America and the Caribbean Region Country Department 1
The symposium was sponsored by the Agriculture and Rural Development Department and the Training and Management Development Division of the Policy, Planning and Information Department. This volume is the work of these departments and the Publications Department. It contains papers presented at both the plenary and group discussion sessions. It is designed to be a permanent record to further enhance the knowledge of Bank staff working in agriculture and rural development and as a means of exchanging knowledge with other leaders working in agricultural development.

A special word of appreciation is extended to Ms. Gracie Ochieng, AGR, for her diligent and tireless work in typing the many drafts of individual papers and the final manuscript.
OPENING REMARKS

Barber B. Conable

INTRODUCTION

It is good to begin a new year by thinking carefully about agriculture, one of the oldest development challenges. This symposium provides an important opportunity to refresh your thinking, and I am pleased that I have been invited to participate, giving me the chance to renew my commitment to you and the work you do.

The margin of life on earth is six-to-eight inches of topsoil. In a sense, you are custodians of that precious resource and, therefore, of mankind's survival. In the World Bank family, no skills are more valued than yours, no insights more needed. Your findings on agricultural production and your views on how to improve it and the lives of farmers throughout the developing world are critically important.

Traditionally, agriculture has made up a major portion of the Bank's total lending program. This will continue. The imperatives of development cannot be ignored. In many countries, with many groups of people, there is no other vehicle for improvement of the quality of life than agriculture.

THREE CHALLENGES: TRADE, TECHNOLOGY, ENVIRONMENT

Today, rather than focus on the aggregate numbers, however, I would like to focus on some of the specific challenges ahead. These challenges arise where agriculture intersects with trade, with technology and with environmental concerns.

The Bank has an important role in helping farmers and farming nations to master these challenges. But we must not measure either our commitment or our success primarily by the volume of our lending, or the thickness of the papers we publish, or the numbers of research and pilot projects we undertake.

The real test of our contribution is our ability to get others to perform. As rich, powerful and knowledgeable as this remarkable institution is, the World Bank is not the Almighty. In agriculture, as in every area, ours is the role of Prometheus, not Demeter.

Your work is that of creators, of innovators, of counselors and co-financers. It requires -- simultaneously -- both individual inquiry and practical collaboration. I admire your dedication to those tasks, and I am proud of the talents you bring to them.

Barber B. Conable is President, The World Bank.
TRADE

Farming and the Global Market

In the global marketplace, no sector is more protected than agriculture. And developing countries suffer most from this discrimination.

The official development assistance developing countries receive is worth only half as much as the cost to them of the trade barriers the donors nations have put in place. Non-tariff barriers alone now affect over 50 percent of all OECD imports of raw agricultural material. Twenty years ago, only two percent were affected.

Benefits to LDCS

Phasing out agricultural trade distortions would alter dramatically the economic map of the world. It would put food exporters from Uruguay to India, from Brazil to the Philippines, on sound footing for sustained growth. And for most food-importing nations, higher world prices would bring an internal shift into agricultural production from less efficient sectors.

GATT Outlook

This second Green Revolution, if it is to come, will be launched at the green-felt negotiating tables of the GATT. The outcome of the Uruguay Round is far from certain. Indeed, a growing trans-Atlantic trade confrontation over agriculture is a real possibility. For the developing world, that calamity is best described by the African saying: "When elephants fight, it is the grass that gets trampled."

Bank Staff as Trade Policy Advocates

Clearly, the Bank cannot be a neutral observer. I will do my share. I will use whatever influence I have as President of the World Bank.

The Bank effort must be amplified by your expertise, however. I ask you, in your contacts with other agriculturalists at all levels and in both industrial and developing countries, to raise the issue of trade.

You can do so positively -- explaining the development gains to be won in a less distorted global market. You can do so practically -- urging domestic policy reforms that will make internal markets, pricing, tax and subsidy policies more free and more supportive of small farmers. And you should do so prospectively -- beginning now to help prepare agricultural policies in the developing nations for the competitive challenges to come when, as I hope, the GATT agrees on a liberalized trading regime in agriculture.

TECHNOLOGY: APPLYING THE CONTINUING REVOLUTION

The main beneficiaries of trade reform, of course, will be the world's efficient, competitive farmers. Technology is the key agent in
raising agricultural efficiency, and the Bank must be a key player in the adoption of productive farming know-how in the developing world.

You already have had some success in this area. Two projects from the 1970s come to mind: advanced sprinkler irrigation in the Doukkala area of Morocco, and improved water management at the Rio Sinaloa project in Mexico.

A more recent and much larger investment -- combining drainage and integrated farming development in the lower Indus valley -- teaches an even greater lesson about frontier technology and the teamwork required to design, manage and finance it. While the Bank has a leadership role in this multi-purpose investment, we are working with six donors -- the Saudis, Swiss, Canadians, Americans, OPEC and the ADB -- and with the Pakistan Government on co-financing.

The management of this eight-year, multi-billion dollar enterprise from conception to conclusion is a Bank-size job. We must learn from this experience, and look more energetically for other joint ventures and willing partners.

Technical Skills: How Can We Keep Up?

Because of the dynamic character of contemporary agriculture, we need to be creative in developing investment in agriculture. Does our creativity represent an adequate response to the current character of the agriculture sector with all its dynamism? Do our programs use the full range of emerging production technologies? And, most importantly, as I stressed at a similar meeting two years ago, do our investments result in a sustainable resource base upon which the future of agriculture ultimately depends?

These are difficult questions, but today's program indicates that considerable thought is being given to such questions. The primary emphasis of this symposium on innovations in resource management is most appropriate.

It is also important that we have the right staffing patterns and skill mixes here at the Bank. We must be preoccupied with our technical skills in agriculture given the aging of many of our specialists. I ask you to make a special effort to maintain and recruit much-needed agricultural and forestry expertise. The Bank's catalytic effect depends on the technical know-how our borrowers expect and need.

Thinking Globally: Cooperation with CGIAR, et al.

On another issue, we must improve our work as a go-between for innovators and users of technology. You have access to vast resources of information and analysis developed within and outside the Bank. The transfer of this knowledge from your minds to the hands of farmers can be a great contribution to development.

It is important that we continue to help finance the experiments of the CGIAR centers and other research pioneers. But we must also be more
active in spreading their findings to the field, and more imaginative in cross-fertilizing between distant laboratories exploring related problems.

**Thinking Small: Cooperation with NGOs**

Finally, in technology, the Bank -- as big as it is -- must learn better how to think small. Much promising invention in developing world agriculture is the product of fieldwork by non-governmental organizations.

From NGOs have come innovative, cheap ideas, such as:

* lines of rock to hold water and halt soil erosion on the edge of the Sahara;
* designs for new, fuel-efficient stoves -- even some that are solar powered;
* tree planting, even in the middle of African grain fields, to increase fertility and act as windbreaks.

Frankly, I read more about these experiments in the popular press than in Bank papers. I know that not every journalistic success story is a lasting success. Nevertheless, the Bank should work to make its contacts with NGOs more productive. We scare them by our size. They confuse us by their diversity.

To keep pace with technological advance, we must be constantly curious and constantly in touch. This sharing can begin within the Bank, but should also extend vigorously outward to draw in the expertise of the NGOs.

**ENVIRONMENT**

Our outreach efforts can also contribute significantly to the third challenge: protecting the natural environment. It is no accident that some of the NGO initiatives to improve the output of poor farmers also carry potential environmental benefits. Poverty, itself, can be a toxic force, driving farmers onto fragile soil and into vulnerable forests, depleting -- for survival today -- scarce resources that contain the seeds of tomorrow's growth.

As the strongest, single force in the fight against global poverty, the Bank has a leadership role, as well, in environmental protection. The specific challenge to the Agriculture and Rural Development Department is to strengthen the complementarity between poverty alleviation and natural resource management in the area of sustainable agriculture.

I am not preaching "organic-or-nothing" farming techniques. But the uses of crop rotation for soil renewal, of plant and waste recycling for fertilizer, and of natural herbicides and pesticides need not be limited to farmland in the developed nations.

Such ideas need to be studied, tested and adapted to the climates and conditions of the Third World. To some extent, they already are. The
Bank, however, could gauge more attentively the environmental consequences of some agricultural development. When we support cotton growers, for instance, are we counting the economic and environmental costs of pesticide dependency? Are we keeping track of pest control research in Taiwan, England, Texas and California?

And finally, but critical to our catalytic role in promoting sustainable agriculture, are we using our leverage as investors to ensure the growth of a support structure that will keep a start-up investment paying off over longer periods of time? From managing technology to opening lines of credit, from providing extension services to training and developing manpower, we must help governments put their agricultural programs into a healthy institutional as well as natural environment.

CONCLUSION: CONTINUUM INTO AGRO-INDUSTRY

I have outlined three practical policy challenges -- broad and immediate ones -- for your consideration and response. To close my remarks and open the floor to questions, I want to put forward a final challenge -- one that today in Asia and Africa, at least, may seem more distant than real.

What if all your dedicated work succeeds? What if the Bank contributes to new and lasting progress in agricultural development? I ask this question now because we need to look ahead and into the continuum that starts with seeds and soil, water and skill, and moves to processing and farm exports.

Somewhere along the way, modern farming will mean more food from fewer farmers and more jobs in agro-industries. In Latin America, Europe and the Middle East, the Bank has gained experience in easing that transition, in spurring that growth. It is my hope that in Asia and Africa, we can do more to promote such diversification and to see that as the logical, necessary continuation of our work in agricultural development.

I hope we will be ready for that challenge. It could be the subject of a future symposium.

For now, I appreciate having the opportunity to open this one. I wish you success in all your work. Thank you.
SESSION I:

ISSUES AFFECTING THE POTENTIAL FOR

IMPROVED RESOURCE MANAGEMENT
ISSUES AFFECTING THE POTENTIAL FOR IMPROVED RESOURCE MANAGEMENT

A PROGNOSIS ON WORLD AGRICULTURE IN THE LATE 1980s -- P. O'Brien

Patrick O'Brien, Director, Commodity Economics Division, USDA, analyzes the health of current world agriculture and examines the implications of several trends for the 1990s. He indicates that the health of world agriculture has seldom been better, but the sector has also seldom been more at risk.

After more than three decades of generally uninterrupted growth, agriculture is producing more product at lower real prices than at any time in recorded history. This is the case even though natural resource limitations have made a larger share of the sector's growth in output dependent on productivity growth. At the same time that agriculture has seen record breaking productivity gains, it has also managed to reduce its draw on the other sectors of the world economy, reflected in changing terms of trade between agriculture and the industrial sectors as well as in the changing composition of and pace of growth in most countries' general economies.

With this record of accomplishment, why the concern about the longer run outlook for agriculture? This is because post-war accomplishments have come at notable costs that raise questions about future gains. These questions range from issues of regional disparity to wider concerns about agriculture's technology base, technology's link to the environment, and the world market as a viable source of supply and outlet for farm products.

Sub-Saharan Africa is the marked exception to regional agricultural gains. Even with imports and aid expanding, consumption has stagnated. The situation is deteriorating fast enough in many countries to weaken overall economic performance and threaten political stability. In a broader sense, the "African problem" masks a more general one of poverty amidst plenty. Many poor countries and the poor within even wealthier countries have shared little in post-war gains. The cap effective buying power puts on growth in consumption among the poor is one of the most intractable problems facing the sector in the 1990s.

The technology issues of the 1990s involve questions of 1) how viable is the petroleum-dependent technology base that undergirded past gains in productivity as the base for future growth? And 2) how much pressure will future growth put on the environment? Will oil supplies be adequate and prices low enough to support trend growth in productivity? Also, high-productivity inputs have been found to be a major source of
environmental pollution. Can countries with fragile environments and not very sophisticated delivery systems afford to boost output through adoption of these technologies?

After more than 30 years of expansion measured in terms of the volume of products traded and the countries routinely buying and selling, the world market stagnated during much of the 1980s. A growing number of countries in the 1980s have found the cost of participating in a bearish market too great and have taken steps to weaken or cut their linkage. Liberalizing trade could reinforce post-war gains as well as free up large public monies currently subsidizing agriculture for use elsewhere in the world economy. In either case, without resolution of the current confrontation, one of the institutions underpinning post-war agricultural gains could find itself increasingly hamstrung in the 1990s and beyond.

What do the above issues mean for the prospects for improved resource management? In general terms, they suggest that the margin for error in managing the world's agriculture has narrowed. These technology, environment and trade questions have to be answered if we are to move into the 1990s and beyond on anything like the post-war trajectory to date.

MANAGEMENT OF COMMON PROPERTY NATURAL RESOURCES: OVERVIEW OF BANK EXPERIENCE -- D.W. Bromley and M. Cernea

The authors seek to introduce greater conceptual clarity to discussions of the topic of common property by carefully defining its characteristics vis-a-vis three other types of property regimes -- state property, private property and open access regimes. They argue that many of the problems with development projects concerned with natural resource management (including some Bank projects reviewed) stem from a misunderstanding of the essence of common property and a mistaken application of the "tragedy of the commons" metaphor to common property situations. Common property regimes are not a free-for-all (an open access regime) but are instead rather well-structured arrangements in which group size in known and enforced, management rules are developed, incentives exist for co-owners to adhere to the accepted institutional arrangements, and sanctions work to ensure compliance. Because of the confusion introduced by the tragedy of the commons metaphor, the potential of common property regimes has not been properly understood. More generally, the authors argue, resource management interventions must emphasize the social arrangements among people as they interact with each other and the natural resource base, with particular attention to incentives and sanctions for influencing individual behavior.
INTRODUCTION

As your symposium agenda indicates, my assignment is to report on the health of world agriculture as an introduction to your sessions on innovation in resource management.

Prognosticating about agriculture continues to be a popular pastime -- what with the shift from shortages in the 1970s to surpluses in the 1980s and the advent of large-scale computer-based simulation modeling. What I plan to do here today, however, is to avoid the model jargon and detailed commodity projections that have come to hallmark prognostication about world agriculture in particular. I will focus instead on a few basic global trends in an effort to put the state of the sector at the close of the 1980s into a longer term context. I will close by drawing implications for the resource management issues you will be focusing on this afternoon and tomorrow.

NOTABLE ACCOMPLISHMENT

Standing here as we do in the late 1980s, the health of the world agricultural sector has seldom been better -- droughts, floods, and other acts of nature notwithstanding. But, the sector has also seldom been more at risk. After more than three decades of generally uninterrupted growth, agriculture is producing more product at lower real prices than at any time in our recorded history. However, the sector also faces a broad range of technological, environmental, and policy challenges serious enough to raise questions about continued progress at the post-war pace.

Three Decades of Progress

Despite serious weather problems in key countries both in 1987 and 1988, world agricultural production in the second half of the 1980s is almost twice as large as output in the early 1960s. The sector has set new output records in 20 of the last 29 years, with average gains of 2.3 percent per year.

As Graph 1 indicates, this post-war growth has been sufficient to offset unprecedented population growth and feed an added 2 billion people. Using grain data to augment aggregate production indices, world per capita production of wheat, feed grains, and rice have increased 295 kilograms in

Partrick O'Brien is Director, Commodity Economics Division, USDA.
Graph 1. World Agricultural Production
Index 1976-78 = 100

1987-88 Data are estimates
the early 1960s to 365 kilograms in the late 1980s (Graph 2). This increase has supported both strong gains in direct consumption of grain as food and a sharp increase in indirect consumption of grain in the form of livestock products. What with these other gains, caloric intake of all foods is up over 10 percent since 1960, and over a fifth of the total is now made up of livestock products compared with less than a tenth in the early 1960s.

**Notable Accomplishments**

This record of growth and our position in the late 1980s is even more noteworthy if natural resource constraints, agriculture's changing position vis-a-vis other sectors of the world economy, and the role trade has played are taken into account.

Increasingly constraining natural resource limitations have made a large and larger share of the sector's growth in output dependent over time on productivity gains, i.e., extracting more units of crop and livestock output per unit of natural resource or man-made input committed to production. The clearest indication of this shifting in the source of growth is the post-war period's record of slowing expansion in agriculture's land base in general and its irrigated acreage in particular. Graph 3 makes this point again using grain data. Grain area has changed relatively little, and in some cases due to shifts from other crops; hence, total agricultural area has expanded even less than these data imply. Simply stated, the sector has had to sustain 2.5-2.7 percent average annual increases in grain yields to sustain 2.3-2.5 percent increases in output over the last three decades.

At the same time that agriculture posted record-breaking productivity growth rates, it also managed to reduce its draw on the other sectors of the world economy. This phenomenon is reflected in changing terms of trade between the agricultural and industrial sectors as well as in the changing composition of and pace of growth in most countries' general economies (Graph 4). Using IMF commodity price indices, it is possible to calculate both the equivalent of a world consumer price index and a food price index. Comparing the two provides a benchmark measure of how world agriculture has fared.

With the exception of a short-lived interruption in the mid-1970s, agriculture's terms of trade have declined sharply since 1960. The same unit of agricultural output bought less than half the goods and services from elsewhere in the economy of the typical country at the end of the 1980s than it did at the start of the 1960s. Equally important, expanding supplies of food at generally falling real prices helped to support accelerating growth in other sectors. Hence, despite impressive growth, agriculture has shrunk from accounting for roughly half of GNP in countries like India in the early 1960s to less than a third in the late 1980s.

What with wide difference in individual countries' production and consumption growth patterns, considerable expansion in world trade was also necessary over the post-war period to share the sector's general gain across regions. As Graph 5 indicates, growth in trade was almost two and a half times the pace of growth in production.
Graph 2. World Grain Production

Million Metric Tons

Kilograms per Capita

Early 60's  Late 60's  Early 70's  Late 70's  Early 80's  Late 80's

Total
Per Capita
Graph 3. Sources of Growth in Grain Production
Index 1976-78 = 100
Graph 4. Agriculture’s Changing Terms of Trade
Index 1976-78 = 100
Graph 5. Growth in World Agricultural Trade
Index 1976-78 =100

1987 Data are estimates
The emergence of a viable world market depended on a number of breakthroughs. Not least of these was the development of transportation infrastructure and the international financial system necessary to move products between countries more freely. The general liberalization in trade policies accomplished in the 1960s and to a lesser extent in the 1970s was equally critical in allowing products to move more freely between countries. Whatever its origins, however, the emergence of a post-war world market freed up growth in production from slow growth in consumption in resource and/or technology-rich countries. Conversely, it also freed up growth in consumption from slow growth in output in countries with limited production potential.

**NOTABLE COSTS**

With this record of accomplishment, why the concern about the longer run outlook for agriculture reflected in your symposium topics? Why the concern now with the major world commodity markets faced with what are widely perceived to be chronic surpluses even after the 1988 U.S. drought?

On closer examination, the post-war period's notable accomplishments have come at notable costs -- costs large enough to raise questions about future gains. These questions range from issues of regional disparity, i.e., the African food problem, to wider concerns about agriculture's technology base, technology's link to the environment, and the world market as a viable source of supply and outlet for farm products.

**African Deterioration**

While growth in trade has worked to ensure wide regional participation in global gains, Sub-Saharan Africa stands out as the most marked exception. Food production per capita has actually declined 15 percent in a more or less steady pattern since 1960. Even with imports and aid expanding sharply, consumption has stagnated, with grain intake fluctuating between 100 to 120 kilograms per capita (Graph 6).

This deteriorating African situation currently involves more moral than political or economic questions. African buying power is too limited to translate food shortages into pressure on the world market. To date, the link between Sub-Saharan Africa and the world market has been largely through aid -- food aid to meet the most pressing human needs and financial and technical aid to reverse indigenous food production declines. However, the situation is deteriorating fast enough in many countries to weaken their overall economic performance and threaten political stability. Hence, dealing with the African problem could well become a world agricultural priority in an indirect but no less effective way.

In a broader sense, country and regional averages hide a number of other "African problems" -- poverty amidst plenty. While FAO food balance sheets suggest general progress, poor countries and the poor within even wealthier countries have shared little in post-war gains. While agricultural prices have fallen sharply, they have left many still too poor to translate much more than basic human needs into effective market demand. The cap effective buying power puts on growth in consumption among the poor is one of the most intractable problems facing the sector in 1990s.
Graph 6. Sub-Saharan Africa: Grain Production and Consumption per Capita
Agricultural Technology and the Environment

In simplest terms, the technology issues of the 1990s are fast becoming questions of:

- How viable is the petroleum-dependent technology base that undergirded past gains in productivity as a base for future growth? and
- How much pressure will future growth in productivity put on the environment?

Post-war gains in productivity have been closely linked to the development of a largely petroleum-based agricultural technology in the scientifically advanced countries and its transfer, with considerable local adaptation, to developing countries. Growth in crop yields in particular has depended heavily on expanding use of a package of man-made "high-productivity" inputs including chemical fertilizers and pesticides. Indeed, much of the plant science of the post-war period has focused on strengthening varietal responsiveness to increased fertilizer application and the use of chemical crop protectants to boost output.

Graph 7 puts increased dependence on this "agrochemical package" into perspective using data on grain yields and fertilizer use per hectare and simple regression techniques. The data for roughly 100 of the larger countries point to the same high and rising degree of correlation between fertilizer use and crop yields that physical scientists involved in the Green Revolution have long taken for granted. Simply stated, an added unit of fertilizer use at the low end of the applications curve translates into more than a ten-fold increase in crop yields. Even at the upper end of the curve, the trade-off appears to be 3-4 to 1.

This petroleum dependence leads to several questions. Can petroleum-based technology expand fast enough to support trend productivity growth? Independent of this technology growth concern are questions about the viability of the existing technology base. How dependable are petroleum supplies and prices? Petroleum is itself a finite resource potentially subject to near-monopoly OPEC pricing. Many experts expect increasingly tight supply and higher prices in the 1990s independent of any OPEC action. Will oil supplies be adequate and prices low enough to support trend growth in productivity -- particularly when agriculture can have trouble bidding energy away from other uses without significantly higher commodity prices?

Another question relates to the pace at which alternative technologies are put in place. Yes, the emerging technologies of the late 1980s are far less dependent on petroleum-based inputs. Some new technologies actually allow operators to maintain or expand output with lower use of petroleum-based inputs. At issue, though, is how fast a new generation of technologies can be developed and how quickly they can be passed from scientists to farmers, particularly farmers outside a few technologically advanced countries.
Graph 7. Crop Yield-Fertilizer Use

Yield (kg/ha)

Fertilizer Use (kg/ha)
Independent of the petroleum supply and price issue is the environmental aspect of the technology issue. Many high-productivity inputs have been found to be a major source of environmental pollution. Fertilizer and pesticide pollution of groundwater has grown to be a major issue in the U.S., Japan, and most European countries. Graph 8 indicates high levels of groundwater contamination in the U.S. in areas of little or no industrial activities -- predominantly agricultural areas marked by heavy use of agrochemicals. The graph is taken from a recent ERS/USDA study indicating that the drinking water of an estimated 50 million people in the U.S. comes from groundwater that is potentially contaminated from agricultural chemicals. Approximately 19 million of these people get their water from private wells which are most vulnerable.

Using U.S. fertilizer application rates (rates well below levels in most of Europe and countries like Japan, Korea, and Egypt) as a reference point, can countries with even more fragile environments and less sophisticated delivery systems afford to boost output through adoption of existing technologies? Conversely, can countries under the greatest pressure to expand agricultural output afford not to adopt productivity-enhancing technologies even at unknown but increasingly certain environmental costs?

A Viable World Market

Signs of stress in the world market for farm products are no less serious concerns than questions about technology and the environment. After more than 30 years of expansion measured both in terms of the volume of products traded and the countries routinely buying and selling, the world market has stagnated during much of the 1980s. A number of factors have contributed to this slowdown. Among them have been international macroeconomic and debt problems that have hit many developing countries particularly hard.

But this slowed growth in the world market is frankly less worrisome than the deteriorating trade relationships underlying and reinforcing it. Competition among exporters for market share and friction between importers and exporters over market access have intensified enough to threaten longer term market viability.

This market viability issue is most easily cast in terms of a shrinking or expanding world production and consumption adjustment base and resulting changes in individual countries' costs and benefits from trading. Importers and exporters use the world market largely to stabilize their domestic agricultures -- exporting to dispose of surpluses and importing to fill demand over and above local production. In linking themselves directly to the world market, however, trading countries expose themselves to 'importing' other countries' instability through world market price fluctuations. The magnitude of these world price fluctuations depends in turn on how large a production and consumption base is available to absorb disruptions.

So long as the world market's production and consumption base is large enough to absorb any single country's or group of countries' instability without too large a swing in world prices, the benefits of
Graph 8.

Areas of Potential Groundwater Contamination from Agricultural Chemicals

- Nitrates Only
- Pesticides Only
- Pesticides and Nitrates
participation outweigh costs. A shrinking production and consumption adjustment base works conversely to widen world price swings and participation costs. A growing number of countries in the 1980s have found the cost of participating in a bearish world market too great and have taken policy steps to weaken or cut their linkage. This has led in turn to more erosion.

This world market question can be stated in terms of opportunities as well as risk. The producer and consumer subsidy measures developed for a large number of countries and commodities to support trade liberalization talks point to the potential for large world efficiency gains (Graph 9). Producer subsidies, with all their trade distortion and resource misallocation side-effects, range from as high as 75 percent in Japan to 40 percent for the OECD countries as a group. This suggests liberalizing trade could reinforce post-war gains as well as free up the large public monies currently subsidizing agriculture -- approaching $150 billion in the OECD countries -- for use elsewhere in the world economy (Graph 10).

In either case, without resolution of the current confrontation, one of the institutions underpinning post-war agricultural gains could find itself increasingly ham-strung in the 1990s and beyond.

CONCLUSION

As prognostications go, the current state of world agriculture has seldom been better or more at risk. Three decades of progress have put the sector in the position to produce more product than ever before while reducing its call on the rest of the world economy's goods and services. However, these notable post-war accomplishments have not been without notable cost. While the food scarcity scares of the mid and late 1970s may have proven ill-founded, they have been replaced with less dramatic but no less real questions about our technology base, our environment, and the viability of the world market -- all three critical components of future progress.

What does all of this mean for the resource management topics you will be discussing at this symposium? In general terms, these questions suggest that the margin for error in managing the world's agriculture has narrowed. This margin widened significantly with post-war technology and trade advances; the world could double output with real prices falling even with what basic economics tells us were less than optimal policies in place in many countries. Another round of environmentally-positive technology breakthroughs combined with trade advances could widen this margin again. But until it does, we need to exercise far more caution in sector management.

Regarding resources more explicitly, the issue becomes one of ensuring that renewable land and water resources remain renewable. This is particularly true of water but of soils and broader ecosystems as well. The budding low-input sustainable agriculture program in the U.S. suggests that the traditional farm management skills required to integrate farming systems, manage mixed crop and livestock enterprises, and evaluate alternative input strategies will be increasingly critical.
Graph 9.

Estimated Total Support in 1986
(With Contribution by Commodity Group)
Graph 10.

Rates of Support for Agriculture in 1986
Producer Subsidy Equivalent

Percent

<table>
<thead>
<tr>
<th>Country</th>
<th>Rate</th>
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<tbody>
<tr>
<td>United States</td>
<td>28</td>
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<tr>
<td>Canada</td>
<td>41</td>
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<tr>
<td>European Community</td>
<td>34</td>
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<td>O. West Europe</td>
<td>47</td>
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<tr>
<td>Japan</td>
<td>75</td>
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<tr>
<td>Australia</td>
<td>13</td>
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<td>New Zealand</td>
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Lastly, biotechnology takes on an added significance in this environment. It is not only the latest advance in a long history; it could become the advance that consolidates past productivity gains and provides for future growth with substantially less risk to the environment.

Finally in closing, let me be clear. The questions I have raised here do not necessarily point toward a return to the shortages of the 1970s or the surpluses of the 1980s. Nor do they constitute an exhaustive list of challenges facing the sector; clearly, issues like climate change belong in such a catalog. However, these technology, environment, and trade issues are questions that have to be answered if we are to move into the 1990s and beyond on anything like the post-war trajectory to date.
MANAGEMENT OF COMMON PROPERTY NATURAL RESOURCES:
OVERVIEW OF BANK EXPERIENCE

Daniel W. Bromley and Michael Cernea

INTRODUCTION

The Bank's interest in the management of common property natural resources is tangible recognition of the importance of these resources to the economic well being of millions of families in every region of the world. Though the rangelands of Sahelian Africa receive much of the attention, the issues are present in all of Asia, as well as in Latin America. While most agricultural development assistance has been targeted to private lands, the non-private lands that we call the public domain have been only occasionally blessed with technical and financial interventions. And, sadly, most of those interventions have not begun to show the success of projects on the private domain.

This differential success has led the development community to several mistaken conclusions about what is wrong. One mistake is to assume that if only the public domain could be converted to private land all would be well. This assumption is not only historically and analytically false, but it is seriously at odds with prevailing social and cultural norms. If development consists in destroying existing social arrangements, then most of us would likely disavow any interest in "development." A second common mistake of development interventions on the public domain is to assume that the national government must assume management control of natural resources in order to save them from the locals. This idea too is both historically and logically false.

Those who care about land and related natural resources as they influence economic well being find themselves on the horns of a dilemma. Complete privatization (that is, individualization) of many resources seems to be an infeasible strategy for cultural, economic, and ecological reasons. Nationalization of resources for management by central governments is equally hopeless. This polarity is reinforced by the serious misunderstanding in the literature of the essence of common

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1/ A more extensive document on this topic will appear as a World Bank publication under the title The Management of Common Property Natural Resources: Some Conceptual and Operational Fallacies.
property, and by the folk wisdom deriving from Garrett Hardin and his mis-named allegory of the "tragedy of the commons." Every sophomore in economics can recite a story about free riders, prisoner's dilemmas, and the destruction of the commons. With this middle ground so devastated by incorrect analysis, the development community is forced to search in vain for a paradigm that will avoid the false promises of either privatization or nationalization.

Our comments are devoted to the rehabilitation of a conceptual model for managing renewable natural resources in the developing world. This is of vital importance for how we do agricultural development projects for several reasons.

First, virtually every Bank-assisted project must inevitably deal, explicitly or implicitly, with the economic and sociological question of tenurial systems over natural resources. Relatively often, Bank-assisted intervention induces a change in property regimes. Bank staff make judgments and reach decisions about maintaining, reinforcing, or changing a variety of property regimes. For example, decisions are taken to promote state or group property regimes over a project-financed natural resource, or about privatizing a particular resource. Additionally, decisions might be taken about a mix of state ownership with group usufruct (use) rights. Further, Bank staff are often asked to make a series of implicit assumptions about the possible chain of consequences of projects that will promote modifications in property regimes. Thus, much project work requires conceptual clarity about what those types of property regimes are, and how they work.

Second, environmental concerns have moved up on the development agenda in recent years. In agriculture, the core of environmental concerns is natural resources management. However, as any agriculturalist knows, no one can recommend, invent, or impose resource management regimes that preclude any human use of the ecosystem. The ability to use -- productively and sustainably -- the ecosystem depends critically on the management patterns at work under one or another property regime -- whether common property, state property, individual property, or some combination thereof. Hence, environmental reasons are another key motive for renewed attention to property regimes over natural resources.

Third, we would note the recent concerns with sustainable development, a notion that goes beyond environmental concerns as such, and speaks to the full array of economic activity in a country -- including agriculture. Many collectively managed resources will play a central role in policies for sustainable development.

Finally, common property resource management has recently become the subject of careful study by a number of social scientists -- economists, sociologists, anthropologists, cultural geographers, historians, and political scientists. This recent body of knowledge deserves careful attention.

We will offer here a brief summary of our recent review of a number of World Bank projects concerned with development of the public domain. We will then turn our attention to the paradigm that seems to
offer hope for sustainable management of local level natural resources such as fuelwood, range forage, fisheries, and water. This paradigm will concern the re-establishment of common property regimes that were undermined and destroyed first by external political and economic domination (we know it as colonialism in many places), and later by the rise of the urban-oriented nation-state.

OVERVIEW OF BANK PROJECTS

In reviewing the experience of Bank projects concerned with the public domain, one is struck by repeated instances of government inattention and condescension towards those who depend upon the public domain for the majority of their livelihood. Unfortunately, one finds this attitude reflected in the Trans-Juba Livestock Project (Somalia), the Botswana Land and Livestock Project, the North Sumatra Smallholder Development Project (Indonesia), the Himalayan Watershed Management Project (India), and the Tunisia Rural Development Project. Another pattern -- epitomized by the Northern Agricultural Development Project in Thailand -- is for governments to show so little trust that turnkey projects are "dropped into" rural areas, complete with managers, until the locals are "ready" to assume responsibility. This contempt for small farmers and pastoralists is quite evident in many other countries.

In the Ivory Coast, for instance, commercial loggers have long engaged in wanton high-grading of timber stocks, leaving the lesser-valued timber for others to poach and burn so as to provide agricultural plots. As the better stocks have disappeared the value of recent timber marketings has fallen, putting yet more pressure on the remaining stands so as to sustain export earnings. These practices have -- in a familiar pattern -- been legislated against, but only indifferently enforced. In fact, since independence the Government of the Ivory Coast has pursued an extremely destructive course of action toward its forests so as to earn foreign exchange and tax revenues. As a result loggers continue to exploit the remaining forests, and farmers have followed roads developed for logging operations, establishing cocoa, coffee and food crops with "slash and burn" farming. Such intrusions have also begun in the classified forest reserves and national parks. The government now estimates that this process transforms about 400,000 ha of unspoiled high forest per year. If this continues, the Ivory Coast could become a net importer of timber before the end of the century.

Bank reports for the Ivory Coast mention a persistent practice in renewable resource management -- governments showing more interest in the symptoms of problems than in the root cause of those problems. Specifically, we are told that the continued degradation of forests by logging poses scant ecological threat. However, it is reported that the subsequent invasion by land-hungry farmers imposes severe damage on the remaining forest cover causing increased soil erosion, reduced rainfall, and lower water tables. Hence, the "Government is becoming more conservation-minded in its approach to forestry in particular, and to natural resources in general"

Notice that while the government is unwilling to threaten the political power of the commercial loggers who savage the forest, the
entrance of small farmers into the cleared space is viewed as an important ecological crisis that motivates the Government to become "conservation minded." Is it easier to get "conservation minded" against farmers than against loggers who generate foreign exchange and commercial timber? There seems little interest in dealing with the conditions that cause farmers to invade the cleared forest. But it is clear in the Government's mind that the farmers are the "enemy" of the forest. "Conservation" then becomes an anti-farmer activity, doing little to endear it (conservation) to the masses in the villages upon whose shoulders the success of such programs will ultimately fall. Wouldn't it be more reasonable to undertake development interventions to deal with the land-use problems of the farmers than to blame them for degradation and set them against conservation? Successful conservation programs in the developing countries must be coincident with farmers' interests, not contrary to them.

On a more positive note, four projects in our review show particularly encouraging processes and results. The Middle Atlas-Central Area-Agriculture Development Project in Morocco, the Yogyakarta Rural Development Project in Indonesia, the Eastern Senegal Livestock Project, and the Niger First Forestry Project all illustrate, in various ways, the trust of the central government and Bank that is necessary if projects on the public domain are to succeed. In these projects local people were consulted in conception and formulation, managerial authority was ceded to the local level, external administration was both unobtrusive and withdrawn in a timely fashion, and the necessary discipline was imposed by the local authorities where it was both knowledgeably administered, and not resented by the locals.

Successful projects will hinge on the careful identification of the relevant social unit -- or the relevant unit of social organization. That is, great care must be exercised in determining, at the local level, the appropriate body that will assume primary managerial responsibility for the project. One of us has previously written of the problems that arise when an improper unit of social organization is singled out for project responsibility. The example was a community forestry project in Azad Kasmir, Pakistan, but the principles apply to any type of project. The conditions which can cause difficulties for project success are: (1) large, heterogeneous communities with prominent splits or strata; (2) local "leaders" unwilling or unable to exercise authority; (3) fragmented control over land resources; (4) unclear tenure over community lands, and hence uncertain managerial jurisdiction; (5) the failure to negotiate contracts for the distribution of project benefits before the benefits begin to appear and are appropriated by the powerful segments of the community; and (6) the lack of prior collective action within the community concerning other managerial responsibilities (Cernea, 1985, p. 281).

The burden of development assistance is not just to deposit projects in the developing countries. It is, instead, to create the conditions under which people living in those countries can engage in

\[2/\] For a discussion of the need for a "constitution" early in the project cycle -- with specific reference to irrigation -- see (Bromley, 1982; and Bromley, Taylor and Parker, 1980).
meaningful actions that will improve their lives. The success of such efforts will depend, critically, on how projects deal with local people, and how we let people deal with projects.

A recent Bank review of livestock project experience notes the overwhelming importance of misunderstood institutional factors in explaining the rather dismal record in that sector. The decline in Bank lending for livestock projects, and the general unease within the development community over livestock interventions, suggest that much work remains to be done before we can confidently move forward on livestock lending. The indifferent success of social forestry projects is further evidence of the difficulties still to be faced. Problems arising from such projects occur not simply from a failure to understand the institutional dimensions of economic behavior at the village level, though this is undoubtedly important. Rather, the more serious failure occurs because of ethnocentric analysis that is unable to connect intellectually with the world into which such projects are imposed.

The difficulty in making an intellectual connection arises from a point made earlier. Specifically, the "tragedy of the commons" metaphor has offered false logic and distorted history. The certitude with which Hardin offered the inevitable tragedy, and a general naivete regarding both history and concepts of property rights, encouraged too many individuals to accept at face value the policy conclusions that seemed to flow from the Hardin allegory. The conventional wisdom that grew up around the so-called "tragedy of the commons" meant that it was difficult to make the essential intellectual connection with resource management regimes in the developing countries. Many planners or other development administrators would observe a situation in which there is no obvious management regime in place and conclude that it is a situation of "common property." Perhaps they would even cite the logically contradictory aphorism that "everybody's property is nobody's property." When resource degradation was also observed this would corroborate the "inevitable tragedy of the commons" and the misconstrued picture was complete. This diagnosis further invited inappropriate policy recommendations since the process that led to such prescriptions was erroneous.

PROPERTY REGIMES AND RESOURCES

The task before us is to help correct the misperceptions and logical fallacies that flow from the "tragedy of the commons" story. To accomplish that, it is first necessary to have a clear idea of property concepts that form the essence of a resource regime. By a resource regime we mean a structure of rights and duties that characterizes the relationship of individuals to one another with respect to that particular resource. Institutional arrangements are established to define the property regime over land and related natural resources -- whether that regime be one we would call state property, private (individual) property, or one of common property. These institutional arrangements define one individual vis-a-vis others, both within the group (if there is one), and with individuals outside of the group. We can define property relations between two or more individuals (or groups) by stating that one party has an interest that is protected by a right only when all others have a duty. It is essential to understand that property is not an object such as land,
but rather is a right to a benefit stream that is only as secure as the duty of all others to respect the conditions that protect that stream. When one has a right one has the expectation in both the law and in practice that one's claims will be respected by those with duty. The mischief to come from the term "common property" is that one tends to think of "property" as land rather than more correctly as the claim to a benefit stream that is protected by social convention or by a structure of entitlements.

Before defining several main types of property regimes over various natural resources, it is useful to recall that the recent interest in the nature and status of common property was triggered not by pure academic concerns, but rather by the practical problems faced in development interventions. The development community has gradually come to realize that it will not be successful in addressing resource degradation at the local level so long as the very nature of property and authority systems over natural resources are seriously misunderstood in policy formulation and in the design of donor-assistance programs. In this context, common property regimes have attracted considerable analysis and debate, with both researchers and development practitioners distancing themselves more and more from the stereotype of the "tragedy of the commons."

Our primary purpose here is to challenge the fallacy of received doctrine about group owned/managed natural resources in the developing world. Among these regimes, common property carries the false and misplaced burden of "inevitable" resource degradation that properly belongs instead to situations of open access resources. At the same time, we note that the very essence of a common property regime -- a small-scale community irrigation scheme -- is rarely recognized as such. For some time now, Hardin's allegory of the "tragedy" has been the dominant paradigm within which social scientists assess natural resource issues. As such, it appears explicitly and implicitly in the formulation of many programs and projects. Unfortunately, its power as a metaphor is not matched by its capacity for specifying the strengths and weaknesses of existing resource management regimes. By confusing an open access regime (a free-for-all) with a common property regime (in which group size and behavioral rules are specified), the metaphor denies the very possibility for collective action for which the potential is considerable in the developing world. The Hardin metaphor is not only socially and culturally naive, it is historically false. Worse, it deflects analytical attention away from the actual organizational arrangements that make common property regimes "going concerns." By masking the essence of resource management regimes, it is little wonder that the only viable resource regimes appear to be privatization or nationalization.

When resource degradation is observed, those with incomplete knowledge of such matters may well attribute that degradation to an assumed -- but not necessarily existing -- regime of "common property." They will then often be led to reason that if only private property rights could be established to replace the "commons" the problem would be solved. Yet when resource degradation is observed on private lands -- soil erosion, water pollution -- the cause is assumed not to lie with the property structure at all, but is attributed, instead, to unduly high rates of time preference on
the part of the owner, or some incentive problem that can be rectified with taxes or bribes. This asymmetry of logic -- blaming the absence of private property in one instance, and slipping to alternative causal explanations when private property is present -- obscures rather than clarifies the real issues involved.

Several recent events, including new socioeconomic research in various developing countries, give cause for optimism in the efficacy of common property regimes under well-defined circumstances. The U.S. National Academy of Sciences has produced an impressive volume reporting many instances of successful common property regimes in a variety of countries. The volume also documents the ways in which various pressures have caused the dissolution of particular resource management regimes. The results of this research would seem promising for a clearer design and implementation strategy for agricultural projects that deal with such natural resources (National Academy of Sciences, 1986). A second recent book entitled *The Question of the Commons* provides additional evidence of the confusion sown by the fallacy of "inevitable" degradation of collectively managed resources (McCay and Acheson, 1988). The authors of this volume make clear that common property regimes survive and thrive. Finally, a recently published anthology under the title of *Whose Trees?: Proprietary Dimensions of Forestry* documents the property rights issues pertinent to successful reforestation efforts in the developing countries (Fortmann and Bruce, 1988). These and other volumes, plus a sense that the development community is increasingly open to innovative ideas about resource management regimes, suggest optimism that the simplistic answers of the recent past -- when the *a priori* "solution" was privatization (individual property) or nationalization (state property) -- are now being reconsidered.

In elaborating the possible property regimes, it is sufficient to consider four possibilities: (1) state property; (2) private property; (3) common property; and (4) non-property (open access).

**State Property Regimes**

In a state property regime ownership and control over use rests in the hands of the state. Individuals and groups may be able to make use of the resources, but only at the forbearance of the state. National (or state) forests, national (or state) parks, and military reservations are examples of state property regimes. Shifts from state property to other types, or vice versa, are possible. For instance, the 1957 nationalization of Nepal's village forests by the government converted a common property regime at the village level into a state property regime. However, in the absence of effective enforcement of the new property regime, coupled with the villagers' perception that "their" forests had been expropriated by the government, the resource became -- for all practical purposes -- an open-access resource which villagers felt free to squander.

Notice that the state may either directly manage the use of state-owned natural resources through government agencies or lease them to groups or individuals who are thus given usufruct rights over such resources for a specified period of time. An example is the "tree growing associations" created experimentally in West Bengal (and elsewhere in India) consisting
of groups of landless farmers who are given a block of public land for tree planting. The members are not granted land titles, but the group is given usufruct rights on the land and ownership rights of its produce.

**Private Property Regimes**

The most familiar property regime is that of private property. While most think of private property as individual property, note that all corporate property is private property, yet it is administered by a group. Also recall the pervasive duties that attend the private control of land and related resources; few "owners" are entirely free to do as they wish with such assets.

It is appropriate here to mention several fallacies about private property that dominate received wisdom in development circles. The first "truth" concerns land ownership and investment in agricultural land. Call this the investment fallacy. We are often told that secure titles are needed so that banks will extend credit to farmers, and so that there will be an incentive for farmers to invest in land improvements. We do not quarrel with the fact that banks will not extend certain kinds of credit without secure land titles. Our question focuses, rather, on the logical necessity of having secure title in order to obtain long-term credit.

There is, in theory, no compelling reason why agricultural credit cannot be extended to farmers in the absence of land as collateral. Since interest rates are the price of money -- including the risk of default -- there is a market-clearing price for agricultural credit for farmers able to pledge only their crop -- or their bullock -- as collateral. The fact that lending organizations demand ownership does not make it necessary in theory -- only in practice. Agricultural credit markets have operated throughout history without private ownership of land. And the local saving societies (or circles) so prevalent in most developing countries have default rates significantly below those of the "formal" credit sector where titles seem to be so essential. If the argument is that land as collateral is a necessary condition for adequate levels of agricultural lending then that is an empirical question that can be addressed in different settings in which the term "adequate" is defined, and in which other policy instruments for mobilizing credit are also considered.

The second part of the investment fallacy is that farmers will not invest without secure title -- that is, ownership. The assertion fails to admit that a lease for 15-25 years provides security of tenure over a planning horizon that is relevant under most reasonable assumptions of farmers' rates of time preference. Recall that at a discount rate of 10 percent, future benefits beyond 20-25 years are essentially zero; it is therefore unnecessary to provide security beyond that time. Leases can easily have rollover provisions that protect some reasonable planning horizon for the farmer. The necessary condition for security is an enforceable lease, not deed of ownership.

The confusion in thinking under discussion here arises from a failure to distinguish policy instruments from policy objectives. Security is the policy objective, property (or ownership) is the policy instrument; when an alternative way can be found to accomplish the objective, no great
loss is suffered by the choice of instrument. By definition, policy instruments are mere mechanisms for accomplishing particular objectives. If private property and a corresponding title is the policy objective of the Government -- or of the Bank -- then that should be so stated. In the absence of that declaration secure tenure is the policy objective and one can then undertake a search for the most effective policy instrument. Private property rights may be one of these candidate instruments, but it is certainly not the only one.

In this regard we call attention to another presentation at this symposium (Migot-Adholla, et al., 1988). The paper reports on work in progress in Africa concerning land tenure and agricultural production. The authors suggest that it is best to avoid "broad generalizations about the supposed inefficiencies of indigenous land tenure systems in sub-Saharan Africa, and of the need for simplistic interventions such as the enactment of national land laws or land registration (Migot-Adholla, et al. 1988, p. 14)."

The paper continues by noting that:

...where indigenous social fabric has been eroded so that the traditional institutions are weak, reliance on "elders" who are often no more than government appointees not conversant either with customary tenure rules or the niceties of land registration statutes may lead to injustices. This then suggests a strategy that predicates land registration programs on demand from the bottom rather than imposition from above. It also suggests the need to make adequate provisions for efficient administration of land including the updating of records. Kenya's experience over thirty years suggests that land registration without other supportive services and appropriate macroeconomic conditions is not likely to improve security or promote credit markets in most of sub-Saharan Africa. Given its high cost of implementation and maintenance it is doubtful that universal land registration should be adopted as a national program by most African countries at present (Migot-Adholla, et al. 1988, pp. 15-16).

We now turn to the fallacy of stewardship, in which one is concerned with the relationship between land tenure and, say, soil conservation. This argument overlooks the possibility for long-term leases with various incentives to cause tenants to behave in ways consistent with the owner's wishes. There is absolutely no reason why tenants cannot have secure leases, and there surely is no reason why leases cannot have clauses outlining acceptable -- and prohibited -- practices. That is, such contracts would contain performance criteria defining conditions under which the terms of the lease shall continue to be honored by the lessor. One is required to assume absolute ignorance -- or indifference -- on the part of landowners to suggest that tenants can squander soil at their discretion. If there is a problem with tenants dissipating soil, the fault lies with the objective function of the owner, or with the nature of the contract between tenant and owner. We note, in this regard, that empirical
evidence in the United States has yet to demonstrate that tenure is in any way related to soil conservation behavior. Again, the problem is not found in the particular property regime in force, but in the objectives of those with ownership rights, and/or with the nature of the contracts that exist among economic agents.

Consider now the fallacy of absenteeism. It is often said that absentee ownership leads to "under-exploitation." But if land is producing less than it otherwise might then this is a matter of the relative prices of agricultural inputs and outputs, and the level of agricultural income vis-a-vis other alternatives. To focus on tenure is to miss the essence of the issue, and it is to confuse fundamentally different things.

Let us consider now the final fallacy, that of ownership and productivity. Essentially, the argument goes that collective ownership means that land will produce less than if that very same land were under private ownership. While Soviet agriculture is often cited as the proof of this logic, recall that Soviet agriculture is not a situation of common property among the peasants, but rather one of state land worked by individuals under various institutional arrangements (collective farms or state farms). Let us put it as plainly as possible: land at the extensive margin -- that is forest land or rangeland -- is collectively owned and managed precisely because it is of low productivity. Notice we did not say that such lands are of low productivity because they are collectively owned. In the developing countries, indeed even in Switzerland, land at the extensive margin is collectively owned because it is not of sufficient inherent productivity to justify private ownership. One of us makes this point more fully elsewhere (Bromley, 1989).

These fallacies, individually and collectively, will often constitute the rationale for private property in land and related natural resources in the developing countries. It behooves us all to examine our implicit or explicit faith in such propositions when we next undertake project or program responsibilities.

Common Property Regimes

The third regime is the common property regime. First, note that common property represents private property for the group, and that individuals have rights (and duties) in a common property regime (Ciriacy-Wantrup and Bishop, 1975). In one important sense then, common property has something very much in common with private property -- exclusion of non-owners. Common property is corporate group property. The property-owning groups vary in nature, size, and internal structure across a broad spectrum, but they are social units with definite membership and boundaries, with certain common interests, with at least some interaction among members, with common cultural norms, and often their own endogenous authority systems. These groupings hold customary ownership of certain natural resources such as farm land, grazing land, and water sources.

Note that common property of this kind is fundamentally different from the land-based property regimes in collective farms or agricultural cooperatives in the centrally planned socialist economies of Eastern Europe and the Soviet Union. Land in these entities does not belong to the
members of the collective as common property. Rather, the land belongs to
the state. The profound restructuring now going on within Soviet
agriculture, similar in several respects to what is happening in China, is
revealing the effects of state property on management patterns for natural
resources that are not common (or group) property. In contrast, the
customary common property regimes in the developing world are characterized
by group/corporate ownership with management authority vested in the
respective group or its leaders.

Let us mention, if only briefly, the incentives that exist in a
common property regime. This is important in view of the fact that
received doctrine would have us believe that the only incentive is to
pillage and plunder natural resources. To the contrary, a common property
regime is defined by group ownership in which the behaviors of all members
of the group are open for all to see. In the developing countries it is
not stretching the truth to say that -- at the local level -- conformity
with group norms reflects the effectiveness of sanctions against antisocial
behavior. An effective common property regime thus has a built-in
incentive structure that encourages compliance with existing conventions
and institutions. Unfortunately, in many settings, those sanctions and
incentives have become inoperative -- or dysfunctional -- largely because
of pressures and forces beyond the control of the group. But that does not
undermine the essential point that in a social setting in which individual
conformity to group norms is the dominant ethic, common property regimes
offer precisely the incentive compatibility that is vital for effective
performance.

**Open Access Regimes**

Finally we have the open access situation in which there is no
property. Because there are no property rights in an open access
situation, it is logically inconsistent to assert -- as many often do --
that "everybody's property is nobody's property." It can only be said that
"everybody's access is nobody's property." Whether it is a fishery,
grazing forage, or fuelwood, a resource under an open access regime will
belong to the party to first exercise control over it. The investment in
(or improvement of) open access regimes must first focus on this
institutional dimension. If property and management arrangements are not
determined, and if the investment is in the form of a capital asset such as
improved tree species or range revegetation, the institutional vacuum of
open access insures that use rates will eventually deplete the asset.

**Choice of Property Arrangements**

Before closing we turn to a brief discussion of property
arrangements and the important question of sustainable management of
natural resources. The major distinction among the first three types of
resource regimes rests with the decision-making process that goes with the
respective property regimes. Specifically, the private property regime is
usually regarded as one in which a single owner can decide what shall be
done. Those inclined to regard private property as the most efficient
institutional form will usually have this in mind. They would point out
that even a well-organized common property regime still requires consensus
among all of the co-owners before certain actions can be taken. It is this
transaction cost that will be blamed for the cumbersome nature of common property regimes -- even assuming that the group has managed to solve the problems of group size and free riding. We would point out, however, that the very notion of "transaction costs" is culturally specific -- one person's tedious meeting (a cost) may be another's most enjoyable activity (a benefit).

In a situation of open access each potential user has complete autonomy with respect to use of the resource since no one has the legal ability to keep others out; the natural resource is subject to the rule of capture and belongs to no one until it is in someone's physical possession. There are no property rights in this regime, there is only possession. That is, property -- a social contract that defines an individual and an object of value vis-a-vis all other individuals -- cannot exist when an individual must physically capture the object before he/she can exercise effective control. Having property means not having to stand guard over something; the social recognition that gives property its content means that others have a duty to respect the owner's interest in the thing owned.

That leaves the common property regime. While not appropriate in all settings, we suggest that its potential has not been properly understood because of the false reputation arising from the "tragedy of the commons" allegory. Common property regimes have been undermined by external pressures that have destroyed the political and economic vitality of those bodies responsible for management of shared resources. In some instances this autonomy was destroyed long ago. In other cases it was a victim of colonialism, and then of the rise of the nation-state. Common property is private property for the group and in that sense it is a group decision regarding who shall be excluded. But when options for gainful and promising exclusion of excess population have been destroyed by surrounding political and economic events, then those engaged in the joint use of a resource are left with no option but to eat into their capital. However, to blame this situation on their failure to create private property is absurd. Common property (res communis) is not the free-for-all of open access resources (res nullius). Individuals have rights and obligations in situations of common property, just as in private property situations. The difference between private and common property is not to be found in the nature of the rights and duties as much as it is in the number to which inclusion or exclusion applies. The difference is also found in the unwillingness of the group to evict redundant individuals when that eviction will almost certainly relegate the evicted to starvation. In a sense, the group agrees to lower its own standard of living rather than to single out particular members for disinheritance.

We have talked earlier of the need to rehabilitate common property regimes. The question becomes one of how this might proceed. We find a convenient example in the alteration of herders' access to certain grazing lands, as a result of which they are no longer able to use -- without explicit permission, and perhaps payment -- lands that have customarily belonged to a village unit, or to another tribal entity. This change converts those lands from an open access regime to one of common property for the members of the village. With this institutional change enforced through an adequate authority system, one could then begin to address the question of use rates of those within the relevant decision unit (the
village). Recent work by Bank staff in Somalia and Chad suggest that such efforts may soon bear fruit.\(^3\)

We know, of course, that some resource degradation arises from population growth within the relevant decision unit. This use, though exceeding the ability of the renewable resource to sustain its annual yield, cannot be stopped because of the nominal right of every villager to take what he/she needs to survive. The breakdown of the common-property regime arises because of the failure of the decision-making process within the group, and from the inability of the group's authority system to enforce its own decisions. There is a failure to deal with the obvious reality that as village population grows, and therefore as the number of rights holders grows apace, the total demands on the resource will ultimately exceed its rate of natural regeneration. If, for instance, the village believes that all of this larger population has a right to take what is needed, then it is obvious that no villager has a right to anything other than what he/she can capture by being there first. A common property regime for the group becomes -- de facto -- an open access regime for those within the group.

To improve the situation requires a reduction in total offtake until the resource base can generate sufficient annual yield to meet the needs of the new (lower) harvesting, plus allow for some continued regeneration. The obvious problem is to meet the reduced needs of those deemed to be excessive claimants on the resource base until that regenerative capacity is restored. Alternatively, if it is determined that the resource will never be able to sustain the level of demands to be placed on it, then there must be some capital investment to augment it. But capital investment in the absence of a prior institutional solution will simply assure that the new asset is squandered as the old one was.

Hence with open access regimes the necessary precondition for any successful development assistance effort is that the property regime be converted away from open access. Whether it goes to private property, to common property, or to state property is a policy choice that will have to be made on the basis of the conditions at hand. Regardless of which specific regime is chosen, it will require work to establish a new set of rules. Those rules must be made known to all pertinent individuals and social authority systems must be created to assure that those new rules are followed. As regards the comparative advantage of one institutional choice over another, we point out that to individualize resources under a regime of private property in the developing countries will usually conflict with prevailing sociocultural values. Depending on the nature of the asset -- and on the sociocultural characteristics of its users -- we suggest that it may often be more appropriate to restore a common property regime than to attempt to impose thoroughgoing privatization.

It is also likely that a state property regime will be proposed to address the resource degradation problem. A striking feature of the last two decades of development assistance has been the rise of national government influence on the management of local natural resources through central regulatory policies, new legal frameworks, project financing, and direct

\(^3/\) Personal communication with James Coates and Cornelis DeHaan, World Bank
administration. However, most analysts agree that this shift in the locus of control has not resulted in effective natural resource management. It has, instead, simply weakened local customary regimes. The appearance of management through the establishment of governmental agencies, and the aura of coherent policy by issuance of decrees prohibiting entry to state property, has led to continued degradation of resources under the management of government agencies. If the current degradation of state lands is to be arrested, it will require that current practices of indifferent enforcement be corrected, and that staffing levels and incentives be sufficient to administer and manage that domain which the government has taken unto itself. The state has quite often taken unto itself far more resource management authority than it can reasonably be expected to carry out. More critically, it has set the government against the peasant when, in fact, successful resource management requires the opposite circumstances. This is confirmed by the structural changes that appear to be promoted since 1987 in Soviet agriculture. The striking failures of nationalized land and centralized management control may well hold one of the most important development lessons of the last half-century.

SUMMARY AND CONCLUSION

The following points capture the essence of our position on common property resource issues in development.

- The term "common property" has been misunderstood and falsely defined for the past 25 years. Common property regimes are not the free-for-all that they have been described to be, but are rather well-structured arrangements in which group size is known and enforced, management rules are developed, incentives exist for co-owners to follow the accepted institutional arrangements, and sanctions work to ensure compliance.

- Resource degradation in the developing countries, while incorrectly attributed to "common property resources", actually originates in the dissolution of local-level institutional arrangements whose very purpose was to give rise to resource use patterns that were sustainable.

- The dissolution of local institutional arrangements arose from a combination of powerful rulers at some remove from the village, colonial administration, and the rise of the nation state. Urban-oriented national governments have not replaced these former resource management regimes.

- When local-level institutional arrangements were undermined or destroyed, the erstwhile common property regimes were converted into ones of open access in which the rule of capture drove each individual to get as much as possible before others did. While this has been referred to as the "tragedy of the commons", it is, in reality, the "tragedy of open access."
- Development assistance in natural resources and agriculture will only succeed if programs and projects become more concerned with those individuals using natural resources, and less preoccupied with the particular commodities around which projects have traditionally been organized. That is, we must talk less of "livestock projects" or of "fuelwood projects" or of "water projects" and focus instead on the people whose very livelihood depends upon livestock, or fuelwood, or water points.

- Natural resource projects in the developing countries that do not actively incorporate the local users will ultimately fail. The notion that national (or even regional) governments can effectively manage local natural resources is largely without empirical support.

- And finally, to be successful, development interventions concerned with natural resources and sustainable agriculture must emphasize the social arrangements among people as they interact with each other -- and with the natural resource base. An essential ingredient in program and project formulation and implementation is the existence of incentives and sanctions for influencing the individual behaviors of those who live in the local area, and who depend upon the natural resource in question. This means that our emphasis must shift from things (trees, water, fish, fuelwood) to people.

In closing we are encouraged by a new attitude that seems prevalent within the Bank. One recalls the various phases and fads in development assistance -- from import substitution, to appropriate technology, to the "poorest of the poor", to basic human needs, to integrated rural development, to "privatization", and now on to -- apparently -- sustainable development and the environment. But sustainable development and natural resources cannot really be passing fads since they are at the very core of the development problem. The fact that Bank staff are not certain exactly how to proceed in this new situation is the most encouraging sign of all. Certitude and confidence can lead to the arrogance of simple answers to very complex problems. There are no easy solutions to these problems and caution is very appropriate. Our discussions with a number of staff during the course of this review reveal a renewed curiosity about the processes by which poor people in marginal environments make a living. That many are willing to inquire, to question, and to learn is very heartening. There seems to be a recognition that the lending portfolio will -- and must -- shift from one that saw natural resources as extractive opportunities, to one that sees the natural resources of agriculture as the very foundation upon which poor people will build their future.

One should not despair that the easy answers are elusive. Let us search for those answers with the assurance that the right answer will only emerge as we ask the right questions. We are encouraged that the development community seems to have passed through the reductionist phase of development assistance -- a phase in which all solutions were reduced to
simple absolutes. We now embark upon the dialectic phase, in which one probes and searches for the right questions to ask, and only indirectly discovers the set of feasible answers. Out of this process it seems reasonable to suppose that all of us will once again discover the economic and social role of land and related natural resources, and the patterns of social interaction that influence how people use and depend upon those resources.

The first generation of livestock and natural resource projects may have been failures in a strict sense, but they are wonderful teachers for this new phase of program and project activity. Let us proceed with confidence but not condescension; aggressive but not arrogant. It is more difficult to do projects now that we know more than we did ten years ago. But with that learning comes the chance to do even better.
REFERENCES


SESSION II:

INNOVATION IN RESOURCE MANAGEMENT:

FIVE MAJOR AREAS
INNOVATION IN RESOURCE MANAGEMENT: FIVE MAJOR AREAS

SUMMARY

1. WATER RESOURCE MANAGEMENT -- MEETING THE WATER DEMANDS FOR IRRIGATION AND OTHER COMPETING SECTORS

ISSUES AND OPTIONS IN IRRIGATION FINANCE -- G.T. O'Mara

The paper explores the potential for achieving a more efficient, effective approach to World Bank financing of irrigation. Analytically, the discussion is framed in terms of two polar types of irrigation supply: 1) the public policy utility model, which emphasizes efficient delivery of a well-defined irrigation service; and 2) the government fiscal model, which looks at irrigation as only one among many government activities directed toward agriculture. World Bank irrigation pricing policy experience is reviewed in terms of three pricing objectives for the design of irrigation service fees: economic efficiency, income distribution and public savings. It is argued that in each case Bank guidelines for achieving these objectives have proved unsatisfactory.

Given the demonstrated inadequacy of existing guidelines concerning irrigation finance and the growing dissatisfaction with borrower compliance, the author offers four propositions that could constitute a better framework for irrigation lending: 1) accept the basic institutions and values of borrowing countries; 2) approach the finance of irrigation as a policy adjustment issue; 3) assign tax policy instruments to appropriate policy objectives; and 4) embed preservation of renewable natural resources into project design and appraisal. The author concludes with a call for policy discussions within the Bank to address the difficult issues the paper raises.

WATER RESOURCES MANAGEMENT -- B. Albinson and D.J.W. Berkoff

The paper's central theme is the need to view water resources in their totality, with specific reference to river basin management and irrigation systems management. It is argued that there is no alternative to comprehensive river basin planning that can inform the process of choosing between competing water uses and that can facilitate change and adaptation as circumstances and pressures on water resources change. The problem is not one of lack of innovation in the techniques of river basin
analysis but one of why so little use is made of existing techniques. It is argued that the Bank should be more active in developing borrowers', as well as its own, technical and institutional capacity for river basin planning and management.

Irrigation system management must also be viewed in its totality. Illustrations are provided to show that a seemingly straightforward objective such as water savings can be jeopardized by the failure to take the whole system into account. Similarly, in the massive smallholder systems of Asia, realistic assessment is required of the various water constraints and physical and management characteristics of the distribution system that limit the feasibility of a pure demand approach ("system flexibility"), however desirable the latter may be in principle. Of particular concern is the need to not overestimate how far "down" the distribution system control can be effectively extended. Above all, innovation must take into account the total system and be realistic concerning the conditions that will be encountered.

2. WATERSHED MANAGEMENT AND SOIL CONSERVATION

A REVIEW OF EXISTING SOIL CONSERVATION TECHNOLOGIES AND A PROPOSED METHOD OF SOIL CONSERVATION USING CONTOUR FARMING PRACTICES BACKED BY VETIVER GRASS HEDGE BARRIERS -- R.G. Grimshaw

The literature is reviewed on the impact of soil conservation technologies on erosion rates and sediment yields, on soil moisture and surface runoff, and on productivity and yield. In each case the evidence suggests that vegetative systems are generally more effective than structured soil and moisture conservation systems. World Bank experience in India with a vegetative systems approach is then described. This involves the use of Vetiver grass hedges in combination with contour farming. It is argued that this approach represents a significant improvement upon structured soil conservation systems.

3. THE USE OF GROUND WATER -- EXPERIENCE IN SUB-SAHARAN AFRICA

THE USE OF GROUND WATER -- EXPERIENCE IN SUB-SAHARAN AFRICA -- S.J. Carr

A description is provided of successful World Bank experience in two states of Nigeria with promotion of small-scale pump technology for
horticultural crop and wheat production. Explanations are provided for why farmers have quickly adopted this new technology, e.g., the pumps are easily transported and are easily serviced by local mechanics with expertise in repairing similar type motorcycle engines. Significant further expansion in the use of this technology will occur only when tubewell drilling is given over to local teams using hand operated equipment, rather than being done by more expensive government personnel. A second need is to identify alternative crop varieties and cropping patterns that match this irrigation situation and for which a large, future, undistorted market is more certain than is the case for horticultural crops and wheat.

4. LAND ISSUES -- TENURE AND PRODUCTIVITY

LAND TENURE SECURITY AND AGRICULTURAL PRODUCTION
IN SUB-SAHARAN AFRICA -- S. Migot-Adholla, et al.

The paper synthesizes available evidence on the relationship between indigenous land tenure systems and agricultural development in Sub-Saharan Africa. It draws on existing literature and an on-going World Bank study involving field surveys in Ghana, Kenya and Rwanda. It is argued, based on the literature, that the tribally sanctioned right of continuous unchallenged use of agricultural land is the most critical measure of security of tenure and that formal titling is unlikely to afford significantly increased protection so as to engender greater long-term investment in the land.

Preliminary evidence from the World Bank study for Ghana and Rwanda indicates that many farmers enjoy transfer rights for their lands. In addition, the right of continuous unchallenged occupation emerges as more important to African farmers than the ability to sell or make other land transactions. The authors conclude by identifying two salient features of Sub-Saharan land tenure systems. First, individualization of rights to land is increasing in response to commercialization and population pressure. Moreover, this is occurring in quite different legal environments. Second, population pressure alone may not be sufficient to sustain the transformation of land rights toward individualization. Where commercialization is low and off-farm employment opportunities are lacking, social groups often attempt to retain some control over land rights as a form of social security. This sometimes hampers the individual's ability to capitalize on land improvements through the land market or to use land as collateral. The appropriate policy response, it is argued, is not the simplistic solution of enactment of land legislation. Instead efforts should be made to improve economic opportunities and then to nurture changes in indigenous land tenure systems. Moreover, broad generalizations about the supposed inefficiencies of indigenous land tenure systems in Sub-Saharan Africa should be avoided.
THE IMPLICATIONS OF LAND REGISTRATION AND TITLING IN THAILAND
-- G. Feder

The paper reviews the economic theory underlying the emergence of the institution of state-initiated land registration and titling, whose purpose is to reduce landownership insecurity. It is argued that ownership security enhances investment incentives and facilitates better access to credit, thus generating higher farm productivity. The results of several studies from rural Thailand are reviewed. In these studies, the performance of squatters, who lack ownership security, is compared to that of titled farmers. The evidence confirms that squatters are at a significant disadvantage in gaining access to institutional credit because they cannot provide land as collateral. However, where non-institutional credit is abundant, squatters' disadvantages are less severe, as non-institutional lenders do not usually require collateral. The evidence cited also confirms that farm investment in equipment and land improvements is higher among titled farmers, and that their use of inputs and level of output per unit of land is higher as well. The value of titled land is significantly higher than that of untitled land. Differences in economic performance are, however, smaller where the supply of non-institutional credit is dominant. It is argued that the provision of full legal ownership to squatters is a beneficial policy provided that environmental and equity concerns are addressed.

5. FORESTRY RESEARCH

CONTAINING TROPICAL DEFORESTATION: A REVIEW OF PRIORITY AREAS FOR TECHNOLOGICAL AND POLICY RESEARCH -- J. Spears

Promising research topics are reviewed that have the potential to make a decisive contribution to the Tropical Forest Action Plan objectives of containing tropical deforestation, ensuring the basic needs of the rural and urban poor for food, fuelwood, fodder and shelter, preserving the biological diversity of tropical rainforests, and maximizing the potential of forests to contribute a sustainable source of employment, income generation and export earnings. The potential for research in five main areas is examined: 1) forestry research aimed at sustaining food production, improved food security and protection of soil and water resources; 2) tree breeding and improvement programs; 3) utilization and forest products research; 4) conservation of natural forest ecosystems and biological diversity; 5) policy research aimed at addressing the underlying causes of deforestation and formulation of incentives that will encourage indigenous peoples' involvement in tropical forest management and reforestation.
ISSUES AND OPTIONS IN IRRIGATION FINANCE

Gerald T. O'Mara

INTRODUCTION

The use of man-made structures under human control to alter the temporal and spatial distribution of water provided by the natural hydrological cycle goes back thousands of years. Yet the economic, political and legal issues associated with irrigation remain sources of conflict in human societies to this very day. Some societies regard the water from the hydrological cycle as a God-given commodity and object to arrangements which require payment for access to irrigation (for a review of water law systems, see Radosevich (1988)). Moreover, mother nature can be capricious in her distribution over time of ambient rain and snowfall; and the bounty from nature following the laws of physics tends to create its own pattern of distribution in the absence of human intervention.

The natural patterns of distribution are often taken as given by legal systems in assigning property rights to water. Thus, the riparian rights legal doctrine assigns rights of use to property owners whose land touches upon a stream, river, or lake created by natural drainage flows. When demand for use tends to exceed supply (in years of low flows) along parts of a natural drainage system, the historical rights legal doctrine often supersedes in an effort to establish well defined legal rights. However, this precedent-based criterion -- "first in time, first in right" -- puts latecomers in a disadvantaged position and thus provides an incentive for promotion of investments that will increase the rate of capture of naturally occurring flows as well as facilitating their distribution over time.

Since water rights are problematic in the absences of clear legal definition and effective enforcement, the supply available to any user depends on the actions of other users and potential users. This physical linkage between users makes it difficult to finance and organize irrigation investments privately, except in the case of tubewells abstracting from groundwater where land owners face no significant legal restraints. (For a discussion of the economic effects of physical linkages between irrigating farmers, see O'Mara (1988)). In simple consequence, irrigation supply comes overwhelmingly from investments by some branch of government, even in countries such as the U.S. where custom strongly prefers private sector development.

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When the stage of significant public sector investments is reached, the natural pattern of drainage is changed, and the allocation of water supply inevitably becomes a matter of public policy. Note, however, that distribution is constrained by topography and the large increase in cost that occurs when water must be pumped uphill. Despite this constraint, the introduction of surface irrigation to an arid or semi-arid region creates a production potential that is very large in relation to previous production. The value of this potential production when realized minus the social opportunity costs of all nonwater inputs defines the rent that is available to be distributed via public policy. To the extent that policy permits access to irrigation water at less than its marginal value in agricultural production, the irrigation rent is captured by land owners and ultimately capitalized into land values. Thus, charges for irrigation services inevitably have strong distributional implications; and the determination of such charges is almost invariably subject to a political process. For example, a political leadership that assigns large irrigation rents to a favored group of land owners may create a powerful supportive constituency that will ensure political control over many years. The introduction of surface irrigation to more humid regions as a supplement to rainfed flows is similar except that the irrigation rent will be smaller per unit of land.

Models of Irrigation Supply

Analytical characterizations of irrigation supply tend to conform to one of two polar types: 1) the public policy utility model, and 2) the government fiscal model. The former emphasizes efficient delivery of a well-defined irrigation service, and the latter looks at irrigation as only one among many governmental activities directed toward agriculture.

The Public Utility Model

This model consciously seeks the analogy of irrigation supply with the specialized supply of services such as electricity or telecommunications. It envisions a quasi-autonomous organization which supplies clearly specified irrigation services to a clientele of irrigating farmers in a river basin or similar natural irrigation unit. The irrigation utility controls investment, operations and maintenance decisions, assesses and collects irrigation service fees, and arranges long-term finance by issuing bonds. Irrigation service fees are set such that they cover the costs of the irrigation utility. If government wishes to subsidize irrigating farmers, then the subsidies are paid to the utility in return for setting fees at a level that is less than cost.

In principle, the utility has an incentive to provide irrigation services efficiently (if it is diligently regulated and monitored) and should provide no more or less service than farmers are willing to pay for. In practice, once subsidy is admitted, the simple efficiency claims for the utility model no longer hold. In addition, once sustained operation comes to depend on subsidy, it is very likely that the utility will no longer be as responsive to farmer demands.
The Government Fiscal Model

This model views governments as irresistibly drawn to intervene in agriculture by means of taxes or subsidies on the prices of outputs and inputs by means of investment in infrastructure, research and extension, and by means of services such as irrigation, pest control, marketing of outputs and inputs, commodity inspection and grading. From this perspective, the provision and pricing of irrigation services is simply one among many interventions by government, and both efficiency and equity concerns require the consistency of irrigation policy with the other governmental interventions in agriculture.

The fiscal model finds no special merit in either financial or operational autonomy. Irrigation revenues are collected in the same fashion as any other tax, and irrigation investments, operations and maintenance are part of the general government budget and subjected to the same fiscal scrutiny. Thus, routine maintenance of an irrigation system must promise marginal returns equal to the marginal cost of government revenue even in times of fiscal stringency if it is to be fully funded on a sustained basis.

It also follows that there is no necessary connection between payment of irrigation service fees and the financing of irrigation investments, operations and maintenance. Moreover, the information and high level management requirements for determination of consistent, efficient and equitable policies toward agriculture are increased by at least an order of magnitude. In consequence, many developing country governments are unable to generate policies toward agriculture that are consistent, efficient and equitable.

WORLD BANK IRRIGATION PRICING POLICY

From the beginning, Bank policy emphasized recovery of all costs from project beneficiaries. This policy was re-affirmed by Operational Policy Memorandum (OPM) No. 2.61 (March 1971), which admitted that agricultural projects were sometimes an exception, but added that "as a minimum, operational and maintenance (O&M) costs should be recovered completely." This was the policy in place for the sequence of irrigation projects assessed in the latest Operations Evaluation Department (OED) review ("World Bank Lending Conditionality: A Review of Cost Recovery in Irrigation Projects", June 1986), which is discussed below.

However, cost recovery policy was significantly changed in 1976 with Central Projects Memorandum (CPM) No. 8.4, which imposed detailed instructions with respect to the progressive taxation of incremental project rents. The policy of CPM 8.4 was slightly revised to provide more flexibility in implementation by Central Project Note (CPN) No. 2.10 in 1980. This policy statement, which is now called OPN 2.10, is the operant current policy.

The policy instructions of OPN 2.10 set forth three pricing objectives for the design of irrigation service fees: economic efficiency, income distribution and public savings. The instructions under each objective will be discussed in turn.
Economic Efficiency

The instruction is in terms of "efficiency prices", which are not defined, and it recommends volumetric pricing (where possible) of irrigation service fees. Clearly it is intended that utility maximizing farmer irrigators should be given an incentive to apply irrigation water up to the point at which the value of the expected utility from an additional unit of water would be equal to its marginal cost. If all farmers have the same expected utility and the private marginal cost (i.e., unit irrigation service fee) is equal to the marginal social cost of irrigation water, then the marginal condition for economic efficiency (Pareto optimality) is met. However, only a tiny minority of irrigating farmers in developing countries face volumetric pricing of water and can obtain additional water on demand (even within limits). All other farmers receive an exogenously determined allocation that varies stochastically from period to period (this neglects the fortunate few that have a tubewell). Such farmers form expectations of how much water they will receive (and when) over a cropping cycle and allocate the expected quantity so as to maximize their expected utility. That is, they allocate expected deliveries to given crop acreages according to farm specific shadow prices.

The irrigation service fee (usually area based) is perceived as a lump sum tax which is irrelevant to the farmers' water allocation decisions. The quantity allocation to farmers, insofar as system design permits choices, is accomplished by the irrigation system managers under guidelines from their political masters. There is no reason why such an allocation cannot be efficient. To achieve efficiency consistently, however, requires appropriate incentives for system managers, detailed information on the value of the marginal product of water across farm types and regions, and for many countries enabling legislation. OPN 2.10 does not consider these possibilities, but rather notes that "other methods of assessing charges may also have to be considered to ensure an equitable income impact of the project and an adequate recovery of project costs."

Income Distribution

This instruction is seemingly more precise. It asserts that taxes (irrigation service fees) to capture a share of project benefits should take into account the ability of different farmers to pay. That is, benefit taxes should be progressive although "taking into account disincentives, tax evasion and problems of cost collection." The indicator of benefits is the incremental value at the farm level of what we have called the irrigation rent (net of irrigation service fees or their equivalent). Farmers below a critical consumption level (CCL) would not be taxed, while those above that level would be taxed progressively as income increased above the critical level.

Note that this instruction requires the calculation of income on a farm by farm basis, although a proxy such as farm size or marketed output might be used, and then assessing irrigation service charges under a progressive schedule. The information requirements for implementation of this instruction are considerable, as are the opportunities for arbitrary assessment by tax collectors. Moreover, the income distribution
instruction is totally at variance with the thrust of the economic efficiency instruction.

Public Savings

This instruction aims at increasing the volume of investable resources in the hands of the government in preference to additional consumption by at least the more affluent citizens. However, it recognizes a potential conflict with the income distribution objective if many of the project beneficiaries are poor. It is noteworthy for the absence of any instructions on project sustainability or replicability.

In summary, existing policy guidelines provide little guidance in applying multiple criteria for pricing of irrigation service fees. In particular, the income distribution instruction seems unworkable and inconsistent with the spirit of the economic efficiency instruction. The project analyst is left free to develop his own weights for the several objectives; and in that sense, anything goes. One suspects that the unworkable income distribution guidelines have been mostly ignored. The spirit of OPN 2.10 is clearly laissez faire. It recognizes that "efficiency pricing" may be in conflict with the other objectives and suggests that other forms of taxation, such as a land tax or a betterment tax might be substituted. Presumably these taxes may be set at levels which do not conflict with other objectives. The instruction on benefit taxes also advises that the effects of a project on revenues from other taxes should be taken into consideration, i.e., increments in other revenues due to the project should be deducted from the irrigation rent on which water charges or benefit taxes may be levied. OPN 2.10 goes on to observe that: "There is no prima facie reason why any particular share of costs, such as O&M costs, should normally be recovered."

A further note on financing operations and maintenance (O&M) was issued by OPS in 1984. This note asked that assurances be required (at the appraisal stage) that sufficient funds would be available for O&M. It also specified that there should be an analysis of how the fiscal system affects farmer incentives. Perhaps most interestingly, the 1984 note did not require that O&M costs be covered by direct cost recovery from project beneficiaries. It should be noted that none of these instructions asked for an analysis of the consistency of the many government interventions in agriculture with the proposed scheme for irrigation service fees. In particular, there was no reference to an analysis of direct and indirect taxation of agricultural outputs. Nor was any justification ever given for using irrigation water fees as a vehicle for income redistribution when much more efficient means for targeting the poor were available.

A BRIEF REVIEW OF BANK IRRIGATION COST RECOVERY EXPERIENCE

This section summarizes documented Bank experience and is based on the aforementioned OED review of June 1986. As noted above, the review covers the period up to 1976, when relatively unambiguous policy guidelines were in place. The long gestation period for implementation of irrigation projects and the lack of consistent guidelines over the 1976-88 period make it likely that the appearance of a similar review for that period is some years away.
Since the overall assessment of Bank experience given in the summary of the 1986 OED review is clear and concise, it is repeated here:

"Overall, the cost recovery record in irrigation projects has not been good. Frequently, the Bank's requirements as expressed in lending covenants, particularly with respect to recovery of investment costs, have been so vague that compliance or noncompliance is difficult to determine. In at least two-thirds of the projects reviewed the covenant requiring that cost recovery satisfy O&M funding has not been complied with. The proportion of O&M costs recovered was frequently between 15 and 45 percent. In addition, there were very few cases where capital costs were recovered."

The OED report goes on to note that O&M of irrigation systems was considered satisfactory at audit in only about half of the projects. Compliance with cost recovery covenants was assessed as satisfactory in only 15 percent of the cases. When the pricing covenants required a socio-economic survey and it was implemented, the recommendations were "generally not applied". The response of Bank operations staff to noncompliance with cost recovery covenants has been quite variable, covering the gamut from refusal to consider further financing of irrigation projects to no reaction at all.

**SOME REASONS FOR NONCOMPLIANCE WITH IRRIGATION LENDING CONDITIONALITY**

The 1986 OED review on irrigation cost recovery singles out three major reasons for the record of noncompliance with cost recovery covenants: 1) the often heavy burden of direct and indirect taxes already imposed on agriculture; 2) unreliable water supply due to poor O&M of irrigation systems; and 3) the lack of government commitment. The evidence with respect to each reason will be briefly assessed in turn.

**Direct and Indirect Taxes on Agriculture**

The most comprehensive and consistent evidence on direct and indirect taxation of agriculture comes from the World Bank comparative study of the political economy of agricultural pricing policies directed by Anne O. Krueger, Maurice Schiff & Alberto Valdes (hereinafter KSV). This study provides estimates from country-level research studied for eighteen developing countries. The initially published results focus on the impact of direct and indirect policies on the prices of major export and import-competing commodities. For details of the KSV methodology, the reader is referred to their published papers.

Table 1 (from KSV) presents their estimates of nominal direct, indirect and total intervention for representative export crops in sixteen countries over the period 1975-79 and 1980-84. The numbers on direct intervention give an estimate of the percentage by which domestic producer prices deviated from the border price (adjusted for transport, storage, other costs and quality differentials) measured at the official exchange rate. The estimates of indirect effects make allowance for the effect of
### Table 1: Direct, Indirect, and Total Nominal Protection Rates for Exported Products (percent)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Wheat</td>
<td>-25</td>
<td>-16</td>
<td>-41</td>
<td>-13</td>
<td>-37</td>
<td>-50</td>
</tr>
<tr>
<td>Brazil</td>
<td>Soybeans</td>
<td>-8</td>
<td>-32</td>
<td>-40</td>
<td>-19</td>
<td>-14</td>
<td>-33</td>
</tr>
<tr>
<td>Chile</td>
<td>Grapes</td>
<td>1</td>
<td>22</td>
<td>23</td>
<td>0</td>
<td>-7</td>
<td>-7</td>
</tr>
<tr>
<td>Colombia</td>
<td>Coffee</td>
<td>-7</td>
<td>-25</td>
<td>-32</td>
<td>-5</td>
<td>-34</td>
<td>-39</td>
</tr>
<tr>
<td>Cote D'Ivoire</td>
<td>Cocoa</td>
<td>-31</td>
<td>-33</td>
<td>-64</td>
<td>-21</td>
<td>-26</td>
<td>-47</td>
</tr>
<tr>
<td>Egypt</td>
<td>Cotton</td>
<td>-36</td>
<td>-18</td>
<td>-54</td>
<td>-22</td>
<td>-14</td>
<td>-36</td>
</tr>
<tr>
<td>Ghana</td>
<td>Cocoa</td>
<td>26</td>
<td>-66</td>
<td>-40</td>
<td>34</td>
<td>-89</td>
<td>-55</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Rubber</td>
<td>-25</td>
<td>-4</td>
<td>-29</td>
<td>-18</td>
<td>-10</td>
<td>-28</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Cotton</td>
<td>-12</td>
<td>-48</td>
<td>-60</td>
<td>-7</td>
<td>-35</td>
<td>-42</td>
</tr>
<tr>
<td>Philippines</td>
<td>Copra</td>
<td>-11</td>
<td>-27</td>
<td>-38</td>
<td>-26</td>
<td>-28</td>
<td>-54</td>
</tr>
<tr>
<td>Portugal</td>
<td>Tomatoes</td>
<td>17</td>
<td>-5</td>
<td>12</td>
<td>17</td>
<td>-13</td>
<td>4</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>Rubber</td>
<td>-29</td>
<td>-35</td>
<td>-64</td>
<td>-31</td>
<td>-31</td>
<td>-62</td>
</tr>
<tr>
<td>Turkey</td>
<td>Tobacco</td>
<td>2</td>
<td>-40</td>
<td>-38</td>
<td>-28</td>
<td>-35</td>
<td>-63</td>
</tr>
<tr>
<td>Zambia</td>
<td>Tobacco</td>
<td>1</td>
<td>-42</td>
<td>-41</td>
<td>7</td>
<td>-57</td>
<td>-50</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>-11</td>
<td>-25</td>
<td>-36</td>
<td>-11</td>
<td>-29</td>
<td>-40</td>
</tr>
</tbody>
</table>


**Note:** Korea and Morocco are not included because all main agricultural products are imported.

The direct nominal protection rate is defined as the difference between the total and the indirect nominal protection rates, or equivalently as the ratio of (1) the difference between the relative producer price and the relative border price, and (2) the relative adjusted border price measured at the equilibrium exchange rate and in the absence of all trade policies.

Trade and macroeconomic policies on the real exchange rate and the extent of protection given to nonagricultural commodities. The total effect is simply the sum of the direct and indirect interventions. For the sixteen countries and representative export crops listed in Table 1 the total of direct and indirect taxation of agricultural exports averaged about 40 percent over the 1975-84 period. For most countries, there was significant taxation of exports at both the direct and indirect levels. All of these
countries are Bank borrowers, and many have borrowed to finance irrigation projects -- e.g., Egypt, Malaysia, Pakistan, Philippines, Portugal, Sri Lanka, Thailand, and Turkey. Clearly, the dominant pattern is one of heavy taxation of agricultural exports, with indirect taxation via trade and macro-economic policy accounting on average for about two-thirds of the total.

Table 2 (from KSV) presents comparable data for representative import-competing food crops in 16 countries. In contrast to the export crops, which were taxed at both the direct and indirect levels on average, the import-competing commodities are usually given significant direct protection, but then are indirectly taxed at higher rates so that the total effect is taxation of import-competing crops on average by about five percent. However, if two countries which have given exceptional protection to rice -- Korea and Malaysia -- are excluded, the average for total protection changes to -15 and 18 percent for the two periods. Some countries tax import-competing commodities at both levels, achieving total protection of about -60 percent in the cases of Pakistan (wheat) and Zambia (corn).

While discrimination against agriculture is well known, the KSV results provide quantitative measures of the degree of bias against agriculture. In the face of such massive direct and indirect taxation of agricultural commodities, it is not surprising that farmers resent additional taxation. Nor is it surprising that many governments are reluctant to impose additional taxes on farmers. In fact, many of their direct agricultural interventions, e.g., subsidies on irrigation water, fertilizer, pesticides and credit, are in the nature of second-best measures designed to offset (at least partially) the disincentives to agricultural output from macroeconomic, trade and agricultural pricing policies.

**Unreliable Water Supply**

If operations and maintenance are not adequate, or if the irrigation system is poorly designed, water supply may not be dependable. In such circumstances, farmers are understandably reluctant to pay irrigation service fees, particularly if they are confident that system managers will not cut off their supply for nonpayment. Since the design of irrigation systems in most developing countries prevents system operators from discriminating between paying and nonpaying farmers, the threat of loss of supply seems remote to many farmers. Moreover, in most cases, system operators do not depend on irrigation service fees for finance of O&M. Thus, while good O&M may be a necessary condition for adequate direct cost recovery, it is not sufficient since many countries follow the fiscal model which commingles irrigation fees with general government revenues and finances irrigation O&M from the general government budget.

Bank policy and practice have often implicitly assumed that governments follow the public utility model of irrigation service provision when in fact they do not. In addition, as Wade (1979, 1982) has demonstrated, in some countries O&M funds are used by the irrigation system managers for private rent collection. In the light of these hard realities, many irrigation economists now argue that taxation of
Table 2: Direct, Indirect, and Total Nominal Protection Rates for Imported Food Products
(percent)

<table>
<thead>
<tr>
<th>Country</th>
<th>Product</th>
<th>1975-79</th>
<th>1980-84</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>Indirect</td>
</tr>
<tr>
<td>Brazil</td>
<td>Wheat</td>
<td>35</td>
<td>-32</td>
</tr>
<tr>
<td>Chile</td>
<td>Wheat</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Colombia</td>
<td>Wheat</td>
<td>5</td>
<td>-25</td>
</tr>
<tr>
<td>Cote D'Ivoire</td>
<td>Rice</td>
<td>8</td>
<td>-33</td>
</tr>
<tr>
<td>Dominican</td>
<td>Rice</td>
<td>20</td>
<td>-18</td>
</tr>
<tr>
<td>Egypt</td>
<td>Rice</td>
<td>79</td>
<td>-66</td>
</tr>
<tr>
<td>Ghana</td>
<td>Rice</td>
<td>91</td>
<td>-18</td>
</tr>
<tr>
<td>Korea</td>
<td>Rice</td>
<td>38</td>
<td>-4</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Wheat</td>
<td>-7</td>
<td>-12</td>
</tr>
<tr>
<td>Morocco</td>
<td>Wheat</td>
<td>-13</td>
<td>-48</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Wheat</td>
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<td>-27</td>
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<tr>
<td>Philippines</td>
<td>Corn</td>
<td>15</td>
<td>-5</td>
</tr>
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<td>Portugal</td>
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<td>-35</td>
</tr>
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<td>Sri Lanka</td>
<td>Rice</td>
<td>28</td>
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</tr>
<tr>
<td>Turkey</td>
<td>Wheat</td>
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<td>-42</td>
</tr>
<tr>
<td>Zambia</td>
<td>Corn</td>
<td>20</td>
<td>-25</td>
</tr>
</tbody>
</table>


Note: Argentina and Thailand are not included because their main food products are exported.

Turkey was a net exporter of wheat in some years, and in the Dominican Republic rice was not traded in some years.

The Direct nominal protection rate is defined as the difference between the total and the indirect nominal protection rates, or equivalently as the ratio of (1) the difference between the relative producer price and the relative border price, and (2) the relative adjusted border price measured at the equilibrium exchange rate and in the absence of all trade policies.

Agricultural output or a tax on agricultural land value are more efficient methods of cost recovery since farmers are not asked to pay for ineffective or unreliable irrigation services that fail to produce a net gain in value of production, or equivalently in land values. Of course, taxation of
agricultural commodities inevitably means taxation of marketed agricultural surplus since farm or village level transactions are virtually impossible to tax in the sense of yielding positive net revenue.

To the extent that the conditions of the public utility model of irrigation service provision are met, the linkage of O&M with collection of irrigation service fees is real. Farmers will understand that their fees finance O&M, and irrigation managers will seek to efficiently collect service fees since they finance their own salaries and perquisites. In such an institutional context, the participation of farmers in tertiary and quarternary level O&M is more natural, though not without problems of the free-rider sort. Bank experience with water user associations is still quite limited, and the results are quite mixed. However, given an irrigation utility institutional context, farmers will quite naturally monitor the activities of the irrigation system managers; and in such cases, it seems sensible to formalize the monitoring role by electing farmer representatives to boards of directors who oversee irrigation system management.

**Government Commitment**

In the final analysis, unless the government of the country is committed to a policy and stands ready to implement it, the policy is null and void. Thus, any and all failures in compliance with covenants to loan agreements can be regarded as due to a lack of government commitment. Equivalently, it can be said that such failure also reflects a lack of commitment on the part of the lending institution when it asks for a covenant that experience and good judgement suggest will not be honored in practice.

Certainly, the Bank has been guilty of insisting on cost recovery policies that clearly are inconsistent with the policies of borrowing governments, especially when the implied change is for a particular project. A continuing dialogue with such a government, through special studies and policy-based lending, may be a more efficacious approach to sustainability and replicability of infrastructure investments than covenants inserted in loan agreements on a project by project basis. A case in point is the government of India, which has stated in writing more than once that its policy is different from the Bank’s and that it does not expect irrigation projects to generate revenues or recover costs to ensure sustainability after completion.

**A FRAMEWORK FOR DESIGN OF EFFICIENT AND ACCEPTABLE IRRIGATION FINANCE**

The previous discussion, by reviewing the Bank’s experience with conditionality on irrigation project lending and considering the major reasons for noncompliance with irrigation lending covenants, has highlighted the growing dissatisfaction with past practice. It remains to synthesize the hard lessons from experience into a better framework for irrigation lending. We believe that the lessons from experience and straightforward application of economic understanding can be boiled down to a set of propositions that do indeed comprise the better framework that is needed. These propositions are presented and discussed in sequence below.
1. Accept the basic institutions and values of borrowing countries. This is fundamental and in general has been the guiding philosophy of the Bank. Where we cannot do this, we do not lend. However, in irrigation lending a misguided zeal for the public utility model has led the Bank to insist on cost recovery covenants that are not acceptable to some borrowing countries. This is not to deny the evident virtues of the public utility model of irrigation finance, but simply to recognize that some countries have objections to it that are deepseated. In general, countries that find the fiscal model of irrigation finance more acceptable, i.e., virtually all former British colonies, will have some problems with the public utility model. Moreover, they are correct in their concerns for the narrow focus of the public utility model. It does not take into account other government interventions that impact on farmers.

2. Approach the finance of irrigation operations, maintenance and replacement as a policy adjustment issue rather than an issue of project design. Most of the irrigation projects financed in countries with major irrigation infrastructure, i.e., most of the Bank-financed irrigation projects, are ultimately managed by large existing bureaucracies for which the additional capacity from the project is small in relation to the total capacity managed. They are most unlikely to change existing practices simply to accommodate a small increment to total capacity. If they do seem to accept a covenant in a project lending document that would appear to require such change, the result may simply be that some other canals of the system will temporarily receive less O&M funding. It is not clear that anything has been gained by the transfer of funds induced by such a project loan covenant.

On the other hand, conditionality attached to policy-based lending could and should apply to the entire system. Such considerations apply with particular force to countries that operate according to the fiscal model since there is no linkage between direct cost recovery and financing of O&M. Even in countries that operate according to a modified public utility model, the setting of irrigation service fees will almost always involve some element of subsidy. The level of this subsidy should take into account other government interventions, and it is therefore more easily handled as a policy adjustment issue.

3. Assign tax policy instruments only to appropriate policy objectives. The need for this proposition should be evident from the problems generated by the failure of efforts to overload irrigation service fees with multiple objectives. As Tinbergen demonstrated decades ago, only one policy target can be assigned to a policy instrument if unequivocal results are to be obtained. Given the multiplicity of government interventions in all countries, the problem is not a lack of instruments but their appropriate assignment and the determination of instrument levels that best achieve overall welfare. Of course, the decisions that trade off gains and losses for various policy objectives are made at the highest political level, and these are typically resolved through the budgetary process. Budget requests from various elements of government are assessed by budgeting offices or treasuries, and revised allocations are returned in a multi-stage, iterative process. When playing a role in the budgetary game, no finance minister or budget office director with his wits about him
is going to look on irrigation service fees as an instrument of achieving income distributional objectives. In the first place, farmers receiving irrigation services are not the poorest of the poor. The latter are landless laborers and rainfed small farmers. Secondly, attempting to collect a tax by discriminating between irrigation recipients on the basis of income is unworkable. There are better instruments for achieving income distributinal targets.

At first glance, it is not clear whether economic efficiency or cost recovery is the proper assignment of irrigation service fees. However, when irrigation services are not priced volumetrically and available to irrigators on demand, then irrigation fees are properly perceived as lump-sum taxes. Since these restrictive conditions obtain for only a tiny minority of irrigators in developing countries, for the vast majority of such farmers irrigation fees are irrelevant to their water allocation decisions. They do the best they can with the amount of water they expect to get from the irrigation system by assigning a personal scarcity price to water and allocating what they expect to get on their land in such a way as to maximize their private welfare. Thus, we are left with cost recovery to achieve resource and project sustainability as the appropriate assignment of irrigation service fees. Some analysts have argued that the transfer of large irrigation rents induces a political demand for irrigation services that results in excessive investment in irrigation (cf. Newbery (1987)). However, this is not an argument over the marginal conditions for Pareto efficiency, but rather is concerned with the political economy of large irrigation subsidies. The optimal setting of irrigation service fees for cost recovery should certainly be sufficient to avoid excessive political demand for irrigation subsidies.

4. Embed preservation of renewable natural resources as the central focus of irrigation project design and insist on covenants that ensure both water resource and project sustainability. The major criticism of Bank-financed irrigation projects that comes from external sources, and it is heard increasingly, is that these investments have failed to adequately safeguard the natural environment. Without going into the substance of these charges -- though they deserve a response on a suitable occasion -- the Bank clearly should make every effort to ensure that valid environmental concerns are safeguarded in all decisions concerning project and policy lending. This means that sustainability as applied to irrigation projects must be interpreted broadly to include the environment as well as physical irrigation investments (with the sole exception of nonrenewable water resources). (For a discussion of sustainability as applied to irrigation, see O'Mara (1988)).

The environmental issue that is typically encountered in surface irrigation projects is that of waterlogging and salinization due to inadequate drainage. Project specification and planning must make provision for adequate drainage in all projects. This does not mean that drainage investments need to be constructed prior to a realized need, but rather that a foreseeable future drainage requirement should be treated as integral to the project. That is, discounted costs and benefits due to future drainage investments should be included in the calculation of the overall project rate of return. However, drainage investment costs would
not be included in the project loan. Rather, they would be treated as a necessary future time slice investment.

**IMPLICATIONS OF THE FRAMEWORK FOR IRRIGATION FINANCE FOR BANK IRRIGATION LENDING**

In order to put the proposed framework in context, this section develops its implications for irrigation lending. These implications are advanced as suggestions with respect to the directions that Bank policy might take in clarifying existing policy and removing the sources of some legitimate concerns. The implications are put forward in the form of specific guidelines in order to give them a concreteness that would facilitate discussion by the many specialists involved in irrigation lending.

1. Cease insisting on a modified public utility model in project design. It is clear that the present approach is unacceptable to many borrowing countries. In addition, the public utility model ignores the many other interventions by government that impact on agriculture. The utility model is optimal for a first-best world in which other interventions by government are neutral with respect to resource allocation and distributional policy is handled by lump-sum taxes. However, its application to a second-best world offers no assurance that such application would lead to an improvement in either efficiency or equity.

2. Base policy on an analysis of the totality of government interventions. The basic problem with a second-best world is that there is no assurance that any single intervention will provide an improvement in either efficiency or equity without conducting an analysis of the impact of all government interventions. This is a daunting requirement and causes analysts to seek approximate answers which require less information and lead to a more transparent analysis. However, the choice of the right approximation and its interpretation for policy purposes is skill intensive. In this sense, the proposed policy guideline remains essentially valid. In one way or another, the analyst must take account of the totality of government intervention in assessing the impact on a given sector or group of people. The previous discussion of the indirect impact on agriculture of macroeconomic and trade policy as quantified by Krueger, Schiff and Valdes has shown that anything less will be inadequate. This does not mean that agricultural, natural resource and irrigation economists concerned with irrigation lending must be retrained to acquire macroeconomic skills. It does mean that the macroeconomists working on country policy problems must be part of the team reviewing both project and policy lending related to irrigation; and that on occasion it will be necessary to bring in consultants with the specialized skills needed to assess overall policy impacts. As a first approximation, it would seem desirable that country macroeconomists use the Krueger-Schiff-Valdes methodology to determine indirect commodity-specific impacts of macroeconomic and trade policy.

3. Accept indirect cost recovery as valid where it exists, but insist on a rigorous accounting of the equity issues of irrigation rent transfer. Funds are fungible! If government is recovering costs indirectly, this is sufficient in principle to assure sustainability.
However, the equity issues need to be confronted. In general, the recipients of irrigation rent transfers are not the poorest of the poor. These are usually landless laborers and rainfed small farmers. In addition, to the extent that irrigation investments result in lower domestic prices for nontradable foods, the irrigation benefit is transferred to consumers of these goods. Clearly, the equity issues of irrigation rent transfers require analysis of the distributional effects of government interventions on both the demand and supply sides. This can be done, but it requires skilled analysts and usually some data collection. General principles and some applications to agriculture are discussed in the volume edited by Newbery and Stern (1987), especially Chapter 13 (by Newbery) and Chapter 16 (by Sah and Stiglitz).

To deal with countries, such as India, which reject direct irrigation service fees and claim that irrigation rent transfers should be part of a distributional policy, a complex analysis of distributional effects would seem to be required. Moreover, the results might indicate the need for extensive tax adjustments. For less refractory borrowers who accept the principle of irrigation service fees, a less complex analysis should be adequate in many cases. In general, one would expect that significant irrigation service fees would be indicated. If direct cost recovery is to be meaningful, these fees must be indexed, either to an index of prices received by farmers or to a cost of living index. The analytical work required to confront the equity issues of irrigation rent transfer is best carried out in connection with policy-based lending. Repetition of this specialized work for each irrigation project would be unnecessary and wasteful.

4. **Insist on covenants guaranteeing that adequate operating and maintenance funds will be available and utilized efficiently.** This requirement should be the cornerstone of the irrigation lending dialogue. As already noted, the requirement should be systemwide to be meaningful. However, the covenant could be routinely inserted in both project and policy loan agreements. Disregard of this covenant should set off an alarm requiring a strong response by the Bank. Continued noncompliance would require cessation of all irrigation lending if the Bank is to retain credibility with respect to its irrigation portfolio.

5. **Require review of project design and appraisal by consultants with appropriate environmental skills.** The mandatory review by environmental specialists is to safeguard the natural environment affected by irrigation projects. Such a review is clearly implied by recent policy statements by the top management of the Bank. The environmental specialists most likely to be needed for environmental impact assessments of irrigation projects are hydrogeologists and drainage engineers. Other skills that may be needed on occasion include foresters, and soils and soil transport specialists.

**SUMMARY**

Up to 1976, Bank policy emphasized recovery of all costs, or at a minimum complete recovery of operations and maintenance costs. Subsequently, policy specified three pricing objectives for design of irrigation service fees: economic efficiency, income distribution and
public savings. The economic efficiency objective was framed in irrelevant terms, while the quite detailed income distribution objective instructions were unworkable. This leaves the public savings objective for which there were not any clear-cut, unambiguous instructions. Thus, for the past 12 years, effective formal policy guidelines for irrigation cost recovery have been nonexistent. Of course, Bank lending for irrigation has been active over the 1976-88 period, which leaves the clear inference that informal rules of thumb for designing cost recovery covenants have existed. Unfortunately, an OED review of loan conditionality concerning irrigation cost recovery for this period has not yet been produced. However, the 1986 OED review of this topic covering the period up to 1976 disclosed that the record was not good in that earlier period. In at least two-thirds of the projects reviewed, the covenant requiring that cost recovery at least cover O&M costs had not been complied with. In many cases, the covenants concerning cost recovery were so vague that it was difficult to determine whether there had been compliance or not. O&M of the irrigation systems concerned was considered satisfactory at audit in only about half of the projects.

Given the demonstrated inadequacy of existing guidelines concerning irrigation finance and the growing dissatisfaction with borrower compliance, a synthesis of the hard lessons from Bank lending experience into a better framework for irrigation lending is needed. This paper suggests that four basic propositions distilled from Bank experience can serve as the basis for such a framework:

i. Accept the basic institutions and values of borrowing countries.

ii. Approach the finance of irrigation as a policy adjustment issue.

iii. Assign tax policy instruments to appropriate policy objectives.

iv. Embed preservation of renewable natural resources into project design and appraisal.

These propositions yield a number of implications for irrigation finance that would change existing practice. The first two imply that the Bank would cease insisting on a modified public utility model in the design of irrigation project finance; and instead base irrigation finance on the totality of government interventions.

The clear lesson from the Krueger-Schiff-Valdes study is that most countries prefer to impose direct and indirect taxes on agricultural commodity outputs. This taxation is usually massive and further taxes on farmers can only be imposed on cost recovery or equity grounds. Often, additional taxation will not be justified. This determination requires, however, a thorough-going economic analysis that goes beyond direct taxation. Replication of the KSV methodology (where necessary) would seem to be an obvious first step in such an analysis.
Abandoning the pretense of a linkage between direct cost recovery and adequate O&M where none in fact exists means that both appraisal and subsequent supervision must insist on covenants guaranteeing that adequate O&M funds will be available and utilized efficiently. This topic should be the cornerstone of the dialogue on irrigation with the borrowing country.

The third proposition means abandoning the futile attempt to address income distributional objectives via irrigation service fees. There are more efficient tax instruments for this objective. Instead, irrigation fees should be assigned to the public savings or cost recovery objective when they are justified by an analysis of overall government intervention. Where they are justified, they must be indexed to avoid erosion of the revenue base by inflation. Finally, the proposition addressed to natural resource preservation implies that project design and appraisal will require review by consultants with appropriate environmental skills.

**EPILOGUE**

This paper is a modest effort to clear away the confusion surrounding irrigation finance both inside and outside of the Bank. That there is a need for a policy dialogue within the institution on this topic is increasingly apparent. Given the evident need, I have tried to go back to first principles and attempted to get it right. Whether or not I have succeeded is for others to say. Certainly, this paper represents the first and not the last shot in the latest controversy over irrigation policy within the Bank. Also, lest we forget, the outside world is observing and commenting on our actions. Thus, Steinberg (1983) observed in a USAID conference volume, "It is significant that to date the World Bank has no policy paper on irrigation, as there are internal disputes on such matters as water-user fees and technological issues such as the lining of canals."
REFERENCES


Radosевич, George, 1988, "Legal Considerations for Coping with Externalities in Irrigated Agriculture", Chapter 3 in O'Mara, ed.


INTRODUCTION

This symposium examines "Innovation in Resource Management" and this session "Water Resource Management: Meeting the Water Demands for Irrigation and Other Competing Sectors". This is a wide field and we are in no position to fully discuss its many facets. Innovation is taking place over a whole range of issues related to water: in resource assessment and hydrology, in systems planning and evaluation, in engineering design and construction, and in water measurement and control, not to speak of new developments in the sectors that utilize water directly or indirectly -- agriculture, hydro-power, flood control, navigation, municipal water supply, industry and fisheries, to name just the most significant.

As a matter of record, however, in many developing countries, innovations in water resources management have been imported which have not always produced the hoped for results. These include advanced computational methods without commensurate data collection, partial solutions that fail to take account of response elsewhere in the system, design concepts which fail to respect practical conditions in the field, and the use of sophisticated structural materials without the ability to control their quality in the field. We view "modern" concrete lining and structures as greatly inferior to the hewn masonry structures of 80-100 years ago and there are disturbing numbers of such systems which require reconstruction or rehabilitation after a few years use. Inferior quality of construction can put an intolerable strain on the operation and maintenance of any innovation.

Rather, therefore, than trying to introduce this subject with a survey of technical innovation, we felt it better to introduce it in terms of some conceptual issues affecting innovation in the context of our work. Construction quality is not directly discussed although this should not detract from its pervasive importance. The paper is organized with reference to two major subjects: river basin management and irrigation systems management. On-farm irrigation is another important subject for an
agricultural symposium but will be referred to only in relation to its
interactions with system management. The discussion is based primarily on
Asian experience but we believe the arguments have general applicability.

Whether the paper adequately deals with "innovation in water
resource management" is for the reader to judge. Indeed, in some respects
it may seem that we are advocating a retreat to less advanced approaches.
Nevertheless we feel that these issues, simple though they may seem, should
have a greater influence on the Bank's activities than they have sometimes
had to date.

RIVER BASIN MANAGEMENT

The need to view water resources in their totality is self-
evident. Water is a finite resource that is fundamental not only to
agriculture but to general development. Pressures on this resource are
mounting at an accelerating rate in every country of the world and, as a
result, conflicts within countries and between countries will grow,
impacting on basic economic, social and environmental conditions and having
increasingly serious political implications.

There is thus no alternative to comprehensive river basin planning
and management to: (i) ensure that interactions between different users
and purposes are fully taken into account, (ii) limit development to what
is feasible with the water resource available, (iii) create a framework
within which allocations between competing users can be made in line with
government priorities, (iv) establish operating rules for responding to
variability from year-to-year and within each season, and (v) facilitate
continued review and adaptation as circumstances change and pressures on
the resource mount.

Water resource development requires an analysis of water yield,
storage, distribution and consumption. These are normally analyzed
separately although in principle there is no reason why the entire water
resource of a basin cannot be modelled as a unified system providing
sufficient data is available. Techniques long available include those to
generate catchment yield from rainfall; those using stochastic methods
based on generated or actual catchment yields to meet demand as modified by
reservoir operations and distribution practices; those for analyzing
groundwater movements and balances; and those for estimating consumption,
including crop water requirements.

Advances in simulation in particular provide an increasingly
powerful tool to explore alternatives and to aid real time operations.
Examples in Asia where these have been successfully introduced for the
management of water distribution in a basin include those adopted for the
Mahaweli in Sri Lanka and the Chao Phraya in Thailand. Attempts have also
been made to utilize optimization models, including linear and non-linear
programming techniques to integrate physical and economic constraints, a
notable example being that by the Bank for the Indus Basin.

Methods of estimating irrigation demand are, perhaps, an area of
particular weakness in current practice since they normally assume full
biological demand rather than the degree of stress found in the majority of
systems. Effective rainfall and irrigation efficiencies are also often dealt with by gross coefficients of obscure origin, while little practical use is made of detailed soils data since the spatial distribution in the system is difficult to analyze with current methods.

Practical applications and the development of more sophisticated approaches have been inhibited by limitations in the data base, including information on meteorology, hydrology, soils and topography. High resolution satellite imagery and remote sensing will provide an unprecedented source of up-to-date data and there is a priority need to develop automatic transfer of data from imagery to the current models. Development of fully unified models will take time. Approaches which show promise include the System Hydraulique Europe program in Europe, and some research programs by the Hydraulic Engineering Center in the U.S. and Ontario University in Canada. Each provides the potential for integrating the total hydrology of a river basin -- catchment, runoff, surface distribution, groundwater, drainage etc. -- in a modular fashion permitting any degree of refinement on specific aspects within a total basin framework.

There is nothing new in advocating comprehensive river basin planning and operations and text books, guidelines and plans for specific basins line the shelves. Nevertheless, it is also true that many of our borrowers continue to plan, develop and operate discrete projects without sufficient reference to their impact on, and integration with, other activities in the basin. The issue is not therefore so much innovation in the techniques of river basin analysis as why so little use has been made of techniques long available.

India is a good example where official recognition of the need for coordinated basin operations goes back at least to draft legislation prepared in the 1950s, was reiterated in the 1972 Irrigation Report and in many other documents, and where a renewed effort is under way in preparation for the Eighth Plan. Yet giant facilities continue to be operated in a traditional ad hoc manner and single purpose development programs proceed without recognizing that, by the time they are completed, they will serve and affect a multitude of other users. The reasons for this are well known, and perhaps do not need elaboration, not the least being the political pressures that affect rational management.

Thus, not only are many of our borrowers a long way behind current technology; in some cases they have yet to take the first steps. "Innovation" in such a context may be no more than establishing the basic organizational framework or introducing the concept of simulation, with attempts to introduce more advanced technologies representing a case of the best being the enemy of the good. Even these limited objectives are, however, sometimes given surprisingly little emphasis by the Bank, which itself may have only limited knowledge of how its own projects interact within a basin program. Even less well studied are operations, in particular how these should respond over time and to year-to-year variability. Developments in a major river basin may take decades and proposals for basin management cannot simply assume the final result nor can they simply assume the average year. Yet surprisingly little attention is given to ensuring that clear, unambiguous guidelines are established.
It is suggested that the Bank should give these issues greater importance by:

- Requiring that borrowers initiate comprehensive resources data collection, planning, development and management in support of all water-related projects;

- Promoting the necessary institutional adjustments required to effectively carry out the above:

- Coordinating internal Bank efforts and procedures to ensure consistency in approach and results within each country; and

- Securing a technical capacity within the Bank to address these issues and support the Bank's activities in the field.

As a first step, Asia Region proposes to form Country Water Resources Committees within each Country Department comprised of representatives of the sector divisions most directly involved in water resource use -- power, agriculture, urban and industrial -- together with Technical Department representation. The first such committee has been established for Indonesia and has alerted staff to potential inconsistencies and duplications in Bank activities, notably in relation to the greater Jakarta region, and has laid the basis for a more coherent approach to institutional proposals and management practices. If proven useful, additional committees will be established for other major countries in the region.

**IRRIGATION MANAGEMENT**

As in the case of river basin operations, management of a surface irrigation scheme must be viewed in its totality. Innovations which fail to take the whole system into account can go wrong, and pilot programs that are confined to one aspect can be very misleading. In this context total system means the distribution of water from the headworks to the plant together with the drainage of excess water and salts. It also means the interaction between engineering design, agricultural requirements and the socio-economic setting within which water distribution must take place.

Taking the whole system into account is not necessarily the same thing as tackling everything at once. The complexity of physical, social and financial constraints may rule this out. However, it does mean that the success of any one innovation will be dependant on resolution of constraints elsewhere in the system. There is no point in attempting too much in one area if the results are negated by the response elsewhere. As in the case of a river basin, innovation in a practical context may fall well behind theoretical potential.

**Water Savings**

A straightforward example of failure to take the whole system into account relates to water savings. Water savings is an objective of many technical innovations, ranging from lining of channels, to improved control and measurement, to advanced systems of on-farm water distribution.
Clearly, other things being equal, saving water must be a good thing. Its pursuit without regard to the total picture, however, can on occasion be wasteful or even damaging. For instance:

- If drainage from one project provides the water supply for another, then if water is saved in the former either the latter must go without or it must be provided with water in another way, possibly with great difficulty or at great cost. Examples could be given where these seemingly obvious effects have been ignored.

- Even within a project, if the area is underlain by fresh groundwater or the system contains reservoirs fed by drainage, water saving may substitute supplies under local control with surface supplies that are inevitably less responsive to farmer needs. Recent work by Dhawan in India suggests that, in both alluvial and hard rock environments, the indirect returns from groundwater recharge can be as much as twice the direct returns from surface supply even allowing for the costs of pumping.

- If the main system supplies are inherently variable or uncertain, expensive on-farm investments in land levelling, etc. may be required as a result of over-irrigation as the farmer utilizes excess water to avoid risk. Similarly, sophisticated water saving investments in the main system supply, besides often being unmanageable, may be wasteful if farmers are unwilling or unable to afford complementary on-farm investments.

- If water is relatively abundant -- for instance early in the development of a major system -- neither farmers nor scheme managers may accept careful management, and may be unwilling to utilize or maintain facilities designed for future scarcity.

- At its simplest, if experience suggests that construction quality or sophisticated operation cannot be assured, investments to save water may repeatedly fail.

**System Flexibility**

Another frequent objective of innovation is "flexibility", a characteristic that in itself also seems inherently desirable. Irrigation supplies should meet the requirements of the farmer on his farm. Since requirements vary over time and differ between farms, the distribution of water should be flexible down to the farmgate, flexibility in this context referring to all three factors which go to make up water delivery -- flow rate, period of flow and frequency of irrigation. Complete flexibility would permit the farmer to obtain water when and in the amounts that he wishes, in other words, would provide water on demand. Since he would have full control on-farm, a demand system would enable the farmer to fully exploit the characteristics of his soil reservoir to meet crop requirements and control salt accumulation.
In practice, water constraints and the physical and management capabilities of the distribution system limit the feasibility of introducing a pure demand approach even in the most advanced surface irrigation systems. In Asia, and no doubt in most other developing areas, these constraints are further compounded by the size of the command areas, the large number of farms, their very small average size, and the relative poverty of most farmers. Pilot programs are inherently bound to fail no matter what results are reported during the period when they are closely supervised.

If water is limited, it is the economic return to water rather than to land that ideally should be the determining consideration. Since the farmer seeks to maximize returns to land and other inputs, constraints must be placed on the amount that he can draw from the system. Pricing can help ration supplies but water rights evolve in many ways and price is virtually never the primary determinant of use: in the developing countries of Asia, in particular, price can have only a very limited role since volumetric measurement is impractical, at least at the farm level. Since demand and supply cannot be balanced in the market place, scheme managers must ration the available water in some other way. In other words, they must establish an irrigation service. It is the adequacy with which this irrigation service is defined and communicated to the farmer, and the reliability with which it is provided, that determines the farmer’s response and hence the success of the surface system. Since the farmer cannot receive all the water he wants, he must know what it is he will receive if he is to plan his activities.

How flexible should this irrigation service be? Flexibility by definition implies control of the management of both the flow rate and the time of flow. If a flexible supply is to be provided at the farmgate, then this requires control down to the farmgate and this is exactly what is attempted in many modernization programs. The distribution system is extended to each farm or field, adjustable gates and other controls are provided to permit variable flow to a low level, and measuring devices such as Parshall flumes are constructed at the head of each watercourse.

If farms are relatively large, if communications are good, and if agriculture is uniformly high value, this can be managed and the costs can be afforded. However, in the massive smallholder systems of Asia, experience has shown that this degree of control is simply not possible. The hydraulic instability of water flows in large distribution networks, the difficulty of frequently adjusting large numbers of gates to account for such variations, the extreme pressures on scarce water and poor communications are some of the most important factors that make detailed control impossible. If water is temporarily abundant, system operators relax and seek to satisfy the last farmer even at the cost of high operational losses elsewhere in the system. If it is scarce, farmers, in tacit agreement with low level system employees, take matters into their own hands resulting in head end/tail end problems, interference with gate settings, damage to the distribution system, failure to monitor flows and other ills. If control cannot be maintained, flexibility thus opens up opportunities for abuse and contributes to the problem.
This inability to exercise detailed control is not simply a temporary stage until low level staff are "trained" in their responsibilities or farmers are "educated" to accept their fair share of water. It is inherent in the conditions found in these schemes. When a low level employee allows a farmer to take more than his fair share, he is perfectly aware that this is wrong but he is poorly paid and is unwilling to work against the interests of those he must live with. When a farmer damages a structure, he knows it is unfair to others but may rationalize his actions by the fact that there is always someone else who is better off. Indeed, given population growth and the pace at which urban jobs can be created, farm sizes are likely to become smaller, water supplies to become increasingly scarce, and conditions to deteriorate further. Ideally the problems this creates should be contained by farmers exercising self discipline through effective farmer organizations. Otherwise, the only realistic alternative is to design systems so that interference is inherently more difficult and distribution is inherently more automatic.

Furthermore, the costs associated with some loss of flexibility can be overstated. Reference is often made to the more demanding requirements of high yielding varieties and high value diversified cropping, and this is undoubtedly valid for some countries where complementary on farm investments in drip, sprinkler and other advanced techniques can be justified. But in most of Asia surface systems will continue to predominantly support basic food grains, fibers and oilseeds. In terms of control, they will never compete with private groundwater which, certainly in the Indian sub-continent, can account for all the high value cropping that the market can bear. It may be unfair to limit the opportunities of those without access to groundwater but then it is unfair to limit those without access to irrigation. If detailed control cannot be assured, and is not really necessary, and cannot be afforded by the agriculture it supports, then there is no point in trying to achieve it no matter how many special pilot programs indicate benefits to the contrary.

Flexibility is nevertheless clearly necessary at some levels in the system. "Active regulation" is essential in the main distribution system so that variable discharges can be handled in response to river flows or differing seasonal or within-season scheduling requirements. It is also essential at the farmer level since the useable rate of flow greatly exceeds the needs of a smallholder and, except to an extent in paddy systems, farmers must take turns if stream size problems are to be avoided. A gray area lies in between. If this cannot be managed by the irrigation agency, and if farmer control at this level is impracticable, then the alternative must be some form of automatic or "passive regulation".

**Structured Systems**

The important determinant is the level at which agency control can be guaranteed since this will decide the size of the service area to which a common irrigation service is to be provided. We have called this the level at which the system is to be "structured". In India we have concluded that this must be at least at the head of the minor -- that is serving a service area of say 200-300 ha -- but in the well established systems of N.W. India and Pakistan, which have demonstrated the success of
a "structured" approach over many decades, it has often been higher. Government investment within the service area is of course still required. However, many modernization programs have assumed that extension of the distribution system, say, to each farm should also be accompanied by active control to each farm. It is this failure to anticipate how the system will operate in practice that lies behind many of the difficulties faced in irrigation schemes. As a general rule, it is undoubtedly more important to be conservative, possibly moving further down into the system at a later date, than to risk losing control.

Above the service area, the system must be actively regulated, that is, it must be capable, within design limits, of delivering variable flows so as to provide the specified service at the head of each service area. In many cases, the service provided may be similar for all service areas. However, subject to the share of each service area and the system's capacity, there is no reason why it should not vary in response to differing cropping patterns or soil conditions or farmer preferences. "Flexibility" can therefore be provided in a structured system at the level of the service area. For instance, innovation in the N.W. Indian systems could well be towards greater differentiation of this service. Techniques to simplify and improve the regulated supply are clearly warranted and have been given inadequate attention in the past. These can range from simple automatic structures to facilitate flow management in traditional systems, such as long-crested weirs, modular offtakes and broad crested weir measuring devices, to more advanced downstream control or controlled volume systems. Provided the quality of construction and operation can be assured, innovation therefore has an important role to play at this level and in many instances can simplify rather than complicate the management task.

Within the service area, the options are often more limited. At the farm level, if turns can be managed in a flexible manner by mutual agreement, then all to the good. In some contexts such flexibility is essential, for instance, in many paddy systems where micro-topography affects local run-off patterns, or in systems with substantial local variability as in some hard rock areas of South India and Sri Lanka, or, if rainfed and irrigated crops are intermixed. In these instances, it may be necessary to provide adequate supplies during each irrigation for the full area commanded to ensure that mutual cooperation does not break down. In other cases, with scarce supplies, cooperation has proved difficult to establish. Under the relatively uniform conditions found in North India and Pakistan, this has led to formalizing the turn system in the "warabundi" under which each farmer is allocated supplies in proportion to his land area but in amounts inadequate for his full farm. Not only does each farmer know clearly what to expect, but he must respond to scarcity -- both in his cropping and in his investment activities, e.g., through groundwater development -- so that returns to water tend to be maximized.

Above the level at which turns must be instituted, mutual agreement is even more difficult to attain and passive regulation may be required, e.g., constant on/off discharge and proportional division. Not only does this mean many fewer gates to be controlled but it simplifies monitoring (canals must run full or be empty) and greatly reduces incentives for farmer interference. If the parent canal runs full and the
outlet is proportional, there is no way that a farmer can increase discharge without major interference (e.g., enlarging the outlet rather than removing or adjusting the gate). If the parent canal is closed, there is no point in such interference. If distribution is automatic, then if changes are introduced or management relaxes, the system still performs.

In the longer term, if farmer organizations prove able to manage supplies satisfactorily within the service area, then the arguments in favor of proportional distribution no longer hold, and the service provided might increasingly include variable flow as well as variable timing. Such organizations have shown their capacities in small communal systems where they exercise full control over the source of supply as well as distribution. However, at least in the Indian sub-continent, they have yet to prove replicable in major schemes under conditions of scarcity. Pilot projects -- such as the Mohini cooperative in Gujarat -- on examination are almost always found to receive special treatment. They are thus comparable to the politicized organizations commonly established to press for additional water, usually at the expense of others, rather than being representative of management under the scarcity conditions prevailing over the scheme as a whole.

Establishing an Irrigation Service

Innovation must therefore take into account the total system and the irrigation service to be provided must be realistic under prevailing conditions. It is not possible to describe all the factors involved in deciding on this service but they obviously include:

- reservoir/diversion operating rules for different purposes (agriculture, power, flood protection, municipal and industrial, fisheries);
- the broad cropping strategy: paddy/non-paddy, seasonal pattern, opening and closing dates, etc.;
- irrigation schedules specifying the frequency of irrigation, the period of each irrigation and the discharge;
- rules for responding to variability in supply, rainfall, emergencies, etc.;

For all new schemes, a Plan of Operations and Maintenance (POM) is an essential pre-requisite before the system is designed. Guidelines for such a plan have been prepared by the Asia Region and are being increasingly used for projects in India and elsewhere. For existing schemes, the task is more complex and a basic understanding of present design objectives and performance, and how these have evolved over time, is essential before the POM can be revised. The National Water Management Project in India represents one attempt to institute this process on a systematic basis, and Guidelines prepared for this project suggest how it might be carried out in practice.
CONCLUSION

Innovation is a two-edged sword. At the most basic level, inferior construction quality or inadequate data can put an intolerable strain on the operation and maintenance of any innovation. If quality cannot be assured, it may be preferable to adopt technically or financially less risky solutions or stay with proven traditional methods. Even if quality can be assured, innovation must take into account the total system and be realistic concerning the conditions that will be encountered. If partial solutions are adopted that fail to take account of responses elsewhere in the system, or design concepts are adopted which do not respect practical conditions in the field, then innovation will likely fail.
A REVIEW OF EXISTING SOIL CONSERVATION TECHNOLOGIES 
AND A PROPOSED METHOD OF SOIL CONSERVATION USING 
CONTOUR FARMING PRACTICES BACKED BY VETIVER GRASS HEDGE BARRIERS

Richard G. Grimshaw

BACKGROUND

Erosion of the land surface continues at an alarming rate as rising populations in the developing world exploit the remaining potential arable lands and overuse or misuse land that should be used otherwise. Conservation measures have generally failed -- in many cases because they have been inappropriately designed and constructed, or because the user sees no direct economic benefit, or because they are too expensive to construct and maintain at a time of rising labor costs and labor shortages.

With few exceptions, in those developing countries that are dominated by small farmers, engineered soil conservation systems have neither significantly reduced erosion nor have significantly increased yields of crops through improved moisture conservation. Often such measures have accelerated erosion and have removed precious water off the land, resulting in lower crop yields.

IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON EROSION RATES AND SEDIMENT YIELDS

A recent review of the literature suggests that vegetative systems, in conjunction with appropriate cultivation practices, are in most cases superior to engineered systems of protection. No-till/stubble mulch systems (39) can decrease sediment yields 70 percent to 90 percent, and contour cultivation (based on 30 years of experimentation in India) will decrease sediment yield, by itself, 30 percent in comparison to up and down the slope cultivation (14). This latter fact, until only recently, was generally ignored by soil conservationists and extension workers alike.

Contour bunds, unless maintained, have a limited life span of two to five years (25); and at slopes above 11 percent fill rapidly with silt and have trap efficiencies of the order of 30 percent to 50 percent the first year, and zero percent the second (39). Contour bunds have been found to be useful only where the soils are well drained; otherwise they are susceptible to breaching and failure, as well as causing water logging (India-Maharashtra vertisols) on badly drained soils (52, 63).

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Sediment yields have been found to increase 17 times (21, 35, 56) with outward sloping terraces, as practiced in Nepal and India, compared to inward sloping bench terraces. No differences in sediment yield were found between the less costly approaches of graded terraces and hillside ditching versus bench terracing.

Shifting cultivation by traditional practitioners on steep slopes has been found to result in little accelerated erosion, but if practiced by newcomers to the area has resulted in disaster (64). Along these lines, hand cultivation compared to ploughing and harrowing or mouldboard ploughing has been found to decrease sediment yields by almost 40 percent.

Structural approaches to soil conservation are nearly always found to be site specific in their application. For example (42), on 9 percent slopes on shallow erodible sand, contour bunds have increased sediment yields 200 percent, whereas on a 32 percent slope contour bunds have reduced sediment yields 25 percent, 77 percent, 99.9 percent dependent on whether the bunds were placed every 10 rows, every five rows, or every row. Terraces are more expensive per ton of soil erosion reduction than any other alternative for soil erosion control and are prone to failure on structurally unsound soils (6, 23, 28, 50, 58, 61, 67).

Permanent grass cover as an alternative to wheat has been found to decrease sediment yields 98 percent on 8 percent slopes (16). Another study (65) showed a 200 percent increase in sediment yields from intensive short duration grazing of grass. Manuring and mulching have proven effective in reducing sediment yields on slopes of 2 percent to 25 percent; decreases of 73 percent to 98 percent, depending on whether used alone or in combination, have been reported (5, 17).

Broad bed and furrow systems have been found to increase yields on poorly drained vertisols. Other studies have indicated a problem with structural instability where furrowing and bunding have been used on a fine textured soil (44, 47).

**IMPACTS OF SOIL CONSERVATION TECHNOLOGIES ON SOIL MOISTURE AND SURFACE RUNOFF**

Evidence from a number of studies (1, 19, 32, 41, 54, 62) of small watersheds has shown that land clearing increases surface runoff, especially when carried out by heavy equipment. Poor land management increases surface runoff; significant reduction in surface runoff is associated with intensive land management (50).

The effects of grass barriers or strips have not been well investigated, though it appears that they do have an impact on surface runoff. On 15 percent to 22 percent slopes, grass strips have been found to reduce surface runoff 9 percent compared to bare soil, and planting grass strips on the edge of bench terraces on 28 percent slopes has been shown to reduce surface runoff 69 percent compared to unplanted terraces (34).

Mulching significantly reduces surface runoff. Generally, the heavier the mulching the greater the reduction in runoff. Mulch
Applications have been found to reduce surface runoff by 16 percent to 89 percent on slopes ranging from 1 percent to 46 percent (17, 31, 34, 43).

Cultivation practices (20, 45, 51) also reduce surface runoff; infiltration increases ranging from 72 percent to 860 percent have been observed as a result of different tillage and cultivation practices, compared to untilled land, due to increased surface roughness which slows down or detains surface runoff. Reports from India on contour cultivation and planting, based on 30 years of observations, indicate that this practice alone will reduce runoff by 25 percent when compared to cultivation up and down the slope. Other studies (13, 21, 34) have found a decrease in runoff of 70 percent on a 25 percent slope and an 82 percent decrease on a 20 percent slope when contouring has been combined with mulching. Ridged and furrowed plots have demonstrated deeper percolation of water, increases of 121 percent in soil moisture storage, and decreases in surface runoff of the order of 31 percent to 47 percent (53, 66).

Earthen bunds require frequent maintenance and repair, and under some conditions, such as vertisols, are impractical (8, 59). Grading of bunds and putting them on the contour can reduce runoff 23 percent to 37 percent, when compared to ungraded, unkontoured bunds; however, this may still be not worthwhile as a 50 percent decrease in depth of percolation and a 70 percent increase in surface runoff have been observed with bunded versus unbundled plots (55, 56).

Terraces, when used in conjunction with other improved practices, do provide for moisture conservation, but their effects vary significantly with site and climate. Studies have indicated no change in surface runoff between terraced and contour planted maize on 2 percent to 18 percent slopes, between terraced and unterraced land, on coarse textured soils and other soils with low moisture holding capacity. Direct measurements (55) of soil moisture have shown either no changes from terracing, that any changes are temporal and may only be observed during the rainy season, or that there was a 50 percent decrease in the depth to which water percolated. Terraces, when compared to graded furrows on gentle slopes, have been found to increase surface runoff on the order of 25 percent with the greatest increases coming during small storms (21, 26, 50). Compared to unterraced plots, terraces have been found to increase surface runoff if the antecedent moisture conditions are high, or decrease it if they are low. Surface runoff increases of up to 140 percent have been observed as a result of terracing and significant increases in peak discharges, and time to peak discharge, and decreases in soil moisture and low flows have been observed as a result of completely terracing small watersheds (2, 37, 38, 56, 60).

**Impacts of Soil Conservation Technologies on Productivity and Yield**

Most studies show decreases in crop yields and nutrient losses due to soil erosion. On shallow tropical soils productivity may decline more rapidly than on similar temperate soils. The amount of yield losses vary significantly and are site specific. Rough figures on soil removal trials (29, 30, 33, 40) show that the removal of 5 cm of soil reduces yield by 62 percent, 10 cm of soil reduces yield by 66 percent, and 20 cm of soil...
reduces yield by 81 percent. Drought effects are magnified on eroded soils and water use efficiency of crops is decreased; a 4 percent to 5 percent decrease in plant available water in eroded soil has been shown to cause a 12 percent to 36 percent decrease in yield.

Vegetative soil covers (60) have been shown to conserve or increase soil nutrients. Mulches, in particular, have been shown to increase yields substantially (11, 36, 43, 48, 49, 57). The mechanical clearing of land compared to slash and burn (12, 46, 54) has had yield impacts ranging from zero to 16 percent to 74 percent yield declines in various crops; subsequent fertilizer applications to the mechanically cleared plots did not return yields to the level of slash and burn plots. Tillage systems that incorporate fertilizers into the soil have beneficial effects on yield increases. Contour cultivation and ridging across the slope have resulted in yield increases of 6 percent to 66 percent on 3 percent to 32 percent slopes when compared to up and down the slope cultivation (9, 14, 35, 36, 43). Ripped furrows in semi-arid zones have shown 250 percent and 300 percent yield increases over non-ripped areas (7, 15). These findings are supported by observations from tree planting on ripped areas in India.

ICRISAT experiments (27) indicate that bunds and other conservation structures have failed to show any significant increase in yield. On poorly drained vertisols that have been bunded, yields have decreased eight years out of eight due to ponding of water and interference with tillage practices (21). Yet bunds continue to be constructed on these soils by Government agencies.

There are conflicting results on the yield impact of terracing. Differences can be mainly traced to soil differences and to the amount of top soil disturbed during construction (3, 4, 10, 18, 21, 22, 24, 29, 35, 60). Bench terraces, in particular, require deep fertile soils on moderate slopes to permit top soil removal necessary for levelling. Yields have been found to be 18 percent to 32 percent higher on vegetative terraces due to lack of soil disturbance (21).

**COSTS OF SOIL CONSERVATION METHODS**

The costs of soil conservation structures vary enormously and, unfortunately, accurate data is difficult to obtain. Bank estimates include:

<table>
<thead>
<tr>
<th>Method</th>
<th>Year</th>
<th>Cost (US$)</th>
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<tbody>
<tr>
<td>Bench terraces - India</td>
<td>1983</td>
<td>526 per ha</td>
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<tr>
<td>Bench terraces - China</td>
<td>1987</td>
<td>594 per ha</td>
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<tr>
<td>Bench terraces - Indonesia</td>
<td>1979</td>
<td>355 per ha</td>
</tr>
<tr>
<td>Bench terraces - Korea</td>
<td>1976</td>
<td>2,417 per ha</td>
</tr>
<tr>
<td>Contour/graded bunds - India</td>
<td>1983</td>
<td>45 per ha</td>
</tr>
</tbody>
</table>

1/ Maheshwaram Pilot Watershed Project, Andhra Pradesh.
Generally, conservation works have been poorly costed and "actual" costs probably do not reflect true costs due to "leakage", etc. Some costs, such as waterway costs, are often totally ignored. In any event, the costs for structured systems are generally high and development on a wide basis is severely constrained due to budget deficiencies. It is rare that farmers develop structured systems on their own, unless to reclaim land, as most indications are that only moderate economic benefits materialize from such efforts.

Since 1973 Bank-financed pilot projects in the Indian states of Andhra Pradesh, Karnataka, Maharashtra, and Madhya Pradesh have confirmed the doubtful benefits of structured conservation systems on alfisols and vertisols on undulating land forms where the rainfall rarely exceeds 700 mm and is extremely erratic. An evaluation by the Government of Karnataka of a large selected catchment (90,125 ha) indicates the failures of the engineered system (see Annex 1).

As a general conclusion, structured soil and moisture conservation systems must be site specific, and require detailed and accurate engineering and design if they are to be effective. In most countries the latter is difficult to achieve. All structured systems require maintenance -- generally a rare event. Most of the evidence suggests that conservation works reduce soil losses, but do not reduce runoff significantly and in some cases have a negative impact on soil moisture. As a general conclusion, vegetative systems are more effective both for soil and moisture conservation. An effective vegetative system should comprise a dense vegetative hedge (on the contour) of either a grass or a shrub that has deep roots; has strong and dense leaves and stems; is drought, fire, livestock and flood resistant; has the ability to survive inundation; is not a weed; takes up minimum land area; and does not harbor pests or diseases. *Vetiveria zizanioides*, a clump grass, exhibits all these characteristics and more. Vetiver grass is unique in that it thrives in arid and humid conditions, seems to grow on any soil (including shallow rocky "soils"), and survives wide temperature ranges.

**A NEW APPROACH -- INSITU SOIL AND MOISTURE CONSERVATION USING A VEGETATIVE SYSTEM**

Indian project and Bank staff, the latter resident in India, identified a vegetative system as an alternative to engineered structures that they believed would be better suited to conditions and would result in significant economic benefits to farmers due to its low cost and moisture conservation characteristics. It was agreed to implement concurrently and correctly two systems that had been tested for a long time; both meeting the criteria of being low cost and replicable:

- **Contour Farming.** Most farmers plough and cultivate up and down the slope with the result that water runoff is concentrated, and significant moisture is lost to the soil. By ploughing and cultivating on the contour using dead furrows every four or five meters, significant
yield increases -- more than 100 percent -- at no cost have been obtained under farmer conditions; soil moisture is increased through reduced runoff, and subsequent soil losses are also reduced (see Annex 2). The contour lines are permanently fixed through the use of Vetiver grass vegetative key lines.

Vetiver Grass Hedges. *Vetiveria zizanioides* has been used as a very effective vegetative hedge in the West Indies and Fiji for about 50 years, and in South India for more than 100 years. Under such conditions, soil erosion has been mainly halted, natural terraces sometimes three to four meters high have built up behind the vetiver hedge, and soil and moisture losses have been minimized. We find that Vetiver grass, which exhibits all the characteristics and more to meet the requirements of an effective vegetative system, is anatomically a hydrophite, but exhibits xerophytic characteristics and, therefore, thrives under very wet (3,000 mm) and very dry (300 mm) conditions. Although a tropical grass, we find it growing well as far north as 29 degrees latitude surviving frequent frosts and temperatures as low as -9 degrees centigrade. It has been identified near Stillwater, Oklahoma where temperatures are as low as -16 degrees centigrade. Its sap has a high salt content which explains its drought and saline resistivity. Vetiver grass is unique; there is no other grass known with the same characteristics or qualities for soil and moisture conservation.

The projects initiated the substitution of earth bunds by Vetiver hedge barriers some three years ago; farmer demand for the hedges is growing logarithmically - 100 ha in 1986; 1,000 ha in 1987, and 10,000 ha in 1988. The State of Andhra Pradesh expects to protect another 40,000 ha in 1988! Most importantly, we have now found that many farmers near Mysore (India) have been using Vetiver as a hedge for at least 100 years, exhibiting all the favorable characteristics associated with the grass. Benefits as described by farmers are outlined in Annex 3.

In India, a number of other states are initiating Vetiver programs, including Orissa, Tamil Nadu, Rajasthan, and Gujarat. The main restraint to expansion is the lack of nurseries and planting materials, as well as a reluctance by some soil conservation engineers to discard past practices (there are in some countries large vested interests in soil conservation funding).

Other countries have started similar programs -- Nigeria, using *Vetiveria nigratana*; and the Philippines and Sri Lanka with *Vetiveria zizanioides*. Most recently, we have found *Vetiveria zizanioides* in China used for commercial perfume manufacture in Jiangxi and Fujian Provinces

(latitude 29 N). As mentioned above, both Fiji and some of the West Indian islands have used the technology for up to 50 or 60 years and are once again renewing their interest in its use.

The developments in India and Nigeria are the first serious and successful attempts to spread the technology to the semi-arid and arid zones. The Red Soils Project in China will, starting in the Spring of 1989, initiate what is likely to become a very large program. The latter will initially concentrate on protecting existing terraces to reduce the current high rate of soil and water loss. The program will also initiate some trials for tea garden protection on very steep eroding soils, and for soil moisture improvement on forest lands.

We are still unsure of its climatic limitations, although we do know that the grass grows over a wide range of rainfall, soils, and temperatures. The technology is not site specific, is low cost, replicable, and can be introduced without dependence on engineering agencies. There is a lot of scope for further testing its limitations, as well as investigating many of its anatomical, physiological, and agronomic features. Interesting and important work should be undertaken to further improve our knowledge of husbandry practices involving the use of Vetiver.

Results to date are limited to field observations by farmers and project staff. Yield response to contour farming methods confirms earlier research findings, and crop cuttings suggest onfarm yield increases from 100 percent to 600 percent. Field trials have now commenced (Andhra Pradesh Agriculture University) on the effect of Vetiver hedges on soil moisture improvement and soil retention. The results are likely to back visual observations obtained to date indicating significant improvements. Farmers clearly like the system as demonstrated by the high adoption rates and growing demand for Vetiver.
REFERENCES


ANNEX 1

TUNGABHADRA RIVER VALLEY PROJECT. EVALUATION BY M&E UNIT OF DOA KARNATAKA

- 1000 mm av rainfall;
- 90,125 ha contour bunded over 12 years (1975/76 - 1986/87) at a cost of Rps 33.6 million;
- 85 percent of bunds still existed -- but the majority were incomplete;
- 15 percent removed or eroded away;
- of existing bunds, 50 percent were intact, remainder either damaged or partly ploughed back;
- 69 percent of farmers had ploughed them back;
- majority of existing bunds reduced in size by 20 percent to 40 percent; 30 percent were aged out;
- damage to bunds was caused by breaching, as they could not withstand storms -- in other words, they had been underdesigned;
- only 15 percent of waste weirs remained undamaged;
- bunds not maintained mainly for financial reasons, also because farmers saw little economic value in their use;
- bunds and inter-bund levelling showed no significant crop yield improvements over unbunded and unlevelled inter-bunds;
- difference in levels in technology uptake between bunded and non-bunded areas negligible; likewise, there was no difference in crop yields;
- 52 mandays per hectare were used for bund construction, equivalent to approximately Rps 520 per hectare;

The above evaluation generally reflects a typical soil conservation system in India -- there are exceptions, but they are rare and are difficult to replicate.
The data below were gathered and analyzed by the Andhra Pradesh University during the year 1987. Rainfall approx. 750 mm.

**Soil Moisture**
- Sowing along the slope: 1.30 cm/60 cm soil
- Sowing across the slope: 2.04
- Sowing on contour line: 2.30
- Sowing on contour & dead furrow: 2.62

**Yield of Sorghum CSH-5 (13 farmer fields)**
- Sowing along the slope: 22.1 q/ha
- Sowing across the slope: 27.1
- Sowing on contour line: 32.7
- Sowing on contour & dead furrow: 39.9

**Yield of Castor (8 farmer fields)**
- Sowing along the slope: 9.64 q/ha
- Sowing across the slope: 13.71
- Sowing on contour line: 16.96
- Sowing on contour & dead furrow: 19.64

**Other Data**
Using contour cultivation Bhindi yield increased by 55 percent from 35 to 55 q/ha.

**Runoff in Castor**
- $T_1$ = sowing along the slope
- $T_2$ = sowing on the contour
- $T_3$ = sowing on the contour with ridges and furrows

<table>
<thead>
<tr>
<th>Rainfall Occurrence</th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>.06</td>
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<td>2</td>
<td>.09</td>
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<tr>
<td>10</td>
<td>.34</td>
<td>.25</td>
<td>.18</td>
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</tbody>
</table>
ANNEX 3

LIST OF KEY ISSUES FROM VILLAGES IN GUNDALPET TALUKA NEAR MYSORE, INDIA

General

Vetiver grass, commonly known as Khus Khus in India, has been used by farmers in Gundalpet Taluka for many generations, principally as a hedge on field boundaries. The practice is at least 100 years old. So far, 28 villages have been identified as using the system, involving thousands of farmers. Gundalpet has an average rainfall of about 650 mm. Its soils are shallow alfisols, and the land can be best described as gently rolling (maximum 5 percent slope). The benefits as set out below were described by farmers and their families -- both young and old. Most of these benefits are confirmed by new users in other parts of south India.

- Complete low (30 cm) boundary hedge, land ownership demarcation;
- Fodder cut every two weeks throughout the year -- equivalent production of 14 tons per ha;
- Soil moisture improvements as evidenced by more even crop growth and good yields, particularly in dry years;
- Less risky farming -- higher use of fertilizers compared to non-practitioners;
- Retention of fertilizer in farmers fields;
- Complete barrier against creeping weed grasses such as Cynodon dactylis.

Erosion Control

- Soil erosion control -- terraces up to one meter high on slopes of about 3 percent have developed over time.
- Micro catchments have fully stabilized, with virtually no evidence of erosion;
- Stream bed/bank erosion has been minimized.

Soil Moisture Improvement

- Ground water tables appear higher in protected areas as measured by well water levels;
- Soil moisture improvement particularly when associated with contour cultivation -- significant yield improvements recognized by farmers.
System Cost to Farmer

- Maintenance cost is virtually zero;
- Establishment cost per hectare when using hired labor: digging of planting material -- Rps 80; planting slips Rps 40. Total cost Rps 120.

Other Characteristics Confirmed at Gundalpet

- Vetiver grass is resistant to all pests and diseases (farmer observations during living memory);
- Crops grow close to vetiver with no yield loss;
- Hedges are easily maintained to 50 cm width by close ploughing -- thus, minimum land loss to cultivation (compared to five to six meters for contour bunds);
- Fire resistant;
- Seeds do not germinate and therefore vetiver does not become a weed;
- It makes excellent mulch, thatch, and brooms.
BACKGROUND

FAO estimates that there are about two million ha in Nigeria that have potential for irrigation. It is estimated that of this some 800,000 ha are currently used by farmers. As with any national figures from Nigeria, these need to be accepted with caution but clearly farmers are making extensive opportune use of water in flooded plains, swamps and seasonally inundated depressions. In addition to this, the government has embarked upon a high cost scheme of formal large scale irrigation. It has developed about 66,000 ha at a cost of some $30,000 per ha but of this only about 30,000 ha are actually being irrigated. The World Bank has resisted strong pressure from the Nigerian government to become involved in these projects and instead has focused its attention on encouraging small scale, low cost irrigation by individual farmers. It is about this initiative that I want to speak this afternoon.

I will focus on two states in the northern part of Nigeria -- Kano and Sakoto. Both include large areas that receive less than 700 mm of rain per year over about 140 days and have a cool dry period in December and January followed by increasingly hot, windy arid conditions. Both have riverine systems, which in the dry season include sandy river beds without surface water, and extensive flood plains with shallow aquifers. These resources have been used for many generations to produce dry season vegetables using hand dug wells, shadoufs and baling methods.

SMALL SCALE IRRIGATION INITIATIVES

It was into this situation that two Bank-funded projects sought to introduce new technology to extend the use of the existing natural resource and production skills. There were four basic components:

- replacement of shadoufs and balers with small petrol driven portable engines;
- replacement of shallow wells on the plains (fadamas) with tubewells;

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1/ This paper focuses on one country -- Nigeria -- and, in detail, on one area.
replacement of shallow holes in the river beds with washbores; and

encouragement of alternative crops for irrigation.

At the end of five years of development the situation is as follows:

**Kano**

- 38,000 pumps have been bought for cash through project stores in addition to unknown, but considerable, numbers from private traders;
- 1,400 tubewells are in use;
- 2,500 washbores are in use; and
- there has been some diversification of cropping.

**Sokoto**

- 15,000 pumps have been bought through project stores plus others from traders;
- 1,900 tubewells are in use;
- there has been little washbore development; and
- there has been some diversification of cropping.

I will analyze the reasons for farmer interest in parts of this technology, compare the experience in the two states and detail some of the challenges that now face these programs.

**REASONS FOR FARMER INTEREST**

There are a number of reasons why farmers in this area took up at least part of the program and particularly the small pumps. I believe that these are important in considering the replicability of this experience:

- there is a long tradition of dry season irrigation in the area;
- farmers were constrained by the amount of water that could be lifted by hand, and by rapidly rising wages resulting from the oil boom;
- the small pumps, which could be carried on a donkey or a motor cycle, readily fit into a situation in which farmers had multiple small gardens and wanted to keep their pumps at home at night for security reasons;
motorcycles of similar engine design to those on the pumps were common in the area. Consequently farmers had some familiarity with such engines and there were small scale mechanic services in most villages capable of handling engine repairs;

until 1986 there was a major distortion in the exchange rate, which made the pumps cheap in relation to local food prices;

since 1986 there have been some government subsidies to further encourage this development combined with a major distortion in the local price of wheat;

there are large urban markets in Nigeria, some good major trunk roads linking the north and south and there is a fairly aggressive private sector marketing system;

the projects provided the capital and technical support for importing equipment and spare parts, organizing drilling and input distribution; and

there were substantial capital resources in the rural areas deriving in part from the oil boom, which enabled individuals to mobilize the necessary cash resources for this venture.

DIFFERENCE BETWEEN THE TWO PROJECTS

There are several differences in the way irrigation has developed in recent years in these two states, which suggest lessons for other areas with comparable development potential.

Kano

The project was initially run by a British consulting firm. Anxious to make an immediate impact, it brought in four sets of modern motorized drilling equipment and drilled many hundreds of tubewells in quite a short period of time. This gave the project quite a high profile and elicited managerial support. Those staff have gone, the equipment is wearing out and the pace of tubewell development is slowing down.

Sokoto

The project irrigation initiative was in the hands of an individual who believed passionately that viable development could only come through the use of simple, locally manufactured hand operated equipment. This was considered "primitive" by project management and elicited little operational support for the irrigation component. After a very slow start there is now local capacity to manufacture rigs and there are a number of teams of young men who are competent to work them. In consequence, Sokoto is now in a stronger position than Kano to expand its tubewell program.
The other difference between the states concerns the degree of population pressure. Kano has much greater population pressure than Sokoto and people are more open to diversify out of rainfed agriculture into a much more labor and capital intensive system. As with many new technologies a careful assessment of the correct timing of its introduction can profoundly impact how well it adopted.

**FARMER INITIATIVES**

It has been interesting to observe how quickly farmers have adapted to a new technology and demonstrated their readiness to innovate. Some examples are:

- the rapid development of a rental market in micro plots of irrigated land;
- the development of a rental market in pumps;
- the production of green maize for export to the Lagos market and of carrots as a convenience food for sale at bus parks;
- the development of specialist farms producing only onion sets for sale to other growers; and
- farmers jetting washbores for their neighbors with adaptations of their own equipment.

**CHALLENGES TO FUTURE EXPANSION**

Hydro-geological surveys of these states have been carried out and initial estimates indicate that there are approximately 200,000 ha of shallow aquifer that are suitable for development. There are two main challenges to agricultural staff responsible for making fuller use of this potential. One is institutional and the other is technical.

The sinking of tubewells by both machine and handrigs has been carried out by project staff so far. This seriously limits the number of wells that are sunk and farmer demand is well ahead of staff performance. It also raises costs as staff draw civil service salaries unrelated to performance, demand overnight allowances and motorized transport to work sites and for moving equipment. Only when the drilling is given over to local teams with hand operated equipment will there be a major development of the potential. A hundred units scattered through the areas with the greatest potential, operated by local residents using ox carts for transport, would result in a quantum leap in development. To date pressure from Bank missions to privatize the operation has failed to bring about any change in the projects' determination to run this as a government exercise. The challenge remains as to how to change this approach.

The second challenge is technical. The rapid expansion of small pump use to date has been built on two major groups of crops:

- horticultural produce, mainly onions, tomatoes, peppers and green maize. The market for these is finite and a major
expansion into tens of thousands of hectares of new irrigation could not be based solely on these high value crops;

- wheat. Northern Nigeria does not have comparative advantage as a wheat producer because it has such a short period during which temperatures are low enough to induce flowering. The ban on wheat imports has raised the farmgate price to $850 per ton, which is highly attractive. An analysis of farm costs and returns indicates that farmers would move out of the crop at about $400 per ton, which is well above any undistorted import parity price projection.

The cold weather that makes wheat growing technically possible eliminates cowpeas as a potential crop for the main irrigation season. Research on cold tolerant rice is continuing but the later stages of growth of this crop take place at a time of extremely high levels of evaporation and water demand is so great as to be uneconomic at undistorted prices. Maize is the crop on which a lot of attention is now being focused with the possibility of fitting in an intercrop of a very short season cowpea planted after the weather has warmed up. In most areas the floodplains are under water in the wet season, but in others cultivation is possible and in these areas pumps are being used to provide supplementary irrigation for rice.

Because the horticultural market is not yet fully saturated project staff have not all grasped the urgency of the need to develop varieties and cropping patterns for this particular irrigation situation. Until this is done the pace of development will be dependent upon the less satisfactory basis of serious price distortions.

CONCLUSION

In an area of low and unreliable rainfall it makes good sense to look for alternative resources to stimulate agricultural growth. Experience in Nigeria has shown that when a potential exists and a new technology is correctly identified and timed there can be rapid uptake by farmers. The challenge is to develop plants and systems that match the new technology for large scale production in comparatively undistorted markets.
INTRODUCTION

The skewed distribution of land characteristic of some Asian and Latin American countries is still insignificant in Africa. Thus concern with redistributive aspects of land tenure reform is not an urgent policy question. The fundamental question behind the recent upsurge of interest in rules governing access, control and use of agricultural resources in Sub-Saharan Africa relates to the extent to which indigenous tenure systems are a constraint on agricultural development. Generally, discussion of this question tends to divide along ideological lines. Some give prominence to narrow economic interpretations emphasizing market forces and productive efficiency. Others assert the predominance of innate sociocultural characteristics of tenure arrangements and concerns with social justice.

Critics of indigenous African tenure systems have argued that they constrain agricultural productivity since individual farmers lack secure property rights and are discouraged from adopting long-term investment and production strategies. It is argued that the solution to this problem lies in individualization of tenure and registration of titles (Swynnerton, 1954; Simpson, 1967). An unfounded but very important assumption in this argument is that the rural economy in Africa would subsequently be fully integrated into national economies and rural factors would enjoy perfect markets. So far, this has proved true in very few isolated instances and does not permit broad generalization.

Opponents of tenure individualization have focussed on its supposed negative impact on land distribution and social equality. Based on ex post evaluations of tenure reform programs in Kenya and Botswana, it has been observed that individualization of tenure has led to land grabbing, concentration, landlessness and increasing marginalization as those in positions of economic and political power take advantage of the less powerful (Brokensha and Glazier, 1973; Coldham, 1978; Njeru, 1978; Okoth-Ogendo, 1986; Achola, 1980). A major problem inherent in such ex
post assessments is that they proceed from an overly idealized perception of the status quo ante. In addition, they tend to confound influences on the observed inequality that may result from factors quite apart from those specific to land tenure. Given these analytical problems, categorical assertions about the relationship between land tenure reform and social equality are not acceptable.

The goal of this paper is to synthesize available evidence on the relationship between indigenous land tenure systems and agricultural development in Sub-Saharan Africa. The paper draws on existing literature on indigenous land tenure systems and on preliminary results from an ongoing study in the Agricultural Policies Division of the World Bank. Through field surveys in Ghana, Kenya and Rwanda, the study is attempting to quantify some important relationships that have previously only been qualitatively described. This provides the basis for a discussion of the conditions under which policy interventions may or may not be required to improve the efficiency of land and other rural factor markets.

INDIGENOUS LAND TENURE SYSTEMS

A major misconception about indigenous land tenure in Africa revolves around the terms "customary", "communal", or "corporate" often used to describe the social arrangements governing allocation and use of land. These terms not only conjure up an image of static, antiquarian and immutable normative systems but also connote a greater level of cooperation in production and social egalitarianism than is supported by historical evidence. Although doubt has intermittently been raised about the communal and egalitarian attributes of indigenous tenure systems, the myth enjoys a tenacious persistence that has only recently begun to fade as a result of concerted and careful examination (Noronha, 1985; Berry, 1988; Bruce, 1988; Chanock, 1985).

Sub-Saharan Africa is characterized by a diversity of farming systems ranging from long forest fallows in areas of low population density to nearly continuous, multiple crop cultivation in areas of high population density. Between these extremes are a wide range of farming systems characterized by relatively shorter (than long forest) but varying fallow periods. In addition to population density, factors influencing the length of fallow include ecological conditions, soil quality, political organization, inheritance patterns, agricultural technology and degree of commercialization. Given the diversity of environmental conditions and cultures, it is hardly surprising that Africa exhibits a wide range of seemingly different land tenure systems.

In spite of the varied cultures, there are some striking similarities in existing land tenure arrangements. Where land is relatively abundant, the control of land allocation has historically tended to reside in social groups rather than individuals or families. But this notion is valid only in a highly generalized sense. In common practice, access and use of land by individuals and families is usually regulated by intricate customary traditions which vest control in minimal kinship or residential groups in a variety of usufructuary arrangements. While members of the social group exercising control over land allocation have rights of access and use of pasture and other common property resources,
rights over farmland are more clearly defined. Even under shifting cultivation, families enjoy more or less continuous usufructuary rights over specific parcels of land, provided the period of fallow is not inordinately long so as to suggest the land has been abandoned. As fallow periods become relatively shorter and cultivation of plots relatively continuous, land is held by households and is inherited in accordance with prevailing customary rules.

There are exceptions where individuals and families may be guaranteed access to an amount of land but not a specific plot. It is conceivable that in such systems, where use rights for cultivation of seasonal crops rotate each year or after several years, individuals may not be enthusiastic about making long-term investments in soil improvement. But these kinds of arrangements are increasingly disintegrating under pressure of agricultural commercialization and population increase and are today found only in isolated pockets, for instance, in South-Eastern Nigeria or Western Sudan.

In the majority of cases, individual rights to land under indigenous tenure rules are essentially exclusive although they fall short of private property. For instance, other members of the community may have secondary concurrent or sequential rights that permit entry, the collection of firewood and the products of wild trees growing on the land or construction material and the grazing of livestock on the stubble once a crop is harvested. In situations characterized by rapid population growth and increased commercialization of agriculture, the necessity of making long-term improvements in the land has hastened the emergence of relatively more exclusive individual rights as well as some land sales. Evidence from Ghana, Kenya and Chaggaland in Tanzania, however, indicates that some land sales were already taking place at the beginning of the colonial era (Kenyatta, 1938; Simpson, 1976; Noronha, 1985; Moore, 1986; Bates, 1986). It is likely that some sales took place even before this period. These transformations, at best only inchoate in a few isolated communities, were hastened by administrative regulations during the colonial period and after.

Except where expropriation of land for white settlement or commercial plantations was undertaken (Kenya, Zimbabwe, Eastern Zaire), no systematic legislative program was launched by the major colonial powers to change the conditions of access and use of land. But as a strategy of control, colonial administrators often forged political alliances with local rural elites and in some cases designated some of the local notables as "chiefs", even in societies where there was no tradition of chiefdoms. In other instances, one among rival contenders to a chiefly position would be declared paramount chief and assigned powers over a defined territory. The notion of a clearly bounded socio-political unit identified with a definite territorial area governed by some "customary" ruler is largely a myth conveniently created by those whose interest it served. A consequence of the rigidities introduced by such delimitation of ethnic and subethnic boundaries is that it froze the regional migratory processes through which communities had previously adapted to land shortage by extending resource utilization and settlement into unpopulated land frontiers or by incorporation into communities controlling land surpluses.
The endorsement by colonial powers of what they believed to be traditional authority structures, including the indigenous systems of land rights, was in part an administrative convenience. The colonial state created a form of citizenship in which rights were dependent on "tribal" as well as "national" membership (Chanock, 1985; Bates, 1986; Woodman, 1987). This arrangement was consistent with the dual economies that characterized the colonial situation. The nascent formal sector could thus recruit labor from the "tribal" sector at what amounted to subsistence wages and disband it when economic circumstances necessitated. Labor so disbanded was readily reincorporated in the "tribal" economy where, due to their "citizenship", individuals were guaranteed rights of access to land, and therefore economic and social welfare.

Lack of social security in formal sector activities has not significantly changed in most of Africa during the post independence era. Thus, it remains the case that African urban workers have to maintain their "tribal" membership in order to ensure rights over agricultural land. Insofar as this reinforces "tribal" social structures, it also underlines the importance of rural social formations as the vehicles through which access to productive resources continues to be ensured. As the land frontier has diminished, inheritance of family land has emerged as the most significant method of acquisition of agricultural land. While rights to land so inherited are sufficiently secure, security of tenure is further enhanced by continuous occupation and cultivation -- a process which may also lead to improvements that augment the capital value of land and its potential productivity. But such investment in land improvement has occurred only in a limited fashion in areas characterized by greater integration of rural areas into the market economy or by population intensive cultivation.

In situations characterized by low returns to agriculture, African farmers have sought income earning opportunities in nonfarm activities. Yet they have also retained their rights over rural land by investing in the maintenance of rural social relations and agricultural activities. This may be seen not only as an affirmation of ones "tribal citizenship" but more significantly as premium payment to ensure secure rights of access to lineage land, which, in the specific circumstances, represents both old age "pension" and social insurance (Eades, 1980; Murray, 1981; Berry, 1988). The consequence is that, given the macroeconomic environment in much of Africa, the right of continuous, unchallenged use of agricultural land is perhaps the most critical measure of security of tenure. A formal title certificate or other official document is merely an affirmation of this social guarantee, but it does not create it. To the extent that the social system sanctions transactions in land, including share tenancies, borrowing, pledging and purchases, such transactions are accorded sufficient recognition and those involved enjoy as much protection as the formal land tenure legislation is likely to give. It is a moot point, therefore, whether indigenous tenure systems discourage long-term investment in land.

So far quantitative studies of the relationship between land tenure and agricultural productivity have been undertaken mainly in Asia, focussing on questions of sharecropping, wage rates, interlinking factor markets and their influences on incomes (Hayami and Ruttan, 1971; North,
1981; Cheung, 1969; Rosenzweig, 1978; Binswanger and Rosenzweig, 1984; Roumasset, 1979; Hayami and Kikuchi, 1971). These studies have helped in shaping the focus of the so-called "new institutional economics". Recently attention has concentrated on the operations of rural factor markets, land tenure institutions and farm productivity (Feeny, 1975; and Feder, et al., 1986). But none of these studies have been replicated in Africa.

EVIDENCE FROM AGRAP'S AFRICAN LAND RIGHTS STUDY

In an attempt to provide a quantitative assessment of the relationship between land tenure and access to credit, land improvement investments, and productivity of land, the Agricultural Policies Division (AGRAP) is undertaking research in Ghana, Kenya and Rwanda. Within each country, two or three study regions have been selected so that the resultant matrix of regions and countries captures a wide range of situations with respect to population density, the degree of commercialization, legal and institutional heritage and existing land laws.

In Ghana, where chiefs are traditionally powerful and national land laws are ineffective, two of the three study regions chosen encompass low population density areas, namely, Wassa (cocoa growing) and Ejura (food crop) regions. The third region, Anloga, is a highly commercialized, shallot growing area with an exceptionally high population density (200 persons per square kilometer).

Kenya represents an African country with a nationwide program of land registration. Almost all agricultural land has been titled for some time. Two high population density areas were chosen to evaluate the impact of land titling. Land was registered in the 1960s in Nyeri, which has had longer experience with land titling than the second of the study regions, Kakamega. Both regions are dominated by smallholders, but there is a potentially useful contrast between traditionally settled and government settled farms in both areas.

In Rwanda, there are strong national land laws (e.g., selling is restricted), which are meant to be enforced by the local communities. Population pressure is high. There are few nonfarm economic opportunities and soil erosion is an increasing problem in this mountainous country. The three prefectures chosen for the study, Butare, Gitarama and Ruhengeri, represent an interesting cross-section of agroclimatic conditions, with Ruhengeri being a slightly more fertile and highly populated region than the other two prefectures.

Farm surveys were conducted within each of the study regions to obtain pertinent details about each parcel of land owned or operated by the sampled household. Data collected include the mode of acquisition of the parcel, the rights that the farmer perceives he/she holds over that piece of land, the history of improvements made on the parcel, the incidence of any land dispute that has occurred, use of the parcel as collateral, and

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2/ The data from Kenya were not ready for analysis at the time this paper was written and therefore are not reported on in the paper.
details about the parcel’s location, soil quality, size, and topography. Supporting information about the size, composition and socioeconomic characteristics of the household were also collected together with data about its credit history.

These data are to be used to identify and measure the relationships between tenure security and the use of credit and inputs, land improvements, and productivity. Feder et al. (1988) have hypothesized that enhancement of tenure security leads to increased demand for inputs and land improvement by farmers if the increased security of tenure implies a greater likelihood of reaping the benefits from such activities. Increased security may also lead to a greater supply of credit from lenders, especially if it leads to acceptance of land collateral and its subsequent commoditization. Both the demand and supply side effects lead to the hypothesis that enhanced tenure security will increase productivity.

While theoretically appealing, testing these relationships depends upon successfully measuring tenure security. This is difficult because the concept of tenure security is abstract. Tenure security involves the ability of a farmer to cultivate a piece of land on a continuous basis, free from imposition, dispute, or approbation from outside sources as well as the ability to claim returns from inputs or land improvements while operating the land. In an attempt to capture such perceptions by farmers, we asked them whether they had various use and transfer rights over their parcels. We believe that the bundle of rights associated with a parcel of land is a good, albeit imperfect, measure of tenure security.

While full analysis of the survey data will not be completed for some months, we are able to present some preliminary insights of a largely descriptive nature with respect to Ghana and Rwanda. This is done with a view to supporting the arguments presented in the preceding section.

First, we turn to the issue of land security. Tables 1A & 1B summarize the rights that farmers perceive they hold over individual parcels of land. Within each study region, the incidence of various use and transfer rights are shown for three types of land categorized by the breadth of transfer rights existing in the parcel. The first is "limited duration" land, which includes those fields for which the farmer has no permanent transfer or alienation rights. The "within lineage" category describes parcels that may be permanently transferred but only within the family or lineage (i.e., through gift or bequest). Finally, "permanent transfer" lands are those that may be alienated outside the lineage through the right to sell.

It is hypothesized that the greatest level of security corresponds to the "permanent transfer" parcels while the "within lineage" and "limited duration" lands represent middle level and low level security, respectively. This ordering is based upon two factors. First, it is assumed that some permanent alienation ability confers greater security than the case of no permanent alienation ability. Second, the ability to sell land usually supersedes the ability to alienate land within the lineage.

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The area of each parcel was measured by the survey teams.
The majority of farmers possess the ability to influence or make decisions on the use and transfer of the fields that they cultivate. Looking only at the Ghanaian regions (Table 1A), it is interesting to note that for a given region the prevalence of most use rights does not differ significantly over the rights groupings. The case differs in Rwanda where the categories appear to imply a different set of use rights (Table 1B). In both countries, the ability to transfer land varies considerably between "limited duration", "within lineage" and "permanent transfer" lands.

<table>
<thead>
<tr>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use Rights</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grow annual crops for more than one season</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Choice of annual crop</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Grow perennial crops</td>
<td>94</td>
<td>98</td>
</tr>
<tr>
<td>Make permanent improvements</td>
<td>94</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Transfer Rights</strong></th>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rent the land</td>
<td>14</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>Pledge the land</td>
<td>14</td>
<td>79</td>
<td>96</td>
</tr>
<tr>
<td>Mortgage the land</td>
<td>14</td>
<td>95</td>
<td>99</td>
</tr>
<tr>
<td>Bequeath the land</td>
<td>0</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>Give the land</td>
<td>0</td>
<td>80</td>
<td>96</td>
</tr>
<tr>
<td>Sell the land</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Register the land</td>
<td>26</td>
<td>100</td>
<td>94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Number of parcels</strong></th>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>239</td>
<td>539</td>
<td>343</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Percentage of parcels within each region</strong></th>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>29</td>
<td>65</td>
<td>53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Population density</strong></th>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>200</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
Table 1B: Incidence of Rights in Rwanda
by Level of Security: 1987
(Percentage of fields for which rights exist)

<table>
<thead>
<tr>
<th>USE RIGHTS</th>
<th>RUHENGERI</th>
<th>BUTARE</th>
<th>GITARAMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited Duration</td>
<td>Within Lineage</td>
<td>Permanent Transfer</td>
<td>Limited Duration</td>
</tr>
<tr>
<td>Grow annual crops indefinitely</td>
<td>49</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>Choice of annual crop</td>
<td>97</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>Grow perennial crops</td>
<td>33</td>
<td>94</td>
<td>99</td>
</tr>
<tr>
<td>Make permanent improvements</td>
<td>76</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRANSFER RIGHTS</th>
<th>RUHENGERI</th>
<th>BUTARE</th>
<th>GITARAMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rent the land</td>
<td>19</td>
<td>65</td>
<td>100</td>
</tr>
<tr>
<td>Pledge the land</td>
<td>4</td>
<td>71</td>
<td>97</td>
</tr>
<tr>
<td>Mortgage the land</td>
<td>4</td>
<td>71</td>
<td>99</td>
</tr>
<tr>
<td>Bequeath the land</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Give the land</td>
<td>0</td>
<td>0</td>
<td>97</td>
</tr>
<tr>
<td>Sell the land</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Register the land</td>
<td>9</td>
<td>88</td>
<td>99</td>
</tr>
<tr>
<td>Total number of parcels</td>
<td>86</td>
<td>17</td>
<td>453</td>
</tr>
<tr>
<td>Percentage of parcels within each region</td>
<td>15</td>
<td>4</td>
<td>81</td>
</tr>
<tr>
<td>Population density</td>
<td>367</td>
<td>342</td>
<td>270</td>
</tr>
</tbody>
</table>

Controlling for the category of rights, there is very limited variation in the ability to transfer land across regions and countries. For example, nearly all farmers with "permanent transfer" parcels enjoy the right to make transfers regardless of whether they are from the land scarce region of Ruhengeri or the land abundant area of Wassa. There is also a widespread ability across regions to make land transfers (except sales) in the "within lineage" category.

It is apparent from Tables 1A & 1B that rights approaching individual ownership are widespread in the study regions. For example, the percentage of fields that can be sold by farmers (those in the "permanent
The ability to permanently transfer land does not always manifest itself in terms of land transactions, however. The incidence of land acquisition via sales, rentals, and pledges is reported in Table 2. Land sales are relatively more common in the Wassa and Ruhengeri areas where 18 and 17.4 percent of fields were purchased, respectively. In other regions, land sales occurred much less frequently, ranging from 8.1 percent in Gitarama to 0.9 percent in Anloga. The incidence of renting or pledging land was highest in Anloga, amounting to 40.8 percent of land acquisitions, followed distantly by the Butare prefecture at 15.7 percent. Note that in every region the percentage of inherited, allocated, and gifted lands together accounted for over one-half of all land acquisitions.

Table 2: Mode of Land Acquisition in Ghana and Rwanda: 1987
(Percentage of total parcels)

<table>
<thead>
<tr>
<th></th>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
<th>RUHENGERI</th>
<th>BUTARE</th>
<th>GITARAMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased</td>
<td>18.0</td>
<td>0.9</td>
<td>6.3</td>
<td>17.4</td>
<td>3.2</td>
<td>8.1</td>
</tr>
<tr>
<td>Inherited</td>
<td>6.3</td>
<td>57.5</td>
<td>22.1</td>
<td>46.6</td>
<td>43.4</td>
<td>49.5</td>
</tr>
<tr>
<td>Allocated</td>
<td>35.7</td>
<td>0.0</td>
<td>8.1</td>
<td>4.0</td>
<td>4.9</td>
<td>15.6</td>
</tr>
<tr>
<td>Gifted</td>
<td>11.4</td>
<td>0.8</td>
<td>19.9</td>
<td>8.3</td>
<td>5.6</td>
<td>4.1</td>
</tr>
<tr>
<td>Appropriated</td>
<td>18.7</td>
<td>0.0</td>
<td>7.0</td>
<td>0.5</td>
<td>3.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Other permanent</td>
<td>1.7</td>
<td>0.0</td>
<td>0.4</td>
<td>6.3</td>
<td>4.1</td>
<td>0.2</td>
</tr>
<tr>
<td>acquisitions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rented</td>
<td>7.0</td>
<td>21.5</td>
<td>9.6</td>
<td>7.4</td>
<td>15.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Pledged</td>
<td>0.1</td>
<td>19.3</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Borrowed/temporary</td>
<td>1.1</td>
<td>0.0</td>
<td>22.8</td>
<td>9.5</td>
<td>19.4</td>
<td>13.2</td>
</tr>
<tr>
<td>allocation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squatter</td>
<td>0.0</td>
<td>0.0</td>
<td>3.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

As argued earlier, the evolution of land rights towards individual ownership is hastened by, among others factors, higher population density and increased commercialization. In Ghana, the heavily populated and commercialized region of Anloga contains relatively few cases of owned
land, which cannot be transferred outside the family or lineage (some inherited parcels fall into the "limited duration" category). This also holds true for Ruhengeri, as evidenced by the low proportion of "within lineage" land in this relatively more commercialized and densely populated prefecture.

The aforementioned ability to permanently transfer land or to actually sell land is found in areas in which formal government land titling is virtually nonexistent and where legal restrictions sometimes outlaw land sales (e.g., Rwanda). There were no registered parcels among any of those sampled in both Ghana and Rwanda. A few farmers hold contracts or chief's certificates for the land, but the vast majority have no documents on their parcels.

Despite the lack of formal titling, farmers in the study regions have been able to obtain credit, with varying degrees of success. As noted in Table 3, the percentage of households receiving credit (from any source for 1987 in Ghana and 1986-87 in Rwanda) was 47.8 percent in Anloga, 41.0 in Ruhengeri and 22.0 percent in Wassa, but significantly less in other regions.

Very different credit patterns emerge, when comparing Ghana to Rwanda. The vast majority of loans in all Ghanaian regions were farm-related, while only a third in Rwanda were for agricultural purposes. Formal creditors were used quite extensively in Ghana, accounting for 74.5 percent and 57.5 percent of the number of credit approvals in Anloga and Wassa, respectively. In both Ruhengeri and Butare, there was no lending from formal institutions. The use of land as collateral for credit varied by region. Only in Ejura, where only nine loans were received, was land not used as collateral. Otherwise, the incidence of obtaining credit ranged from 34.5 percent in Anloga to 11.9 percent in Ruhengeri.

These results support the argument that African land tenure systems do not appear to be insecure. First, as noted in Tables 1A & 1B, many farmers enjoy transfer rights on their lands (although in some cases, these rights are subject to approval by family or lineage members). However, the right of continuous unchallenged occupation emerges as more significant to African farmers than their ability to sell or make other land transactions. Recall that nearly all surveyed farmers enjoyed the right of continuous use of land, even those on leased lands (see Tables 1A & 1B). Second, the incidence of land disputes is quite low. The percentage of fields having been disputed was reported as 9.5 percent in Wassa, 4.4 percent in Anloga, 2.9 percent in Ejura, and 3.8 percent in Rwanda. During the most recent year, only four disputes arose in the total sample of 3,406 fields.

**POLICY IMPLICATIONS**

Two salient features of Sub-Saharan indigenous land tenure systems emerge from our analysis. First, there is mounting evidence that the individualization of rights to land is increasing in response to the effects of increased commercialization and population pressure. Evidence from both Rwanda and Ghana indicates purchases are becoming an increasingly important means of acquiring land. This rise is not new, however, and has
been occurring for quite some time. Interestingly, this rise in individualization has occurred under very different legal environments. It took place in Kenya, which has a history of land registration and government intervention in land matters, but also in Ghana and Rwanda where the governments have been less active in providing and enforcing a strict and well defined legal environment for land transactions.

<table>
<thead>
<tr>
<th>Category</th>
<th>WASSA</th>
<th>ANLOGA</th>
<th>EJURA</th>
<th>RUHENGÉRI</th>
<th>BUTARE</th>
<th>GITARAMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farms receiving credit</td>
<td>22.0</td>
<td>47.8</td>
<td>5.7</td>
<td>41.0</td>
<td>12.7</td>
<td>13.8</td>
</tr>
<tr>
<td>Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formal lenders</td>
<td>57.5</td>
<td>74.5</td>
<td>66.6</td>
<td>0.0</td>
<td>0.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Informal sources</td>
<td>42.5</td>
<td>25.5</td>
<td>33.4</td>
<td>100.0</td>
<td>100.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Relatives</td>
<td>(15.2)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farming</td>
<td>69.7</td>
<td>94.5</td>
<td>88.9</td>
<td>26.2</td>
<td>50.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Nonfarming</td>
<td>30.3</td>
<td>5.5</td>
<td>11.1</td>
<td>73.8</td>
<td>50.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Collateral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>21.2</td>
<td>34.5</td>
<td>0.0</td>
<td>11.9</td>
<td>28.6</td>
<td>25.0</td>
</tr>
<tr>
<td>Other</td>
<td>66.6</td>
<td>63.6</td>
<td>77.8</td>
<td>4.8</td>
<td>0.0</td>
<td>60.0</td>
</tr>
<tr>
<td>None</td>
<td>12.2</td>
<td>1.9</td>
<td>22.2</td>
<td>73.8</td>
<td>50.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Total Number of Loans</td>
<td>33</td>
<td>55</td>
<td>9</td>
<td>42</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Total Number of Loans</td>
<td>150</td>
<td>115</td>
<td>158</td>
<td>61</td>
<td>79</td>
<td>80</td>
</tr>
</tbody>
</table>

* For Rwanda, the data reflect both 1986 and 1987.

The second feature relates to the degree of individualization of rights across regions and is more speculative at this stage of our analysis. It appears from our analysis of Rwanda that population pressure alone may not be sufficient to sustain the transformation of land rights.
towards individualization. Where commercialization is low and off-farm employment opportunities are lacking, social groups may retain some control over land rights as a form of social security. This does not imply that "within lineage" land is any less secure for the individual in terms of use rights. However, by preserving access to land for other members of the family or lineage, the individual's ability to capitalize on land improvements through the land market, or to use land as collateral to obtain credit, may be hampered. Contrary to conventional wisdom, this adaptation should probably be seen as an efficient community response to the low level equilibrium trap characterizing the agricultural sector in many regions of Africa. The appropriate policy response is not to enact land legislation, but to remove the constraints on the system that necessitate the need for such a social security system.

While detailed policy prescriptions must await completion of our research, two general recommendations can be made at this time. First, it is necessary to avoid broad generalizations about the supposed inefficiencies of indigenous land tenure systems in Sub-Saharan Africa and the need for simplistic interventions such as the enactment of national land laws or land registration. Second, because the transformation of Africa's land tenure systems is often constrained by the technical and economic context in which they operate, and they appear to evolve towards more individualized forms of ownership as economic opportunities improve, the appropriate policy response should be to first improve opportunities and then nurture appropriate changes in the indigenous land tenure systems. This requires a flexible and adaptable approach suitable to the specifics of local conditions and a systems approach rather than narrow land policy intervention.

Seen within this context, land registration itself is not a panacea for the problems of low investment in African agriculture. It is unlikely to be economical in regions where the prevailing technology is already a constraint on the evolution of individualized forms of land ownership. Further, when introduced prematurely or not backed up by efficient land administration systems with which to maintain and update records, land registration may actually distort rather than reduce transaction costs by increasing the risk of fraudulent sales by illegitimate claimants. The recent decision in Kenya to refer land cases to local elders rather than the magistrate courts attests to the inadequacy of the registration system in some parts of the country where its introduction was probably premature.

Where the indigenous social fabric has been eroded so that the traditional institutions are weak, reliance on "elders" who are often no more than government appointees not conversant either with indigenous tenure rules or the intricacies of land registration statutes may lead to injustices. This suggests a strategy that predicates land registration programs on demand from the bottom rather than imposition from above. It also suggests the need to make adequate provisions for efficient

4/ Of course, there are other social, political, and cultural factors that influence the degree of individualization of rights.
administration of land legislation, including the updating of records. Kenya's experience over thirty years suggests that land registration without other supportive services and appropriate macro-economic conditions is not likely to improve security or promote credit markets in most of Sub-Saharan Africa. Given its high cost of implementation and maintenance, it is questionable whether a national program of universal land registration should be adopted by most African countries at present.

\[5/\] Data collected in the Njoro (White highlands) region of Kenya indicate that, after controlling for other household and parcel characteristics, titling did not have a significant effect on land improvement (Blarel and Carter and Wiebe (work in progress)).
REFERENCES


THE IMPLICATIONS OF LAND REGISTRATION
AND TITLING IN THAILAND

Gershon Feder

INTRODUCTION

As agriculture becomes more commercialized and land values increase, the incidence of land disputes and consequently tenure insecurity increase as well. This pattern has been documented by many scholars in several countries (Feeny, 1982, p. 95; Clark, 1969; Baron, 1978, p. 27; Kemp, 1981, p. 15). Agricultural development is also accompanied by an increase in land transactions (sales, rentals) as individuals seek to adjust the land input to efficient levels compatible with other endowments, such as farming skills and family size. But as transactions increasingly involve individuals who are not closely related, uncertainty over entitlement to transfer land rights becomes a relevant factor. One institution which evolved to reduce or eliminate ownership uncertainty is the provision of official ownership certification to owners, (e.g., title) and the maintenance of a legal system capable of enforcing and protecting property rights.

Insecure land rights imply increased uncertainty for farmers regarding their ability to benefit from investments designed to improve the productive capacity of their farms. With increased uncertainty, investment incentives are reduced and current consumption is preferred. With lower capital accumulation, the demand for variable inputs that are complementary to capital is also reduced. Here again, official recognition of land rights (through registration and titling) and the protection of these rights through an effective legal system are institutional developments to enhance productivity.

Secure legal titles can improve a farmer’s access to cheaper, longer-term and a larger volume of institutional credit. Land has several attributes which make it a desirable collateral asset (Binswanger and Rosenzweig, 1986). Because a clear legal title is often necessary for the mortgaging of land, a title can provide easier access to credit, especially from institutional lenders that do not have personal or detailed information on the borrower (Dorner and Saliba, 1981, p. 23; Aku, 1986, p. 24; Feder et al., 1988b). Non-institutional lenders usually base their decisions on personal familiarity with the borrower and they have alternative means for enforcing repayment (e.g., social pressures) that are not available to institutional lenders. Access to non-institutional credit is therefore less affected by possession of land titles. However, such credit is usually much more expensive than institutional credit and is mostly

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short term. Constrained and more expensive credit leads to low factor/land ratios and lower productivity. Since both variable inputs and capital are lower among farmers without secure ownership, their output is expected to be lower than if they had secure ownership.

The above arguments suggest the hypothesis that ownership insecurity causes lower farm productivity because investment incentives are reduced and access to credit is limited. An extension of this hypothesis is the proposition that the market value of land that is not securely owned (e.g., untitled land) will be less than that of an identical tract of land that is securely owned. This follows from the fact that the value of land reflects the stream of net incomes that it generates over a long horizon. The conceptual framework outlined above is summarized in Figure 1.

At an aggregate level, the discussion implies that the institution of land registration and titling can have significant economic consequences in the agricultural sector. This paper opens with a review of evidence from various countries and then focuses on the results of a case study in Thailand dealing with the economic implications of land ownership security, where security is defined as possession of legal ownership documents. The results substantiate the conceptual framework outlined above.

REVIEW OF EMPIRICAL EVIDENCE

Quantitative evidence on the link between secure legal ownership and use of credit is rather limited. A study in Costa Rica by Seligson (1982) showed that before the titling program began, 18 percent of the farmers sampled had obtained credit. After the program, 31.7 percent had obtained credit. Credit improved mainly for owners of large farms; the average farm size for those who post-title got credit was 9 ha and 7.3 ha for those who did not. These results reflect not only supply changes, but also demand shifts. Similarly, recent data on a titling program in Jamaica (IDB, 1986) indicate that almost half of the title recipients increased their borrowing relative to the pre-project level.

In a study of land transactions in the Central Plain of Thailand, Stifel (1976) observed widespread use of title certificates as security for non-institutional loans. These loans involve land collateral which is neither registered in the Land Office nor recognized by law. The "unregistered mortgages" are prevalent for small or short-term loans. In these transactions, creditors have no legal rights to the land. However, since the creditors physically possess the title deed, they can prevent the farmer from legally transferring ownership to other parties. This practice also restricts the farmer's access to additional credit from other lenders and therefore provides the lender with some protection against the borrower possibly incurring excessive debt. As an indication of how widespread this practice is, Stifel (1976) found in one village in the highly developed Central Plain region that the number of these unregistered mortgages was three times greater than the number of registered ones.

Both the effects of secured ownership on credit availability and the effects on investment incentives imply that farmers without secure ownership will have less investments and land improvements, lower use of variable inputs, and lower productivity per unit of land. Empirical evidence confirming these propositions is scant. A study of the economic
Figure 1: Land Ownership Security and Farm Productivity: A Conceptual Framework

- Titled Land
  - More Security to Farmer
    - More Demand for Investment
      - (input complementarity)
        - More Demand for Variable Input
          - More Variable Input Use
            - Higher Output Per Acre
  - More Security to Lender
    - More Supply of Cheaper Long Term Credit
      - More Investment
        - More Supply of Cheaper Short Term Credit
          - More Variable Input Use
implications of land titling in Costa Rica (Salas et al., 1970) found positive correlations (in the range of .40 to .67) between the degree of ownership security and farm investment per unit of land. Similarly, data from three Brazilian states in 1978 reviewed by Villamizar (1985) revealed that capital per hectare is substantially higher on titled land than on undocumented or encroached land. The analysis was done for different farm size groups; the proposition held within most groups.

Several studies have focused on the impact of ownership security on output or income. The earliest study, conducted in Costa Rica (Salas et al., 1970), found a positive correlation in one province of .53 between income per unit of land and ownership security. In another province, however, the correlation was negative, although quite weak (-.07). A study of the Brazilian state of Maranhao (cited in IDB, 1986, pp. 186-189) concluded that granting full legal ownership to squatters and undocumented occupiers would increase their income by 200 percent. The same report quotes recent data from Ecuador indicating that income levels of titled farmers were double those of untitled farmers, holding the amount of land owned constant (IDB, 1986, p. 187).

As mentioned earlier, constrained credit may produce efficiency losses when the optimal mix of farm activities is affected. For instance, in Costa Rica it has been reported that it is easier to obtain credit using cattle as collateral than it is using land for which the farmer does not possess a full formal title. In this example, as a consequence of the credit constraints, farmers without title tended to shift from crop production to cattle raising even though the land may have been better suited for growing rice and beans (Dorner and Saliba, 1981, p. 23).

Recent survey results from Jamaica indicate that titled farmers had a substantially higher incidence (almost double) of permanent and semi-permanent crops as compared to untitled farmers. Indeed, a third of the recipients of titles under a government program reported that following the change in their status they planted more permanent and semi-permanent crops than they did before the project (IDB, 1986, p. 189).

DEVELOPMENT OF LAND RIGHTS IN THAILAND

Thailand has been a land abundant country throughout most of its history. Widespread forest clearing and settlement of frontier areas accommodated the needs of the expanding population and were tolerated with few restrictions until fairly recent times. As land was readily available and agricultural activity was subsistence-oriented, any Thai citizen could claim land to provide for his family, and rights to use land were by custom rather than formally recorded. Labor was a binding constraint on agriculture.

In the second half of the 19th century there was a transition from property rights in labor to property rights in land, induced by the opening of the country to international trade and the increased commercialization of rice production (Feeny, 1982). Title documents for rice land were established in the main rice producing areas in the 1860's through the 1880's. Land laws were revised several times, including (in 1901) the introduction of the Torrens system of land titles. The system prevailing today is based on the Land Code of 1954, which defines the powers and
duties of the Minister of the Interior and the Department of Lands regarding the allocation and acquisition of state land. It contains procedures for the issuance of documents recognizing title to land and the maintenance of the land register.

Lack of funds and inadequate administrative infrastructure to provide full title to all eligible farmers, problems which afflict many less developed countries, are also characteristic of Thailand. As a result, relatively few farmers have obtained full title. Only six percent of privately held land in Thailand is titled. Recently, the government undertook efforts to enhance the land titling capacity with funding from the World Bank and other aid agencies.

According to the 1954 Land Code, there are two main types of secure land documents. These correspond to two phases of land acquisition, namely, legal possession and utilization. Legal possession is documented in a full unrestricted title deed called N.S.-4. This document enables the owner to sell, transfer and legally mortgage the land. It is issued on the basis of an accurate ground survey and is registered in the provincial land register, with clear identification of the property by boundary mark stones.

The documents related to the phase of utilization are N.S.-3 and N.S.-3K -- "Certificate of Use" or "Exploitation Testimonial". These documents certify that the occupant has made use of the land for a prescribed period of time and they can be converted to a title deed with the completion of certain legal steps. For all practical purposes there is very little difference between N.S.-3 and N.S.-3K documents. In the study areas discussed below, the occurrence of full title deeds (N.S.-4) is practically nil, and the N.S.-3 and N.S.3-K documents are classified as "titled land" for the purposes of analysis.

Like many other developing countries, Thailand is faced with the problem of illegal occupation and utilization of state-owned land by large numbers of farmers. Most of the squatters are settled in areas officially classified as forest reserves. It is estimated that at least 33 million rai of land (21 percent of land under private occupation) classified as forest reserve land is actually under cultivation by squatters. Thus, only about half of the land under cultivation in Thailand (whether legally held or not) is covered by secure land documents.

Many of the squatters have had de facto possession of the land for many years, but they cannot obtain titles or certificates of utilization. As squatter areas can be found side by side with the non-forest reserve areas (i.e., same agro-climatic and geographic areas), it was possible to apply a cross-section farm level analysis without the difficulty of measuring the influence of environmental and infrastructural differences, or changes over time. Two different regions, namely, the Central and Northeast of Thailand, are covered by the study reported in this paper, involving parts of four provinces: Lop Buri (in the Central Plain), Nakhon Ratchasima, Chaiyaphum and Khon Kaen (in the northeast). In each province, farmers with secure land ownership (outside forest reserve) and neighboring farmers with insecure ownership (inside forest reserve) were sampled.
Lop Buri province is located in the Central Plain, while the other three provinces are located in the Northeast and are typical of other provinces in that region. The weather pattern in Lop Buri is more stable, the transportation infrastructure more developed and the soil more fertile as compared to the northeastern provinces, which are drought-prone. For these reasons the study area in Lop Buri province is more commercialized, with most farmers growing cash crops such as cotton, sorghum, maize, tobacco and mungbeans, in addition to rice. In the northeast, farmers grow mostly rice and cassava. The latter is a commercial crop but of low value and unstable market.

In the four provinces under the study, eviction of squatters is not very common. This is indeed the pattern in most of Thailand, as socio-political constraints and the large number of individuals concerned force the government to maintain the status quo. Thus squatters are rarely evicted, yet they are not allowed to obtain legal ownership of the land they operate. A survey among farmers indicated that the most important benefit farmers perceive in titled ownership is improved access to credit (Feder et al., 1988c).

LAND OWNERSHIP SECURITY AND ACCESS TO CREDIT IN RURAL THAILAND

Economic theory suggests that institutional lenders, due to the high transaction cost of acquiring borrower specific information, will be more inclined than non-institutional lenders to use land collateral as a device to reduce lending risk (Feder et al., 1988b). Squatters in Thailand cannot obtain titles on lands that were formally state lands and they cannot therefore acquire formal proof of ownership; neither can they legally sell their land. While (illegal) land sales are actually taking place in squatter areas at the same level as in legally settled areas, use of land as collateral is not feasible for squatters. As a result, they cannot have the same access to institutional credit (duration, magnitude), which is available to farmers who provide land as collateral.

Data from the four provinces studied show that in Lop Buri province, which is more commercialized, traders are the source of about half of all loans and provide the bulk of non-institutional credit. Their role is less significant in the less commercialized northeastern provinces. The existence of many traders in Lop Buri and their active involvement in the provision of credit is compatible with the favorable agro-climatic conditions and the prevalence of high-value cash crops in the province (Feder et al., 1988c). Most of the loans in the study areas are short-term (twelve months or less), but almost all of the medium and long-term loans were provided by institutional lenders and titled farmers received such loans more frequently than untitled farmers.

As predicted by theory, an overwhelming majority of the non-institutional loans were granted without collateral, while the majority of the institutional loans were covered by some type of loan security. The type of loan security utilized in borrowing from institutional lenders differed significantly between titled and untitled farmers. Lacking ability to offer land as a collateral, untitled farmers were obliged to provide a collateral substitute, namely, group guarantee. Titled farmers, on the other hand, provided their land as collateral in about half of the institutional loans in the northeastern provinces, and in more than three
quarters of the institutional loans in Lop Buri province. Group guarantee is less desirable to lenders than land collateral and data on loan magnitudes (per unit of land owned) indicated that in all provinces institutional loans covered by land collateral were larger than loans without collateral or loans with group guarantee.

An econometric analysis of credit supply and demand using a disequilibrium estimation framework confirmed that farmers providing land collateral are offered larger amounts of institutional credit than those providing other security or no security, holding all other characteristics constant (Feder et al., 1988b, 1988c). The data also indicate that in Lop Buri province, the non-institutional loan amount per unit of land is substantially higher than the mean institutional loan amount for comparable collateral categories. Similarly, unsecured non-institutional loans in Lop Buri are substantially higher than comparable loans in other provinces. The abundance of non-institutional credit supply in Lop Buri, and the fact that it can be obtained without land collateral, suggest that the effect of legal land titles (and the better access to institutional credit which they entail) on economic activity will be less in this province as compared to the other provinces in the study. However, the evidence substantiates the hypothesis that farmers with secure ownership enjoy significant advantages in access to institutional credit as compared to squatters.

LAND OWNERSHIP SECURITY AND LAND VALUES

The theory discussed above suggests the hypothesis that titled land has a higher price than untitled land of identical quality. Data presented in Feder et al. (1988c), pertaining to four Thai provinces, indeed show that the mean prices of titled land are substantially higher than the mean prices of untitled land (line 1 of Table 1).

Table 1: Effects of Land Title on Land Value

<table>
<thead>
<tr>
<th>Province</th>
<th>Lop Buri</th>
<th>Nakhon-Ratchasima</th>
<th>Khon-Kaen</th>
<th>Chaiyaphum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Ratio of mean titled land price to mean untitled land price in sample</td>
<td>1.221</td>
<td>2.958</td>
<td>2.076</td>
<td>1.531</td>
</tr>
<tr>
<td>2) Ratio of titled land price to untitled land price calculated from hedonic price equation a/</td>
<td>1.250</td>
<td>2.326</td>
<td>2.128</td>
<td>1.539</td>
</tr>
<tr>
<td></td>
<td>(5.48)</td>
<td>(14.29)</td>
<td>(11.10)</td>
<td>(8.52)</td>
</tr>
<tr>
<td>3) Sample size</td>
<td>431</td>
<td>536</td>
<td>447</td>
<td>464</td>
</tr>
</tbody>
</table>

a/ Hedonic price equation reported in Chalamwong and Feder, 1988, and Feder et al., 1988c. Number in parenthesis indicates the associated t value.
Comparisons of average prices are valid only if the distribution of various attributes of land which may affect the price are identical. In order to remove this rather restrictive assumption, the data on the physical attributes of each tract provided by the farmers were utilized in a hedonic price analysis (Chalamwong and Feder, 1988). In this analysis the title status of each tract was entered as a dummy variable, thus estimating the ceteris paribus effect of possessing a land title, controlling for differences in soil type, slope, location, etc. The estimates, summarized in line 2 of Table 1, indicate that legal title is a most significant factor in explaining the variation in land prices. However, in Lop Buri province the value of the parameter is lower than in the other provinces. This is compatible with the earlier discussion of access to credit by titled and untitled farmers in the different provinces. The hedonic price analysis confirms that the price of untitled land is substantially lower than that of titled land in all provinces.

THE IMPACT OF OWNERSHIP SECURITY ON INVESTMENT, INPUT USE AND OUTPUT

Economic theory suggests that ownership security in the form of legal titles will induce higher rates of investments in equipment and in land improvements, both because of better incentives and because of the advantages in access to institutional credit. These propositions were investigated by Feder and Onchan (1987), who considered both capital formation (investment in equipment) and investment in two types of land improvements.

The analysis of the value of capital owned by titled and untitled farmers was done in a regression framework, controlling for the value of capital farmers had when they became decision makers on the farm they presently own and for other attributes which affect capital formation. The impact of titles on capital formation, as estimated in these regressions, is reported in line 1 of Table 2. The estimates for the northeastern provinces confirm that ownership security induces higher capital accumulation. In Lop Buri province the coefficient for ownership security is positive, but it is not significantly different from zero. As in the analysis of land values, this result is compatible with the ample supply of non-institutional credit available in that province.

Feder and Onchan (1987) analyzed the adoption of two types of land-embodied investments which enhance or maintain the productive capacity of land by preventing erosion or moisture loss: (a) bunding (dividing the field into sub-plots by raised earth walls, thus allowing better water control and moisture retention); and (b) clearing of stumps (increasing the productive surface area and facilitating better and faster soil preparation utilizing mechanized power). The analysis employs a logit model, controlling for various farmer and land attributes, and representing the impact of titles through a dummy variable for those tracts of land which were titled. The estimated coefficients from the logit equations are presented in lines (2) and (3) of Table 2 (translated to percentage equivalents). The probability that land will be improved by bunding is significantly higher on titled plots in two of the provinces. In the estimates for land improvement by clearing of stumps, possession of titles significantly increases the probability of adoption in three of the provinces.
With higher capital intensity, variable input use per unit of land will be higher due to the complementarity between capital and other inputs. Furthermore, when short-term credit is a binding constraint, farmers with titled land are expected to use more variable inputs as a result of their better access to cheaper short-term credit. With higher input use per unit of land, output will be higher on lands owned by titled farmers.

Table 2: Effects of Titles on Investment, Input Use and Output (expressed as percent difference between titled and untitled farmers, holding all other attributes constant)

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>Lop Buri</th>
<th>Nakhon-Ratchasima</th>
<th>Khon-Kaen</th>
<th>Chaiyaphum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Capital Formation</td>
<td>4.4</td>
<td>105.0*</td>
<td>253.2*</td>
<td>55.9*</td>
</tr>
<tr>
<td>2)</td>
<td>Land Bunding</td>
<td>18.4</td>
<td>69.5*</td>
<td>41.1*</td>
<td>2.8</td>
</tr>
<tr>
<td>3)</td>
<td>Clearing of Stumps</td>
<td>12.3*</td>
<td>47.4*</td>
<td>29.3*</td>
<td>.005</td>
</tr>
<tr>
<td>4)</td>
<td>Use of Labor</td>
<td>14.7*</td>
<td>14.7*</td>
<td>8.2*</td>
<td>n.a.</td>
</tr>
<tr>
<td>5)</td>
<td>Use of Draft Power</td>
<td>-5.4</td>
<td>38.7*</td>
<td>26.9*</td>
<td>n.a.</td>
</tr>
<tr>
<td>6)</td>
<td>Use of Other Inputs</td>
<td>18.4</td>
<td>24.6*</td>
<td>34.8*</td>
<td>n.a.</td>
</tr>
<tr>
<td>7)</td>
<td>Output</td>
<td>4.5</td>
<td>11.8*</td>
<td>26.7*</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

* Denotes significance at a 90 percent (one-tailed) confidence level.

These propositions were studied by Feder (1987) for three Thai provinces, using reduced form regressions. The impact of titled ownership was estimated while controlling for differences in land quality and in other physical and economic characteristics of the land using a quality index derived from analysis of land values. Differences in farmer attributes were also accounted for. The results from the Feder (1987) study (translated to percentage equivalent terms) are presented in lines (4-7) of Table 2. For the northeastern provinces, there are significant differences in input use and output between titled and untitled farmers: the use of labor is higher by 8-15 percent, draft power is higher by 27-39 percent, and the use of other inputs is higher by 25-35 percent. Output per unit of land is higher by 12-27 percent. In Lop Buri province, as observed in the analysis of capital formation, differences between titled and untitled farmers tend to be smaller and not statistically significant.

Given the low incidence of eviction and land disputes in most areas of Thailand, and the opinions of farmers regarding the most important
benefit of titles, the material reviewed above suggests that in Thailand much of the impact of secure title stems from improved access to institutional credit. This is not necessarily the case in other countries, especially in areas where eviction, disputes and other risks generating insecurity are prevalent.

POLICY IMPLICATIONS

The analysis of Thai data demonstrates that the possession of legal land ownership documents in Thailand has a substantial impact on farmers' agricultural performance. Chalamwong and Feder (1988) have also shown that awarding title documents to farmers lacking such status (i.e., squatters), while entailing costs of surveying and adjudication, has a very high economic payoff in most of the areas studied as the benefits outweigh by a wide margin the relatively small costs of certifying legal ownership. Given the evidence that limited access to institutional credit is the main constraint affecting squatters' productivity in rural Thailand, some may argue that their problem can be resolved by enacting decrees forcing banks to relax their collateral policies. If such policies were enforceable, they would likely cause substantial costs in consequent subsidization of banking operations because the repayment performance for non-collateralized loans is worse than that for the collateralized loans.

Similarly, policies which provide Thai squatters with limited formal status (e.g., a non-transferrable lease from the state, or usufruct certificate), yet restrict their ability to transfer or mortgage land, will not significantly improve squatters' performance. Such policies do not alter squatters' access to institutional credit. Feder et al. (1988a) studied areas in Thailand where squatters were provided with usufruct certificates of the type referred to above. It was shown that such certificates, when awarded to squatters in areas where they are well established, are not an effective policy for improving their economic performance. The situation may be quite different in other countries where squatters face significant ownership insecurity due to eviction risk and land disputes. In such areas, even limited formal status may enhance ownership security and induce farmers to increase investment and land conservation efforts.

Some of the opposition to the granting of full ownership rights to squatters in Thailand stems from concern that such an act will increase further encroachment on the remaining forest lands. Forest depletion is a serious problem in Thailand and this argument needs to be examined. However, the root cause of the steady decline in forest areas is population growth in rural areas and insufficient enforcement of restrictions on the use of forest lands. This dynamic process will not be much affected unless strict enforcement of forest conservation and protection measures becomes a priority, with adequate budgetary allocations and political backing.

A logical policy in a situation such as the one in Thailand would be to provide full ownership rights to squatters in agriculturally suitable areas that are not expected to be reforested. The effectiveness of such a policy -- if it is adopted on a large scale -- would require complementary policies affecting the aggregate supply of institutional credit to
agriculture. Due care would need to be taken so as not to introduce distortions in credit markets through government interventions.

There are additional factors to consider. Some squatters have settled in areas where continuing cultivation causes environmental damage. In these areas control of the land may be better left to the state. Similarly, consideration must be given to equity issues. Experience in other countries indicates that when squatters are provided with opportunities for legal ownership, or when the land rights system is being changed by government intervention, land grabbing by wealthy or powerful elements of the society is a real risk. Therefore, the design and implementation of policies providing titles and formal recognition of land rights should contain safeguards against negative equity implications such as limiting the amount of land which can be claimed and allowing local institutions (farmer associations) to have an input.

If the administrative capacity to consistently maintain land records is limited, and if the ability to protect those who have official recognition through an efficient legal system is lacking, a policy of titling will not be sustainable. Within a few years after implementation, the official record will become useless and the cost and effort invested in implementing the system will be wasted. A long-term commitment and a realistic assessment of the limitations of the administrative and legal system are required before titling policies are undertaken.
REFERENCES


BACKGROUND

Tropical Deforestation: Its Negative Impact

Deforestation threatens the sustainability of development. Millions of people living in the tropics depend on forests for their survival. Forests and trees are a major source of food, fuel, fiber, fodder and other necessities.

Forests and farm trees improve the productivity of farming systems, thus contributing to food security. They stabilize watersheds and reduce erosion and flooding. They provide wood for energy, raw materials for construction, fiber products such as paper, and countless other goods and services needed to improve human welfare.

In more subtle ways, forests contribute to global welfare -- for example, providing the genetic material which now underlies many of our basic foods and generating employment opportunities. Tropical forests will become increasingly important in meeting the future needs of an expanding global population.

Despite the significant contributions made by forests and trees in the tropics, every year more than 11 million hectares are being destroyed. Investment in forest conservation and reforestation is lagging way behind the levels needed to sustain forest cover, an adequate stock of farm trees and an assured supply of essential forest products.

The negative impacts of deforestation, forest degradation and loss of farm trees in the tropics are growing. They include:

- increasing soil degradation and desertification, which lead to food insecurity;
- declining water quality, which affects human health;

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Note: A more detailed version of this paper is available as Environment Department Working Paper No. 10, World Bank.
• rising costs for hydropower and irrigation projects as dam reservoirs become filled with silt from erosion;

• hardship and misery for a rising population of people who cannot find fuelwood and who cannot afford alternative fuels;

• declines in productive employment because wood, both as a raw material and a fuel for industry, is becoming scarce and expensive;

• declining foreign exchange earnings and increasing import bills for forest products as forests are depleted of commercial woods;

• loss of biological diversity and the gene pool which has been so important in supplying the basic genetic material underlying many of our important food products and medicines;

• the cutting and burning of tropical forests is contributing to atmospheric emissions of greenhouse gases, thereby amplifying the problem of global warming.

The Tropical Forest Action Plan: Bellagio I

In mid-1987 the Rockefeller Foundation, World Bank, UNDP and FAO jointly sponsored a meeting of 26 world leaders at the Rockefeller Bellagio Center to discuss the issue of tropical deforestation. The meeting reviewed and endorsed a Tropical Forest Action Plan (TFAP), jointly sponsored by national governments and leading aid agencies, that would address these issues. This TFAP focussed on five main aspects of the problem:

• forestry's role in land use, in particular the potential of forests and farm trees to contribute to sustainable agriculture and to protection of soil and water resources;

• conservation and increased supplies of fuelwood;

• sustained forestry and forest industries management for production of essential wood products (saw logs, wood based panels, pulp and paper);

• protection of biological diversity in natural forests;

• strengthening of forestry education, training, research and extension.

The TFAP called for at least a doubling of aid agency flows for forest conservation within a three year period and accelerated assistance for long range forest conservation strategies in the 56 developing countries that are worst affected by deforestation. The response of the aid community has been positive. Aid community allocations for forest conservation have more than doubled. Forest conservation strategy planning exercises have been completed in nine countries and are ongoing in a
An interagency Forestry Advisor's Group has been established to focus on cross-cutting issues that could act as a constraint to implementation of the TFAP.

**Strengthening of Forestry Research: Bellagio II**

At the 6th meeting of the Advisor's Group in late 1987, it was agreed to focus on the issue of the current weakness of the tropical forestry research base. Compared with agriculture, there exists in forestry nothing remotely similar to the CGIAR Centers that played such a decisive role in bringing about the Green Revolution and making possible a significant increase in developing country food supplies.

By contrast, past forestry research has been spread over a very wide range of topics, often with little coordination. Partly because of the long term nature of forestry research, funding has been erratic. Many forest research projects with promising potential have been abandoned before they have had time to produce meaningful results.

A Second Rockefeller Foundation Forestry meeting was held in November 1988 to review forestry research needs for underpinning the TFAP and institutional options for strengthening forestry research. This paper was prepared as an input to that meeting. It reviews some of the more promising research technologies that could underpin the TFAP. It provides a starting point for a review of the institutional options for strengthening forestry research, which are discussed in the main Bellagio II Conference Paper, "A Global Research Strategy for Tropical Forests".

**Priority Research Areas**

This paper reviews promising research topics that have potential to make a decisive contribution to the TFAP objectives of containing tropical deforestation, ensuring the basic needs of the rural and urban poor for food, fuelwood, fodder and shelter, preserving the biological diversity of tropical rainforests, and maximizing the potential of forests to contribute a sustainable source of employment, income generation and export earnings.

It recommends concentration of research effort in five main areas:

- forestry research aimed at sustaining food production, improved food security and protection of soil and water resources
- tree breeding and improvement programs
- utilization and forest products research
- conservation of natural forest ecosystems and biological diversity
- policy research aimed at addressing the underlying causes of deforestation and formulation of incentives that will encourage indigenous peoples' involvement in tropical forest management and reforestation
SUSTAINING FOOD PRODUCTION AND FOOD SECURITY

There is incontrovertible evidence that upland forests, tropical rainforests, savannah woodlands and farm trees play an important role in sustaining food production and in protecting the soil and water resources on which agriculture depends. Maintaining forest cover and ensuring an adequate stock of farm trees could sustain food production by many developing country farmers at significantly higher levels than would be the case if all forests and trees were to be destroyed.

Agroforestry farming systems can help the developing world to achieve the 50 to 60 percent greater agricultural output that will be required by the year 2000 to feed an additional 1.7 billion people. They are particularly relevant to reclamation of agricultural wastelands and maintaining the nutrient status of impoverished tropical soils. A substantial part of the additional fuelwood and tree fodder requirements of expanding human and livestock populations will be derived as a by-product of agroforestry.

Some of the more promising agriculture related forestry research technologies include:

- **Nitrogen Fixing Leguminous Trees**

  Support is required for increased planting of leguminous nitrogen fixing trees such as *Gliricidia*, *Sesbania*, *Casuarina*, and *Leucaena* species that can significantly contribute to maintenance of soil nitrogen, reduced dependence on artificial fertilizer, improved soil structure and improvement of crop yields. This is a key issue for thousands of small developing country farmers who either cannot afford to purchase fertilizer or who live in remote areas where it is not available.

  The pioneering work of the Nitrogen Fixing Tree Association (NFTA), and in particular of Brewbaker (1988) and Dommergues (1987) has demonstrated the potential. What is needed is accelerated field trials of selected provenances of leguminous tree species with high nitrogen fixing potential. Molecular cloning and recombination techniques could lead to development of new strains of *Rhizobium* and *Frankia* (mycorrhizal fungi that stimulate nodule formation and nitrogen fixation).

- **Alley Cropping**

  Emerging agroforestry technologies such as 'alley cropping'\(^2\) have the potential to maintain food crop production while

\(^2\) A farming system that combines growing of agriculture food crops interspersed with hedges of trees that are regularly pruned. Tree leaves are used as a green manure to mulch and to protect the soil and increase nutrient status. The system ensures crop and soil protection as well as a sustainable source of fuelwood and tree fodder.
simultaneously contributing to maintenance of soil structure, fuelwood and fodder supply.

The advantages of alley cropping technology have been demonstrated by the International Institute for Tropical Agriculture (IITA). It has particular relevance for tropical rainforest lands that are under pressure for increased agricultural settlement (e.g., Brazil, Cote d'Ivoire and Indonesia). Sanchez (1984) and Lal (1988) have identified specific research needs. Questions that urgently need further field research include choice of appropriate tree species, quantification of the economic trade-off between alley cropping and other farming systems, and incentives to stimulate rapid farmer adoption of this technology.

- **Direct Seeding**

Direct seeding (as opposed to more traditional dependence on raising of polythene potted stock in centralized tree nurseries) has the potential, in appropriate ecological situations, to decrease planting costs at least five-fold and to facilitate rapid spread of low-cost reforestation in remoter rural areas. This is a particularly relevant technology for making an early and significant contribution to on-farm fuelwood/fodder needs and to reclamation of degraded wastelands and watersheds; also for accelerating the adoption of agroforestry. See the Beijer Institute's study of Western Kenya experience (1985) and the National Academy of Sciences (1981) review of the potential for aerial reseeding. Research needs include provenance selection, seed collection, storage and pelletisation techniques, particularly of leguminous multi-purpose species.

- **Shelterbelts**

Introduction of appropriately spaced tree shelterbelts can increase crop yields by some 15 to 20 percent as well as provide a source of essential fodder and fuelwood. This is of special importance for arid zone environments (see Niger Majia Valley and Egyptian experience described by El-Lakany, 1987).

Research needs have been suggested by Anderson (1987). Special emphasis needs to be directed towards improved understanding of the economic costs and benefits of tree shelterbelts and of incentives to encourage more widespread shelterbelt planting.

- **Fodder Trees**

Protection and improved management of upland fodder trees as researched by Singh (1982), Panday (1982) and Fleming (1983) could at least double fodder tree yields over the coming decade. This is an issue of vital concern to several million
people living in the upland watersheds of the Himalayan region where sustainable farming systems depend to a very high degree on animal derived manure. Research priorities for increased fodder production have been reviewed by Panday. There are striking differences in the productivity of different fodder tree species. Provenance selection and improved harvesting systems for existing fodder trees are two of the more important areas for research.

- **Increasing the Productivity of Arid Zone Rangelands**

Maintaining an adequate cover of savannah woodland trees can ensure between a 30 and 70 percent increase in grass and protein production, significantly raise the carrying capacity of rangelands and contribute to livestock weight gain (Enriquez, 1983; Bille, 1977; Pratchell, 1987; Farnsworth, 1976). Research needs include optimization of tree/pasture cover, choice of appropriate browse and tree fodder species and minimization of allelopathic effects.

- **Pollarding and Coppicing of On-farm Trees**

Pollarding, coppicing and similar on-farm tree management systems can increase biomass productivity and significantly reduce the number of trees required to sustain a family's essential fuelwood requirements (Fishwick, 1979). To date there has been almost no systematic research on on-farm tree harvesting and management practices.

- **Close Espacement Biomass Planting**

As demonstrated by Zsuffa (1985), closely spaced planting of fuelwood trees can shorten rotations and has the potential for at least a three-fold increase in short-term availability of biomass. Research issues relate to nutrient depletion and economic trade-offs between closer and more widely spaced planting along the lines of recent work by Ryan (1988).

- **Increasing Fuelwood Output from Natural Forests**

Protection and management via appropriate timing of harvesting, early burning and improved lopping techniques has the potential to double fuelwood yield in the natural savannah woodlands of Africa (Openshaw, 1986; Winterbottom and Hazlewood, 1987). Such management practices need to be systematically tested in different ecological zones as recommended by IUFRO (1986).

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3/ A management system that lops off the top of vigorously growing trees and encourages sprouting of branches that are then periodically lopped for fuelwood or fodder.
• **Low-cost Soil Conservation Techniques**

Vigorous research into application of low cost soil conservation methods for upland areas such as the planting of Vetiver grass (*Vetiveria Zizoides*) (Grimshaw, 1987) has the potential for major reductions in the costs of upland soil conservation and reclamation measures.

• **Incentives for Rehabilitation of Degraded Watersheds**

The work of researchers such as Pereira (1972), Achlil (1984), Trustrum (1983), and Wiersum (1984) has clearly demonstrated the potential for forests in upland catchments to regulate water flow, to reduce the risk of landslides, and to reduce sedimentation and disruption of downstream water flow. Applied socio-economic policy research is necessary to test incentives which can lead to more effective involvement of local people in watershed management (de Camino, 1987). Such research has major implications for reclamation of some 150 million hectares of degraded tropical watersheds.

**TREE BREEDING AND IMPROVEMENT PROGRAMS**

Over the course of several centuries, plant selection, breeding and improvement in agriculture has raised the potential for biomass yields close to the upper biological limits of potential productivity (from less than 5 to over 20 tons of dry biomass per hectare per year). By contrast, tree selection breeding and improvement programs are still in their infancy. Because of this it is still possible to achieve spectacular gains in biomass output simply through provenance selection and development of improved seed strains.

Vegetative propagation and cloning technology has demonstrated the potential for at least doubling yields by application of root hormone to leaf bud material from superior trees and by use of grafting techniques. Tissue culture, while still not widely used, is another emerging and promising area for ensuring genetically improved strains of fast growing species.

Tree breeding and improvement research is the key to ensuring supplies of improved seed or tree planting stock for more productive agroforestry, fuelwood, cash crop tree farming, and industrial reforestation programs. At least a doubling in yield of the more important tree species within a decade is a reasonable target. Several examples of successful tree breeding and improvement programs that have already achieved this can be identified:

• **Provenance Trials**

Provenance trials of "*Eucalyptus camaldulensis*" in Nigeria have demonstrated more than a three-fold difference in yield between the slowest growing provenances (5 cubic meters per
hectare per annum) and the fastest (17 cubic meters per hectare per annum).

In the Congo and Brazil, the yield of Eucalyptus plantations has been increased by 80 percent by selection of the best seed sources (Chaperon, 1978; Brune and Zobel, 1981).

An FAO project on genetic resources of the arid zones covering eight countries collected different provenances of mainly Acacia and Prosopis species over the period 1980-87. A total of 280 well documented provenances were collected and seed distributed for field testing. Significant gains in yield are being recorded.

The establishment of seed banks of selected provenances, especially of indigenous species, is already being undertaken by, for example, Centre Technique Forestier Tropicale (CTFT) in Africa, the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia and the Oxford Forestry Institute (OFI). Significant yield increases have been achieved.

- Vegetative Propagation

Use of vegetative propagation technologies has enabled the Aracruz Company in Brazil to raise the productivity of its industrial plantations from an average of 25 to more than 50 cubic meters per hectare within a 10-year period. Similar results were demonstrated by CTFT working in Congo PR with Eucalyptus species.

Leakey (1987) of the Institute of Terrestrial Ecology has demonstrated very promising results by vegetative propagation of more valuable West African tropical hardwoods (e.g., Triplochiton and Terminalia species) in Cameroons.

Similar work is being undertaken by the Sabah Softwoods Company in Malaysia working with Gmelina arborea.

- Tissue Culture

The use of tissue culture can shorten the time necessary to reproduce a large stock of planting material with desirable yield potential or disease resistance characteristics. The possibilities of tissue culture of forest tree species have been reviewed by Bonga and Durzan (1982). The cost of plantlets and the sophistication of the technique make it unlikely that in the immediate future this will replace the use of cuttings for large-scale reforestation in tropical areas. Its nearer-term use is likely to be in establishing "super-tree" orchards to produce seeds or cuttings. Technology is fast developing and further work on
embryogenesis could conceivably lead to significant reductions in cost and a breakthrough in the scope for wider application of this technology (Brown and Sommer, 1982).

UTILIZATION AND FOREST PRODUCTS RESEARCH

A key to improving the productivity of developing country forests is to make better use of what already exists. Typically, logging operations in the West Africa region or in the Latin American Amazon depend to a high degree on some 5 to 10 more valuable species out of the 300 or more that exist in the natural forest. Forest products research has a vital role to play in widening the range of species that can be utilized. It can help ensure an adequate supply of raw material and improved efficiency for small-scale village forest industries that account for a very significant proportion of rural employment and incomes. Effective utilization of wood (through preservation techniques or through improved processing technology) can more than triple the life of fence posts, timber buildings, etc. Many of the forest products technologies that have been pioneered by developed country research institutions could be readily transferred to the tropics.

Some of the more promising forest products research experiences with potential for wider replication include:

- **Timber Utilization and Grading**

  Timber utilization and timber grading research such as that carried out in Malaysia made it possible within a period of 15 years to increase the number of species in commercial use from 100 to more than 600 (Salleh Mohd. Nor, 1988). Similar progress in species utilization has been recorded in Costa Rica and other countries.

  Market research and promotion of new species is especially important. For example, ten years ago rubber wood was unknown as a commercial species in Malaysia. Research on species properties, processing, protection and utilization opened up new markets. As a result Malaysia now exports over 250,000 cubic meters of rubber wood with a value in excess of US$10 million a year.

- **Use of Wood Wastes**

  Research aimed at encouraging a shift from solid timber to reconstituted wood has enabled the U.S. timber industry to make effective use of wood waste and to more than double recovery of utilisable wood. Bengsten (1984) demonstrated economic rates of return of about 20 percent for substitution of solid timber by particle board. Several of the wood waste utilization technologies that are now in widespread use in the developed countries are appropriate for rapid adoption by developing countries.
Timber Engineering

In Kenya, Keen (1969) has demonstrated the potential of improved wood engineering (use of laminated beams based on utilization of small size waste timber) to greatly extend the possibilities for timber based buildings.

Timber Preservation

In the hot, wet tropics, preservation treatment that increases the life of a simple wooden house from 5 to 10 years could reduce by half a villager's time spent on building and rebuilding (Levy, 1982).

CONSERVATION OF NATURAL FOREST ECOSYSTEMS AND BIOLOGICAL DIVERSITY

Tropical forests produce an extraordinarily wide range of products essential to human survival, health and trade. In addition to industrial wood, natural forests (particularly tropical rainforests) provide a myriad of other useful products such as essential foods, oils, gums, latexes, resins, tannins, steroids, waxes, fibers and pharmaceutical products. More than 50 percent of modern medicines come from the natural world and a large proportion of these from tropical forest plants. In Indonesia research has revealed that many food plants now taken for granted (including vegetables, fruits, nuts, edible oils, spices and flavorings) are derived from the tropical forests. Non-wood products brought in US$120 million in 1982. Most of the associated harvesting and production activity involved employment in local economies whereas much of Indonesia's industrial timber export value is retained by timber companies.

Specific examples of research topics that merit early replication and increased support include:

Tropical Forest Plant Foods

The Amazon Basin work of Plotkin (1988) has documented the importance of ethnobotanical research to improve knowledge of the potential of tropical forest plant based foods, particularly for the subsistence and medicinal needs of forest dwelling tribal peoples. For example, research by Dourojeanni (1978) concluded that in the Ucayali region of the Peruvian Amazon some 85 percent of annual protein came from wild game and fish. Similar research work by Grivetti (1976), Okafor (1980) and Becker (1983) has documented the wide range of forest based plant foods used in Africa.

Medicinal Products

Myers (1983) has made a case for increased research into the medicinal properties of tropical forest plants suggesting that some 1,400 tropical forest species may have potential anti-cancer properties. The most well-known is a Madagascar plant the 'Rosy Periwinkle' from which is derived a drug used
for the treatment of leukemia. Sales of the drug exceed US$100 million per year world wide. Sundaresh (1982) has reviewed the potential of medicinal plants in India.

- **Tropical Forest Germ Plasm**

Smith, Plucknet and Williams (1987) have reviewed the extent to which many important agricultural crops depend on forest derived germ plasm for broadening their genetic base, maintaining yields and enhancing their capacity for resistance to insect pests and fungal diseases. They point out the need for an all-out research effort to identify, preserve and enhance rainforest-derived germ plasm of commercially important agricultural crops such as coffee, cocoa, oil palm, rubber.

- **Unidentified Plants and Insects**

Scientific research could conceivably identify potential uses for currently under-utilized or unidentified plants and insects such as the Cameroon weevil *Elaeidobius Kamerunius* which, when introduced to Malaysia, led to a more than 12 percent increase in fruiting of oil palm and a more than US$50 million per annum increase in foreign exchange earnings Goodland (1985) and Salleh Mohd. Nor (1988).

**POLICY RESEARCH**

Many of the policy initiatives for containing tropical deforestation will have to come from outside the forestry sector (Spears and Ayensu, 1985). Past policy research aimed at developing a better understanding of the linkages between forestry and other sectors. Research on economic and/or other policy reforms that could help to reduce pressure on natural forests has been weak. Policy reforms are needed to address fundamental issues such as inequitable land tenure, inappropriate timber taxation, and concession and fiscal incentive policies.

Examples of key policy research topics that have potential for a high pay-off include:

- **Land Tenure**

Research into alternative land tenure systems can provide insights concerning increasing security of tenure for shifting cultivators and incentives for reforestation of agricultural wastelands or eroded upland watersheds. For example, policy research, coupled with land consolidation and titling programs, has been a key factor in accelerated reforestation in the Philippines under the PICOP program. In West Bengal and Gujarat States in India, security of title has provided a powerful incentive for reforestation of under-utilized agricultural wastelands.
• **Incentives for People Involvement in Forest Conservation and Management**

Sociological and economic research is needed to develop a better understanding of the incentives that could encourage peoples' involvement in forest management and/or reforestation. Experimental approaches for encouraging charcoal "user groups" to take over management responsibility for areas of savannah woodland in Niger have been suggested by Floor (1986). In Nepal the government is experimenting with allocation of government owned forest lands to individual panchyats. Encouraging results have been described by Campbell and Bhattara (1983).

• **Timber and Fuelwood Pricing Policy**

Research by Repetto (1988) of the World Resources Institute analyzed the losses incurred by tropical hardwood exporting countries such as Indonesia, the Philippines and Ghana, in which timber stumpage taxes fail to capture the economic value of the resource. Such research has provided a basis for in-country policy dialogue and compelling economic arguments for raising the level of timber stumpage prices. Similar pricing policy interventions are critical to more effective conservation and use of fuelwood resources as recently reviewed by Nelson (1988) for Sudan.

• **Inappropriate Fiscal Incentives**

Policy research by Mihar (1988) has reviewed policy reform options for reducing pressure on forests in the Brazilian Amazon. Specifically, he identified the need for the phasing out of fiscal incentives for livestock projects; a moratorium on use of fiscal incentive funds for development of pig iron projects in the greater Carajas region (that would destroy large areas of forest for charcoal production); refusal to grant land titles to speculators in forest lands; allocation of longer-term concessions to individuals or producer associations undertaking environmentally sound extractive activities in designated areas (e.g., rubber tapping); and increased effort to improve the administration and collection of taxes that could have beneficial effects on land use.

Policy research along the above lines, if followed up by intensive policy dialogue and government commitment to appropriate policy reforms, could make a decisive contribution to saving not only the Amazon basin forests but also the tropical rainforests of Africa and Asia.
REFERENCES


Enriquez, G. 1983. Breve resume de los resultados del experimento central de plantas perennes de La Montana. In L. Babbar (ed), Curso corto intensivo: Practicas agroforestales con enfasis en la medicion y evaluacion de parametos biologicos

Dourojeanni, M. 1978. The integrated management of forest wildlife as a source of protein for rural populations. Eighth World Forest Congress, Agenda Items No. B.FFF/8-0


IUFRO. 1986. Tree Improvement and Silvopastural Management in Sahelian and North Sudanian Africa.


Smith, Nigel J.H., Donald L. Plucknett, and J.T. Williams. 1987. Tropical
Forests and Crop Genetic Resources.


Sundaresh, I. 1982. Export Potential of Medicinal Plants and Their
Derivatives from India. Cultivation and Utilization of Medicinal
Plants. Ed. by C.K. Atal and B.M. Kapur, Regional Research
Laboratory, Jammu-Tawi (India).

Slip Erosion on Hill Country Pasture Production in New Zealand.
Proceedings of Second International Conference on Soil Erosion and
Conservation, Honolulu.

Wiersum, F. 1984. Surface erosion under various tropical agroforestry
systems. Pp. 231-239 in C. O'Loughlin and A. Pearce (eds.)
Proceedings of a Symposium on Effects of Forest Land Use on

development: Making the connection. Ambio 16(2-3):100-110.

Zsuffa, L. (IUFRO) 1985. Spacing and Thinning, with Particular Reference
to the Production of Biomass for Energy. Faculty of Forestry,
University of Toronto.
SESSION III:

BIOTECHNOLOGY -- A REVIEW OF THE STATE OF THE ART
BIOTECHNOLOGY: A REVIEW OF THE STATE OF THE ART

SUMMARY

BIOTECHNOLOGY FOR PLANT PRODUCTION: SUMMARY PAPER -- P. Dart

An essential aspect of achieving success with biotechnologies is to closely link them with conventional biological research. Biotechnology's usefulness is predicated on the existence of well-supported, in-country agricultural research programs, especially in plant breeding. A number of technical developments in the biotechnology of plant production are described. These include tissue culture techniques and genetic engineering techniques involving recombinant DNA technologies. Some results of genetic engineering research are outlined in terms of its ability to produce plants with herbicide resistance, disease resistance (especially to viruses), insect resistance and enhanced nutrition. Lastly, developments in the diagnosis of plant diseases made possible by biotechnology are briefly described.

BIOTECHNOLOGY IN LIVESTOCK PRODUCTION -- E.P. Cunningham

Developments in three areas of the biotechnology of livestock production are described. First, recent embryo technology makes it possible to superovulate cows and to recover nonsurgically up to thirty embryos at a time. The principal benefit conferred by this technique is the ability to produce more calves from a cow than would be possible with normal reproduction. Various additional present and potential advantages from embryo technology are also listed. Second, gene technology makes possible the incorporation of exogenous genes into an animal genotype and their expression in derived generations of the same animal. Potential benefits of this gene technology are listed. Third, hormone and immuno technology involves techniques that have been in use for some time. The most dramatic is recombinant growth hormone, or somatotropin, which increases milk production by 15-30 percent. Other developments listed have led to improved productivity and animal health. Lastly, four areas are outlined in which the biotechnology of livestock production has particular potential for developing countries.
Biotechnology is not a revolutionary technological development, at least in the sense conveyed in the popular press. Its major applications follow in an evolutionary way from the petrochemical green revolution technologies. Its agricultural productivity and output increases are unlikely to be substantially above those achieved by green revolution technologies in the 1960s and 1970s. It is, however, an important technology because it will become a common technical basis of many disparate sectors that are central to improvement of developing country living standards. Also, it will help address some of the agronomic and ecological problems and productivity ceilings of green revolution technologies.

Biotechnology will have a number of production impacts. Among the more important are industrial substitutionism (substituting an industrially produced commodity for an agricultural one) and agricultural product substitutionism (improvements in agricultural inputs that lead to increased productivity and competition, and ultimately shifts in comparative advantage, among agricultural commodities). The benefits of biotechnology will be uneven. Over the medium term, they will likely exacerbate developed-developing world disparities in agricultural productivity. The first generation of biotechnology inputs will be applied disproportionately to luxury commodities, not staples, and will be deployed first and foremost in a handful of developing countries. The general tendency will be for biotechnology products to be most applicable to the operations of large scale farmers.

In the absence of major coordinated policy interventions by development agencies, the LDCs seem likely to absorb the cost of biotechnical innovations initially, while the benefits will be slower in coming. A number of policy interventions are critical. Research priorities must be established that can yield broad socioeconomic benefits. International development agencies must play a lead role in financing the development of human capital in LDC and LDC-oriented biotechnology. Especially important is support for improved "traditional" agricultural research capacity, which is essential if the promises of biotechnology are to be realized.

The author argues that private sector biotechnology research has an important role to play in developing country research, especially in increasing the worldwide production of oilseed crops, an area that to date has not been the focus of international research. The current and projected future imbalance in the worldwide supply of and demand for fats and oils is first described. The dramatic rise in the importance of Canadian canola (rapeseed) as a source of food oil and meal for animal feed is then outlined. Particular attention is devoted to a description of
developments in biotechnology that have made this rapid increase in rapeseed production possible. Lastly, several issues are set forth that need to be addressed if the international agricultural community is to access the tools of biotechnology. These include developing mechanisms for enabling the private sector to recover the full costs of its investments, protection of intellectual property rights, and devising mutually satisfactory commercial frameworks for private sector-developing country collaboration.
Biotechnology promises much for agricultural production in both the industrialized and developing countries. Sales of agricultural biotechnology products are currently estimated at US$ 25 million with the expectation that sales will increase to US$ 700 million by 1993.

Recent developments in the use of recombinant DNA, gene mapping, plant transformation systems and new diagnostic techniques based on monoclonal antibodies or DNA probes have opened up exciting possibilities for increasing the efficiency of agricultural production. Biotechnologies are, however, only a part of the process of developing an improved agricultural commodity. They need to be linked closely with conventional techniques of plant production and subsequent processing.

The development of efficient appropriate biotechnologies requires an integration of more conventional biological research with techniques for DNA manipulation. This is not easy to achieve since funding for biotechnology research is often perceived as competing with funding for other agricultural research activities. Maintaining an appropriate balance within research groups and melding skills across the spectrum of activity required to develop a new product are key issues for the successful use of biotechnology. Fostering the development of new biotechnologies that link effectively with existing biological knowledge requires research leadership of the highest order, lest researchers divide into two camps -- the new and elite versus the conventional. It is essential that an integrated approach be adopted.

Biotechnology research is often seen as expensive. Indeed, relatively large teams of skilled well trained researchers are often required. For example, twelve scientists are listed as authors for one of the early papers on the use of virus protection of plants based on the use of a coat protein gene. Research projects involving DNA manipulation require a large commitment of equipment and supplies and a critical mass of trained personnel to be effective.

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Note: This summary paper abstracts from Prof. Dart's presentation at the Symposium and Project Paper No. 2 of the World Bank-ISNAR-Australian Government Biotechnology Study, entitled, "Current Status of Biotechnology in Relation to Plant Production in Developing Countries: Introductory Paper".
Recombinant DNA technologies provide new and effective ways to manipulate genetic material, thereby improving plants, controlling their pests and enhancing their nutrition. Other less sophisticated biotechnologies are also important in that they may have a more immediate impact on crop production in developing countries.

Biotechnology is not a panacea. Its usefulness is predicated on the existence of well-supported in-country programs in agricultural research, particularly in plant breeding.

Developing countries have an invaluable asset for biotechnology in their germplasm resources. Preserving and cataloging these resources are prerequisites for making the most of the new biotechnologies.

Techniques for manipulating plant reproduction are already in use in many developing countries. Clonal propagation using tissue culture techniques has much potential. These techniques include meristem and bud culture to free plants of virus and viroids; micropropagation to multiply desirable germplasm of vegetables, fruits, oil palm and forest trees; anther culture to develop homozygous plants; production of secondary metabolites from tissue culture; development of desirable plant types by somaclonal variation; and rescue of embryos formed by unusually wide crosses to give protoplasts which are used as the basis of a novel hybrid.

Genetic engineering involves locating, by molecular techniques, DNA coding for a desirable trait, excising the DNA by restriction enzymes, transferring it to another plant cell by a "vector" and regenerating that cell into a plant. The most commonly used vector is a bacterium, Agrobacterium, which has a natural mechanism to inject bacterial DNA into certain species of plants.

It has proved difficult to regenerate many species transformed with foreign DNA. Also, monocots, which include all the major cereals, are not infected by Agrobacterium. This has led to the development of new techniques for the introduction of foreign DNA into plant cells. These include electrophoration and the use of microprojectiles.

Transformation of rice protoplasts has been reported by direct DNA uptake using an electric field to punch holes in the cell membrane (electrophoration). Success with several species has been achieved by shooting microprojectiles of cadmium or gold coated with vector DNA into protoplasts or embryonic cells using a high voltage pulsed electric field. Successful demonstration of transformation by the technique of adding DNA to the cut style of a flower just after the pollen tube has passed through, or the direct injection of DNA into the ovule, has opened up the possibilities for plant transformation. Most transformation research has been done with tobacco, tomato, petunia, potato, lucerne, maize, rice, poplar, walnut, Stylosanthes and cotton.

One way of finding the location of genes and incorporating new genetic material is to use "transposable" pieces of DNA, or jumping genes, which spontaneously insert into otherwise stable DNA often causing a mutation. The level of gene expression is governed by promoter DNA elements and these in turn are modified by enhancers, which determine the
rate of transcription of the structural or coding part of the gene. Modification of promoters, including the construction of chimaeric genes with promoters that are under plant development control, offers unique opportunities to control the pattern and level of "products" arising from the novel foreign gene.

Hybrid vigor is a desirable trait but often the mechanics of making hybrids precludes their commercial use. Recombinant DNA techniques are being used to clone genes for self-incompatibility in plants in the hope of engineering plants that become self infertile, thus widening the range of hybrids that can be made readily.

Genetic engineering research has concentrated on the development of plants with herbicide resistance, disease resistance, particularly virus resistance, and insect resistance. Tobacco and tomato plants resistant to lepidopteran insect grubs have been genetically engineered by addition of the gene which produces the protein toxin from the bacterium Bacillus thuringiensis. Cowpea plants produce a trypsin inhibitor gene, which provides some insect resistance as the insects eating plant material containing the inhibitor cannot digest proteins. Cloning this gene into tobacco plants has increased their resistance to the tobacco budworm and Heliothis. Such insect resistant plants should prove useful in developing countries.

There has been less success with fungal resistance although plants containing genes coding for pathogenesis-related proteins, which degrade fungal cell walls, are being tested. Other genes for production of a glucanase and the proteinase inhibitor from potato are expressed in tobacco on wounding and offer prospects for disease control. Molecular genetic interactions in plant disease represent a burgeoning field of research, including identification of genes for resistance, susceptibility, production of phytoalexins, fungal toxins and virulence. Similar rapid developments are occurring in understanding bacterial diseases such as those induced by Pseudomonas and Xanthomonas.

Given government restrictions on the use of many nematocides, much funding is going into research on novel ways to control nematode damage, e.g., use of monoclonal antibodies to locate glands secreting plant-degrading enzymes thereby pointing to compounds, perhaps the product of plant genes, that might turn off the enzyme production. Also being examined are egg hatching factors and root secretions, which repel nematodes or block chemoreception.

The most interesting developments in plant disease resistance relate to plant virus resistance. Washington State University and Monsanto scientists have cloned the genes coding for the coat protein of tobacco mosaic virus (TMV). Tobacco and tomato plants engineered to express this gene were resistant to TMV. Alfalfa mosaic virus and potato virus X resistance have similarly been developed and the prospects are good for many other viruses.

A different approach used the satellite RNA genes from cucumber mosaic virus and tobacco ringspot virus to protect the plants from virus. There is a danger that mutations in the satellite DNA may induce a
hypervirulent form of the satellite. Scientists from the Commonwealth Scientific and Industrial Research Organization's Division of Plant Industry, Canberra, Australia discovered a "genetic scissors" which specifically cut viral DNA produced in plant cells before it is packaged into the protein coat. This "ribozyme" offers a unique way to control gene expression by destroying the messenger RNA transcribed from the chromosomal DNA so that no protein product can be produced.

Genetic engineering has also produced tobacco and alfalfa plants with enhanced nutritional quality by transforming them with genes for seed proteins from peas, which have a high level of sulfur containing amino acids. Cereals deficient in lysine may also be upgraded nutritionally by introducing genes for lysine production into them.

Diagnosis of plant diseases by new serological techniques offers the promise of developing very sensitive field kits. Their potential use in developing countries will depend on the cost of the assays and available means to do something about the disease once diagnosed. Enzymo-Linked Immuno Sorbent Assay (ELISA) is already being used by quarantine agencies to index germplasm for virus diseases. These new diagnostics are based on the use of monoclonal antibodies and DNA probes.

Naturally occurring changes in DNA nucleotide sequences result in changes in the length of DNA fragments formed on digestion with restriction enzymes. These restriction fragment length polymorphisms (RFLPs) can serve as a linkage map for genetic traits -- a very powerful new tool for breeders. There is a need for the development of RFLP maps for the major tropical crops, including the crops of interest to the International Agricultural Research Centers.
INTRODUCTION

About a decade ago, biotechnology burst forth on the world. Useful applied sciences like biochemistry, genetics, physiology and pathology acquired some new techniques, and a new name. They also acquired some new people. But most of all they acquired a new glamour.

One result of all this excitement was a considerable loss of perspective, at least in the agricultural field. Prophets of the new technology have generally underestimated the pace of technical innovation and overstated the probable flow of useful end products. In particular, the degree of hype which surrounded the first wave of stock market speculation in biotechnology was built on some very unrealistic expectations. There were several reasons for this. Much of the fundamental scientific development originated in laboratories which had little knowledge of the existing technology of food production into which the new technologies must fit and with which the new technologies must also compete. Stock market commentators, bedazzled by, but essentially ignorant of the claims of genetic engineering, and almost as uninformed about the agricultural markets which must ultimately remunerate this innovation, for the most part got it wrong. As a result, the first wave of biotechnology investment has generally been a financial disaster, though in many cases a technical triumph. OTA (1984) reported that none of the specialist biotech companies among 219 which they catalogued had achieved an operating profit. In 1986, the industry was still, overall, a loss maker (Fox, 1987), with prospects of profit seen mainly in the diagnostics field.

The first generation of biotechnology has coincided with a very much sharpened perspective on world food markets and production systems. In the last decade, the slowing down of population growth, the leveling off in consumption patterns, and the steady progress of agricultural technology have produced a systematic surplus of food of all kinds in the developed world. This has consequences both for producers and consumers. Consumers now generally spend less than 20 percent of their income on food and are more concerned with choice, taste, health and presentation than they are with further reductions in the cost of food. Producers are operating in a buyer’s market. In Europe and North America they have been going out of business at the rate of over three percent per annum and absorbing real price reductions of the same order. The market pull for technical advances in agricultural productivity is therefore not what it was a few decades

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ago. In fact, as we can see in the case of BST for increased milk production in dairy cows, such a leap in technology is generally regarded as bad news by dairy farmers.

The developing world now contains 70 percent of humanity and in a generation it will contain 90 percent. In all regions except Africa, current technology has allowed food production to advance faster than population growth in the last twenty-five years. The requirement is to double food production in the next twenty-five and possibly to double again in the following generation. The major challenge to biotechnology, and indeed to all food production technology, lies therefore in the poor countries and not in the rich. Paradoxically, the rich countries can afford it, but don't particularly need it, while the poor countries need it, but often cannot afford it.

A further factor in the biotechnology revolution is that, partly because of its origins, and partly to give better leverage to its claims for attention and funding, it has been accompanied by some distancing of the new technology from the old. Conventional plant and animal breeding programs, by moving genes around within species, have achieved enormous gains in productivity. Most aspects of the new biotechnology, if they are to be applied to the same ultimate objectives, must be incorporated into these programs. A good example from the past is artificial insemination (AI) in cattle, which was developed in the 1930s, and by the 1950s was an integral part of modern dairy cattle breeding systems.

The roots of the recent revolution in biotechnology lie in three particular discoveries: of enzymes to cut and splice DNA; of vectors to move DNA fragments between species; and of fused cells which combine the ability to grow in culture with the ability to produce specific antibodies. The application of these techniques to the improvement of livestock production is now beginning. As is often the case, the most useful advances are more likely to occur in unexpected areas. Biotechnology is advancing over a broad front, which includes embryo technology and many aspects of the physiology, immunology and nutrition of farm animals. The spectrum of possible applications is shown in Figure 1.

**EMBRYO TECHNOLOGY**

Over the last twenty years, the techniques for recovery, storage and implantation of embryos have been perfected. It is now possible to superovulate cows, and to recover nonsurgically up to thirty embryos at a time. Average yield is about four embryos. Freezing in liquid nitrogen and thawing are now routine operations, with relatively small effects on viability. Implantation with an insemination gun is also now a nonsurgical routine.

The principal benefit conferred by this technique is the ability to produce more calves from a cow than would be possible with normal reproduction. While in theory each cow has perhaps 75,000 potential eggs in her ovaries, she will normally give birth to about four calves in an average lifetime. With current techniques of embryo transfer, this could readily be increased to twenty-five calves, and in some cases to over one
Fig. 1. Biotechnology in animal production
hundred. The benefits of increasing the reproductive rate of selected cows in this way are:

- Genetically outstanding cows can contribute more to the breeding program. This is most useful if their sons are being selected for use in AI.

- Specially designed breeding schemes to take advantage of the increased intensity of female selection, combined with increased generation turnover, can increase (up to double) the rate of genetic change over that achievable in a conventional selection program.

Additional potential advantages from present embryo transfer technology are:

- The possibility of increasing the twinning rate by either implanting two embryos, or by following a normal insemination with the transfer of a single embryo.

- The rapid expansion of rare genetic stocks, for example, of a new breed.

- The transfer of specialized genotypes (e.g., pure beef breeds) of higher value into cows of lower potential (e.g., undeveloped local breed).

- Reduction in the cost of international transport of stock by import of embryos rather than of live animals.

- Avoiding the environmental shock to susceptible imported genotypes by having them born to dams of local breeds rather than importing them as live animals.

The following new and related developments can provide additional benefits.

- Sexing of embryos (now possible) or of semen (not yet possible, but being actively researched). This could increase selection intensities further and could permit greater specialization in beef and milk production functions of a dual purpose population.

- *In vitro* fertilization. This technique, now showing great promise in research studies, has enormous potential for increasing the benefits achievable in breeding programs. The first commercial services based on IVF started up this year in Ireland and Britain. Its main impact will be to reduce the cost of embryos, and therefore to make embryo transfer techniques economically feasible on a wide scale, and in circumstances where the cost of present techniques cannot be justified.

- Embryo splitting to produce identical individuals. This technique has been possible for several years and has
considerable application in improving the efficiency of research studies. At present levels, it has limited additional benefits in a breeding program.

- Embryo cloning. The production of multiple copies of an embryo by nuclear transplantation is now possible. The main limitation is the supply of host oocytes. However, the current expectation is that repeated cloning will be a commercial reality within a few years. It could have a major impact on cattle breeding in both developed and developing countries.

GENE TECHNOLOGY

Modern DNA manipulation technology began in 1973 with the discovery of endonucleases, enzymes which cut the DNA molecule. It is now possible to cut DNA in a variety of ways, to splice it together, to delete or insert sections of DNA, and to determine the sequence of, and to synthesize, sections of DNA.

In parallel with this, techniques have been developed for the insertion of DNA into plant and animal cells in such a way that they are incorporated into the genome of the plant or animal concerned. In plants, naturally-occurring vectors called plasmids are used to carry the DNA into the cell. In animals, the usual technique is direct injection of 100 to 1000 copies of the DNA sequence into the pronucleus of a one-cell embryo.

In 1980, the first experiment was completed which demonstrated the incorporation of exogenous genes into an animal genotype and their subsequent expression in derived generations from the same animal. This gene transfer technology has been facilitated more in animals than in plants because it could be superimposed on the highly developed embryo culture and transfer technology. In the case of plants, while gene transfer was relatively easy, the regeneration of whole plants from transformed tissue was, in certain species, extremely difficult.

Gene transfer work in animals was pioneered in the mouse and is now well established in that species (Jaenisch, 1988). Successful production of transgenic farm animals has so far been reported from seven centres (Table 1). In almost all cases the DNA sequence transferred codes for growth hormone.

What are the potential benefits of the use of gene technology in animals?

- It is possible to insert in the animal genome the capacity to synthesize proteins which are not normal to that animal and which may have particular value. In Britain, for example, the gene for the synthesis of human blood clotting factor IX has been transferred to sheep in which it is expressed in milk (Wilmut, Clark and Simons, 1988). The intention is that the factor, which is highly valuable, can then be isolated from sheep milk and thus be made available at greatly reduced cost. The extent to which
Table 1: Reported production of transgenic livestock (from Ward, 1988)

<table>
<thead>
<tr>
<th>Center</th>
<th>Species</th>
<th>Gene</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA USDA-Beltsville Ohio State</td>
<td>pigs, sheep, rabbits pigs</td>
<td>GH, GHRH</td>
</tr>
<tr>
<td>UK Edinburgh University</td>
<td>sheep</td>
<td>FIX, TK, AT</td>
</tr>
<tr>
<td>Germany Tech. U. Munich</td>
<td>pigs</td>
<td>GH</td>
</tr>
<tr>
<td>Australia CSIRO Adelaide</td>
<td>sheep pigs</td>
<td>GH</td>
</tr>
<tr>
<td>Canada U. Calgary</td>
<td>cattle</td>
<td>?</td>
</tr>
</tbody>
</table>

GH = growth hormone, GHRH = growth hormone releasing factor, FIX = human factor IX, TK = Thymidine Kinase, AT = Antitrypsin

This technology will be useful depends on the identification of proteins of high value, which are difficult to either synthesize or produce biologically by conventional means.

- It may be possible to identify genes in one species which could usefully be transferred to another species. A good example is the booroola gene in sheep, which greatly increases fertility, and which could be useful in cattle. Most of the interest so far has concentrated on growth hormone, mainly because the gene for growth hormone in some species has been identified.

- Proteins with biological effect, such as growth hormone, can be transferred into bacterial or fungal culture and produced cheaply. They can then be subsequently administered to animals, with substantial effects on production. This is the case with growth hormone, now commercially available, with demonstrated large effects on milk production in cows (Chilliard, 1988) and on growth rate in pigs (Hanrahan, 1988).

- It may be possible to locate genes with important effects, e.g., for trypanotolerance in cattle, and to use this technique to make more effective selection for the characteristic. Considerable effort is being devoted to this in the African context.

- It may be possible to identify marker sites throughout the genome, which can then be used to assist selection for quantitative traits, affected by many genes, such as milk production or growth
rate (Beckman and Soller, 1987). This was expected to be the case twenty years ago when biochemical polymorphism was first widely investigated. The promise of that time has not been fulfilled. It remains to be seen whether the greater range of markers available through DNA technology can be more effectively used.

- The same techniques could be used to measure genetic distance between populations. This information could then be used to make more precise use of different breed resources in crossing and selection programs.

**HORMONE AND IMMUNO TECHNOLOGY**

This area involves development of techniques which have been in use for a long time. For example, the manipulation of light or nutrition has long been used to modify hormonal and hence fertility levels.

The most dramatic product of biotechnology currently available is recombinant growth hormone, or somatotropin (BST). When administered regularly to dairy cows during lactation, it increases milk output by 15-30 percent and also increases the efficiency of milk production. There appear to be no problems of undesirable residues in milk and the likelihood is that this technique will come into general use in the years ahead. The main technical problem remaining to be resolved is that of an efficient delivery system since current use requires regular injections.

The family of growth promoting agents known as anabolic steroids has been in widespread use for many years. However, public concerns over residues in meat have led to their being banned by the European community and by some other countries. Other metabolic agents, such as beta agonists, have been shown in experiments to have even larger effects, but are not yet available for general use (Quirke and Schmid, 1988).

The hormone system can be manipulated to achieve improvements in productivity. One example is the use of immunization against the hormone inhibin in sheep, which causes increased endogenous production of FSH, resulting in an increased ovulation rate and ultimately higher fertility of the order of 30 percent. Considerable research has been undertaken to find a similar technique for use in cattle. In addition, there is also much research on the question of immunization techniques to stimulate growth in several species.

Finally, a number of products have been developed which have a direct application to animal health. New, improved or cheaper vaccines against a number of diseases have been produced by recombinant DNA technology. These include vaccines against foot and mouth disease, enteric diseases and ectoparasites (Table 2).

A number of agents have been developed which stimulate the immune system and thus enhance general disease resistance. These are generally based on interferon (which also has an antiviral function) and lymphokines. One current use of these products is as a vaccine enhancing agent.
Table 2: Vaccines and their developers (from Van Brunt, 1987)

<table>
<thead>
<tr>
<th>Category</th>
<th>Disease</th>
<th>Developer</th>
</tr>
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<tbody>
<tr>
<td>Avian:</td>
<td>Coccidiosis</td>
<td>Genex and A.H. Robins</td>
</tr>
<tr>
<td>Avian:</td>
<td>Coccidiosis</td>
<td>Codon and Salsbury Labs</td>
</tr>
<tr>
<td>Avian:</td>
<td>Newcastle Virus</td>
<td>Codon</td>
</tr>
<tr>
<td>Bovine:</td>
<td>Papilloma Virus</td>
<td>Molecular Genetics</td>
</tr>
<tr>
<td>Bovine:</td>
<td>Viral Diarrhea</td>
<td>California Biotechnology</td>
</tr>
<tr>
<td>Bovine:</td>
<td>Brucellosis</td>
<td>Ribi ImmunoChem</td>
</tr>
<tr>
<td>Bovine:</td>
<td>Rinderpest</td>
<td>USDA and University of California, Davis</td>
</tr>
<tr>
<td>Swine:</td>
<td>Parvovirus</td>
<td>Applied Biotechnology</td>
</tr>
<tr>
<td>Swine:</td>
<td>Dysentery</td>
<td>Codon</td>
</tr>
<tr>
<td>Equine:</td>
<td>Influenza</td>
<td>California Biotechnology</td>
</tr>
<tr>
<td>Equine:</td>
<td>Herpes</td>
<td>Applied Biotechnology</td>
</tr>
<tr>
<td>Companion:</td>
<td>Canine Parvovirus</td>
<td>Applied Biotechnology</td>
</tr>
<tr>
<td>Companion:</td>
<td>Feline Panleukopenia</td>
<td>Applied Biotechnology</td>
</tr>
<tr>
<td>Companion:</td>
<td>Antifertility</td>
<td>California Biotechnology</td>
</tr>
</tbody>
</table>

Monoclonal antibody techniques have been used to develop a wide range of diagnostic kits. In one case, a therapeutic monoclonal, "Genecol 99", has been developed which is effective against bacterial infections that cause scours in calves.

**Relevance in Developing Countries**

It is difficult to gauge the future pace and utility of biotechnology, in both the developed and developing world. The experience of the past ten years has been that interesting technical developments have been achieved more rapidly than was generally predicted: successful gene transfer in animals, *in vitro* fertilization, cloning of embryos, sexing of semen. With the exception of diagnostics, each development seems to uncover new layers of complexity in application and, as a result, to push the prospect of practical application further into the future.

A further generalization is that the results of biotechnology are likely to be more useful to producers already using high technology than to those operating less intensively. Thus, the use of BST in dairy production is expected to accentuate the competitive advantage of large scale high-producing dairy enterprises to the disadvantage of family scale operations.

Bearing this factor in mind, much of the promise of animal biotechnology is equally applicable in the developed and developing world. However, the experience is that, as with many aspects of advanced technology, the capacity of small scale producers in poor countries to use
it is often limited. However, the following four areas seem to have particular relevance and potential for at least some developing countries:

- **Vaccines.** Genetic engineering provides the opportunity to develop new vaccines, not just against virus diseases but against bacterial and a variety of parasitic agents. In addition, it may be possible to tailormake vaccines for greater effectiveness and less risk. This area should hold considerable potential for increasing control over endemic diseases like foot and mouth disease, rinderpest (Yilma, 1988), and possibly even trypanosomiasis.

- **Embryo technology.** Artificial insemination has had limited but in some cases (e.g., India) significant impact in developing countries. Embryo transfer technology has a more limited role, but again could be highly significant in specific cases. One possibility, which is no longer in the realm of science fiction, is the replacement of conventional breeding of cows by implantation of sexed frozen embryos of a specific genotype, e.g., an F1 taurus-indicus cross.

- In the improvement of local cattle populations, conventional breeding schemes are difficult to implement because the infrastructure of performance recording is not in place. Instead, interest is turning towards nucleus breeding schemes which could generate high rates of genetic improvement. This in turn can then be spread through the population. In nucleus herds, it should be feasible to take full advantage of the acceleration in genetic improvement programs which can be achieved by use of embryo transfer and eventually cloning and sexing of embryos.

- Again, because of the difficulty of operating conventional improvement schemes in developing countries, the use of DNA probes to genetically identify superior individuals for particular traits like resistance to a disease could become important (Beckman, 1988).
REFERENCES


MODERN BIOTECHNOLOGY: ITS PROSPECTIVE PRODUCTION 
AND SOCIOECONOMIC IMPACTS

Frederick H. Buttel

INTRODUCTION

While modern agricultural biotechnology\(^1\) is in its infancy and very few biotechnology products have reached farmers' fields and feedlots, it is already a controversial technology. This is not surprising for several major reasons. First, biotechnology is a broadly-applicable technology that will have a myriad of effects on social institutions. Second, the emergent literature on biotechnology suggests that its impacts will range from the strongly positive to, quite possibly, the strongly negative, with shades in-between. Third, since biotechnology will be a major agricultural technology that comes on the heels of the green revolution, social science and lay observers will inevitably approach biotechnology on terms similar to those used with its relatively controversial predecessor.

Much as was the case with the theoretical and research literature on the green revolution, important insights germane to agricultural development policy can be gleaned from the full range of the literature's disparate viewpoints (see, for example, the noteworthy attempt by Lipton with Longhurst, 1985, to do so with respect to the green revolution). However, there is a major difference between the green revolution and agricultural biotechnology literatures; whereas the former was largely based on \textit{ex post} assessment of data, the latter relies on a variety of \textit{ex ante} methodologies because of the fact that biotechnology applications in

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\footnotesize{Note: This paper is based on a larger report prepared for the ISNAR/World Bank/Australian Government Biotechnology Study.}

\footnotesize{\(^1\) In this paper I will focus on "modern" biotechnology (see Persley, 1988, for a discussion of the notion of modern biotechnology for purposes of the World Bank/ISNAR/Australian government biotechnology study. See National Research Council (1986), Office of Technology Assessment (1981, 1984, 1986), and Board on Science and Technology for International Development (1982) for nontechnical summaries of the applications of modern biotechnology to agriculture and food. See IRRI (1984) and TAC (1988) for discussions of biotechnology activities in the International Agricultural Research Centers (IARCs) of the Consultative Group on International Agricultural Research.}
the developing world are in their infancy. The \textit{ex ante} nature of the biotechnology literature adds a layer of uncertainty to the already difficult task of assessing the consequences of technological change. The error term for \textit{ex ante} assessments -- even the most competent and systematic -- is large. Claims that \textit{ex ante} data afford a clear vision of the future must be treated skeptically. Nonetheless, \textit{ex ante} technology assessment is an essential activity in policy formulation for international organizations and development agencies -- particularly in an area such as biotechnology, which is almost certain to have a major influence on the development paths of the low-income countries for many decades.

In this paper I will address several topics. I will begin with a discussion of what is arguably one of the key, though often unrecognized, issues pertaining to biotechnology: the issue of the degree to which biotechnology will be a "revolutionary" technology. Thereafter I will address what I feel are some of the most important considerations regarding the productivity and other socioeconomic impacts of this new technology. My concluding comments will stress some of the major challenges and uncertainties surrounding biotechnology in international development.

Before proceeding, it is useful to stress that biotechnology represents a diversity of scientific techniques and potential products -- a diversity that is often not well recognized by proponents and opponents alike. Biotechnology ranges from technically complex, often expensive, molecular-level techniques, typified by recombinant DNA, to far more routinized, cheaper techniques such as cell and tissue culture. Further, it is increasingly apparent that biotechnology will be applied in a wide spectrum of production sectors, ranging from agriculture, food, energy and forestry to chemicals, pharmaceuticals, mining, and environmental control. Within each sector there are research thrusts -- and a growing trickle of finished products -- that range from being "development-friendly" to "development-hostile." Most importantly, as will be stressed below, the kinds of biotechnologies that will be developed, in both the developed and developing worlds, will be largely a function of research priorities that are selected and of the forces that shape these research priorities.

\textbf{AGRICULTURAL BIOTECHNOLOGY: HOW REVOLUTIONARY?}

Biotechnology, not unlike most new technical forms, has received no small amount of fanfare, if not "hype." As the commercial biotechnology industry emerged in the developed countries in the late 1970s and early 1980s, a wide range of actors -- private firms, scientists, research administrators, and many development agency personnel -- found themselves aggressively promoting this technology. A good many social scientists, myself included (cf. Buttel, 1986a), were prompted to see biotechnology in "revolutionary" terms. Biotechnology became proclaimed a "revolutionary technology" on several grounds -- that it would lead to "miracle" products, to major agricultural productivity and output increases, to major changes in the social relations of agricultural production and exchange, to changes in research institutions, and so on. Interestingly, the notion of biotechnology being a revolutionary technical form has been particularly prevalent among many of biotechnology's strongest supporters and most vehement critics.
With a growing body of evidence at hand, we are now better able to assess claims about the revolutionary nature of biotechnology. The following points seem warranted (see Buttel, 1989, for a more general treatment). First, the major applications of biotechnology that are being pursued for agriculture in the late 1980s appear to be primarily those that follow in an evolutionary (and not "revolutionary") way from the "petrochemical/green revolution" technologies of the post-World War II period. For example, the major research goals essentially involve using the tools of biotechnology to help solve or "patch up" the problems caused by existing technologies (e.g., developing herbicide-tolerant crop varieties in order to rationalize pesticide usage and weed control). Put somewhat differently, the research priorities that might lead to qualitative changes in agricultural production systems, such as increased photosynthetic efficiency or autosufficient biological nitrogen fixation, are now receiving relatively little attention (and virtually none in private R&D).

Second, if by "revolutionary" one means agricultural productivity and output increases substantially above the post-World War II baseline, it seems implausible that, even if reasonably optimistic scenarios for biotechnology innovation over the next two or three decades are realized, the result will be a qualitative disjuncture from this baseline. It is often not well appreciated how formidable this baseline is: a compound annual growth rate of world agricultural output of 2.43 percent (or 0.55 percent per capita) from 1950 to 1985 (U.S. Department of Agriculture, 1986:7). Even if, two or so decades hence, the deployment of agricultural biotechnologies enables agricultural R&D institutions to match the post-World War II track record of global output increase -- and this is by no means assured -- biotechnology will have been no more revolutionary than were the myriad of agricultural improvements worldwide in the 1960s and 1970s.

Third, social scientists and policy makers should be cautious about the "magic bullet" imagery of biotechnology that has predominated over the past decade. After much hype, the only prospective "magic bullet" or "big hit" agricultural biotechnologies on the horizon are some of the animal growth hormones and fat-to-lean repartitioning agents. And while technologies such as bovine growth hormone (bGH) may be exceptional in the extent and immediacy of their productivity impacts (Kalter, 1985), the weight of the ex ante evidence on this technology is shifting toward more modest estimates of its productivity and socioeconomic impacts (Buttel, 1986b; Fallert et al., 1987) under actual farm conditions. For the bulk of the world's population, especially in the poorer developing countries where feed quality and quantity and disease problems are the more pressing problems in livestock production, these animal growth hormone technologies will be of modest relevance. For most of the world's major crop plants there seem to be no "big hit" biotechnology breakthroughs in sight that are even as large as the use of dwarfing genes and repartitioning of biomass in green revolution wheat and rice were in the 1960s.

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This level of performance will by no means be easy to achieve, however, due to ecological constraints, market barriers and other factors.
There are several more general reasons for doubting that biotechnology will be a revolutionary or epoch-making technology (in the Schumpeterian sense): First, biotechnology will mainly be applied in declining industries (i.e., agriculture and food, chemicals, forestry, fisheries, mining). Second, biotechnology will not, in the main, be applicable to the service sector, especially in its dynamic financial and communications services segments, which in all likelihood will be the most vibrant sector in the world economy in the future. Third, biotechnology is mainly a substitution technology, and will not tend to lead to a large number of qualitatively new consumer products (Buttel, 1989).

This is not to say that biotechnology is unimportant as a new technical form for international development. Biotechnology is important -- crucial actually -- but for reasons that have little to do with the (flawed) revolutionary/magic-bullet imagery that has been so widespread. Biotechnology is an important technology because of the fact that it will become a common technical basis of many disparate sectors (pharmaceuticals, chemicals, energy, mining, environmental control, and forestry, in addition to food and agriculture) that are central to improvement of developing country living standards.

Also, biotechnology is a multivalent technology within agriculture. Biotechnology will increase the efficiency of bringing research to bear on solving some of the agronomic and ecological problems and productivity ceilings of "petrochemical/green revolution" technology. Further, biotechnology offers new opportunities for developing agricultural production systems premised on reduced usage of purchased petrochemical inputs, which may be especially important if energy supplies tighten over the next decade or two (Gould, 1988; Wolf, 1986). Perhaps most promising, because biotechnology is especially well suited to incorporating stress tolerances into crop varieties (Wolf, 1986), it should be possible to utilize these new R&D methods to improve agriculture in marginal agroecological zones far more than "green revolutionaries" were able to do (Lipton with Longhurst, 1985; Buttel et al. 1985b).

Biotechnology has promise for obviating what almost certainly will be diminishing returns productivity plateaus associated with petrochemical technologies. Industrial biotechnology (industrial tissue culture, advanced bioprocessing and industrial microbiology) is also ideally suited to maximizing sustainable utilization of renewable natural resources, including traditional sources of plant material as well as prospective new resources that might be derived from the LDCs' diversity of crop and noncrop genetic resources. Finally, as stressed below, biotechnology is likely to have major impacts on the structure and activities of food and fiber processing, which in turn will fundamentally affect agriculture in both the developed and developing countries.

THE PROSPECTIVE PRODUCTION AND SOCIOECONOMIC IMPACTS OF BIOTECHNOLOGY

In a certain sense, a social scientist in the late 1980s can have little intelligent to say about the production impacts of agricultural biotechnology in the developing world. Among the major barriers to prediction of production impacts are the following.
First, as stressed earlier, biotechnology research techniques and prospective products are very diverse (as compared to, for example, very specific technologies such as hybrid corn or HYV wheat), and the developing countries and their economic structures are equally diverse. For example, unlike traditional crop plant research methods, biotechnology is applicable to livestock production and food and fiber manufacturing as well (including the extraction of secondary metabolite products from plants and their industrial tissue culture and industrial microbiology substitutes). Agricultural biotechnologies do not intrinsically have generic characteristics (e.g., high capital intensity and scale economies, or disproportionate applicability to favored agroecological zones) that enable the specificity of *ex ante* assessment possible with particular technologies or technical packages such as HYV wheat. Specific agricultural biotechnology products, however, such as bovine growth hormone (bGH), can be subjected to a meaningful *ex ante* socioeconomic impact assessment. But caution should be exercised in assuming that the prospective impacts of specific agricultural biotechnology products such as bGH can be generalized to agricultural biotechnologies as a whole, especially those to be deployed in developing nations.

Second, the multivalent character of biotechnology provides considerable opportunity for public policy interventions that might very substantially modify predicted socioeconomic effects. For example, although biotechnology is highly applicable to most root, tuber, and plantain crops, the lack of private sector interest in these crops portends a slow rate of biotechnological improvement. If, however, the international development community places a high priority on the application of biotechnology to the improvement of roots, tubers, and plantains, a quite different set of production effects might result.

Third, any assessment of the production impacts of biotechnology will inevitably be clouded by the fact that the initial products of biotechnology R&D are likely to differ substantially from those developed two or so decades hence. For example, while current commercial research priorities tend to stress relatively simple single-gene traits (e.g., herbicide tolerance, disease and pest resistance, "ice-minus" bacteria), future breakthroughs in the molecular biology of major crop plants may make possible improvements in important polygenic traits such as nitrogen fixation and photosynthetic efficiency that could lead to more profound transformations of agriculture than seem likely at present.

Fourth, the nature and pace of biotechnological improvement of crops and livestock -- and hence their production impacts -- will depend upon whether the debt problems and economic stagnation of the developing world ease over the next five to ten years. For example, continued debt problems and stagnation of per capita incomes would be expected to favor

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3/ It should be noted, however, that the first generations of agricultural biotechnologies developed in the industrial countries will tend to be relatively capital intensive. The capital intensity of these biotechnologies will not be due to the biotechnology methods through which they were developed, but rather because of the R&D priorities of the firms that will commercialize them.
biotechnologies applied to export and plantation crops, livestock, and luxury commodities, while more vibrant development and growth in per capita incomes would be more favorable for the diffusion of biotechnologies in basic grain and other staple food crops.

For purposes of this discussion, I will focus on the first generations of biotechnology products (those that are nearing commercialization, are under R&D, and are considered very likely to be deployed within a decade). I will also assume that there will be no fundamental public policy interventions, on the part of either multilateral and bilateral development agencies and organizations or developing country governments, that will significantly modify ongoing trends in R&D. Finally, I will assume that there will be modest economic growth in the developing world (i.e., neither the rapid growth of the 1960s nor the stagnation of the early to mid-1980s).

The first generation of agricultural biotechnology products applied in the developing world will tend to have the following characteristics. First, biotechnological innovation will be primarily market driven in the sense that the biotechnology products that are deployed will mainly be those emphasized in private R&D (particularly by large firms in the developed countries); the market-driven nature of agricultural biotechnology will lead to most of these technologies being relatively capital-intensive.

Second, the application of biotechnology will be very uneven globally. Biotechnologies will be deployed first and most extensively in the developed countries, and then in the developing countries with the greatest market potential (mainly large countries with large numbers of commercial producers of high-value industrial/export crops, green revolution cereal grains, and large temperate animal species and with few restrictions on multinational investments). Smaller, poorer countries will witness little biotechnological innovation in agriculture within the next decade.

Third, biotechnology advances will occur more rapidly in the large temperate livestock species (dairy, swine, and beef) and poultry than in crops. Fourth, the earliest crop biotechnologies will be focused on plant protection traits, followed by crop quality and environmental tolerance traits; advances in nitrogen fixation and photosynthetic efficiency will occur outside of the time frame of this assessment.

Fifth, biotechnological innovation will occur first in high-value horticultural and industrial/plantation crops, and later in the cereal grains and grain legumes. There will tend to be little biotechnological advance in roots, tubers, and plantains (with the plausible exception of the potato) because of the lack of private sector interest in these crops. Sixth, biotechnological innovation is likely to occur more rapidly in agricultural and food product processing than in agriculture itself.

With this background in mind, I will summarize the current literature on the production impacts of biotechnology. Several major points stand out in this literature.
1. An assessment of the economic and productivity impacts of biotechnology must be premised on awareness of the fundamental duality of agricultural biotechnology, namely, that biotechnology will be applied in agricultural product processing (and several other nonfarm industrial sectors) as well as in the improvement of agricultural inputs (Goodman et al., 1987; Wilkinson, 1987). In particular, the production impacts of biotechnology on developing country agriculture are likely to occur at least as much — and probably more — through changes in bioprocessing technology than through innovations in agricultural inputs. Only recently has there been any recognition in the social science literature of the likely importance of the substitution of products from industrial tissue culture and bioprocessing for developing country agricultural export commodities. In principle, virtually any major agricultural commodity that is an industrial input or a source of secondary metabolite products can be displaced by biotechnological production.

The industrial impacts of biotechnology on agriculture, however, will not be confined to medicinals, flavorings, scents, spices, sweeteners, astringents, fragrances, and other useful chemicals. Biotechnology also portends long-term shifts in comparative advantage among commodities as cheap sources of high-quality proteins, starches, oils, and so on (Wilkinson, 1987). With the tools of biotechnology, food and chemical companies will decrease their dependence on particular sources of raw materials — that is, biotechnology will increasingly sever the integrated chain of production that unites specific inputs and final food products (e.g., wheat with Wheaties). This will provide food and chemical companies with the flexibility to make use of a range of alternative sources of starches, proteins, oils, and other chemical intermediates and will enable them to benefit from the multiple-sourcing arrangements that are now common in large-scale nonfarm industry. Further, this industrial substitutionism may relegate an increasing proportion of agriculture to the production of homogeneous, low value added, highly substitutable sources of industrial feedstocks (Goodman et al., 1987; Wilkinson, 1987; van den Doel and Junne, 1986).

2. As noted earlier, it seems unlikely that biotechnology will make possible "revolutionary" increases in agricultural output and productivity in the developing world. More specifically, there does not appear to be on the immediate horizon a set of biotechnologies that would enable output and productivity increases of the magnitude of green revolution rices and wheats during the late 1960s and 1970s. (If, however, advances in the molecular biology of major crop plants permit breakthroughs in photosynthetic efficiency, more dramatic biotechnology impacts on productivity and output could occur in two to four decades.)

The fact that biotechnology will likely not lead to green revolution-style increases in agricultural productivity and output over the next one to two decades should be no cause for disappointment. Biotechnology will have made a significant contribution to human welfare if it permits a more balanced improvement of agriculture — over a wide range of agricultural species, agroecosystems, and socioeconomic groups — and enables annual productivity, production cost, and output improvements at or above the rate of world population growth.
In fact, agricultural biotechnology is best viewed not as a "magic bullet" technology, but rather as a set of techniques that permit agricultural researchers to perform their traditional tasks more rapidly and efficiently. With appropriate public policy interventions, biotechnology could make possible more balanced productivity increases in developing country agriculture than were achieved during the green revolution era (Kenney and Buttel, 1985). A likely scenario for the effects of biotechnology on global agricultural output and productivity is that these new technologies will permit continued increases at or around the post-World War II trend lines (and will obviate the productivity plateaus that would likely have occurred with traditional varietal and chemical inputs).

3. Though biotechnology will in all likelihood extend the long post-World War II phase of global agricultural productivity and output increase several more decades into the future, there are several respects in which this performance is likely to be uneven. As noted earlier, these improvements are almost certain to occur first in the developed countries, and as a result comparative advantage in the production of many agricultural commodities will shift back to or be reinforced in the developed world. In particular, the U.S. and other developed countries may be able to regain their comparative advantages in producing some livestock and high-value horticultural commodities that were lost to portions of the developing world over the past decade (Barker, 1986). Over the medium-term -- that is, until the first generations of biotechnology inputs have become relatively generalized across the globe -- these new technologies are likely to exacerbate developed-developing world disparities in agricultural productivity. The prospect for the developed countries is continued surplus problems (Barker, 1986).

4. For a combination of technical and socioeconomic (largely market) reasons, the first generations of agricultural biotechnology inputs will tend to be applied disproportionately to (relative) luxury commodities -- large livestock species, poultry, high-value horticultural commodities, industrial and export crops -- and more slowly in the basic-staple food crops (Barker, 1986). As a result, there may be a tendency for LDC agricultural resources to be shifted from basic-staple food crops into luxury commodities, particularly if the economic performance of the developing world as a whole lapses into its early 1980s pattern of stagnation. It will also likely be more than a decade, if not more, before biotechnology makes possible food price decreases in the developing world of the magnitude of those of the green revolution (see Lipton with Longhurst, 1985, for evidence on the green revolution).

5. The first generations of biotechnology inputs are likely to be deployed very unevenly across the developing world. In an absence of major public policy interventions in the biotechnology innovation process, these improvements will occur first and most thoroughly in a relative handful of developing countries (e.g., Brazil, Argentina, Malaysia, Taiwan, South Korea). Most importantly, the prospects are not bright for rapid deployment of agricultural biotechnology inputs in the poorest countries of Africa, Latin America, and the Caribbean (OECD Development Centre, 1988).
6. The developing countries that are most likely to benefit first and most extensively from new agricultural biotechnology inputs will generally be those -- such as India, Indonesia, Thailand, China, and so on -- that have experienced relatively successful green revolutions, have achieved food self-sufficiency, and may even be on their way to the typical industrial-country dilemmas of overproduction. Within two decades biotechnology may actually exacerbate agricultural overproduction problems in several developing countries. (In a few developing countries industrial-biotechnology sweetener substitutes have caused land to be shifted from sugar cane to rice and corn production, thereby contributing to overproduction of staple food crops (van den Doel and Junne, 1986:89).)

If, however, developing countries move rapidly to acquire industrial tissue culture and bioprocessing expertise, they will have several options for dealing with overproduction problems. For example, surplus corn or rice can be converted into sweeteners. Likewise, developing country importers of agricultural oils would be able to utilize industrial tissue culture production processes to reduce hard currency outlays for these imported commodities (Wilkinson, 1987).

7. As suggested earlier, the two master production impacts of biotechnology will be industrial substitutionism (substituting an industrially-produced commodity for an agricultural one) and agricultural product substitutionism (improvements in agricultural inputs that lead to increased productivity and competition, and ultimately shifts in comparative advantage, among agricultural commodities). Industrial biotechnological substitutionism will be most likely to occur in sweeteners and in the production of high-value, agriculturally-derived secondary metabolite products such as fragrances, spices, flavorings, medicinals, and astringents). For these commodities, trade (at least between developed and developing countries) is likely to decline. For starches, proteins, and oils over the medium term, the principal production impacts of biotechnology will be those of agricultural product substitutionism -- increased productivity, quite possibly overproduction, and increased competition among products and regions.

Whether increased competition among producers of starches, proteins, and oils will lead to increased world trade is indeterminate. On one hand, agricultural product substitutionism should cause continual shifts in comparative advantage and cause agricultural commodities to be increasingly mobile beyond national borders. On the other hand, biotechnologies offer developed and developing countries that import food the tools for responding to new patterns of domestic demand by exploiting available domestic resources and lessening their reliance on costly imports (Wilkinson, 1987).

8. Because agricultural biotechnology inputs are likely to be relatively capital-intensive, the general tendency will be for these products to be most applicable to the operations of larger farmers and to

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4/ To a considerable degree, however, self-sufficiency has been achieved because of regressive income distribution patterns and stagnation of domestic demand for staple food crops in the developing countries (Wilkinson, 1987).
confer the largest benefits on this group (Ahmed, 1988). These tendencies will likely be strongest for the first generation of biotechnology inputs, which will be applied disproportionately to large animal species, poultry, and high-value horticultural-export-industrial crops that are typically produced under large-farm or plantation conditions. These patterns are likely to be replicated, however, as biotechnologies are extended to cereal grain and other major food crops, though less so in the case of rice than in wheat, sorghum, and other crops that lend themselves to mechanization.

Public policy interventions, however, could significantly alter this pattern (e.g., through a strong public sector emphasis on the crops and technical problems of smallholder peasants and of producers in less favored zones). In particular, a public policy consensus should be developed on the need to develop biotechnology to help revitalize the peasant economies of Africa, by making possible low-cost, locally-adapted technologies (OTA, 1988).

9. Most developing countries can anticipate relatively perverse timing of the costs and benefits of biotechnology. The initial impacts of biotechnology in the developing world will generally be biotechnological displacement of agricultural commodities such as sweeteners and secondary metabolite products. Other costs, such as the use of scarce foreign exchange for purchasing imported biotechnology products and disruptions of local industry, will tend to follow. The benefits of biotechnology -- crop and livestock improvement, industrial biotechnology capability, improvements in health care -- will tend to come later. The poorest developing countries are most likely to experience this temporally asymmetric distribution of costs and benefits. More favored developing countries, with the capability to establish their own biotechnology R&D and production facilities, will generally have a more favorable distribution of costs and benefits of biotechnology over time.

10. Within the food industry biotechnology will have a number of major production impacts (see Wilkinson, 1987). As noted earlier, one of the major impacts of biotechnology will be to "break down the integrated chain of production uniting specific agricultural inputs with final food products" (Wilkinson, 1987:21); that is, agriculturally-produced inputs into food manufacturing will become increasingly interchangeable. Biotechnology will also enable food manufacturers to respond more rapidly to new patterns of food demand. Further, increased competition in the food industry -- especially the imperative to achieve scale economies in producing the newer upscale, highly-differentiated products that are increasingly being emphasized -- is likely to contribute to rapid increases in scale economies in bioprocessing. Up to this point the relative lack of scale economies and low barriers to entry in bioprocessing have been among the conditions making developing country investments in biotechnology R&D capacity especially attractive (Fransman, 1988; Buttel and Kenney, 1988). This "window of opportunity," however, is likely to close relatively rapidly (Fransman, 1988).

CONCLUDING REMARKS

Biotechnology has been oversold in the magic bullet or revolutionary sense. But biotechnology may actually have been undersold as
a set of diverse, multivalent technologies that may permit more balanced, sustainable development than has been the track record of the developing world since World War II.

The many challenges posed by biotechnology are not merely economic ones in the strict sense of the term. Several are, quite frankly, political. I will briefly list only some of the more important uncertainties: the uncertainties of a new agricultural technology that is so dominated by private R&D in large chemical companies at such an early stage, of a technology that will be far more subject to patents and other intellectual property restrictions than were traditional means of agricultural improvement, and of how public research institutions -- particularly the IARCs and national agricultural research institutes in the developing world -- will fare in the evolving division of labor between public and private international agricultural research (see, for example, Buttel, 1988; Buttel et al., 1985a, 1985b, Kenney and Buttel, 1985). Of particular concern is how the new global milieu of high-technology competition will affect the application of biotechnology in the developing world and the developing countries' access to these new technologies. The escalating "war on piracy" (i.e., U.S. trade bill provisions that seek to compel developing countries to refrain from pirating patented technologies with the threat of trade retaliation against violators), along with the privatization of "public" R&D in the developed world as it is increasingly harnessed to serve national technological competition goals (Kenney, 1986), will be a major factor affecting the application of biotechnology to international development.

Unfortunately, the current development of the world biotechnology industry suggests the likelihood of perverse timing of biotechnology applications in most developing-world contexts. In the absence of major coordinated policy interventions by international development agencies, the LDCs seem likely to absorb the costs of biotechnology innovation initially, while the benefits will be slower in coming. Policy interventions by international development agencies will thus be crucial in maximizing the benefits from this new technology.

I would like to conclude by commenting on some of the major biotechnology policy issues to be dealt with by international development agencies. First, one of the key long-term issues in biotechnology and international agricultural development will be research priorities and how they are determined. The multivalency of biotechnology affords a great many technical options. But to realize this promise, it will be crucial for international development agencies to use their scarce financial resources to ensure that "orphan technologies" that can yield broad socioeconomic benefits receive sufficient funding.

Second, international development agencies must come to grips with the fact that the goals of facilitating the rapid development of biotechnology R&D in the developing world and of utilizing biotechnology to improve the living standards of the poorest countries are largely orthogonal (and even contradictory, if one assumes that they compete for the same scarce pool of funds). In general, the ten or so developing countries with sufficient biotechnology R&D capacity to have a realistic hope of experiencing rapid deployment of agricultural biotechnology are
those that have already achieved food self-sufficiency, or worse yet are beginning to experience overproduction. By contrast, the countries that need biotechnology the most are often those with so little agricultural and food research capacity and such small markets that neither public nor private biotechnology R&D is likely for the foreseeable future.

Third, international development agencies must play a leading role in financing the development of human capital in LDC and LDC-oriented biotechnology. But because of the tremendous disparities in biotechnology-relevant R&D capacity among the developing countries (Persley, 1988) and the major costs involved, these agencies' investments in building human capital must be made carefully. As suggested earlier, training biotechnology scientists from countries that lack an effective public agricultural research system and adequate research facilities will yield limited results. Ideally, countries with considerable biotechnology R&D capacity that receive development agency funding for expansion of their biotechnology capabilities should be expected to cooperate and share their materials with neighboring low-income countries. The wide disparities in LDC biotechnology capacity make it increasingly important that multilateral agricultural research institutions (the IARCs and comparable non-IARC institutes), which can develop advanced breeding lines and other materials for use by countries with only rudimentary agricultural research capacity, be very strongly supported by international donors.

Fourth, it is likely that the role of the private sector in international biotechnology efforts will be controversial for some time. While public-private conflicts (e.g., over proprietary restrictions on germplasm, over release of public-domain varieties) will occur, both proponents and opponents of private sector biotechnology in the developing world must recognize a fundamental aspect of private agricultural R&D: private investment in agricultural research seldom occurs in an absence of an effective public agricultural research system (Ruttan, 1982). In general, then, countries in which there is a strong likelihood of successful private sector biotechnology R&D are generally not those where food sufficiency is a major problem for biotechnology to solve. Likewise, in the poorer countries where biotechnology is most urgently needed, the current lack of public agricultural and food research capacity makes it unlikely that there will be any significant private investment in this new technology.

Finally, international development agencies should avoid both biotechnological infatuation and agricultural fundamentalism. Development agencies must recognize that capacity in public agricultural research must precede successful application of biotechnology to agriculture.

This does not, of course, imply that these countries do not have major problems of malnutrition and hunger. But these problems of food access are not mainly those of lack of food production which can be solved by biotechnology or any other production technology. These problems are mainly a function of inequalities of wealth and income, economic stagnation, debt burdens, and so on.

The exceptions are mainly high-value industrial-export crops for which firms find R&D to be privately profitable.
Biotechnology is not a substitute for "traditional" agricultural research, and in fact requires plant breeding, agronomic, and related agricultural research capacity if new biotechnology innovations are to reach farmers' fields. Now more than ever, development agencies must renew their commitment to helping to increase developing country agricultural research capacity if the promises of biotechnology are to be realized. Likewise, despite the attractiveness of applying biotechnology to agricultural improvement, the importance of industrial/food biotechnology must not be forgotten. For many developing countries, nonfarm biotechnology, such as applying industrial bioprocessing techniques to convert underutilized biological materials and genetic diversity into food and other useful substances, will be as or more important than applying biotechnology to the improvement of agricultural inputs.

However appropriate and attractive biotechnology might be for development programs in the LDCs, successful developing-country biotechnology efforts face a number of obstacles. International development agencies must play an active, innovative role if biotechnology is to live up to its promise for agricultural development in the developing world. Agricultural development in the LDCs will ultimately contribute not only to improvement of rural and urban living standards there, but also the economic progress in the developed world as well.
REFERENCES


INTRODUCTION

There is a consensus among the private sector companies involved in biotechnology that they are willing to collaborate in developing country research. This was enunciated at a USAID-sponsored conference in April 1988. The conference participants agreed that there is a need for biotechnology research collaboration (Cohen, pers. comm). Participants included:

- CGIAR Centers, which desire to establish collaborative linkages in biotechnologies consistent with the charter of each center;
- donors, which seek to initiate and foster linkages between the International Agricultural Research Centers and developed country agricultural research institutions;
- developing countries, which seek to develop institutional capacity to facilitate collaboration with developed world research.

Private sector interest in agricultural biotechnology research has increased significantly during the past 5-10 years. Public sector institutions involved in biotechnology research are also doing more collaborative research with the private sector. Private sector biotechnology research no longer stands apart from those parts of the private sector that have been traditionally involved in agriculture. Thus, the seed, agrochemical and animal industries, and now the food processing industry, have committed themselves to doing biotechnology research either in-house or through contractual or joint venture relationships with biotechnology firms or institutions.

Within private sector agricultural biotechnology research, individual firms are amalgamating. In addition, large corporations are becoming more influential in smaller biotechnology research companies because of equity investments. Both large and smaller biotechnology companies are also influencing research in university laboratories as a result of research funding relationships.

These developments may be viewed with some disquiet by non-private sector groups and possibly by the international agricultural research community. However, there are a number of very clear advantages.

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First, considerably more resources are being channelled into agricultural biotechnology and thus the science and technology of biotechnology are developing more rapidly. Secondly, the commercial imperative of the private sector is resulting in the focused application of these technologies to solve real world problems and create new commercial opportunities. Thirdly, there is a greater awareness among those who allocate research resources of the benefits of and issues of concern in carrying out and applying biotechnology. Fourthly, and this is my personal opinion, the changing infrastructure of agricultural research, partly as a result of the application of new technology, will create new opportunities for a more efficient agriculture that will benefit both the developing and the developed world.

**CHANGE AND RESPONSE IN AGRICULTURE**

Agriculture is never a static entity. It has continuously undergone change and will continue to do so. As we approach the twenty-first century, change and response is still occurring. The World Bank and the CGIAR agricultural research system have done much to ameliorate the supply/demand imbalance for food crops, an effort focused primarily on those crops that are a principal source of carbohydrates, namely, cereals and root crops. Far less attention has been devoted to oilseed crops, which are the major source of oils and fats for human consumption. This paper outlines the potential for development of oilseed crop production through the use of biotechnology.

**PRODUCTION AND WORLD CONSUMPTION OF FATS AND OILS**

The production of fats and oils for human and industrial use in 1987/88 was 73.8 million tons (Table 1). Current consumption is almost 75 million tons or 14.8 kg/person worldwide. There are 17 major sources of oils and fats of which annual oilseeds crops contribute 55 percent, plantation crops 19 percent and fish and animal sources 26 percent. Approximately 80 percent of oil and fat production is utilized as food or for food preparation. Due to population increases and increased per capita consumption (1.8 percent per year since 1977/78), total world consumption of oils and fats is forecast to rise by 42 percent (31 million tons) to a total of 105 million tons by the year 2000 (Oil World, 1988).

This demand will stretch the world's oils and fats production capability. More importantly, it will place severe economic hardships on developing countries that depend on imported oils and fats to meet local demand.

During the fifties and sixties soybean oil dominated oil supplies. The U.S. dominance of this market was eroded by the entry of Brazil and Argentina in the seventies. Since the early seventies palm oil has successfully competed with soybean oil as the market leader. Within the last decade, rapeseed and sunflower joined palm oil as the growth leaders. Rapeseed has had the most meteoric rise, moving from eighth position twenty-five years ago to its current position of third after soybean and palm oil. The production of rapeseed oil has been increasing at an average annual rate of 9.4 percent since 1982/83 largely due to increased
production in the EEC and Canada but also in China and India (Oil World Annual, 1988) (Table 2).

**TABLE 1: WORLD PRODUCTION OF OILSEEDS, OIL AND MEAL 1987/88**  
(OIL WORLD ANNUAL, 1988)

<table>
<thead>
<tr>
<th>1987/88</th>
<th>Oilseeds</th>
<th>Oil (million tons)</th>
<th>Meal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Oilseeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td>100.6</td>
<td>15.5</td>
<td>68.6</td>
</tr>
<tr>
<td>Rape</td>
<td>22.8</td>
<td>7.7</td>
<td>12.3</td>
</tr>
<tr>
<td>Sunflower</td>
<td>21.0</td>
<td>7.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Cottonseed</td>
<td>31.4</td>
<td>3.5</td>
<td>13.1</td>
</tr>
<tr>
<td>Groundnut</td>
<td>13.1</td>
<td>3.0</td>
<td>4.3</td>
</tr>
<tr>
<td>Sesame</td>
<td>2.0</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Corn/Corn gluten</td>
<td>-</td>
<td>1.2</td>
<td>11.2</td>
</tr>
<tr>
<td><strong>SUB TOTAL</strong></td>
<td>190.9</td>
<td>39.1</td>
<td>119.0</td>
</tr>
<tr>
<td><strong>Plantation Crops</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palm</td>
<td>-</td>
<td>8.3</td>
<td>-</td>
</tr>
<tr>
<td>Coconut</td>
<td>4.6</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Palm Kernel Oil</td>
<td>2.5</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Olive Oil</td>
<td>-</td>
<td>1.9</td>
<td>-</td>
</tr>
<tr>
<td><strong>SUB TOTAL</strong></td>
<td>7.1</td>
<td>14.0</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>Industrial Vegetable Oils</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linseed</td>
<td>2.6</td>
<td>0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Castor</td>
<td>0.8</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td><strong>SUB TOTAL</strong></td>
<td>3.4</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Animal Fats</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butter (as fat)</td>
<td>-</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>Lard</td>
<td>-</td>
<td>5.6</td>
<td>-</td>
</tr>
<tr>
<td>Tallow and Grease</td>
<td>-</td>
<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td>Fish Oil</td>
<td>-</td>
<td>1.5</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>SUB TOTAL</strong></td>
<td>-</td>
<td>19.6</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>GRAND TOTAL</strong></td>
<td>201.4</td>
<td>73.8</td>
<td>129.7</td>
</tr>
</tbody>
</table>
### TABLE 2: AVERAGE ANNUAL PERCENT CHANGE IN PRODUCTION OF MAJOR OILS AND FATS (1982/83-87/88)

<table>
<thead>
<tr>
<th></th>
<th>Mean ± s.e.</th>
<th>Rangea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapeseed</td>
<td>9.42 ± 2.17</td>
<td>2.0 - 15.9</td>
</tr>
<tr>
<td>Palm</td>
<td>9.08 ± 3.48</td>
<td>(1.0) - 22.5</td>
</tr>
<tr>
<td>Sunflower</td>
<td>4.84 ± 2.15</td>
<td>(2.3) - 12.3</td>
</tr>
<tr>
<td>Groundnut</td>
<td>3.98 ± 5.93</td>
<td>(11.1) - 26.4</td>
</tr>
<tr>
<td>Coconut</td>
<td>2.50 ± 9.33</td>
<td>(18.4) - 41.0</td>
</tr>
<tr>
<td>Soybean</td>
<td>2.16 ± 2.03</td>
<td>(5.9) - 8.0</td>
</tr>
<tr>
<td>Cottonseed</td>
<td>(1.32) ± 3.95</td>
<td>(14.9) - 10.5</td>
</tr>
<tr>
<td>Other Vegetable Oils</td>
<td>1.95 ± 2.49</td>
<td>(7.7) - 7.8</td>
</tr>
<tr>
<td>Total Vegetable Oils</td>
<td>4.30 ± 2.03</td>
<td>2.4) - 10.8</td>
</tr>
<tr>
<td>Animal Fats</td>
<td>0.82 ± 0.87</td>
<td>(2.3) - 3.0</td>
</tr>
<tr>
<td><strong>TOTAL OILS AND FATS</strong></td>
<td><strong>3.36 ± 1.367</strong></td>
<td><strong>(0.7) - 7.6</strong></td>
</tr>
</tbody>
</table>

*a/ Figures in parentheses are negative

While vegetable oil consumption continues to grow at a rate of 4.3 percent per year, oilseed meal consumption has only increased 2.5 percent annually. This trend is likely to continue due to a decreasing rate of consumption of meat and meat products. Because of the greater worldwide demand for oil relative to meal, there will be a continuing shift to oil producing crops with higher oil content.

**WORLDWIDE OILSEED AND OIL PRODUCTION AND OIL CONSUMPTION**

**Excess Producing Regions**

Worldwide, the production of oilseed crops and oils is not in balance with the consumption of food oils. Approximately 20 percent of the world’s oilseed harvest and 32 percent of processed oils and fats are traded internationally every year. Regions with a substantial production of oilseeds and oils in excess of domestic consumption (>200,000 tons) include North America (USA, Canada), South America (Argentina, Brazil) and S.E. Asia (Malaysia, Philippines, Indonesia) (Table 3). Both oilseeds (soybean, sunflower, rapeseed) and oils (palm, soybean, coconut, cottonseed, rapeseed, groundnut, fish, fallow and grease) are exported to oil deficient countries.
### TABLE 3: COUNTRIES WITH A NET EXPORT BALANCE OF OILS AND FATS (1985-87)

<table>
<thead>
<tr>
<th>Country</th>
<th>Oil Exports ('000 tons)</th>
<th>Exported Commodities&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>4500</td>
<td>-</td>
</tr>
<tr>
<td>USA</td>
<td>3700</td>
<td>SB, SF</td>
</tr>
<tr>
<td>Argentina</td>
<td>1900</td>
<td>SB</td>
</tr>
<tr>
<td>Brazil</td>
<td>1360</td>
<td>SB</td>
</tr>
<tr>
<td>Canada</td>
<td>1020</td>
<td>RS, LD</td>
</tr>
<tr>
<td>Philippines</td>
<td>960</td>
<td>-</td>
</tr>
<tr>
<td>Indonesia</td>
<td>740</td>
<td>-</td>
</tr>
<tr>
<td>Australia/ New Zealand</td>
<td>430</td>
<td>-</td>
</tr>
<tr>
<td>Others&lt;sup&gt;b&lt;/sup&gt;</td>
<td>260</td>
<td>FO, PMO, CTO</td>
</tr>
</tbody>
</table>

**TOTAL** 14,870

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<sup>a</sup> CODE

- SB - soybean
- SF - sunflower
- RS - rapeseed
- LD - linseed
- RS - rapeseed oil
- LD - linseed oil
- CNO - cottonseed oil
- CT0 - coconut oil
- PMO - palm oil
- GNO - groundnut oil

- SBO - soybean oil
- SFO - sunflower oil
- RSO - rapeseed oil
- LDO - linseed oil
- CNO - cottonseed oil
- PMO - palm oil
- GNO - groundnut oil

- TG - tallow and grease
- PKO - palm kernel oil
- CNO - corn oil

<sup>b</sup> Chile, Honduras, Sri Lanka, Senegal, Cameroon, Zaire
Oil and Fat Deficient Regions

Both developed and many developing countries of the world experience consistent deficiencies in oilseed and oil producing capability (Table 4). Industrially developed countries (USSR, EEC, Japan, Taiwan, South Korea) preferentially import commodity crops which are crushed locally (Table 4A). Developing countries in Asia, the Middle East, Africa and Central/South America have no, or limited, indigenous crushing capability and must rely on imported oils rather than oilseed grain (Table 4B). Exceptions to this are Mexico, which processes imported grain locally, and India and China, which have substantial crushing capacity for local production even though the crushing technology may be inefficient, i.e., cold press extraction rather than solvent extraction. Collectively, developing countries import almost eight million tons of oil annually, either as oilseeds or as oil (Table 4B + Mexico). At an average price of US$ 375/ton, this represents an import cost of US$ three billion annually.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>DEFICITa (000 tons)</th>
<th>PRODUCTIONb CROPS</th>
<th>OILSEED IMPORTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>USSR</td>
<td>1310</td>
<td>SF, CN</td>
<td>SB</td>
</tr>
<tr>
<td>EEC</td>
<td>2100</td>
<td>RS, SF, SB, CN</td>
<td>SB, GN, LD</td>
</tr>
<tr>
<td>JAPAN</td>
<td>2320</td>
<td>SB</td>
<td>SB, RS</td>
</tr>
<tr>
<td>TAIWAN</td>
<td>400</td>
<td>GN</td>
<td>SB</td>
</tr>
<tr>
<td>SOUTH KOREA</td>
<td>300</td>
<td>SB</td>
<td>SB, (PMO)c</td>
</tr>
<tr>
<td>MEXICO</td>
<td>550</td>
<td>SB, CN, CT</td>
<td>SB, RS, SF (SFO)d</td>
</tr>
<tr>
<td>TOTAL</td>
<td>6580</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a/ As oil equivalents

b/ See code at bottom of Table 4B.

c/ Also imports palm oil

d/ Also imports sunflower oil
TABLE 4: (Continued)

B. AS OIL IMPORTS

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>DEFICIT</th>
<th>PRINCIPAL OIL SOURCES&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOCAL PRODUCTION</td>
</tr>
<tr>
<td>ASIA</td>
<td></td>
<td></td>
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<tr>
<td>INDIA</td>
<td>1480</td>
<td>GN, RS</td>
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<tr>
<td>PAKISTAN</td>
<td>880</td>
<td>CN, RS</td>
</tr>
<tr>
<td>CHINA</td>
<td>450</td>
<td>RS, GN, CN, SB</td>
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<tr>
<td>BANGLADESH</td>
<td>250</td>
<td>RS</td>
</tr>
<tr>
<td>SUB TOTAL</td>
<td>3060</td>
<td></td>
</tr>
<tr>
<td>MIDDLE EAST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRAN</td>
<td>500</td>
<td>CN, SB</td>
</tr>
<tr>
<td>IRAQ</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>TURKEY</td>
<td>220</td>
<td>SF, CN, SB, OL</td>
</tr>
<tr>
<td>OTHER</td>
<td>330</td>
<td>OLO</td>
</tr>
<tr>
<td>SUB TOTAL</td>
<td>1330</td>
<td></td>
</tr>
<tr>
<td>AFRICA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGYPT</td>
<td>670</td>
<td>CH, SB</td>
</tr>
<tr>
<td>ALGERIA</td>
<td>380</td>
<td>OLO</td>
</tr>
<tr>
<td>MOROCCO</td>
<td>260</td>
<td>OLO</td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>210</td>
<td>SF, CN</td>
</tr>
<tr>
<td>OTHER</td>
<td>350</td>
<td>GN, CN, OL</td>
</tr>
<tr>
<td>SUB TOTAL</td>
<td>1870</td>
<td></td>
</tr>
<tr>
<td>CENTRAL/SOUTH AMERICA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUBA</td>
<td>290</td>
<td></td>
</tr>
<tr>
<td>VENEZUELA</td>
<td>260</td>
<td>CN, CT</td>
</tr>
<tr>
<td>OTHER</td>
<td>310</td>
<td></td>
</tr>
<tr>
<td>SUB TOTAL</td>
<td>1060</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>7320</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> CODE

- SB - soybean
- SF - sunflower
- RS - rapeseed
- CN - cottonseed
- GN - groundnut
- LD - linseed
- OL - olive
- CT - coconut
- SBO - soybean oil
- SFO - sunflower oil
- RSO - rapeseed oil
- CNO - cottonseed oil
- CTO - coconut oil
- PMO - palm oil
- GNO - groundnut oil
- TG - tallow and grease
- LDO - linseed oil
- FO - fish oil
- PKO - palm kernel oil
- CNO - corn oil
The current major deficit areas are Asia (India, Pakistan, China), the Middle East (Iran, Iraq, Turkey), North Africa (Egypt, Algeria, Morocco) and Central/South America (Mexico, Cuba, Venezuela). Forecasts indicate that India will remain in a deficit situation for vegetable oils for the foreseeable future with net imports of 2.5 million tons in the year 2000. The USSR is also expected to remain a net importer. There remains a large group of other net importing countries (Table 4B) which will continue to depend on imported oil supplies. Foremost among this group are Pakistan, Bangladesh, North Africa, Iran, Turkey and Mexico (Oil World, 1988).

It should be noted that some of these countries already have substantial local production of annual primary oilseed crops, namely, rapeseed in China, India, Pakistan and Bangladesh; sunflower in Turkey; and soybean in China, India, Turkey, Egypt and Mexico. The greatest opportunity for addressing the oil imbalance in these countries lies in accelerating the development of annual oilseed crops, in particular, rapeseed. As pointed out later, rapeseed has sufficient genetic adaptability to enable successful introduction of the crop into most of the current oil deficient areas.

**CANOLA: A CANADIAN SUCCESS STORY**

Traditional varieties of any of the three main oilseed Brassica species (B. napus, B. campestris, B. juncea) produce an oil which normally has high levels (40-60 percent) of erucic acid (C22:1) and eicosenoic acid (C20:1). These fatty acids have unique characteristics as marine lubricants. Indeed, rapeseed was first cultivated in Canada as a source of marine oil during the Second World War. An extensive series of experiments in the 1940's and 1950's showed that erucic acid was poorly metabolized in laboratory animals and, if fed in quantity, led to heart lesions (Sauer and Kramer, 1983). Subsequently, low erucic acid rapeseed (LEAR) varieties were released in Canada in the late sixties (Stefansson, 1983) and also became the quality standard in Europe in 1976. The absence of erucic acid is conditioned by one gene in B. campestris and two genes in B. napus.

The meal product following oil extraction was limited for use in animal rations because of the high level of glucosinolates. The enzyme myrosinase releases goitrogenic compounds from glucosinolates, which are detrimental to the growth of animals, particularly poultry and swine. In 1967 a Polish cultivar of B. napus, "Bronowski", was identified with only 10 percent of the normal level of glucosinolates and only 7-10 percent erucic acid in the oil. This source of low glucosinolates was rapidly introduced into Canadian LEAR breeding material and was released as double-low rapeseed (the canola standard) varieties in 1974 (Stefansson, 1983). Contemporary research in Germany quickly led to the development of double-low European varieties.

The canola quality standard is being rapidly accepted as the international standard for rapeseed, at least in developed countries. The EC plans to completely switch to canola grade rapeseed by 1991. In Canada, the canola standard has been further modified to specify a erucic acid content of two percent or less. Following the granting of GRAS (generally regarded as safe) status to LEAR oil in the USA in 1985, canola oil was
also given similar status in 1988. Japan only imports canola quality rapeseed for processing as a source of oil for human consumption and meal for animal feed.

In the annals of plant breeding, the Canadian canola story is quite remarkable. In less than twenty years the quality standard of a relatively minor oilseed crop has been dramatically changed. As a result the crop is now the world's third most important source of vegetable oil and the most important annual crop where the primary product of human consumption is oil.

THE BIOTECHNOLOGY OF RAPESEED

The new biotechnologies of protoplast, cell and tissue culture, recombinant DNA, genetic transformation and RFLP genome analysis, along with greater understanding of the biochemistry and molecular biology of plant product synthesis, are unquestionably transforming plant breeding. These techniques are in different stages of development and at different levels of application to plant improvement among various important crop species.

Among the oilseeds, nowhere has the technology developed as rapidly and successfully as in the Brassica crop species, particularly rapeseed. In comparison to all major crop species, biotechnology in rapeseed has more breadth and depth than for any other species.

Tissue and Cell Culture

Most Brassica crop species, and particularly B. napus and B. oleracea, are amenable to tissue and cell culture. Plant regeneration by either organogenesis or embryogenesis is routine for most cultivars.

Protoplast Fusion

In the Brassica species, cytoplasmic organelles (chloroplasts and mitochondria) are only transmitted through the female gametophyte. In rapeseed two important traits are associated with the organelles. Triazine herbicide tolerance is encoded by the chloroplast DNA and cytoplasmic male sterility (CMS) for hybrid seed production is controlled by the mitochondria. Triazine resistant varieties of canola have been developed in Canada by conventional backcrossing.

Combining chloroplast and mitochondrial encoded functions is extremely difficult, if not impossible, by conventional techniques. Protoplast fusion, however, does enable different organelle sources to be combined in a single plant. Following the initial research of Pelletier et al (1983) on intergeneric protoplast fusion in the Cruciferae, CMS and cytoplasmic triazine tolerance have been successfully combined in B. napus by protoplast fusion (Barsby et al, 1987).

Somaclonal Variation

Since its inception (Larkin and Scowcroft, 1981), the concept of somaclonal variation has gained widespread acceptance as a new source of
genetic viability for plant improvement (Scowcroft and Larkin, 1988). The
two principal uses of somaclonal variation are to produce variants
affecting specific traits and to enhance the rate of introgression of alien
genes following interspecific hybridization.

Somaclonal variation is currently used by several research groups,
including Biotechnica Canada, to produce mutants which have altered fatty
acid composition, reduced glucosinolates and earlier maturity and to effect
introgression of disease resistance from alien species into B. napus.

Haploid and Doubled Haploid Systems

In plant breeding programs the development of pure lines and
inbreds from a recombining gene pool requires 5-6 generations of selfing in
order to achieve a level of homozygosity such that important traits are
fixed and to ensure that undesirable recessive traits are eliminated.
Theoretically, the production of homozygous lines in one generation can
save 4-6 years in a breeding program. Haploid systems have been developed
for several species, but only one oilseed crop, namely, rapeseed.

Haploid plants may diploidize spontaneously or the chromosome
number can be doubled by colchicine. Haploid systems in B. campestris are
far less efficient and have not been adequately evaluated in B. juncea.

Currently, many rapeseed/canola breeding programs in Canada,
Europe and Australia utilize anther or microspore culture to produce
doubled haploids. The primary objective is to recover homozygous
recombinants following hybridization and to produce families of inbred
lines for evaluation as parents for hybrid seed production.

Genetic Transformation

Genetic transformation of crop plants can be achieved by a variety
of techniques including the use of Agrobacterium tumefaciens mediated gene
transfer, direct DNA uptake, DNA injection and DNA coated microprojectiles.
New and more efficient techniques for plant transformation are continually
being developed.

In rapeseed, most transformation success has been achieved (Fry et
al, 1987; Pua et al, 1987; Charest et al, 1988) by Agrobacterium mediated
transformation. Recently B. napus has been transformed with a tagged B.
apus seed storage protein gene (napin) under control of its own promoter
and the transformants expressed this engineered gene only in developing
embryos (Radke et al, 1988).

Currently, there is extensive proprietary research to transform
rapeseed with genes that confer herbicide tolerance, pest resistance (B.
thuringiensis toxin, cowpea trypsin inhibitor) and to modify oil quality.
Evaluation of transformed lines is already being carried out under field
conditions to determine the effectiveness of herbicide tolerance and pest
resistance.
Rapeseed Biochemistry and Molecular Biology

In order for biotechnology to have a significant and increasing impact on plant improvement, it is essential that biochemistry and the regulation of genetically controlled functions be understood in more detail. This is true not only for agronomically important traits such as yield, disease and pest resistance, maturity, stress tolerance and resistance to weed competition, but also for the modification of oilseed product characteristics, i.e., oil and meal quality.

Oil Quality

The composition of plant storage lipids depends on the interaction of many enzymes involved in de novo fatty acid biosynthesis, desaturation, chain elongation and triacylglycerol assembly (Harwood, 1988). The extent of fatty acid desaturation appears to be modifiable by conventional plant breeding but the other characteristics probably can only be modified in a meaningful way by recombinant DNA technology. Extensive research is in progress in both the private and public sector to identify the crucial biosynthesis steps in lipid biosynthesis. Much of this research focuses on oilseed rape (Safford et al, 1988) and on a related model species, Arabidopsis thaliana (Somerville et al, 1986).

Meal Quality

The most important meal quality characteristics to be modified are amino acid composition of the meal protein and elimination of undesirable toxic anti-metabolites. The meal of rapeseed contains two principal proteins, cruciferin and napin, both of which are encoded by distinct multigene families. Genes coding for these proteins have been cloned (Josefsson et al, 1987) and by direct insertional mutagenesis it will be possible to alter the amino acid composition to improve the content of limiting amino acids such as lysine and methionine.

The high level of glucosinolates in rapeseed meal (but not canola) makes it unacceptable for monogastric animals such as pigs and poultry. The pathway of glucosinolate synthesis is relatively well understood (Underhill, 1980) and following enzyme purification it will be possible to isolate genes which code for the glucosinolate biosynthetic enzymes. The subsequent elimination of gene activity may be achieved in at least three ways, namely, anti-sense RNA inhibition (van der Krol, 1988), ribozyme destruction of mRNA (Haseloff and Gerlach, 1988) and antibody binding inactivation of enzymes (Carlson, 1988).

Restriction Length Fragment Polymorphism

Detailed genetic linkage maps are fundamental tools for studies of selection, identification and organization of plant genomes. Traditionally, a large number of segregating populations are required to develop linkage maps since only a limited number of segregating loci can be studied in any one cross.

A new class of genetic markers, restriction fragment length polymorphisms (RFLPs), provide the opportunity to obtain detailed genetic
maps from a limited number of crosses. In this approach, cloned DNA sequences are used as probes to analyze specific regions of the plant genome for the presence of polymorphisms at the DNA sequence level. The polymorphism is detected as variation in the length of DNA fragments homologous to a labelled probe after digestion of genomic DNA fragments by electrophoresis. Segregation of many polymorphic RFLP markers in a single cross and the small number of individuals necessary for accurate mapping are the major advantages of RFLP mapping (Beckmann and Soller, 1986).

RFLP maps of oilseed rape will: (a) enable mapping and identification of specific DNA sequences linked to or involved in the regulation of quantitatively and qualitatively determined agronomic traits and the quality and quantity of lipids, proteins and glucosinolates in the seed; (b) assist breeders in the selection of desirable genotypes and so reduce the need for expensive field evaluation; (c) enable the identification of specific inbred lines and cultivars; (d) increase knowledge of the organization and evolution of *Brassica* species.

Integration of Biotechnology with Rapeseed Breeding

In any crop breeding program, the tools of biotechnology will sooner or later become an integral part of breeding strategy. Already some or all of these tools are being utilized in such crops as rice, wheat, maize, potato and tomato. Among the oilseed crops, rapeseed breeders are increasingly exploiting these tools because rapeseed, particularly *B. napus*, is so amendable to a number of the biotechnology developments. The increasing worldwide importance of rapeseed as a primary source of food oil and meal for animal feed, particularly in the developing world, makes the crop a prime candidate for an integrated plant breeding and biotechnology approach.

PRIVATE SECTOR OILSEED BIOTECHNOLOGY AND INTERNATIONAL AGRICULTURAL APPLICATION

In many crops, and particularly rapeseed, the private sector contributes as much if not more than the public sector to the development and application of biotechnology for crop improvement. Private sector companies are not only developing some of the better, more advanced tools of biotechnology, but many of them also have active plant breeding programs.

If the international agricultural community is to access these technologies, a number of issues will have to be resolved.

Who Pays?

Private sector companies are not donor agencies. Moreover, many of their indirect costs -- the leasing and maintenance of facilities and equipment, depreciation, research and administrative management -- are zero base budgeted on an annual basis. These costs need to be recovered in one way or another usually from the contracting agency or a joint venture enterprise. The total cost of a research project in the private sector is 3-4 times direct salary plus operating costs. Donor agencies planning to
access research developments in the private sector will need to take this into account.

**Who Benefits?**

This is always a complex issue and in the final analysis is balanced against the cost of the enterprise. Clearly there has to be a social and economic benefit to the country where, or for whom, the research is to be conducted. The reciprocal benefits accruing to the country involved and the private sector company will usually be determined by negotiation.

**Protection of Intellectual Property**

This is likely the most difficult issue to resolve. Countries differ not only in the extent to which biotechnological discoveries are patentable but also in the degree to which proprietary protection is enforceable. Many developing (and some developed) countries do not have plant variety rights legislation, let alone a mechanism for patenting the discoveries of biotechnology. Private companies frequently depend, at least to some extent, on patents to sustain investor confidence and secure additional investment. For technology that is "owned" by proprietary patents, private sector companies cannot afford the risk that the technology will be widely distributed. Reciprocally, research programs in developing world countries are increasingly likely to develop technology and genes which are patentable at least in some countries of the world. Private companies involved in joint venture collaborations with developing world agricultural programs may be the best vehicle to secure proprietary protection on behalf of the joint venture.

The question of royalty payments on the sale of products containing proprietary technology will tend to be difficult to resolve. Frequently, products such as new crop varieties will be distributed in developing world countries at minimal cost. Thus a royalty position is unlikely to be attractive. Alternatively, recompense for the use of technology could be scheduled over the project development phase and/or linked to specific milestone achievements.

**Commercial Frameworks for Collaboration**

There are several ways in which private sector biotechnology companies and developing countries' agricultural institutes could structure collaborative research ventures. A research contract where the developing country and/or donor agency pays for specific research on technology could involve technology transfer and training of developing country scientists.

Equity financing on a project by project basis is a useful strategy to develop new technology or apply existing technology to a specific problem of strategic importance. It is unlikely that private sector companies would have the resources to apply to a research problem in a developing country, particularly when the return on investment is nebulous. Equity funding of projects would normally give the developing country institute or donor agency ownership of the technology.
Where there is a definable return on investment in biotechnology research, a joint venture is the preferred route for financing the project. In this way both parties subscribe and subsequently both parties share in the profits in proportion to their equity investment in the joint venture. Equity can include technology, germplasm and facilities but cash is also required in order to carry out the research.
REFERENCES


SESSION IV:

LIVESTOCK AND CROPPING SYSTEMS:

RESULTS FROM THE INTERNATIONAL CENTERS
LIVESTOCK AND CROPPING SYSTEMS: 
RESULTS FROM THE INTERNATIONAL RESEARCH CENTERS

SUMMARY

A SUMMARY OF CROP LIVESTOCK INTERACTIONS IN SUB-SAHARAN AFRICA: 
TECHNOLOGIES AND RESEARCH PRIORITIES -- J. McIntire, et al.

The study summarized in the paper is a comparison of crop-livestock interactions across the agroclimates of sub-Saharan Africa, based on an extensive review of the literature and field research in roughly 35 locations in sub-Saharan Africa. The study establishes hypotheses about the level, type and development of interactions as functions of agroclimate, population growth, exogenous technical changes and market access. The fundamental hypothesis is that interactions change in different agroclimates and population densities.

The study addresses two principal arguments in the literature. The first concerns inevitable resource competition between the two activities, especially for land. The second concerns complementarity, defined as one sector's potential contribution of productive inputs to the other. The literature argues that lack of integration is a serious inefficiency in African agriculture because it wastes cheap inputs.

The conclusions of the study are organized as follows. First, conclusions are presented concerning competition and complementarity in crop-livestock interactions, the most important being that competition between crops and animals for land across agroclimates is less acute than generally thought. Next conclusions about the transitions to mixed farming and to specialized production are presented. The principal conclusion is that there is little intensive mixed farming outside the East African and Malgache highlands. Also, there is little specialization in crop or livestock production and, if it exists, it is incomplete.

The authors then present a series of recommended project priorities derived from the research findings. These concern the livestock components of projects and are organized under the topics of commodity, scale, inputs and collateral technologies. Recommendations are presented for projects in the humid, subhumid, semiarid and highland agroclimatic zones. The final section of the paper presents conclusions and research priorities by theme. The themes covered are: animal traction; soil fertility; feed resources and animal fattening; common properties and land rights; credit, investment and income distribution; and the pastoral areas.
FORAGE LEGUME INTERVENTIONS FOR WEST AFRICAN SUBHUMID ZONE
CROP-LIVESTOCK SYSTEMS -- R. von Kaufmann

The paper reports on attempts by ILCA to introduce forage legumes into the crop-livestock systems associated with agro-pastoralism in the subhumid zone of Nigeria. Initial efforts to undersow sorghum with forage legumes (Stylosanthes spp.) were successful in that the crude protein in the dry matter available after harvest was significantly increased without reducing cereal yield. However, there were conflicts between the two crops in terms of peak labor requirements. Thus ILCA tested other forage legumes to find ones that are less competitive for labor but still give reasonable yields of quality dry matter.

Efforts to intersow with stylosanthes also gave promising results but they are of little direct use to herd owners because their fields are too small to grow sufficient quantities to make an impact on their large herds. Thus, ILCA turned to fallow land. A technique was developed whereby seed beds are prepared by trampling by the cattle and fast growing weeds are controlled by early season grazing. It was found that four hectare units of stylo "fodder banks" could be developed that make a significant contribution to herd nutrition.

In order to encourage the cooperation of land owning cultivators, ILCA studied the contribution of stylosanthes to soil fertility. Improvements in almost all characteristics of subhumid soils have been demonstrated after two years of growing stylo. This leads to increased cereal crop yields. Thus, the important finding that forage legumes should be grown in the interest of sustained crop production. Farmers have seen the effect on crop yields and are beginning to plant stylo in their fields and create mini fodder banks. ILCA is exploring further applications of its forage interventions to other parts of the subhumid zone.

PASTURE-CROP TECHNOLOGIES FOR ACID SOIL SAVANNAS AND
RAIN FORESTS OF TROPICAL AMERICA -- J. Toledo, et al.

Pasture-crop technologies appropriate for the acid infertile soils of the Latin American tropics are described and discussed. New, low-input, pasture technology based on the combination of adapted grasses and nitrogen-fixing forage legumes is first described as well as its achievements. Developments in the production of crop cultivars for acid-poor infertile soils are then outlined. These crops are particularly important as pioneer crops to pay for land preparation and application of soil amendments in pasture establishment.

A description is then provided of the role that the new grass-legume pastures can play in the reclamation of two types of pastures. "Torurco" areas are older pastures, closer to the household and managed with higher grazing frequency and with continuous hand or chemical weeding. "Purma" areas are farther away and are more extensively managed with lower stocking rates and minimal weeding, typically managed as part of a shifting
crop-pasture-fallow system. A proposed scheme for using the new grass-legume pastures to improve the "purma" system is described. An economic analysis is then presented for three alternative methods for reclaiming "torurco" areas over a ten year period. The analysis indicates that the highest net present value can be achieved by a non-mechanized, three year application of legume fallow. This approach has substantial advantages over the traditional 10-15 natural fallow approach. Lastly, further research and development needs are presented that are required to overcome constraints to the development of economically sound and sustainable production systems in the savanna and humid tropical ecosystems of Latin America where cattle and crop production is expanding.
INTRODUCTION

The study summarized in this paper is a comparison of crop-livestock interactions across the agroclimates of sub-Saharan Africa (SSA). Crop-livestock interaction is defined as the use of crop output in livestock production and vice versa, and as the exchange of products or factors of production between the two sectors. For example, manure is used for crop production; crop residues are used for feed; herders care for animals entrusted to them by farmers and receive milk as payment. Crop-livestock integration is defined as the merger of the two sectors on the farm in what is usually known as mixed farming.

The study establishes hypotheses about the level, type and development of interactions as functions of agroclimate, population growth, exogenous technical changes and market access. The fundamental hypothesis is that interactions change in different agroclimates (Table 1) and population densities. In sparsely populated arid regions, fodder management consists of grazing pasture and fallow. In cool, densely populated regions, it consists of harvesting crop residues, growing forage crops and feeding grain. Soil fertility maintenance makes the transition from fallowing to paddocking cattle to producing manure. Farming systems shift gradually from hand tools to animal traction to tractors.

OBJECTIVES AND JUSTIFICATION

There are two principal arguments in the crop-livestock literature. One is inevitable resource competition between the two activities, especially for land. In the short term, conflicts occur over high quality grazing; for example, dry season vegetable production interferes with lowland grazing, or irrigation removes land from pasture. In the long term, population growth causes crops to displace pastures generally, reducing grazing quantity and perhaps quality if annual pastures

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Daniel Bourzat is on the staff of the Institut d’Elevage et de Medicine Veterinaire des Pays Tropicaux.

Prabhu Pingali is on the staff of the International Rice Research Institute.
Table 1: Agroclimates in Sub-Saharan Africa

<table>
<thead>
<tr>
<th>Environment</th>
<th>Humid</th>
<th>Subhumid</th>
<th>Semiarid</th>
<th>Highland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main location in</td>
<td>Central</td>
<td>West-central</td>
<td>West</td>
<td>East</td>
</tr>
<tr>
<td>Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of growing</td>
<td>270</td>
<td>&gt;180</td>
<td>90-150</td>
<td>150-365</td>
</tr>
<tr>
<td>period in days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altitude in meters</td>
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<td>0-1000</td>
<td>200-1500</td>
<td>&gt;1200</td>
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<tr>
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<td>wheat, maize</td>
</tr>
<tr>
<td></td>
<td>yam, rice,</td>
<td>maize, yam,</td>
<td>sorghum,</td>
<td>teff, beans</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>groundnut</td>
<td>maize</td>
<td>bananas,</td>
</tr>
<tr>
<td></td>
<td>plantain</td>
<td></td>
<td>groundnut</td>
<td>potatoes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cowpea</td>
<td></td>
</tr>
<tr>
<td>Tsetse challenge</td>
<td>very high</td>
<td>high</td>
<td>low</td>
<td>almost none</td>
</tr>
<tr>
<td>Animal traction</td>
<td>almost none</td>
<td>beginning,</td>
<td>well</td>
<td>general in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>but</td>
<td>developed</td>
<td>Ethiopia,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>generally</td>
<td>in some</td>
<td>common in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rare</td>
<td>areas,</td>
<td>Kenya and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>absent</td>
<td>Madagascar,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>elsewhere</td>
<td>absent in</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>other countries</td>
</tr>
</tbody>
</table>

replace perennials. Competition for labor can also occur as wages rise coincidentally with growing labor requirements for manure production, for fodder production and for animal husbandry. Such competition in the long or short run is said to induce destocking and to reduce income from animal production.

The second argument concerns complementarity, defined as one sector's potential contribution of productive inputs to the other. Examples of complementarity are animal inputs to crops, especially draft power and manure, or crop inputs to livestock, especially crop residues. Complementary inputs are thought to be most efficient when crop and livestock production are integrated on the farm. It is argued repeatedly in the literature that lack of integration is a serious inefficiency in African agriculture because it wastes cheap inputs.
Many policies and development projects are derived from these arguments. The establishment of grazing reserves and group ranches in West and East Africa accepts that there is inevitable land competition between crops and animals. Such reserves attempt to segregate the two, putting animals on poorer land so as to preserve better areas for crops. Any integrated rural development project with a manuring component, an animal traction component, or a crop residue theme tacitly accepts the second argument. If these arguments are invalid, then so are the projects which depend on them.

Many projects, beginning from the assumption that crop-livestock interactions are weak, have attempted to integrate the two by extending specific themes and have failed. Their primary failure has been one of design. The technologies and the institutional innovations promoted have been inappropriate for their locations, farming systems and economic environments. Understanding the degree of competition and complementarity is also vital for policy formulation, especially policies which affect relative prices and comparative advantage in crop or in animal production.

In this study we asked a series of specific questions about crop-livestock interactions which would be relevant to project design, to research programs and to policy formulation.

1. Is crop-livestock competition for resources inevitable unless measures are taken to reduce competition? The study asks: where is there a conflict between crops and animals for land -- in which agroclimates and at which population densities? What have been farmers' responses to such conflicts? How can projects assist those responses to be more efficient?

2. Are feasible interactions inefficient? One purpose of the study is to describe the economic and technical reasons for observed interactions in order to test the hypothesis that they could be more efficient. This amounts to a test of the second argument. Another purpose is to identify profitable techniques of animal traction, feed resources, soil fertility maintenance and animal fattening which are appropriate in different agroclimates.

3. Is crop-livestock integration on the farm a special, transitory case? One possibility is that crop-livestock integration rises and then falls with population density, technical change and market access. A restatement is that crop-livestock integration is temporary and will be replaced in Africa, as in much of Europe and the United States, by specialized crop and animal production. If the hypothesis were confirmed, one could argue that integration is determined largely by exogenous factors and that policies, or specific projects, cannot foster interactions efficiently, or have only limited scope in which to do so.

4. Many projects have started from the assumption that an integrated set of themes, of which animal traction is the centerpiece, is necessary to better crop-livestock interactions. One main purpose of the study is to test that assumption and, from there, to proceed to collateral questions: How can animal traction be developed where it does not exist? How can animal traction be improved where it already exists? What is the association between animal power per se and other aspects of using farm animals such as manuring and forage crops?
5. Many projects have started from the assumption that there is little possibility of improving available feed resources. The study asks: What is the appropriate sequence of feed resource development? Where should the emphasis be in forage crop development?

6. What is the role of manuring in the growth of crop yields and in the maintenance of long term soil fertility? Many assert that manuring can be the basis of a stable productive farming system if animals are properly managed. The study asks: What is the contribution of animals to current soil fertility maintenance? Can manuring maintain long term soil fertility? Are current manuring practices economically justified?

7. Which is the better use of crop residues -- as soil fertility or as feed? Studies in dry regions have shown that restoring crop residues to the soil is necessary to maintain organic matter levels. This practice conflicts with using crop residues for feed and may be economically inefficient if the benefits from feeding crop residues exceed those from putting them in the soil.

8. Under what conditions do farmers adopt more labor-intensive techniques for fodder and animal production? In addition to examining the effects of agroclimate and population density, here we examine the role of modern inputs, especially chemical fertilizers, in inducing a movement away from mixed farming to specialized production. If modern inputs such as chemical fertilizers and feeds were more readily available, would there be more specialization?

9. What mechanisms exist to control pasture access? How strong are they with rapid population growth and what are their implications for herders' access to land? Particular attention is paid to appropriate government policies which affect herders' land rights and to government intervention as a substitute for traditional control mechanisms to arrest environmental degradation.

10. What are the roles of agricultural investment and credit where land has no collateral value and where animals are the principal asset? The dynamics of investment are particularly important where land acquires market value, where non-agricultural employment is available and where credit is an insurance substitute. Credit is repeatedly cited as a constraint to agricultural production yet there is no good empirical basis to evaluate that constraint in Africa because studies of rural finance are sparse and contradictory. Research was therefore organized around the themes of livestock as investment, displacement of livestock by other investments, credit in animal production and cash flow interactions between the two sectors.

11. The cash flow linkages between the crop and livestock sub-sectors must be examined to identify if the profits from one sub-sector are invested in the other. To put the question generally, is lack of integration between crop and animal production a barrier to an efficient capital market in the sense that it raises the costs of acquiring or monitoring investments? To put the question specifically, are dairy profits invested in crop production in a way that profits from off-farm employment are not because crop-livestock integration encourages such investment?
Analysis of the sequence in which interactions become profitable will help determine appropriate projects to promote them. The findings on the structure of crop-livestock interaction will be important for determining the institutional framework and clientele of development efforts. This research will also help identify appropriate land rights policies and when they ought to be enacted in order to minimize distributional problems and maximize efficiency. It will also answer some of the questions on resource allocation and resource use that arise as a result of rapid population growth that in turn leads to inevitable changes in farming systems.

METHODS

A rich data set existed in the literature, especially in the work of ethnographers observing herding and cultivating societies. There was also a mine of information in related agricultural research, especially on soil fertility and animal nutrition. A review was therefore conducted of the ethnographic and scientific literature to outline what was known of interactions. After the initial review, a computerized data bank was constructed from sources allowing quantitative analysis. While this limited the sample size because many secondary sources did not report all variables of interest, it did provide a foundation for comparisons among agroclimatic zones.

We understood that it would be impossible to use the ethnographic or scientific material fully without field observations. Field visits to assess crop-livestock interactions were therefore conducted in roughly 35 locations of sub-Saharan Africa with different agroclimatic conditions, population densities and market access (Table 2). A standard questionnaire was given to groups of farmers and herders to elicit information on crops, livestock, soil fertility techniques, mechanization, land tenure and crop-livestock interactions; this work was usually done by the economists (McIntire and Pingali). The livestock specialist (Bourzat) assessed animal production parameters — feed supplies and management, stock composition, animal diseases and veterinary services.

Although the structured questionnaire guided field interviews, the data do not lend themselves to an analysis of the materials and methods type. Therefore, the following procedure was adopted. A chapter in the main report (not included in this summary paper) outlines results of the field visits to the four principal agroclimatic zones: humid, subhumid, semiarid, and highland. This acquaints the reader with the zones, sketches the interactions and makes preliminary contrasts among sites.¹

¹/ We planned to include eight to ten World Bank crop-livestock projects as field sites in order to evaluate project performance in terms of: a) appropriateness of the technology or practice within the existing farming system and b) distortions in production incentives caused by government policies (e.g., price distortion). For various reasons, this proved impossible. Our analysis of these projects is therefore based largely on document reviews and interviews with project officers, done by Hartwig Schafer, to be published separately.
Table 2: Field sites

<table>
<thead>
<tr>
<th>Country</th>
<th>Site</th>
<th>Environment</th>
<th>Rainfall</th>
<th>Population density</th>
<th>Farming system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burkina</td>
<td>Bama</td>
<td>Semiarid</td>
<td>500</td>
<td>80</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Burkina</td>
<td>Bidi</td>
<td>Semiarid</td>
<td>500</td>
<td>60</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Burkina</td>
<td>Sabouna</td>
<td>Semiarid</td>
<td>500</td>
<td>60</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Burkina</td>
<td>Tondogosso</td>
<td>Semiarid</td>
<td>800</td>
<td>20</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Burkina</td>
<td>Ziga</td>
<td>Semiarid</td>
<td>500</td>
<td>70</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Burundi</td>
<td>Ngozi</td>
<td>Highland</td>
<td>1,250</td>
<td>350</td>
<td>annual</td>
</tr>
<tr>
<td>Congo</td>
<td>Kouilila</td>
<td>Humid</td>
<td>1,550</td>
<td>10</td>
<td>forest fallow</td>
</tr>
<tr>
<td>Congo</td>
<td>LesSaray</td>
<td>Humid</td>
<td>1,600</td>
<td>5</td>
<td>forest fallow</td>
</tr>
<tr>
<td>Cote d'Ivoire</td>
<td>Korhogo</td>
<td>Subhumid</td>
<td>1,200</td>
<td>?</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Debre Berhan</td>
<td>Highland</td>
<td>1,150</td>
<td>85</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Debre Zeit</td>
<td>Highland</td>
<td>850</td>
<td>90</td>
<td>annual</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Inewari</td>
<td>Highland</td>
<td>900</td>
<td>200</td>
<td>multiple cropping</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Fogera</td>
<td>Highland</td>
<td>1,200</td>
<td>?</td>
<td>annual</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Were Ilu</td>
<td>Highland</td>
<td>1,000</td>
<td>250</td>
<td>annual</td>
</tr>
<tr>
<td>Kenya</td>
<td>Machakos</td>
<td>Semiarid</td>
<td>650</td>
<td>?</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Kenya</td>
<td>Muranga</td>
<td>Highland</td>
<td>?</td>
<td>320</td>
<td>annual</td>
</tr>
<tr>
<td>Kenya</td>
<td>Kiambu</td>
<td>Highland</td>
<td>?</td>
<td>?</td>
<td>annual</td>
</tr>
<tr>
<td>Madagascar</td>
<td>Antsirabe</td>
<td>Highland</td>
<td>1,500</td>
<td>100</td>
<td>multiple cropping</td>
</tr>
<tr>
<td>Madagascar</td>
<td>Manjankanadriany</td>
<td>Highland</td>
<td>1,500</td>
<td>150</td>
<td>annual</td>
</tr>
<tr>
<td>Madagascar</td>
<td>Kianjasoa</td>
<td>Semiarid</td>
<td>1,500</td>
<td>10</td>
<td>mixed</td>
</tr>
<tr>
<td>Niger</td>
<td>Dallol Bosso</td>
<td>Semiarid</td>
<td>450</td>
<td>50</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Niger</td>
<td>Zarmaganda</td>
<td>Semiarid</td>
<td>300</td>
<td>15</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Abet</td>
<td>Subhumid</td>
<td>1,500</td>
<td>25</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Fashola</td>
<td>Subhumid</td>
<td>1,250</td>
<td>50</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Ganawuri</td>
<td>Subhumid</td>
<td>1,700</td>
<td>70</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Kufana</td>
<td>Subhumid</td>
<td>1,700</td>
<td>?</td>
<td>grass fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Onitsha</td>
<td>Humid</td>
<td>2,000</td>
<td>200</td>
<td>bush fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Owerri</td>
<td>Humid</td>
<td>2,200</td>
<td>300</td>
<td>forest fallow</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Shaki</td>
<td>Subhumid</td>
<td>1,250</td>
<td>50</td>
<td>forest fallow</td>
</tr>
<tr>
<td>Rwanda</td>
<td>Bugasera</td>
<td>Highland</td>
<td>900</td>
<td>200</td>
<td>multiple cropping</td>
</tr>
<tr>
<td>Zaire</td>
<td>Bukavu</td>
<td>Highland</td>
<td>1,100</td>
<td>150</td>
<td>multiple cropping</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>Masvingo</td>
<td>Semiarid</td>
<td>650</td>
<td>320</td>
<td>multiple cropping</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>Nvuma</td>
<td>Semiarid</td>
<td>650</td>
<td>350</td>
<td>multiple cropping</td>
</tr>
</tbody>
</table>

Cost-benefit models were then constructed from the field and the scientific material. They are reported in four chapters in the main report (not included in this summary paper), which analyze four major themes -- soil fertility, feed resources, animal traction and animal fattening -- with emphasis on resource competition between crops and livestock. Published results of agricultural research provided material for the cost-benefit analysis, but, at every point in the economic analyses, comparisons are made to observations from the literature review and from the field visits. Farm management data provided by ILCA in Niger, Mali, Nigeria and
Ethiopia and by the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) in Niger enabled examination of the profitability of technologies and of their likely impact at various sites.

REVIEW OF CONCLUSIONS

Introduction

The review of conclusions is organized as follows:

1. Conclusions about competition and complementarity are presented as answers to general questions 1 and 2 asked above.

2. Conclusions about the transitions to mixed farming and to specialization are then presented.

3. One of our basic objectives was to determine research priorities by agroclimate. This section recommends appropriate projects by agroclimate and is illustrated in Table 3.

4. A final objective was to determine research priorities by theme (e.g., soil fertility). This is expounded in the final section and is illustrated in Table 4.

Competition and Complementarity in Crop-livestock Interactions

Competition between crops and animals for land across agroclimates is less acute than generally thought. The evidence for this contention is that the highest human and animal population densities are in the East African highlands. There the hypothesized inevitability of land competition has been deferred by the general intensification of farming -- greater crop labor input per unit of land, a shift in the cropping pattern to higher yielding food and forage crops, a shift to more feed efficient animals, and the assiduous use of crop residues as feed. In less favorable agroclimates, which permit much lower land-use intensity, essentially the same techniques have been used.

Within agroclimates, where there is local or seasonal land competition, it is attenuated by imaginative contracts among herders, stock owners and farmers. Such contracts usually involve exchanges of crop residues and manures and thus achieve the objective of greater integration.

Competition with crops for land is not yet the most limiting factor to the stocking rate. A numeric model was devised to analyze land competition between crops and animals in the semiarid and the subhumid zones. The model asked the question: given population density and rainfall, what stocking rates are feasible? Do those stocking rates allow adequate manure production and fallow periods to produce crop yields sufficient to maintain those population densities?
<table>
<thead>
<tr>
<th>Project priorities by agroclimate</th>
<th>Project elements</th>
<th>commodity</th>
<th>scale</th>
<th>input</th>
<th>collateral technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>humid/subhumid, high tryps</strong></td>
<td></td>
<td>1. meat</td>
<td>smallholder, subject to adequate vet care</td>
<td>1. health, 2. feed quality</td>
<td>1. soil fertility effects of leguminous feeds</td>
</tr>
<tr>
<td><strong>subhumid, low tryps</strong></td>
<td></td>
<td>1. meat, 2. traction or milk depending on markets</td>
<td>smallholder, subject to vet care; larger possible near breeding areas</td>
<td>1. feed quality, 2. animal health, 3. forages for quality (extensive)</td>
<td>1. animal traction</td>
</tr>
<tr>
<td><strong>semiarid residue</strong></td>
<td></td>
<td>1. meat</td>
<td>smallholder, some argument for larger-scale finishing</td>
<td>1. feed quantity management</td>
<td>1. crop, 2. manures, 3. fertilizers, 4. economics of by-product use, 5. forage for quality in second season with residual moisture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. traction</td>
<td>argument for larger-scale finishing</td>
<td>2. feed quality</td>
<td></td>
</tr>
<tr>
<td><strong>mechanized highlands</strong></td>
<td></td>
<td>1. milk</td>
<td>smallholder, some argument for larger-scale finishing</td>
<td>1. feed quantity, 2. feed quality</td>
<td>1. fertilizers, 2. manures, 3. crop residue management, 4. forage on marginal land for quality, including double cropping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. traction</td>
<td>argument for larger-scale finishing</td>
<td>2. feed quality</td>
<td></td>
</tr>
<tr>
<td><strong>unmechanized highlands</strong></td>
<td></td>
<td>1. milk/meat</td>
<td>smallholder, some argument for larger-scale finishing</td>
<td>1. feed quantity, 2. feed quality</td>
<td>1. fertilizers, 2. manures, 3. crop residue management, 4. forage on marginal land for quality, including double cropping</td>
</tr>
</tbody>
</table>
### Table 4: Research priorities by theme

<table>
<thead>
<tr>
<th>Research themes</th>
<th>animal traction</th>
<th>soil fertility</th>
<th>feed resources</th>
<th>fattening</th>
</tr>
</thead>
<tbody>
<tr>
<td>humid/subhumid, high</td>
<td>none</td>
<td>1. chemical</td>
<td>1. quality</td>
<td>1. smallstock; health interactions important</td>
</tr>
<tr>
<td>tryps</td>
<td></td>
<td>with some soil fertility contribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>subhumid, low tryps</td>
<td>constraints</td>
<td>1. chemical</td>
<td>1. extensive</td>
<td>1. by-products</td>
</tr>
<tr>
<td></td>
<td>to introduction; association with smallholder fattening</td>
<td></td>
<td>forage legumes</td>
<td>2. forage</td>
</tr>
<tr>
<td>semiarid</td>
<td>reducing feed burden; shorten work period to coincide with natural growth</td>
<td>1. chemical+</td>
<td>2. manuring+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>substitutes for animal traction or other means to reduce feed burden</td>
<td>2. manuring+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mechanized highlands</td>
<td>fertilizers</td>
<td>1. residues++</td>
<td>2. chemical++</td>
<td>milk where</td>
</tr>
<tr>
<td></td>
<td>or manures</td>
<td>3. manuring++</td>
<td></td>
<td>feed burden of draft animals</td>
</tr>
<tr>
<td></td>
<td>depending on economic relations</td>
<td></td>
<td></td>
<td>not too great</td>
</tr>
<tr>
<td>unmechanized highlands</td>
<td>none</td>
<td>fertilizers</td>
<td>cultivated forage on marginal lands; milk production</td>
<td>probably more efficient</td>
</tr>
<tr>
<td></td>
<td>or manures</td>
<td>depending on economic relations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* if feed burden of draft animals cannot be reduced

++ if feed burden of draft animals can be reduced

In the semiarid tropics with 500 mm of annual rainfall, stocking rates are limited by dry season feed at low population densities; the lowest monthly stocking rate is set by the amount of feed in the dry season. As population densities rise, the limiting stocking rate is still
the dry season minimum until population densities rise to 100 persons/sq km, at which point the limiting rate is the cropping season minimum. The pattern is not markedly different with annual rainfall of 1,000 mm.

Expressing the same conclusion from another vantage point, the model was used to examine the relationship between population density, rainfall and base grain yield. Higher base grain yields reduce crop-livestock land conflicts because they allow less land to be cultivated at a given population density. At a base grain yield of 0.25 mt/ha, population density does not affect feasible stocking rates until it reaches 60 persons/sq km; at a base grain yield of 0.5 mt/ha population density has a linear effect on the feasible stocking rate but the latter is always much higher than it would be at the lower base grain yield.

Crop-livestock interactions are technically inefficient but economically efficient. Interactions, especially in the use of manures and crop residues, are technically inefficient in that maximum physical products are never attained. Many experiments have demonstrated that it is possible to manage manures, crop residues and other by-products so as to obtain higher yields from them. In farmers' practices, such yields are not achieved because it would be economically inefficient to do so.

Many technical proposals are rejected by farmers because they are economically inefficient. One is integrating animals directly on the farm. Animal ownership, as a source of manure and power, has too often been confused with management of animals by their owners. Many systems have evolved in which animals are consigned to herders. Absentee ownership does not deprive owners of the benefits of their investments but does relieve them of some of the labor burden of managing them. Critics have also failed to understand the advantages of extensive grazing over intensive animal production, of hand-tool cultivation over mechanization and of extensive soil fertility restoration via fallowing and animal paddocking over intensive restoration with manure production and crop residue incorporation. The basic economic reason for the gap between technical and economic efficiency is that high bulk, low value materials, such as manures, crop residues, and agricultural by-products, do not repay labor intensive management except in densely populated farming systems.

The Transitions to Mixed Farming and to Specialized Production

We hypothesized that mixed farming would replace separate crop and animal production (the first transition). Specialized animal and crop production would later replace mixed farming (the second transition) as markets developed and as consumers paid a premium for quality. These Propositions have received little attention in the literature yet were essential to evaluate both research and development projects proposing intensive or specialized production techniques.

The principal conclusion is that there is little intensive mixed farming outside the East African and Malagache highlands. More extensive mixed farming exists elsewhere, mainly in the West African semiarid tropics, but is not general. The principal barriers to the transition from segregated crop and livestock production to mixed farming have been two,
one affecting overall animal management and one affecting the genesis of animal traction.

If population density is low, extensive grazing is the optimal stocking system and makes crop-livestock integration unnecessary. Low population density affects livestock production indirectly by making pastures and fallows abundant. This implies extensive grazing as the basis of animal production, which in turn involves little demand for labor-intensive feed and housing practices. Extensive grazing further reduces manure use, especially with labor-intensive techniques, and makes it less necessary to keep animals on the farm.

The numerous barriers to the development of animal traction make it difficult, if not impossible, to use traction as the centerpiece for promoting crop-livestock integration. This argument is best made by examining how various environments influence whether animal traction can develop. The first, found all over Africa, is that in which hand cultivation has a cost advantage so that animal traction is economically inefficient. Because animal traction fails in such zones, associating other elements of crop-livestock interactions with animal traction will also fail and may even prevent the extension of otherwise profitable technologies.

Next are zones where animal traction might have a cost advantage but where its development has been stifled by other characteristics of the environment. These zones are the West African subhumid tropics, where animal disease has been the constraint, and the unmechanized highlands, where small hilly farms impede animal traction. Attempts to introduce animal traction in those environments will fail in most instances. Therefore, the effort to tie animal traction to other elements of crop-livestock integration will make the process of introducing those elements unnecessarily slow and expensive.

If the cost conditions for animal traction are met, and if secondary constraints such as disease and topography can be overcome, there are still barriers to animal traction. In such environments, wealthier farmers will usually have begun to cultivate with animals but poorer ones will be unable to do so for lack of capital. Farmers who cannot invest directly in animal traction may be able to use it through a rental market and such markets should be evaluated before recommending any credit purchase scheme.

There is little specialization in crop or livestock production and, if it exists, it is usually incomplete. In such cash crop areas as southern Mali (cotton), central Senegal (groundnut), or highland Rwanda (coffee), few farms rely completely on the cash crop and buy all their food. The principal barrier to the second transition is uncertainty in market food supply, which increases the risks of specialization in cash production. Associated with this are high transport costs, which raise benefits in self sufficiency and lower those in specialization.

A second barrier has been rapid growth in urban labor markets, which raises the opportunity cost of farm labor and lowers the profitability of labor-intensive techniques. If such growth deprives farms
of male labor and obliges women to provide the family food supply, then incentives for market-oriented specialization are reduced further because of the demands on women for domestic work.

A third barrier has been that alternate suppliers of markets paying quality premia have been cheaper than domestic suppliers. Those markets, urban and expatriate ones within Africa, and export ones abroad, have been, in the former case, well served by imports and subsidized government ranches, and, in the latter case, by international competitors.

Specialization is assymetrical favoring crops rather than animals. Specialization in crop production has rarely been matched by specialization in animal production, with the major exception of dairying in Kenya. Specialization in animal production outside the pastoral areas does not occur because farmers find it cheaper to produce their own food and to use the by-products as inputs into an animal production enterprise. Producing only animal products without a crop enterprise to absorb it implies wasting the manure, or selling it, which is not usually an option.

Complete specialization exists almost exclusively among subclasses of producers. The latter are usually those, such as the elderly, with no responsibility for the family food supply who can invest in small scale specialized production.

A specific barrier to the second transition occurs in highland mixed farms. The complexity of the agricultural environment in some mixed farming areas discourages specialization because many different activities are profitable. Those areas (parts of Kenya, Rwanda, Burundi, Zaire, the Cameroon and Madagascar) have long growing seasons, generally good soils and varied topography. Such heterogeneity provides high rates of return to many activities in the farming system and discourages specialization.

Project Priorities by Agroclimate

Introduction

The project recommendations in this section are organized by commodity, scale, inputs and collateral technologies (see Table 3). The section is organized around the livestock components of projects; summarizing by crops would have required too much detail and would have obscured the essentials of crop-livestock interactions. As a preface, one remark is made about specialization's role in project design.

Specialization is inefficient because of product market failures and high transport costs and should not be encouraged as a project basis. While market and transport costs will decline in the long run, some high-bulk low-value materials, especially manures and crop residues, will always be more valuable on the farm than in markets. As long as there is a large difference between farm and market costs, farmers have an incentive to use them and to maintain an animal component in crop production. It is this cost difference between produced and market inputs which produces imperfect specialization and obliges farmers to remain mixed farmers.
Humid Zones

In the tsetse infested humid zones, project emphasis should be on trypanotolerant small ruminants or cattle for smallholders. The short-run commodity priority is meat because of the difficulties of improving milk production. The latter include biological factors such as heat stress in lactating cows, the low milk yields of trypanotolerant stock and economic factors such as cheap imports to coastal markets.

Scale. Such projects should not be associated with state or other large scale enterprises. Because the humid zones are distant from breeding areas and from transhumance routes, they have no natural cost advantage for stratification. Large enterprises would have no advantage in breeding costs because artificial insemination and importation of breeding stock is unnecessary once trypanotolerant stock are established. Not having these advantages means that they could not produce at lower cost than peasant metayeurs in the same environment unless they had greatly superior pasture management, which has not usually been the case.

A successful example is the introduction of Baoule cattle into the Central African Republic. While this is the only well documented example of which we know, it suggests that inexperience with cattle among farmers is not an obstacle to a successful project. This example shows the importance of veterinary services which are, in fact, the main component of project scale; if those services cannot be supplied in this agroclimate, there is some doubt if anything at all should be done in animal production.

Inputs. The main input will be veterinary services. Because crop residues and natural pastures are now partly wasted, extensive animal production would not soon face a feed quantity constraint and it should be possible to raise the stocking rate if animal health can be improved. Although there is a feed quality constraint -- because of the lack of agricultural by-products or sown legumes --, releasing it would probably not provide a high return because of the high cost of quality feeds, the low feed/LW response of trypanotolerant animals and the low potential of intensive milk production.

Collateral Techniques. Projects in the humid zone should not be tied to the use of collateral technologies. Because the values of animal traction and animal manures are low, projects should not force an association between animal production per se and animal inputs to crop production. Where labor constraints are a problem, then attempts at mechanization should first be directed toward non-field operations. Where soil fertility is a problem, especially in areas with high population density, then it should be resolved with continuous mulching techniques (like multi-story cropping) and chemical fertilizers.

Subhumid Zones

In the humid and subhumid zones with no major trypanosomiasis threat, the primary emphasis should be on feed quality with secondary emphasis on other diseases. The essential differences from the humid zones with a major trypanosomiasis threat are that the stocking rate has begun to grow and there is potential for quality animal production because of lower
disease pressure. The basis of animal production is established and the marginal return to feed and health improvement may therefore be much higher.

**Scale.** The conclusion about enterprise scale differs from that in the humid zones with greater animal disease because the subhumid zones have access to natural breeding grounds for feeder stock. If permanent animal reduction is impossible because of disease, large-scale feed lots, with intensive veterinary care, are appropriate because the costs of spreading adequate veterinary care over a large understocked area are too high.

**Inputs.** Appropriate inputs depend on the disease challenge. Where the challenge is strong, the situation is similar to that in the humid zone. Where the challenge is weak, feed quality should be the input emphasized.

**Collateral Techniques.** The association between animal production technologies and collateral technologies is more complicated in this zone. Where it is possible to have permanent animal production -- including among the conditions competent local veterinary services --, the association between animal production and mixed farming should be encouraged. If permanent animal production is possible, there is no reason why stratification principles cannot be applied for smallholder fattening projects. Intensive techniques will probably be unsuccessful, however; projects cannot hope to introduce intensive techniques of manure and crop residue use in sparsely populated areas where animal production is nascent and where veterinary standards are exigent. Where permanent animal production is not possible, the association between animal production and collateral technologies should be avoided.

**Semiarid Zones**

In the semiarid zones, emphasis should be on soil fertility, on feed quality, on the capacity to control epizootics and on improving efficiency in collateral technologies. As in the subhumid zones with weaker disease challenge, animal capital is well established and it is possible to develop higher quality animal production. Unlike those zones, the transition to mixed farming is well advanced and further gains are possible from greater technical and allocative efficiency in resource use.

Where the transition to mixed farming is advanced, the principal uses of feed will be animal traction and meat because the genetic and marketing potential of milk production is so limited. Given the low population density, small urban populations and low incomes of the semiarid tropics, milk production should not be a priority unless world milk prices rise dramatically. Even then the technical constraints to milk production will be great. Meat and animal traction should be the commodity priorities.

**Collateral Techniques.** In this zone the principal constraint to animal production will always be primary production, in which improvements have been difficult to attain. The inherent difficulties of raising productivity are compounded by those of incorporating forage into semiarid smallholder systems. Therefore, an appropriate project sequence for feed
quality is to exploit by-products (including crop residues), for which response and extension have been proven, while maintaining a long-term effort to improve primary production.

While meat is the most profitable current use of feed, the long run growth of the semiarid systems requires animal traction, which carries a feed burden. In the short run, therefore, projects and associated research components should concentrate on defining the more efficient uses of available feeds for fattening or traction. In the long run, projects and research will have to work on reducing competition between crops and animals for crop residues, by-products and introduced feeds.

Because of the basic soil fertility problem in this zone, and because of the rising conflict between crop and animal production, the use of animal manures is critical. However, the research review has shown that manure is probably insufficient in quantity to maintain soil fertility without chemical fertilizers. The field visits have shown that intensive manuring is almost never done and so dramatic quality improvements cannot be foreseen. Therefore, no matter what projects are able to achieve in manure efficiency or in the efficiency of crop residue use, major importance has to be placed on chemical fertilizers in semiarid projects.

Highland Zones

In the mechanized highlands, emphasis should be on reducing the conflict between animal traction and milk production, improving soil fertility and improving efficiency in collateral technologies. It is realistic to consider improved milk production here because its genetic and marketing potential is better. However, its potential is unlikely to be realized without reduced competition for feed between milk and draft animals. Therefore, projects and associated research have to strike an appropriate balance between breed upgrading in cows, changes in species (e.g., to milk goats), and feed technologies in view of existing and induced feed competition.

Because the moisture constraint to crop production and to fertilizer response is less acute than in the semiarid tropics, fertilizer supply has to be the basis of improved soil fertility. This is all the more true in view of the fact that crop residues are essential for draft animal feed and cannot be diverted to soil restitution.

Collateral Techniques. Because feed competition is a serious constraint to animal production, and indirectly to crop production, it follows that technical efficiency in collateral technologies is an important avenue of improvement. Projects should therefore concentrate on other means of reducing the feed burden of draft animals so as to release feeds for other uses such as milk production or soil restitution. Such means would include more efficient tools and mechanization with engines.

In the unmechanized highlands, emphasis should be on soil fertility, on intensive animal animal production and on improving efficiency in collateral technologies. Because the potential of animal traction is so limited, there is no feed conflict between draft and other
animal products. Therefore, the commodity priority, meat or milk, can be chosen simply on the basis of the greater return per unit of feed.

Attempts by these farming systems to reduce labor input through cropping pattern shifts toward permanent crops have acted like mechanization in reducing labor input per unit of output but without conflicting with other feed uses. However, cropping patterns dominated by bananas and cassava cause feed conflicts because they produce small quantities of crop residues.

Conclusions and Research Priorities By Theme

Animal traction

One must distinguish between introducing animal power where it is unknown and improving it where it is known. Research is relatively powerless to foster introduction because the latter depends on the secular evolution of the farming system. Two countries with well developed animal traction -- Ethiopia and Madagascar -- have had almost no research. Two countries with growing animal traction, and some research on the problems associated with it -- Senegal and Nigeria --, have seen little connection between research themes and successful extension.

Conclusions. Animal nutrition is not a major constraint to the introduction of animal traction. Mechanization has occurred without improved feeding of draft animals. Many farmers selectively feed other stock at the expense of draft animals and few farmers adopt improved feeding of draft animals where they are not already a major share of the animal biomass. The reason is that feed is more efficient in milk production or in fattening until the farming system has evolved to the point where mechanization is profitable. At that point, feeding for power competes with feeding for milk or for meat.

Nutrition limits animal production, but not necessarily animal traction, where maintenance of draft animals is costly because feeding for draft conflicts with feeding for milk and meat. Where draft animals are general (the Ethiopian and Madagascar highlands, parts of West Africa, Kenya and Zimbabwe), the feed allocated to them obviously cannot be used for fattening or for milk.

Supplementary feeding of draft animals is likely to fail because of competition from other uses of feeds. Although there is paucity of experiments on how draft animals respond to nutrition x work interactions, their feed response would appear to be less profitable than that of other animals. This is certainly true of draft animal power compared to milk production and is probably true compared to fattening.

Rental markets are resilient. One reason for the failure of new animal traction technologies in Ethiopia is that rental markets enable farmers to acquire power at costs lower than those of the new technologies. These markets exist almost everywhere there is animal traction and are an efficient way of reducing total animal traction costs.
Recommendations. The nutrition of draft animals has been poorly studied and further experiments ought to be carefully reconsidered. Supplementary feeding of draft animals has been mistakenly viewed as a necessary condition for mechanization with animals. This viewpoint is arguable because there are many areas with draft animals where supplementation is given to other animals but not to draft; and there are many sites where traction is common without supplementation of working animals.

The subject has been neglected as a research topic compared to animal health. Knowledge of the extent to which working animal nutrition affects performance is ambiguous. Experiments in Ethiopia have shown little feed intake response to work stress, confirming the point that nutrition is not crucial for the improvement of draft power.

It is logical, but probably incorrect, to assume that forage research is an appropriate theme in developing animal traction. Any further research of this type has to be redesigned to study feed competition between work and other animal products. It is necessary to recall the farming systems where animal traction is common: highland East Africa with cereals as the staple and the semiarid tropics. In the highlands, small farm sizes oblige any new crop to compete for land or it will not be adopted. Land competition restricts forage introduction because farmers are unwilling to use land for forage which could be used for food unless forage is for milk production. In the semiarid tropics, biomass production is low, inducing farmers to produce extensively and obliging any new crop to compete for labor. Labor competition restricts forage introduction because farmers will not use labor to grow forage for low-productivity animals. This resource competition between forage and other crops does not favor its use for draft animals.

Study is needed of methods other than forage crops that can reduce the feed burden of draft animals in high population density areas. If there is a constraint to working capacity, then it might be more profitable to study means other than nutrition. Such means -- rental markets, cow traction, reducing the number of oxen in the span, mechanization with engines, new tools -- could contribute to reducing the feed and capital burdens of animal traction. Even if the marginal return to feeding draft animals is less than that to feeding dairy or meat animals, it may be possible to get that return not with feed but with lighter tools requiring less work. One should not be too optimistic about this avenue. Except for mechanization with engines, we found only one important example in Africa, or in other parts of the developing world where major changes in draft animal management have developed indigenously, and that is cow traction.

Reducing the feed burden of draft animals might have to await exogenous economic changes which encourage mechanization with engines. If wages rise, then it is efficient to replace animals and labor with machines, thus leaving more feed for other stock. Therefore, analyses of tractor mechanization should always include analysis of the benefits of diverting feed from draft animals to other animal products. The benefits are probably highest in highland areas using animal traction and lowest in the semiarid tropics using animal traction.
Soil Fertility

Conclusions. Extensive animal manuring techniques are common and dominate intensive ones except in the East African highlands. The principal manuring techniques are paddocking cattle and throwing unimproved corral dust into fields adjacent to households. Improving manure by mixing it with litter or incorporating it into the soil is rare. Field visits and the literature review showed almost no adoption of intensive manuring techniques except in the densely populated highland countries of East Africa, especially Kenya, Rwanda, and Burundi. Many experiments have verified the benefits of intensive manuring but their labor costs are too high to justify them in most agroclimates.

There is little labor-intensive green manuring and no green manuring with legumes. Examples of intensive green manuring were found only where it is obligatory, such as mulching coffee in Rwanda and Burundi. The main instance of mulching is in multi-story cropping systems in the humid tropics (e.g., eastern Nigeria), but these use little labor. There were rare examples of forage grasses being used for erosion control. The reasons are the excessive labor costs of mulching and the weak crop responses to mulches.

The hypothesis that a fall in the price of chemical fertilizer relative to the price of labor reduces interactions was rejected. Chemical fertilizers were associated with increased interactions in manure use and mechanization, especially with animals. This hypothesis is related to the lack of specialized production; in essence, failures in product markets, especially for food, have made it unprofitable to specialize in cash production.

Competition between crops and animals for crop residues has been seriously misinterpreted, especially in areas with little animal traction. Some experiments suggest that it is better for the long-term sustainability of the farming system to recycle crop residues into the soil and not to feed them to animals. Field visits and the literature review showed, however, that soil recycling of crop residues is almost never done, even where mechanization is common. Where it is done (e.g., western Madagascar), only the stubble is incorporated and most of the straw is fed. The field evidence does not mean that the experiments were wrong in any technical sense but it does imply that they were economically inappropriate.

The current allocation of crop residues to animals is due to the labor intensity of incorporation. The long-term response to incorporation is also a disincentive compared to the immediate benefits of feeding residues to animals. In areas of animal traction, crop residues are a large share of feed intake and their opportunity cost as soil amendments is too high because of the necessity of maintaining draft animals.

Animal manures alone cannot maintain long term soil fertility. Without fallows, manuring can maintain soil fertility only on farms which are too small to be viable. In economic terms, sufficient manure could only be produced at stocking rates so high that they would conflict with crop production via land competition. Improving manure by storage or other
techniques is labor intensive and is economically inefficient compared to fertilizer use.

**Recommendations.** Any experiments with manures or mulches must be designed with realistic nutrient levels, must be amenable to economic analysis and should have labor input as one of the variables to be measured. Failure to adopt apparently profitable manuring techniques suggests that there has been serious bias in the experiments on which those techniques are based.

That fertilizer use is not more widespread in the face of experimental and field evidence suggests a supply constraint to its diffusion that requires specific analysis of fertilizer distribution policies. In contrast to intensive manuring, which has evolved slowly, there are many instances of rapid fertilizer adoption, but low general use of fertilizers. Rapid adoption has occurred in projects, or at other sites with special access to fertilizers, but has not occurred generally.

**Feed Resources and Animal Fattening**

Sown forage has largely failed except where it is used for milk production with crossbred animals. Forage failed because it was incompatible with African farming systems. The literature review and field visits found 'classic' cultivated forage only in association with highland milk production (Kenya) or with dirigiste erosion control programs (Rwanda, Burundi). Too much effort has been put into refining agronomic recommendations for forage, which has little prospect of adoption under any circumstances.

The most successful sown types of forage are intercrops and crop residues. Mixed cropping with grain legumes is successful because the secondary crop does not conflict with the primary. It is successful with Acacia trees for that reason and because the trees come into leaf in the dry season when forage is scarcest.

Enclosing natural pastures, oversowing pastures and grazing in rotation, apart from on heavily subsidized state farms or ranches, have failed almost totally in spite of major research efforts, especially in East Africa. There has been no adoption of introduced forage in the semiarid areas and very little in the subhumid and humid areas. That forage which has been adopted has been usually native grasses, with rare adoption of introduced plants. Unimproved native pastures, crop residues and browse are still the major feeds for the vast majority of African livestock.

Agro-industrial by-products have often succeeded, many times with little research or extension input. They offer advantages, especially low transport costs and little competition for land and labor on the farm, which sown forage does not.

**Recommendations.** Our reasoning about forage crops suggests that feed research has sometimes been misguided and should concentrate more on crop residues and agricultural by-products.
Improvement of crop residues and native grasses by treatment is a promising technology in areas with animal traction because it does not compete for land as do forage crops. Among the treatments, silage is often unsuccessful because tropical grasses are fibrous but treatment with urea may be profitable and has been adopted (e.g., northern Nigeria). If such techniques are intended for feeding draft animals, however, they still confront the obstacle of better response in milk or meat production.

Common Properties and Land Rights

Research in this area was organized around a few main themes: pasture degradation, traditional regulations to limit degradation, and the effects of government policies.

As cultivation expands, do common pastures become concentrated on marginal lands susceptible to degradation? To answer this question, it is necessary to distinguish between marginal lands within an environment -- for example, erodible slopes -- and marginal lands between environments -- for example, the Sahel compared to the highlands. Common pastures occupy both types of marginal lands because they have low inherent productivity in crop production.

Within environments, the expansion of cultivation is accompanied by an increase in the stocking rate. In all areas, this is because of the increased use of crop residues as feed; in areas freed from tsetse, it is also because of the reduction in animal disease. Therefore, expansion of cultivation in areas favorable for crop production has probably reduced pressure on marginal lands.

Within environments, the concentration of grazing on marginal lands is seasonal. Because such lands are not good for cultivation, they are most productive as pastures in the wet season and are ignored in the dry season. Dry season grazing has to concentrate on the best lands because that is where feed is most abundant.

Between environments, the expansion of cultivation occurs on marginal lands. This can be seen in the movement northward in the Sahel and in the movement downward from the highlands of Kenya and Ethiopia.

Between environments, the long-term growth of animal product demand, especially in West Africa, has encouraged degradation of marginal lands. This is probably more important than degradation caused by expansion of cultivation because it is a pure demand effect with no consequences for feed supply.

Do societies regulate access to marginal lands and thereby prevent degradation?

Field visits and the literature review reveal that the main pastoral societies of West Africa controlled resource access but did not prevent resource degradation because they did not control the rate of resource exploitation. While some of the failure of those institutions was due to colonial intervention, which disrupted traditional authority, much of it was due to population growth and to the exogenous growth of demand.
for animal products. It is also true that traditional control did not regulate the overall rate of resource use but regulated the access of outside groups.

Do current policies stop degradation and are there practices societies could adopt to prevent degradation in the face of rapid population growth?

Policies to stop land degradation have failed. These policies focus necessarily on marginal areas of low potential and of low population density and are therefore costly to implement. The best policies have been in the East African highlands, where erosion control has been at least partly successful, in high population density areas of good potential. An unsuccessful case is that of the 'limite nord des cultures' in Niger, an attempt by the colonial and national governments to reserve land north of the 350 mm rainfall isohyet for grazing. Cultivation extends well above this line and has contributed to land degradation.

The allocation of land between cultivators and herders had received attention from anthropologists but little from economists interested in government policies and technical change. The main question was: How do technical changes in crop and in animal production affect the distribution of herds and of land rights?

Policies to protect herders' land rights have been unsuccessful. Herders' rights have not always been affected by technical changes. Examples include the highland areas, from which pure herders have disappeared (e.g., milk production in Kenya), or pastoral areas (e.g., water development in the West African Sahel) where cultivation is marginal and the potential for conflict is reduced. The principal conflicts have occurred at irrigated sites in West Africa. Many such sites are on rivers vital for dry-season grazing. Irrigation has damaged herders' access to water, crop residues and pastures.

How does security of tenure affect incentives to adopt new production technologies?

Tenure has had little effect on adoption of improved techniques. One reason is that such techniques are not well developed for forage production and do not exist at all for the pastoral areas with the possible exceptions of water development and bush clearing. A second is that the principal improved technology is in animal health which is 'tenureless'.

Security of tenure is too often confused with privatization in its effects on economic efficiency. Security of tenure, if it is viewed purely as privatization, is not really relevant. Common forage properties (pastures, browse, crop residues) are common because they are cheap and because no one has an interest in improving them. They exist in animal production systems where mobility is crucial; it is therefore necessary that they remain common because to privatize them would restrict mobility.

Many contracts exist which allow economic efficiency without privatization of cheap resources. Such contracts, including social
relations of reciprocal and mutual aid, are necessary to the survival of extensive animal production in marginal environments.

Where technical or other changes (e.g., urbanization) reduce the benefits from mobility or raise the benefits from common resources, privatization occurs rapidly. We saw this many times with crop residues, which were privatized -- in the sense of asserting exclusive rights to them -- when they became valuable. This occurred at all field sites with animal traction because crop residues are valuable in feeding draft animals.

How do herders acquire access to crop land and how do they maintain access under population pressure?

As long as land is not traded in markets, the land rights of sedentarizing herders are maintained. There are many instances of explicit recognition of long term usufruct (e.g., the Dallol Basso in Niger and the Niger Delta in Mali) in return for token payments. Groups receiving usufruct have no commercial rights and face 'expropriation' as population pressure grows unless they control local politics or parts of the modern state.

The role of the state is probably less important than that of local politics. Most African countries have declared all agricultural land to be the property of the state but, in practice, tenure is more often governed by local custom. In Niger, where the local political power of sedentarizing Fulani is strong, they will probably maintain their land rights. At one densely populated site in the subhumid zone of Nigeria, the political power of long-sedentarized Fulani is weak and their land and grazing rights are tenuous.

Credit, Investment and Income Distribution

We found few instances where land serves as collateral, regardless of the conditions of population density and market access. Examples were in densely populated, highly commercial, eastern Nigeria, where there is a complex system of land pledging, and in highland Kenya, where there is an active land market. The collateral function of land is hampered by restrictions on its alienation. Noronha's 1985 review of African tenure found many sales but few cases of land as loan security. Because the most valuable land is usually rationed, and its private sale restricted or even banned, its collateral function is limited and may not exist at all. In addition, because of restrictions on land holding, it is not necessarily a vehicle for re-investment. No such restrictions exist for animals, and would be impossible to enforce if they did, so animals are superior investments.

Does lack of credit impair investment where animal production has a comparative advantage? What means substitute for credit to finance investment?

2/ However, our field sample was biased because it did not include major areas of commercial tree crop production such as the forest zones of Ghana and Cote d' Ivoire.
In dry zones where animal production has a comparative advantage, credit markets are weak because of the high covariance between the supply of and demand for funds and because there is little demand for credit to finance new technology. Credit is not widely used in such areas, except to finance trade within extended family networks, and is especially rare in financing agricultural investment. While it is obvious that credit provision would improve investment, it is less apparent that subsidized credit can be repaid, as project reviews have shown.

Many credit substitutes exist. One credit substitute, animal borrowing, was identified everywhere. Two others, entrustment and payments in animals for herding labor, were found only in dry zones. These substitutes involve a rich variety of contracts to enforce the performance of the borrower, to maintain long term relations between the lender and the borrower, and to encourage competition among lenders.

If credit constrains animal investments, one solution is to substitute investments requiring a smaller outlay or having a shorter payoff period. Examples are small ruminants for cattle in fattening programs, dairy goats for dairy cattle, pigs and poultry for ruminants.

Integration between crop and animal production has no necessary relation to animal investments. The best examples are the unmechanized parts of the highlands and of the semiarid tropics. In those zones, animals constitute the largest share of farm investment and yet are not always well integrated into farm production; those zones have no animal traction, manure use is low in the semiarid tropics, and crop residues are sometimes not fed in the unmechanized highlands.

As with credit substitutes, many contracts exist to reduce the transactions costs of investments between the crop and animal sectors without crop-livestock integration. The principal contract is animal entrustment, which allows absentee owners to invest in animal production. No analogous contract exists to allow absentee herders to invest in crop production, but this is not a market failure. It is simply a reflection of the asymmetrical labor intensity of crop and animal production.

The Pastoral Areas

Beyond the control of epizootic disease, little technology has been developed for the pastoral areas. Recommendations for pasture improvement, management changes and breed improvement have generally failed. Exceptions are water development, irrigated crop production (for forage and other crops) and stratification as a management tool. Some irrigated crops clearly benefit pastoralists by giving them dry season fodder or by providing them with land for crop production. Some irrigation harms pastoralists if it deprives them of dry season grazing and water.

Stratification of cattle development, based partly on feed lots, is consistent with transhumance. Transhumance is efficient in spreading the risks of variable pasture and water supplies, in exploiting common resources and in raising young animals quickly on cheap range. Transhumance is inefficient in sustaining the rapid growth of immature animals because it has no access to high quality feeds or to associated...
services (health, housing, marketing) necessary to make intensive feeding profitable. The argument for stratification is that it would maintain the advantages of transhumance while overcoming the inability of transhumant producers to achieve rapid weight gains through intensive fattening.

The failure of stratification is not necessarily a failure of technology. Feed lots and smallholder fattening reinforce the advantage of pastoral systems by allowing use of low cost pastures during the growing season and by supplying feed, independent of pasture supply, during the dry season. Unsuccessful feed lots discredited stratification throughout Africa and their failure impelled interest in other pastoral strategies.

Much of the failure of feed lots is due to government price policies, which depress prices to public and private operators. There is indigenous stratification throughout West Africa based on the main advantage of feed lots -- a dry season feed source which compensates for pasture deficiency yet does not interfere with other sources of dry season feed such as river beds and other low-lying areas. Such 'indigenous stratification', based on crop residues and agricultural by-products, has succeeded in many projects because it operates on the same principles but is not hampered by excessive scale and restrictive price policies.
FORAGE LEGUME INTERVENTIONS
FOR WEST AFRICAN SUBHUMID ZONE CROP-LIVESTOCK SYSTEMS

R. von Kaufmann

INTRODUCTION

The subhumid zone forms a relatively lightly populated belt that occupies 21 percent of Africa. It receives 900 to 1500 mm of annual precipitation giving 170 to 280 growing days per annum. Those are exciting statistics in a continent more commonly characterized as drought prone and unable to produce enough food, but until recently the research and development community has not shown commensurate interest. It was believed that tsetse borne human and animal trypanosomiasis prohibited occupation of much of the zone.

There is growing evidence that, although farmers and herders formerly avoided the zone because of the poverty of the soils, they are increasingly settling in the zone due to increasing pressure in the other zones. An aerial survey has revealed that there are about 3.2 million cattle permanently resident in the zone (Bourne and Milligan, 1983) as opposed to the conventional figure of two million transhumant cattle (Jahnke, 1982).

The soils are classified as poor by almost all relevant criteria. They are dense and short of organic matter with consequent poor cation exchange capacity. They typically have an impervious lower layer which restricts water penetration and creates a perched water table. This forces farmers to plant their crops on ridges to avoid water logging. The soil surface is prone to capping. This makes it difficult to work before the rains set in. The surface layer is shallow and prone to erosion. When the fields are bare after harvest, they suffer from deleterious high surface temperatures.

The consequences of the poor soils are that crop yields are low per hectare and, even worse, low per unit of labor. The range vegetation has adequate nutritional quality for productive ruminants for only about three months of the year (Figure 1). This is an important difference with the semiarid zones where it can be assumed that if there is any grass the livestock will be alright. In the subhumid zone it is possible for animals to suffer nutritional distress even when there is abundant biomass. Supplementary feeding with high protein feeds is essential to raise the productivity of cattle in the zone. Since there is insufficient feedstuff on the market, ILCA initiated research on the introduction of forage legumes.

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FIGURE 1

Crude Protein content of grasses related to mean monthly rainfall.

- **rainfall**
- **% CP of grass**

- **Dry**
- **E.wet**
- **P.wet**
- **L.wet**
CONSTRAINTS TO INTRODUCING FORAGE LEGUMES

Most of the cattle in the subhumid zone of Nigeria are owned by sedentarising agro-pastoralists who were, therefore, chosen as the primary target group for ILCA's research aimed at improving the welfare of livestock producers in the zone (Kaufmann et al, 1986). Research revealed numerous constraints to the introduction of forage legumes into the crop-livestock systems associated with agro-pastoralism in all factors of production.

The land on which the vast majority of sedentarising agro-pastoralist live and graze their stock belongs to resident communities of cultivators who regard the agro-pastoralist at best as permanent guests but never as indigenous with inherent rights to land. Any proposed forage intervention will, therefore, have to accord with the cultivators' customary land tenure practices in both mode and scale. It will also have to be of some benefit to the landowner.

The agro-pastoralists are subsistence farmers and will, therefore, tend to devote any spare labor to cropping rather than livestock husbandry. Thus, adoptable interventions will have to require only minimal labor input.

The agro-pastoralists have considerable realizable reserves of capital in their livestock. However, in a situation of open access to grazing areas that are as yet lightly stocked, increased stock numbers are an attractive investment made more so by high inflation. It is improbable that herd owners can be persuaded to invest heavily in untried interventions in such circumstances. Any interventions will have to be relatively cheap.

The agro-pastoralists obviously know much about livestock husbandry and growing food crops. They are also well aware of the value of crop residues for livestock feeding but they have never grown crops specifically for feeding livestock. Potential interventions will have to be relatively simple and independent of machinery.

FORAGE LEGUMES UNDERSOWN OR INTERSOWN WITH CEREAL CROPS

ILCA first attempted to meet the above requirements by undersowing cereal crops with forage legumes. Sorghum was chosen because it was the predominant cereal. *Stylosanthes* spp. was chosen as the forage legume because it was the only one for which sufficient seed was available in Nigeria. The attempt was successful in that the yield of crude protein in the dry matter available after harvest was significantly increased without reducing the cereal yield (Mohamed-Saleem, 1985). However, that was only true if the stylo was planted not less than three weeks after but not more than six weeks after the sorghum (Table 1). This conflicted with other peak labor requirements so ILCA tested other forage legumes to find ones that are less competitive for labor in the early stages but still give reasonable yields of quality dry matter (Table 2).
<table>
<thead>
<tr>
<th>Time of Sowing Stylo</th>
<th>Grain Yield (kg/ha)</th>
<th>Grain Yield Deviation from CO</th>
<th>Fodder Yield</th>
<th>Calculated DCP in Total Fodder (%)</th>
<th>Available Crude Protein (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sole crop (C0)</td>
<td>1226</td>
<td>-</td>
<td>7503</td>
<td>1.09</td>
<td>180</td>
</tr>
<tr>
<td>With crop (C1)</td>
<td>357</td>
<td>-70</td>
<td>1303</td>
<td>5.02</td>
<td>490</td>
</tr>
<tr>
<td>After 3 weeks (C2)</td>
<td>1224</td>
<td></td>
<td>3719</td>
<td>1.78</td>
<td>281</td>
</tr>
<tr>
<td>After 6 weeks (C3)</td>
<td>1287</td>
<td>+5</td>
<td>4260</td>
<td>0.19</td>
<td>179</td>
</tr>
<tr>
<td>After 9 weeks (C4)</td>
<td>1240</td>
<td>+1</td>
<td>3919</td>
<td>0.28</td>
<td>142</td>
</tr>
<tr>
<td>Sole crop (C0)</td>
<td>2192</td>
<td></td>
<td>8796</td>
<td>0.64</td>
<td>255</td>
</tr>
<tr>
<td>With crop (C1)</td>
<td>480</td>
<td>-78</td>
<td>2367</td>
<td>4.66</td>
<td>592</td>
</tr>
<tr>
<td>After 3 weeks (C2)</td>
<td>1550</td>
<td>-29</td>
<td>3524</td>
<td>3.34</td>
<td>493</td>
</tr>
<tr>
<td>After 6 weeks (C3)</td>
<td>1918</td>
<td>-13</td>
<td>5385</td>
<td>1.42</td>
<td>415</td>
</tr>
<tr>
<td>After 9 weeks (C4)</td>
<td>1980</td>
<td>-10</td>
<td>7463</td>
<td>0.01</td>
<td>283</td>
</tr>
</tbody>
</table>

Values in parenthesis indicate actual percentage of CP in the respective fodder.

DCP (Digestible Crude Protein = 0.889 CP - 3.25)

Source: Mohamed-Saleem (1986)
Table 2: Grain and Fodder Yields of Sorghum When Planted Together with Forage Legumes

<table>
<thead>
<tr>
<th>Crop Mixture</th>
<th>Grain Yield</th>
<th>Crop Residue</th>
<th>Legume DM</th>
<th>Total Fodder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole sorghum</td>
<td>1296</td>
<td>4467</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum + S. Hamata</td>
<td>313</td>
<td>1685</td>
<td>2778</td>
<td>4463</td>
</tr>
<tr>
<td>Sorghum + Cook Stylo</td>
<td>388</td>
<td>1555</td>
<td>2063</td>
<td>3618</td>
</tr>
<tr>
<td>Sorghum + M. atropurpureum</td>
<td>356</td>
<td>2111</td>
<td>1296</td>
<td>3407</td>
</tr>
<tr>
<td>Sorghum + C. pascuorum</td>
<td>1019</td>
<td>2981</td>
<td>1204</td>
<td>4185</td>
</tr>
<tr>
<td>Sorghum + A. vaginalis</td>
<td>1092</td>
<td>2519</td>
<td>926</td>
<td>3445</td>
</tr>
<tr>
<td>Sorghum + M. lathyuroides</td>
<td>1297</td>
<td>2741</td>
<td>1481</td>
<td>4222</td>
</tr>
</tbody>
</table>

Source: Mohamed-Saleem (1986)

Encouraged by the IBRD supported Agricultural Development Program, maize is becoming increasingly popular in the zone. This could have very serious consequences for livestock owners who depend on crop residues because by the time the animals can enter the fields, after harvesting is completed in the mixed cropping systems, the maize has virtually no feed value. Fortunately, however, its early maturity makes maize easy to undersow. This characteristic will be increasingly important as maize continues to gain in popularity.

The farmers traditionally use very low plant population rates of about 30,000 plants per hectare. It is possible to capitalize on this by doubling the populations per row and planting *stylosanthes* on alternative rows without lowering crop yields (Figure 2).

Though these techniques gave promising results (Mohamed-Saleem, 1986), they are of little direct use to the herd owners because their fields are too small for them to grow sufficient quantities to make an impact on their herds, which average 50 head. They have also not caught on with the farmers as yet. This is believed to be due to the lack of a market for forage and it is only a matter of time until increasing cultivation and cattle numbers reverse the present situation where the farmers pay the cattle owners to graze their fields to reduce the stubble and deposit manure. In the not too distant future the situation will follow the pattern in more northern areas of Nigeria where the herd owners readily pay for crop residues.
Effect of crop geometry on grain and fodder yields of sorghum – soya bean – stylo mixture.

Yields

<table>
<thead>
<tr>
<th>Grain</th>
<th>1491</th>
<th>1201</th>
<th>1558</th>
<th>1390</th>
<th>1331</th>
</tr>
</thead>
<tbody>
<tr>
<td>sorghum</td>
<td>kg/ha</td>
<td>soya</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6159</td>
<td>5170</td>
<td>5549</td>
<td>5262</td>
<td>4813</td>
<td>1360</td>
</tr>
<tr>
<td>Fodder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sorghum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stylo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: Mohammed Salem (1986)
The above techniques together create a menu of interventions that can be offered to farmers and herd owners when and where the conditions are appropriate. They were developed on farm and are suited to the farmers' conditions and resources (Mohamed-Saleem et al, 1986).

**FORAGE LEGUMES ON FALLOW LAND**

For more immediate application ILCA turned to fallow land. According to the rules of good husbandry about 30 percent of the land should be under fallow at any one time. Coincidentally, that is an area large enough to carry virtually the whole national herd. ILCA developed a technique whereby seed beds can be prepared by trampling by the cattle and fast growing weeds can be controlled by early season grazing. Thus the cattle can be used to cultivate their own supplementary feed (Otsyina et al, 1987). With inputs from the social and animal sciences, it was found that 4 hectare units of stylo 'fodder banks' could be established and they could make a significant contribution to herd nutrition. The effect of access to fodder banks on herd productivity was studied in about 40 herds of which 16 had access to fodder banks. The estimated productivity parameters based on 770 completed lactations are shown in Table 3. The supplemented animals indicated a productivity index (kilograms of calf equivalent produced per 100 kg of dam per annum) gain of 35 percent (Mani et al, in press). This was largely due to an increase in calf survival attributed to increased milk production by their dams. Without assuming any improvement in management or increased culling or offtake rates, it is projected that over 10 years this could lead to a doubling of liveweight and milk offtake from the herd (Figure 3). The productivity index of the supplemented animals still leaves a lot of room for improvement and research is continuing in fodder bank management and additional supplementation with minerals (phosphorous) and molasses/urea.

**Table 3: Effect of Dam Supplementation**

<table>
<thead>
<tr>
<th>Trait</th>
<th>No Supplement</th>
<th>With Supplement</th>
<th>(%) Supplement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow survival (%)</td>
<td>92</td>
<td>96</td>
<td>5</td>
</tr>
<tr>
<td>Calving percentage</td>
<td>54</td>
<td>58</td>
<td>7</td>
</tr>
<tr>
<td>Calf survival (%)</td>
<td>72</td>
<td>86</td>
<td>19</td>
</tr>
<tr>
<td>Calf weight at 1 yr. (kg)</td>
<td>98</td>
<td>103</td>
<td>5</td>
</tr>
<tr>
<td>Lactation yield (kg)</td>
<td>300</td>
<td>313</td>
<td>4</td>
</tr>
<tr>
<td>Productivity Index</td>
<td>51</td>
<td>69</td>
<td>35</td>
</tr>
</tbody>
</table>

Source: Mani et al, 1987
MILK AND LIVEWEIGHT OFFTAKE
WITH AND WITHOUT FODDER BANK INTERVENTION

Source: Hard model projections based on ILCA data
M. Kaufmann & Ore (1988)
Following observation of herd owners use of fodder banks and a better understanding of the differences between the subhumid zone and the semiarid zone, attention is now being given to supplementation in the wet season rather than in the dry season. This involves attempts to put the animals in better condition to weather the dry season and maintain oestrous cyclicity between the present most active periods, namely, during the early rains and during crop residue grazing (Otchere, 1986).

**FORAGE LEGUME BASED CROPPING**

As noted above, if the forage interventions do not benefit the cultivators, it is most unlikely that there will be much uptake even in unused fallow land. In order to encourage the cooperation of the land owning cultivators, ILCA studied the potential contribution of *Stylosanthes* spp. to soil fertility. It has been shown that there are improvements in almost all the characteristics of subhumid soils following two or more years of growing stylo (Table 4). The vigorous root growth reduces the soil density, improves soil moisture penetration and increases the organic matter content (Mohamed-Saleem et al, 1986). If sufficient stubble is left, the soil surface is protected from excessive temperature and the velocity of precipitation is reduced leading to reduced erosion of the precious surface layer (Figure 4).

<table>
<thead>
<tr>
<th>Character</th>
<th>Cropped Soil</th>
<th>Fallow Soil</th>
<th>Hamata Soil 2 yrs</th>
<th>Hamata Soil 3 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Bulk Density (g/cm³)</td>
<td>1.75</td>
<td>1.61</td>
<td>1.54</td>
<td>1.42</td>
</tr>
<tr>
<td>Available Water-Holding Capacity (gm/100gm)</td>
<td>-</td>
<td>7.3</td>
<td>10.6</td>
<td>10.2</td>
</tr>
<tr>
<td>Field Moisture Capacity (gm/100gm)</td>
<td></td>
<td></td>
<td>10.4</td>
<td>-</td>
</tr>
<tr>
<td>Organic Matter Content (%)</td>
<td></td>
<td></td>
<td></td>
<td>18.5</td>
</tr>
<tr>
<td>Values Corrected for Gravel</td>
<td>1.04</td>
<td>1.76</td>
<td>2.72</td>
<td></td>
</tr>
</tbody>
</table>

*Measurements by Dr. P.N. Vine, University of Ibadan*  
*Source: Mohamed-Saleem (1986)*
Total amount of soil collected in slash traps (78 cm rimmed funnels) during one growing season after ridging or vegetative cover cut to ground level.

Source: Mohammed Saleem (1986)
The improvements in the soil lead to increased cereal crop yields as shown for maize in Figure 5 (Tarawali, 1987). Unlike with grass ley rotations, grazed stylo does not make the soil harder to work. There was an overall increase in the labor requirement for crops grown inside fodder banks but that was almost entirely due to the increased harvest, which is a problem farmers will be prepared to live with (Figure 6). This is perhaps the most important finding to date; that forage legumes should be grown in the interest of sustained crop production. If a system of forage legume based cropping is adopted, the livestock will be indirect beneficiaries and an additional source of revenue for the cultivators.

Some farmers who have seen the effect on crop yields have planted stylo in their fields and created mini fodder banks which they are exploiting to supplement their small ruminants in the wet season when grazing is limited by the presence of growing crops. Once established in a field, only a modicum of care is required to ensure that sufficient seed is set for the legume to regenerate under the cereal crop in subsequent years.

It is essential to the maintenance of good stands of legume that the land is cropped periodically in order to reduce the amount of soil nitrogen. This stems the invasion of undesirable nitrophilous grasses and weeds that otherwise cause legume pastures to deteriorate.

RELEVANCE TO THE SUBHUMID ZONE OF WEST AFRICA

With the cooperation of the Land and Water Division of FAO, ILCA is working with the FAO agro-ecological zones model to determine the potential application of its various forage interventions to all parts of the zone (Kassam et al, 1988). Current estimates indicate that stylosanthes based interventions could make significant contributions to agriculture and livestock production in all the countries of West Africa except the Gambia, which is too dry, and Liberia, which is too wet.

Obviously it is not satisfactory to be dependent on one variety or even one species of forage legume so ILCA is working with various national research centers in Nigeria and across West Africa, with the support of GTZ, in an accession testing program involving over 300 different species and varieties. ILCA is currently determining the extent of support for a proposed West African Forage Network that could link NARS and ILCA in future forage research.

CONCLUSION

Interventions suited to small scale traditional livestock and crop husbandry systems have been developed that are potentially beneficial to both cereal cropping and livestock production. The forage legume can be introduced directly in the fields by undersowing or intersowing or into fallow land by using the cattle to prepare seed beds and control fast growing grasses in the early season. The techniques are potentially applicable to at least 8 or 10 West African countries studied and considerable attention is being paid to find alternative forage legumes for security against disease and that suit differing ecological environments.
Grain Yields (maize) inside and outside fodder banks

Source: Tarawali et al. (1987)
Labour input in cropping maize on stylo and non-stylo soils

Source: Tarawali, O., 1985 (unpublished data)

Source: Tarawalt (1987)
REFERENCES


INTRODUCTION

Rural development implies the efficient increase of agricultural productivity for domestic or export markets, or a combination of both. Efficiency in rural development should be measured in terms of increases in real income and rising rural standards of living. However, these increases should not come at the expense of the natural resources base.

Achieving rural development depends on national policies to create the framework in which the agricultural sector can successfully operate (e.g., favorable input/output price ratios, availability of credit, economic stability and security). It also depends on infrastructure development, particularly at early stages in the process when government must provide the social infrastructure to address farmer's needs.

Raising farm productivity during the initial stages of agricultural development often demands low-input technologies that make efficient use of available resources. At the same time, technological innovations should contribute to the conservation of natural resources. These innovations should be capable of responding to improved management practices and increased use of purchased inputs that come with the development process and agricultural intensification.

Development schemes based on appropriate domestic policies and infrastructure development have often failed in the past due to the lack of suitable technology. Farmers have been encouraged to apply imported technologies but these technologies have proved inappropriate for local needs and conditions. This has led to rejection of the proposed technology, ineffective use of development funds and failure to achieve enduring rural development.

In this paper, pasture-crop technologies appropriate for the acid infertile soils of the Latin American tropics are described and discussed. They have the potential to provide the technological basis for sustained rural development of these regions.

Messrs. Toledo, Sere and Loker are leader, economist, and anthropologist, respectively, Tropical Pastures Program, Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.
BACKGROUND

Tropical America has large regions with underutilized lands. The tropical savannas (153 million ha) and humid tropics (513 million ha) are important land resources for the development of the continent (Cochrane et al., 1984). These regions are characterized by year-round growing seasons, gentle topography, good soil physical conditions and abundant water. The main constraint on their development has been the negative chemical characteristics of these heavily weathered soils (Oxisols and Ultisols), including low pH, high aluminum saturation and low base status. The cattle industry in tropical America is far more important relative to other areas of the developing world (East Asia and Africa). There are approximately 250 million head of cattle in the American tropics, roughly 20 percent of the world's total cattle inventory (CIAT, 1988b).

Human population migration is also a notable feature of tropical America. Urbanization is a growing trend in the region. As shown in Table 1, urbanization in South America and Mexico increased from about 45 percent in 1960 to more than 65 percent in 1985. The urban population in Central America increased from about 40 percent to 60 percent in the same period (FAO, 1970-1986). Roughly 20 percent of the region's population has moved to cities in the last 25 years.

Table 1: Urbanization in tropical America (1960-1985)

<table>
<thead>
<tr>
<th>Country</th>
<th>Urban population (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1960</td>
</tr>
<tr>
<td>Tropical South America</td>
<td>47.8</td>
</tr>
<tr>
<td>Bolivia</td>
<td>39.0</td>
</tr>
<tr>
<td>Brazil</td>
<td>48.2</td>
</tr>
<tr>
<td>Colombia</td>
<td>48.5</td>
</tr>
<tr>
<td>Ecuador</td>
<td>42.5</td>
</tr>
<tr>
<td>Paraguay</td>
<td>44.0</td>
</tr>
<tr>
<td>Peru</td>
<td>47.6</td>
</tr>
<tr>
<td>Venezuela</td>
<td>64.9</td>
</tr>
<tr>
<td>Central America</td>
<td>39.5</td>
</tr>
<tr>
<td>Mexico</td>
<td>45.0</td>
</tr>
</tbody>
</table>


At the same time, a significant portion of the rural population has moved from impoverished and crowded areas of the countryside to marginal frontier areas. Patterns of migration and colonization vary among countries and ecosystems. The savannas are initially occupied by well-to-
do ranchers; spontaneous colonization of this ecosystem by the poor is extremely difficult due to the poverty of the soils and original vegetation. However, intensification of land use resulting from the utilization of improved pasture-crop technologies permits subdivision of land and may result in future economic growth and social benefits. The humid tropics, after infrastructure is installed to integrate territories or to open access to timber and oil exploitation, are more attractive to settlers because of higher soil fertility realized through clearing and burning of the original forest biomass. Logging, shifting cultivation and raising cattle are the main production systems in these areas.

Population growth rates in the humid tropics are considerably higher than national averages due to colonization. Areas of active colonization such as Rondonia in Brazil and Ucayali in Peru have population growth rates about three times those of the respective national averages (Table 2).

Population growth and redistribution in tropical American countries have resulted in changes in land distribution and agricultural production systems. Higher demand for food among expanding urban populations and overall population growth have pushed up prices of higher fertility land closer to urban markets. Intensification of land use and expansion of crop production are pushing cattle operations onto marginal and frontier areas where land has a lower opportunity cost.

**Table 2: Effect of colonization on population growth in the humid tropics**

<table>
<thead>
<tr>
<th>Country or region</th>
<th>Population growth rate (1960-1985)</th>
<th>1985</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>2.7</td>
<td>4318.4</td>
</tr>
<tr>
<td>Pará</td>
<td>4.2</td>
<td>3566.4</td>
</tr>
<tr>
<td>Acre</td>
<td>3.4</td>
<td>908.9</td>
</tr>
<tr>
<td>Rondónia</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>2.5</td>
<td>283.1</td>
</tr>
<tr>
<td>Caquetá</td>
<td>4.1</td>
<td>119.8</td>
</tr>
<tr>
<td>Putumayo</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td>2.7</td>
<td>381.9</td>
</tr>
<tr>
<td>San Martín</td>
<td>3.5</td>
<td>270.0</td>
</tr>
<tr>
<td>Ucayali</td>
<td>7.9</td>
<td></td>
</tr>
</tbody>
</table>

**SOURCES:** For Brazil, FIBG (1970-1986); for Colombia, DANE (1967, 1978, 1986); for Peru, Oficina Nacional de Estadísticas y Censo (1961-1972) and OEA (1964-1974)
For example, in 1950, the cattle population in the developed southern Brazilian states of Rio Grande do Sul and Santa Catarina comprised 21.4 percent of the national herd. In 1985, this figure was reduced to 12.7 percent. At the same time, cattle in the Cerrados states of Goiás and Mato Grosso (areas of predominantly acid infertile soils) increased from 15.3 percent of the national herd in 1950 to nearly one-third of the Brazilian cattle population in 1985 (Table 3). Similarly, in Colombia, the fertile Cauca Valley had 7.5 percent of the Colombian herd in 1950. In 1985, its proportion was reduced to only 2.2 percent. In the savanna region of Meta, the percentage of the national herd increased from an insignificant 0.6 percent to 6.1 percent over the same period. And in Caquetá, in the Colombian humid tropics, the cattle population increased from 1.4 percent to 5.5 percent of the national herd over the last thirty-five years.

Table 3: Regional shift of the cattle industry as a contribution to nationals herds in Brazil and Colombia

<table>
<thead>
<tr>
<th>Country or region</th>
<th>1950 (%)</th>
<th>1985 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South (Rio Grande do Sul</td>
<td>21.4</td>
<td>12.7</td>
</tr>
<tr>
<td>and Santa Catarina)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerrados (Goiás and Mato</td>
<td>15.3</td>
<td>31.0</td>
</tr>
<tr>
<td>Gross)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valle (Valle del Cauca)</td>
<td>7.4</td>
<td>2.2</td>
</tr>
<tr>
<td>Amazon (Caquetá)</td>
<td>1.4</td>
<td>5.7</td>
</tr>
<tr>
<td>Llanos (Meta)</td>
<td>0.6</td>
<td>6.1</td>
</tr>
</tbody>
</table>


Marginal and frontier areas with acid and infertile soils are being increasingly incorporated into the national agricultural economies of the region. The lower productivity of cattle and cropping operations on these lands as well as the lack of sustainable production systems in these fragile environments are major concerns of the societies involved.

Beef, milk, rice, maize and, increasingly, sorghum (for animal feed) are major crops in tropical America. The demand for beef and milk has been outpacing growth in production of these commodities. While production grew 2.2 percent for beef and 3.7 percent for dairy products between 1970 and 1981, demand for these products grew 5.3 percent for beef and 5.0 percent for dairy products (CIAT, 1984).

The importance of rice in Latin American diets is a relatively recent phenomenon and its rate of production and consumption has grown dramatically over the last 50 years. In the 1920s, Latin America produced
about 1.07 million metric tons of rice and average consumption per capita was about 14.2 kg per year. During the 1984-86 period, production was 17.2 million metric tons per year and average annual per capita consumption was 45.4 kg. It has been estimated that low-income urban consumers in Latin America spend between 12 percent and 26 percent of food expenditures on beef, 7 percent to 18 percent on milk (Rubinstein and Nores, 1980) and an average of 11 percent on rice (IBE, 1988).

Income growth and urbanization are also increasing demand for animal feed grains such as maize, sorghum and, recently, dried cassava for poultry and swine production. The average growth rate of per capita maize consumption between 1970 and 1982 was 1.8 percent per year in tropical America. Net imports of maize per capita grew from 3 kg during 1961-65 to 25 kg during 1980-82 (CIMMYT, 1987).

The agricultural sector in Latin America is highly dynamic but much can still be done to increase productivity and modernize agriculture on prime lands. However, due to internal policies in these developing countries, agricultural development of marginal and current frontier lands is expanding, particularly in the Cerrados of Brazil and the Llanos of Venezuela, where an extensive transportation infrastructure has been created.

In the Colombian Llanos, despite limited infrastructure, intensification of land use and subdivision of farms are rapidly occurring. Colonization of humid tropical areas is also proceeding rapidly, triggered by socioeconomic conditions in areas of outmigration and the development of infrastructure in this region. Unfortunately, this phenomenon is bringing about resource degradation due mainly to the lack of knowledge about this ecosystem and lack of technology for its efficient use.

The design of new technologies to facilitate the development of these areas of acid infertile soils through economical and ecologically sound pasture-crop production systems is the goal of CIAT’s Tropical Pastures Program.

TECHNOLOGICAL OPTIONS

The success or failure of any technological innovation in agriculture depends on the fit between the proposed technology and specific conditions at the farm and regional level.

Production Components

Crops, pastures, livestock and/or trees must efficiently convert solar energy, water and soil resources into valuable products. These are the genetic bases used in the production system to obtain agricultural yield and income.

Management

Management includes the varying combinations of labor, fertilizer and other inputs, together with the knowledge necessary to organize these elements into effective agricultural production systems. Management also
includes post-harvest utilization, processing, and marketing. Management skills are strongly dependent on tradition, experience and education as well as available production components, natural resources and the farmer's access to capital, credit, machinery and other inputs.

The Market

The farmer's main goal is profit. Farmers strive to manage available resources (labor, land, capital and technology) to optimize production and reduce risk. Strong reliable markets with favorable input/output price ratios are essential for the success of a technology.

Technically sound production components and management can fail because of market deficiencies. Some products have larger and more well-developed markets than others. For products such as rice, beef and milk, marketing constraints are largely limited to the development of infrastructure (to provide access) and favorable prices. The success of other crops that are perishable or novel, and thus have limited demand, (such as fresh cassava and native tropical fruits) is largely contingent on the existence and development of markets.

NEW LOW-INPUT PASTURES FOR ACID INFERTILE SOILS

Through extensive germplasm collection of wild grasses and legumes native to the acid infertile soils of tropical Latin America, Africa and Asia, the germplasm collection of CIAT's Tropical Pastures Program was increased from about 4,000 accessions in 1978 to more than 23,000 accessions in 1988.

Decentralized screening of these materials for adaptation to soil, climate and biotic pressures of the main humid and subhumid ecosystems of tropical American lowlands has produced a new generation of forage grasses and legumes for these regions. This is a continental effort conducted by CIAT in cooperation with national research institutions (NARIs) at four major screening sites representing two major savanna ecosystems: the Llanos (Carimagua, Colombia, in cooperation with ICA) and Cerrados (Planaltina, Brazil, in cooperation with EMBRAPA) as well as the humid tropics of the Amazon basin (Pucallpa, Peru, in cooperation with INIAA and IVITA) and the more intensive cattle production systems of Central America (Costa Rica, in cooperation with MAG and CATIE). Selections made at these four sites are further tested by NARIs throughout the continent at more than 200 sites, where final selections are made for evaluation under grazing, validation on-farm, and for eventual commercial release.

The new generation of materials is resistant to prevalent pests and diseases and requires lower levels of purchased inputs than traditional pasture species. Figure 1 shows that an adapted grass, *Andropogon gayanus* CIAT 621, was successfully established on soils with low phosphorous availability. The same species responds to increased levels of P and liming. The non-adapted grass, *Panicum maximum* cv. Makueni (an imported cultivar), barely survives without liming and only reaches the productivity levels of the adapted species at much higher levels of lime and P application. Effective savings of P and lime are achieved through the use of species adapted to acid infertile soils.
FIGURE 1. Establishment of two grasses under residual effect (10 years) of P fertilization and liming in the Brazilian Cerrados. Taken from Toledo (1985).

Combining adapted grasses with nitrogen-fixing forage legumes reduces the need for the application of expensive nitrogenous fertilizers in pasture establishment and maintenance.

Low-input pasture technology based on adapted grass-legume cultivars is achieving striking levels of productivity in the savanna ecosystem. Figure 2 shows the magnitude of productivity increases of *A. gayanus* alone and in association with the commercially released legumes *Stylosanthes capitata* cv. Capica and the association of the newly released grass and legume cultivars *Brachiaria dictyoneura* cv. Llanero and *Centrosema acutifolium* cv. Vichada. The productivity of the grass-legume associations is twice that of native savanna grassland in terms of liveweight gains per head of cattle and 15-fold in terms of liveweight gains per hectare.

In the last three years, farmers in the Colombian Llanos have established more than 6000 hectares of new grass-legume associations using these pastures as a strategic supplement to the native grassland (CIAT, 1989). The main factor limiting further adoption in Colombia has been legume seed availability. In the Cerrados of Brazil, with an aggressive commercial seed sector, an estimated 500,000 hectares have been planted in *A. gayanus* due to its tolerance to insect pests and better dry-season performance compared with *B. decumbens*.

For the humid tropics, new grass-legume pastures that effectively capture and recycle limited soil nutrients are emerging for the reclamation of degraded lands. They are also being used for the intensification of production on already cleared forest areas.

Moderate to high levels of animal liveweight gains can be expected from this emerging adapted germplasm-based pasture technology. Table 4 shows experimental results of research underway in different areas in the region, indicating that with selected germplasm it is possible to obtain average daily animal gains above 400 g and annual animal gains per hectare superior to 500 kg, especially when legumes are present in satisfactory quantities in the pasture.

Legume contribution to pastures in the humid tropics is reflected not only in additional liveweight gains but also in increased carrying capacity and stability of the sward. Legumes contribute directly and indirectly to higher levels of protein in the diet, especially in the dry season when grass availability is reduced.

Long-term grazing trials comparing grass versus grass-legume pasture performance are needed to assess the contribution of legumes to the productivity of pastures in the humid tropics. Research on the new pasture options has not yet reached this stage. However, we can extrapolate results from wet-season performance in the savanna ecosystem to estimate productivity in more humid ecosystems. Data from a ten-year-old grazing trial at Carimagua in the Colombian Llanos, comparing the association *B. decumbens* + *Pueraria phaseoloides* with *B. decumbens* alone at a stocking rate of two animal units per hectare indicates that the inclusion of the legume raises productivity by only 5 percent during the initial four years (Figure 3). Thereafter, the legume contribution to relative productivity becomes exponential. This suggests the importance of legumes for pasture
**FIGURE 3.** Relative yield of *B. decumbens* + *P. phaseoloides* pastures to *B. decumbens* alone during rainy periods in the Colombian Llanos.

**FIGURE 4.** Marginal cash flow in the establishment of improved pastures with (-----) and without (---) sorghum as companion crop in the Colombian Llanos (Sé and Estrada 1987).
Table 4: Liveweight gains from grass-legume pasture

<table>
<thead>
<tr>
<th>Pasture</th>
<th>No. of years</th>
<th>Stocking rate</th>
<th>Daily gain per animal (g)</th>
<th>Yearly gain per ha (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paspalum notatum (Trenza)a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>Andropogon gayanusC</td>
<td>2</td>
<td>2.1</td>
<td>0.443</td>
<td>340</td>
</tr>
<tr>
<td>Brachiaria humidicolaC</td>
<td>2</td>
<td>2.5</td>
<td>0.580</td>
<td>351</td>
</tr>
<tr>
<td>A. gayanus + S. guianensisb</td>
<td>5</td>
<td>4.4</td>
<td>0.412</td>
<td>660</td>
</tr>
<tr>
<td>A. gayanus + C. macrocarpum</td>
<td>2</td>
<td>3.5</td>
<td>0.510</td>
<td>650</td>
</tr>
<tr>
<td>B. decumbens + D. ovalifoliumd</td>
<td>5</td>
<td>5.5</td>
<td>0.447</td>
<td>897</td>
</tr>
<tr>
<td>B. dictyoneura + D. ovalifoliumb</td>
<td>4</td>
<td>5.0</td>
<td>0.440</td>
<td>803</td>
</tr>
</tbody>
</table>

---

* a/ Quilichao, Colombia (Escobar et al., 1971)
* b/ Quilichao, Colombia (CIAT, 1988c)
* c/ Paragominas, Brazil (EMBRAPA, 1988)
* d/ Yurimaguas, Peru (Dextre et al., 1987)

Stability and sustainability under continuously wet environments. The length of the dry season in the humid tropics varies from zero to three months per year. Thus, the legume contribution is bound to be larger even in the first years through its direct contribution to animal production during the dry period.

**Acid-Poor Soil-Adapted Crops**

Low-cost establishment as well as increased productivity are decisive for the adoption of these new, low-input, pasture technologies in both the savannas and the humid tropics. One possible route for lowering the costs of pasture establishment is the use of pioneer crops to pay for land preparation and the application of soil amendments in the establishment process. This will require crop cultivars adapted to acid infertile soils. Adapted cultivars may also open the possibility for ley farming systems in these regions, using residual fertility and improvements in soil structure provided by the grazing phase of the crop-pasture system. CIAT, CIMMYT and INTSORMIL (International Sorghum and Millet Program) are working on the development of acid soil-adapted lines of rice, maize and sorghum.

**Upland Rice.** The main constraints for developing high-yielding upland rice for the acid soils of the savannas is tolerance to rice blast and grain quality for the consumer. Several selected lines for upland conditions, resulting from crosses of IITA (International Institute of Tropical Agriculture), IRRI (International Rice Research Institute) and EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) materials, were planted in 1988 under three different conditions in the Colombian Llanos. The chemical correction of the soil included the application of 250 kg of dolomitic lime, 60 kg of P2O5, and 40 kg of K2O. Pesticides and herbicides were not applied (CIAT, 1988a). Table 5 shows the yields of the best lines.
Table 5: Grain yields (kg/ha) of rice lines under three contrasting savanna environments of the Colombian Llanos

<table>
<thead>
<tr>
<th>Pedigree</th>
<th>San Martín</th>
<th>Puerto Gaitán</th>
<th>Yopal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT 6947-7-1-2-M</td>
<td>-</td>
<td>1172</td>
<td>3138</td>
</tr>
<tr>
<td>CT 6515-18-1-3-1-2-M</td>
<td>3256</td>
<td>806</td>
<td>2794</td>
</tr>
<tr>
<td>CT 6261-5-7-2P-5-M</td>
<td>-</td>
<td>1396</td>
<td>2594</td>
</tr>
<tr>
<td>CT 6196-33-11-1-3-M</td>
<td>-</td>
<td>1320</td>
<td>2463</td>
</tr>
<tr>
<td>CT 6196-33-2-9-4-M</td>
<td>1112</td>
<td>1025</td>
<td>2400</td>
</tr>
</tbody>
</table>

Checks

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IAC-165</td>
<td>0</td>
<td>1064</td>
<td>2362</td>
</tr>
<tr>
<td>TOX-1011-4-1</td>
<td>0</td>
<td>834</td>
<td>1869</td>
</tr>
<tr>
<td>Oryzica 2</td>
<td>0</td>
<td>0</td>
<td>2275</td>
</tr>
</tbody>
</table>

SOURCE: CIAT, 1988a

compared with the best local controls. The new adapted upland rice lines outyielded the checks in all contrasting locations.

Maize for Acid Soils. Recent efforts of CIMMYT to develop germplasm for "stress" environments in Latin America included the conformation of acid-soil tolerant populations (two yellow, two white) to be improved through recurrent selection. Some of the data on the performance of 613 yellow families in several acid-soil sites are presented in Table 6. Experimental sites were limed to reduce aluminum saturation to about 60 percent and 120 kg of N + 80 kg of P₂O₅ were applied as fertilizers. The 56 selected families significantly outyielded the rejected ones by 1 metric ton per hectare. These results are very encouraging given the importance of maize as a subsistence and cash crop in the farming systems of the savannas and humid tropics.

Table 6: Yield (kg/ha) of selected and rejected maize families for adaptation to acid soil sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Maize yield</th>
<th>Significance of differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selected (56)</td>
<td>Rejected (557)</td>
</tr>
<tr>
<td>Carimagua, Colombia</td>
<td>3980</td>
<td>2080</td>
</tr>
<tr>
<td>Yurimaguas, Peru</td>
<td>3510</td>
<td>1650</td>
</tr>
<tr>
<td>Mindanao, Philippines</td>
<td>1800</td>
<td>860</td>
</tr>
</tbody>
</table>

*** P < .001
SOURCE: Haag and Pandey, 1988
Sorghum in the Acid Savannas. The Oxisols of the Llanos have an average of 88 percent aluminum saturation. The new adapted lines of sorghum being developed by INTSORMIL perform well up to 60 percent Al saturation. Yields of 2 t/ha are obtained in the Llanos with the application of lime to reduce Al saturation to 60 percent, along with 49 kg of N, 13 kg of P, and 40 kg of K per ha. Yields of 3 t/ha were obtained in the fertile soils of the Cauca Valley without the application of lime, P and K.

These superior lines of upland rice, maize, and sorghum will expand crop production in the Oxisols and Ultisols of the savannas and humid tropics of the Americas. They will also contribute to the adoption of the new pasture technology in these ecosystems through their use as cash crops to pay for the upgrading of soil physical and chemical conditions prior to or simultaneous with pasture establishment.

Crop-Pasture Technologies for Tropical Savannas

Seré and Estrada (1987) analyzed the economics of introducing sorghum production in the acid infertile soils of the Colombian Llanos as a semestral crop or as a complement to pasture establishment. The biannual cropping in the Llanos was compared with sorghum production in the Cauca Valley, which has fertile soils and is closer to markets.

Seré and Estrada concluded that higher transportation costs and reduced yields in the Llanos make it more attractive to intensify semestral sorghum production on fertile lands closer to markets. However, the technology could successfully be applied on acid soils closer to markets or in areas with better infrastructure such as the Venezuelan Llanos or the Cerrados of Brazil.

On the other hand, introducing sorghum in the well-drained land of the Colombian Llanos is a potentially attractive alternative. The sorghum would reduce the costs of pasture establishment and provide additional income from the strategic supplementation of cattle with grazed sorghum stubble. During the first years, sorghum substantially improves the cash flow of the investment in pastures (Figure 4). The marginal profitability of pastures established in association with sorghum increases from 34 percent to 52 percent per year for sorghum yields ranging from 1.3 to 2.5 t/ha.

Under the subsidized conditions of the Brazilian Cerrados, 1.5 t/ha of lime and fertilizers (P and K) are applied in on-farm trials to establish legume protein banks of Leucaena leucocephala and S. guianensis in association with a maize crop. The latter is grown to defray costs. Figure 5 shows the cost structure of establishing these Leucaena-Stylo protein banks. The total cost per hectare is high (US$426/ha at the official exchange rate) and inputs represent the largest share (77.3 percent). Maize sales reduced the total cost by 48 percent. High levels of inputs are required in this case because Leucaena is not an acid-soil-tolerant forage tree.
Total cost = US$426
Maize sale = US$203 (48%)
Net cost = US$223

FIGURE 5. Cost structure of the establishment of *Leucaena leucocephala* + *Stylosanthes guianensis* protein banks including corn as cash crop in the Brazilian Cerrados (Saez, personal communication, 1989)

FIGURE 6. Relative increases of Ca, Mg and K under an *A. gayanus* + *P. phaseoloides* pasture at Carimagua, Colombia (CIAT, 1984a).
The high recycling capacity of grass-legume pastures can, over time, maintain nutrients in the topsoil profile. Figure 6 shows the relative increase of K, Mg, and Ca in the upper 20 cm of an Oxisol in the Colombian Llanos after four years under an A. gayanus + P. phaseoloides pasture with maintenance fertilization every second year (CIAT, 1984a). While Ca and Mg more than double their concentration in the topsoil, K remains constant. This concentration of nutrients in the topsoil, together with increased inorganic matter and improved soil structure resulting from grass-legume pastures, provides an improved environment for crop production in these tropical savanna Oxisols.

Although chemical and physical soil conditions strongly influence the success or failure of crops and pastures, soil microbes are also an important component of soil-plant interactions, particularly in these low-input species. Apart from the well-known benefits of legume-rhizobium symbiosis, other microbial processes such as micorrhizae -- which contribute to the uptake of phosphorous -- are also important. Dodd et al. (n.d.a., n.d.b. and n.d.c.), for example, showed the role of sorghum and P. phaseoloides in raising the population of micorrhizal fungi infecting subsequent crops and pastures established in Oxisols of the Colombian Llanos.

The new generation of acid-soil-tolerant crops and pastures (especially rice and sorghum) is expected to contribute greatly to the intensification of land use in these savannas that have been traditionally farmed extensively. The reduction of pasture establishment costs by using crops and the subsequent benefit for crop production from improved soil conditions after grass-legume pastures are extremely important for the development of highly productive and sustainable pasture-crop production systems in the Oxisols and Ultisols of the tropical savannas of Latin America.

**Crops and Pastures in the Humid Tropics**

Pioneer settlers in the humid tropics plant crops such as rice, maize, cassava and cowpeas in systems of shifting cultivation after clearing and burning the forest to temporarily increase soil fertility. The limited surplus generated from cropping activities using this ephemeral soil fertility and family labor, often augmented by on-farm employment, is frequently invested in livestock. Livestock, especially cattle, represent a secure investment that maintains its value in inflationary economies and provides a ready source of cash when marketed. Cattle are gradually integrated into mixed crop-livestock systems through the inclusion of pastures in rotation with annual crops and long bush fallow agricultural cycles. Land degradation due to declining fertility is the major economic and environmental problem for the development of efficient and sustainable production systems in the humid tropics.

Establishing the new grass-legume pastures in these degraded lands requires investments of varying proportions of time, labor and capital. Farmers have developed production systems that combine crops, pastures and bush fallows. Two contrasting examples from the humid tropics are the production systems of Pucallpa, Peru and Caquetá, Colombia. In Pucallpa,
farms average about 59 ha with 41 percent of the area in pastures, 11 percent in crops, 17 percent in secondary forest and 31 percent in primary forest. Cattle average 30 head per farmer with production of beef and milk (Riesco, 1982). In Caquetá, Colombia, dual-purpose farms average 130 ha with 73 percent of the area in pastures, only 3 percent in annual crops, 17 percent in secondary forest and 7 percent in primary forest. Production is dual-purpose (beef and milk) and farmers own an average of 121 cattle (Ramirez and Seré, n.d.).

The quality of pasture and its management is often not uniform on these farms. Areas vary in age after establishment as well as in intensity of use and weed control. Older pastures, closer to the house and corral, are normally managed with higher grazing frequency and pressure and with continuous hand or chemical weeding. These more accessible areas are often degraded into a disclimax native grass community (known locally and referred to here as "torurco") made up of palatable native grasses such as Axonopus compressus and Paspalum conjugatum, with some legumes (Desmodium triflorum, D. ascendens, D. incanum, Aeschynomene americana, and Calopogonium mucunoides) in small proportions. These "torurco" pastures are fairly stable at low productivity levels (<0.8 AU/ha). However, because of overgrazing they can be further degraded into less palatable species such as Homolepsis aturensis, Cyperus spp. and Pteridium spp. (Toledo, 1984).

Soil conditions in these degraded "torurco" grasslands are extremely poor. High levels of compaction and low levels of nutrients are common and seed reserves from the original forest have normally been exhausted. Under these conditions, when grazing is discontinued the regeneration of the forest biomass is extremely slow (Uhl et al., 1988). It may take 15 years to reach the level of biomass displayed by a secondary forest after five years of fallow following two-year crop cycles.

The other part of the pasture area of these farms is more extensively managed with a lower stocking rate and a minimum of weeding. These areas are normally farther away from the central infrastructure of the farm and are less accessible to cattle. They are typically managed in a shifting crop-pasture-fallow system. Crops such as rice and maize are planted every 8-12 years after clearing and burning the secondary forest regrowth (known locally and referred to here as "purma"). Pastures are planted along with, or shortly following, crops and are grazed for three to five years at a low stocking rate with limited weeding. Eventually, these areas are dominated by weeds and shrubs, grazing is interrupted and the area is allowed to go fallow for 8-12 years, after which the vegetation is burned and the cropping cycle begins again. The success and sustainability of these crop-pasture-purma systems depends heavily on maintaining an adequate fallow period.

Reclamation of these contrasting degraded lands requires different approaches. On one hand, in areas of native grassland ("torurco"), higher levels of inputs will be required (machinery, fertilizers, seeds, weed control). After "purma", minimum purchased inputs (seeds) and labor are needed. Figure 7 shows the cost structure of these two reclamation options for Pucallpa, Peru using maize as the cash crop.
After "Torurco"

- Labor (33.7%)
- Machinery (55.6%)
- Inputs (10.7%)

Total cost = US$338
Maize sale = US$93 (28%)
Net cost = US$245

After "Purma"

- Labor (79.6%)
- Inputs (20.4%)

Maize sale = US$100 (80%)

FIGURE 7. Cost structure of pasture reclamation after "Torurco" (degraded grassland) and after "Purma" (secondary forest), including maize as a cash crop in Pucallpa, Perú.
The total cost of reclaiming degraded areas in "torurco" is more than twice that of reclaiming "purmas" and it requires machinery and higher levels of purchased inputs often not available to farmers. The net cost of mechanized reclamation of degraded "torurco" is almost ten times higher than that of traditional reclamation after "purma." However, if capital is available to buy more cattle for the intensification of the pasture component of the production system, the time required for the natural "purma" system to work may be excessive.

One option is to use the new grass-legume pastures to improve the traditional "purma" system. Higher recycling capacity and productivity of the improved pasture technology will allow farmers to make better use of the disturbed lands. This pasture will maintain higher stocking rates for longer periods of time without losses in soil fertility.

At the initial stages of development of a region, an improved crop-pasture-fallow system will probably be the most attractive option. Figure 8 illustrates this option. Land clearing and burning of the primary forest occur after "Time zero." Crops and the grass-legume pastures are established at "Time 1." After the crops are harvested, the N\textsubscript{2}-fixing pastures can be grazed for four years with 2 AU/ha. Simultaneously, selected commercially valuable trees (such as Guazuma crinita, G. ulmifolia, Jacaranda copaia) are allowed to resprout and are protected from weeding (Time 2). During the fifth and sixth years the carrying capacity of the pasture is reduced to 1 AU/ha to compensate for yield reductions expected under a more shady environment (Time 3). After six years of grazing, the land is taken out of production and left fallow for two years, possibly with oversowing of P. phaseoloides or another rapidly growing, high-N\textsubscript{2}-fixing legume to facilitate recovery (Time 4). At the end of the fallow period, any commercially valuable tree species are harvested before the plot is burned and the cycle begins again with the planting of crops and pastures. This system relies on the N\textsubscript{2}-fixing and nutrient cycling of the new pastures, which will easily allow farmers to intensify management and realize a 20-25 percent increase in productivity while avoiding soil degradation. The system requires minimal change on the part of the farmer. The only technological innovation is the use of improved species. The system allows a 50 ha farm to maintain 55-60 head of cattle and produce annual crops on 5 ha of land every year.

In areas of longer term colonization in the humid tropics, a mix of "torurco" and "purma" areas exists. Farmers have low productivity areas close to the farm infrastructure where they most need high productivity. They face the dilemma of moving the center of management closer to the more productive "purmas" or reclaiming the close-in "torurco" areas. Both alternatives are expensive.

An economic analysis was performed on three alternative methods of reclaiming "torurco" areas using a ten-year period as the base line for evaluating economic returns. The assumption is that the three alternatives result in pastures with the same productivity and persistence at the tenth year.
FIGURE 8. Improved crop-pasture—"purma" system.
The Mechanized Reclamation Alternative. The "torurco" is grazed for ten years at low stocking rates (0.65 AU/ha), assuming liveweight gains of 275 grams/head/day, yielding an estimated net yearly income of US$32.70/ha. The area is then mechanized and fertilized to upgrade soil conditions and grass-legume pastures are established along with maize as a cash crop. The cost of pasture establishment is US$244/ha as shown in Figure 7.

The Legume Cocktail Option. The "torurco" is grazed for seven years with the same management and returns specified above. The area is then reclaimed, using a combination of aggressive legume germplasm but without mechanization. Soil chemical and physical properties are improved through sowing legumes such as Centrosema macrocarpum or P. phaseoloides in combination with a fast-growing legume such as S. guianensis. The legumes are planted after heavy grazing, herbicide (Roundup, 1.5 L/ha) is used to control weeds and band application of 70 kg of triple superphosphate is made in strips over 50 percent of the area.

The manual sowing of the legume "cocktail" is done using a digging stick to superficially open the soil in the treated strips. The total labor requirement is 7 man days/ha. Table 7 shows the cost structure of this reclamation option.

After three years with no grazing, enough aerial and root biomass has accumulated to restore soil structure and fertility. The area is then cleared and burned and grass-legume pastures are established along with a maize companion crop with the same US$25/ha cost estimated for establishment of pasture after "purma" (Figure 7). This option requires less labor in clearing but may require more labor in weed control during the establishment phase.

Table 7: Cost of non-mechanized establishment of a legume cocktail in "torurco" grassland

<table>
<thead>
<tr>
<th>Inputs and labor</th>
<th>Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicides (1.5 L of Roundup/ha)</td>
<td>25.50</td>
</tr>
<tr>
<td>Fertilizer (70 kg of SPT/ha)</td>
<td>2.25</td>
</tr>
<tr>
<td>Seeds (3 kg/ha)</td>
<td>9.00</td>
</tr>
<tr>
<td>Total cost of inputs</td>
<td>36.75</td>
</tr>
<tr>
<td>7 men-days/ha</td>
<td>12.25</td>
</tr>
<tr>
<td>Total cost/ha</td>
<td>49.00</td>
</tr>
</tbody>
</table>
This option uses the adaptation of legumes to low-fertility soils, their deep, profuse rooting systems and their capacity to fix nitrogen to accelerate the natural build-up of soil fertility. This replaces 10-15 years of natural fallow with three years of managed legume-cocktail fallow.

"Torurco"-fallow Option. The third alternative evaluated is to eliminate grazing for the entire ten-year period, allowing secondary regrowth to slowly accumulate, and to use the traditional "purma" technology to reclaim the area (costs are US$25/ha. See Figure 7). In this alternative, the farmer must take the area out of production for ten years during the extended fallow period.

Table 8 shows the net cash flow of the three alternatives. The alternative with highest net present value (NPV) ($i = 10$ percent/year) is the non-mechanized, managed legume-cocktail fallow with an NPV of US$124.20, followed by the mechanized option with an NPV of US$106.50. The option of taking the land out of production for ten years has a negative NPV, which explains why farmers do not use this option. This analysis shows the importance of investigating non-mechanized, low-cost reclamation

<table>
<thead>
<tr>
<th>Year</th>
<th>Mech (US$)</th>
<th>Legum (US$)</th>
<th>After (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0</td>
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<tr>
<td></td>
<td>-212.30a</td>
<td>-25.50c</td>
<td>-25.50c</td>
</tr>
</tbody>
</table>

NPV ($i = 10$% /year)  
106.50  
124.20  
-9.80

\[ a = (-245.00 + 32.70) \]

Mechanized net cost of establishment + annual revenue

\[ b = (-49.00 + 32.70) \]

Cocktail net cost of establishment + annual revenue

\[ c = (-25.50) \]

Net cost of establishment after "purma"
techniques similar to option 2 presented here. Pasture reclamation using mechanization, fertilization and pioneer crops may be feasible for larger areas where access to machinery and capital exists.

In Pucallpa, Peru, CIAT is studying several alternative crops for the reclamation of "torurco" grasslands, including rice, maize and cowpeas. Figure 9 shows the effects of fertilizers and land preparation on rice yields. There is a clear interaction between fertilizer response and disk harrowing, with fertilizer response increasing after disk harrowing was applied. The same pattern is illustrated in Figure 10 for cowpeas. However, maize yields were highest with zero tillage. Fertilizer response was reduced with disk harrowing (Figure 11). The response of rice and cowpeas to tillage suggests that soil compaction in degraded "torurco" grasslands is a major constraint for the development of their root systems.

The maize response suggests that compaction is not a constraint for its more vigorous root system. However, the reduction in response to fertilizer with tillage indicates that weed invasion associated with tillage is a major competition constraint for maize productivity. Figure 12 shows the dramatic increase of weeds in tillage treatments due to the activation of seed reserves in the soil and soil mineralization.

Dry matter yields of the grass and legume planted simultaneously with the three crops were reduced by weed competition due to harrowing. This fact shows the importance of weed invasion after land preparation and the potential of maize as a cash crop in non-mechanized pasture reclamation.

RESEARCH AND DEVELOPMENT NEEDS

Further research efforts are required to overcome the major constraints to the development of economically sound and sustainable production systems in the savanna and humid tropical ecosystems where cattle and crop production are currently expanding. These land resources of varying fragility will be increasingly used in the near future in Latin America. Agricultural expansion into the savannas is of minor degradation risk. However, degradation of the soil and loss of biomass in the rain forest areas are a major research and development concern.

A two-pronged research strategy needs to be followed. First, technology should be developed for the intensification of land use in the tropical savannas. This will allow reduction in farm size and make it feasible for land-hungry colonists to settle this less fragile ecosystem, thus reducing pressure on the humid tropical forest areas. Second, pasture-crop-tree technologies that are highly productive and sustainable should be developed to replace degrading production systems found in areas of the humid tropics that are already cleared. This strategy is particularly important for countries with no savanna resources.

Intensification of land use in these two ecosystems is the only way to prevent ever greater rates of deforestation in tropical America in the medium-term by societies interested in increasing their arable land base. Intensification of production on already disturbed sites should be combined with immediate and concerted efforts to preserve sufficiently
FIGURE 9. Rice yield under different fertilization rates and levels of disk harrowing (number of passes), after "torurco" at Pucallpa, Perú (CIAT, 1989).

FIGURE 10. Cowpea yield under different fertilization rates and levels of disk harrowing (number of passes), after "torurco" at Pucallpa, Perú (CIAT, 1989).
Maize (Cuban yellow)

% Recommended fertilizer rate
* 100% = 60 kg N + 40 kg P + 50 kg K + 20 kg S.

FIGURE 11. Maize yield under different fertilization rates and levels of disk harrowing (number of passes), after "torurco" at Pucallpa, Perú (CIAT, 1989).

FIGURE 12. Weed invasion and yield of B. dictyoneura and D. ovalifolium as affected by tillage levels, after "torurco" at Pucallpa, Perú (CIAT, 1989).
large and representative areas of these ecosystems to reduce the threat of species extinction and loss of biodiversity. Proposed research strategies suggest the following priorities:

**Genetic Level**

Further develop highly adapted, productive cultivars of crops, pastures and trees as potential components of mixed agro-silvo-pastoral systems.

**Technological Level**

Study soil-plant-animal-management interactions in different relevant integrated production systems under a range of natural conditions to develop management principles.

**Farm Level**

Study farmers' socioeconomic constraints and natural-resource availability to develop management techniques that optimize profitability and sustainability of production systems. These management techniques should use new genetic materials, develop handling and processing technologies to reduce losses and broaden the market of agricultural products. This is particularly important in native and tree crops with high potential value but limited markets such as cassava, plantains, tropical fruits (cupuazu, guarana, camu-camu, etc.) and native industrial products (timber, resins, fibers, etc.).

**Microregional Level**

Study and characterize the area's natural resources to better organize use of land resources, including the protection and reforestation of more fragile areas.

Develop a microregional communication and marketing infrastructure to activate the rural economy by facilitating the productivity and trade of farm products with high economic potential.

**Regional/National Level**

Define areas of protection and areas to be developed based on sound conservation and economic criteria.

Develop and implement appropriate policies to facilitate regional and national development.

**International Level**

Strengthen national institutional capacity for natural resource appraisal as well as agricultural research and development, enhancing their work through better access to information, equipment and training.

Invest in research on pasture-crop rural development cases in contrasting microregions to learn first-hand the complexities of these systems and appropriate development approaches to increase rural productivity, incomes and sustainability.
CONCLUDING REMARKS

Rural development implies the modification of natural environments as well as the proper use and conservation of natural resources. However, farmers, in their struggle to leave poverty behind, are not worried about regional or global concerns such as conservation of natural resources (erosion, deforestation, watershed management, global warming). They are not aware of the sustainability issue since their main concern is their income. To address present development and conservation problems, a combination of appropriate policies and technologies must be in place. The development of suitable technologies depends on the use of sound genetic materials, knowledge about integration and management in relevant farming systems and the availability of markets for farm products.

Research on integrated tree-livestock-cropping systems based on high inputs, products with limited markets and sophisticated management no doubt will yield interesting papers and information about what can be done "if." These will be nice demonstrations but irrelevant to the possibilities of rural development.

Research and development institutions should work closely together to solve the most pressing technology constraints at the regional level and to increase the productivity of the most important components of existing farming systems. Often, there are only two or three such components in a region and research targets must be chosen carefully. Defining a well-focused target for regional research and development requires coordination to achieve the best use of available genetic, informational and financial resources. The effort should aim to facilitate the adoption of new technologies to increase regional productivity, farmers' incomes and rural well-being. Raising incomes will expand local markets for a variety of goods and services. In this way, regional development, modernization and agricultural intensification can proceed together.
REFERENCES


CIMMYT (Centro Internacional de Mejoramiento de Maíz y Trigo). 1987. 1986 CIMMYT world maize facts and trends: the economics of commercial maize seed production in developing countries. CIMMYT, Mexico City, D.F., Mexico.

Cochrane, T.T.; Sanchez, L.G.; de Acevedo, L.G.; Porras, J.A.; and Garver, C.L. 1984. Land in tropical America, vol. 3. CIAT-EMBRAPA-CPAC.


Dodd, J.C.; Koomen, I.; Arias, I.; and Hayman, D. n.d.a. The management of vesicular-arbuscular mycorrhizal populations in acid-infertile soils of a savanna ecosystem, I: the growth, nutrition and mycorrhizal status of several tropical crops and pasture species following inoculation in the field. (In typescript.)

_______. n.d.b. The management of vesicular-arbuscular mycorrhizal populations in acid-infertile soils of a savanna ecosystem, II: the effect of different pre-crops on the growth, nutrition and mycorrhizal status of Vigna unguiculata and Stylosanthes capitata. (In typescript.)
n.d.c. The management of vesicular-arbuscular mycorrhizal populations in acid-infertile soils of a savanna ecosystem, III: the effects of inoculation and pre-crops on the native VAM spore populations. (In typescript.)


Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. (In preparation.)

Riesco, A.; de la Torre, M.; Reyes, C.; Meini, G.; Huaman, H.; and Garcia, M. Analisis exploratorio de los sistemas de fundo de pequenos productores en la Amazonía, región de Pucallpa. Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) and Centro Internacional de Investigaciones para el Desarrollo (CIID), Lima, Peru. 47 p.


CLOSING SESSION:

AGENDA FOR THE FUTURE
CLOSING REMARKS

Michel J. Petit

What substantive lessons can we draw from this symposium? Let me suggest several:

1) The first relates to the global supply-demand outlook. I am pleased that we had a very professional presentation on this topic by Patrick O'Brien. In addition to the need for a high level of professionalism with respect to this issue, the main conclusion concerns uncertainty about future price trends. We know from economic theory, and from common sense as well, that we do not behave in an uncertain environment in the same way as in an environment without uncertainties.

The extent of uncertainty is tremendous. Periods of overall agricultural shortages are clearly a possibility; but I personally believe that over the next few years the more likely scenario is one of continued surpluses. What will actually happen is far from clear. In the event of a drought in the U.S. next year, we could face a serious shortage problem. So future uncertainty is an extremely important fact of life. It has to be borne in mind and it has to be handled. It is especially important for our borrowing countries in designing their policies and I think it is also extremely important for the way we in the Bank conduct our work.

Another point I would like to stress concerns the importance of developments in three areas: technology, trade and the sustainability of agriculture. I trust you noticed that these were exactly the three areas of challenge that Mr. Conable called attention to in his presentation. The same topics were raised by Patrick O'Brien and these were the three topics that I intended to come back to even before I knew they would be raised by Mr. O'Brien. So we do have consensus on the identification of important issues.

2) A second, large and important main theme of this symposium relates to natural resources. I felt the paper by Dan Bromley and Michael Cernea was very interesting. What I would like to stress is the distinction the authors made between common property and open access situations, which is important but also is probably not well understood. I am convinced that it has important implications. However, I am forced to recognize that in the afternoon discussions, at least the one I participated in, and in the reports which we had at the end of the afternoon, not much reference was made to the Bromley and Cernea framework. Is this because the distinction is irrelevant or because participants did not really have enough time to perceive its importance? I believe that the latter rather than the former is the correct answer.

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Regarding the afternoon groups on natural resource management, what struck me was the extreme diversity of the problems that were touched upon and the fact that resource management is central to sustained development in many respects. Clearly, this is an area in which we have much to do, in which much has been undertaken and which poses tremendous challenges, especially the challenge of the complexity of the issues. Another challenge is the need to mobilize multiple disciplines to examine these issues.

When we discuss natural resources, one issue that emerges is that of the reaction of the environment movement. We, the development community, didn't have to wait for the environment movement to tell us to deal with resource issues. We have been addressing them and we should continue to do so. However, I am convinced at the same time that the environment movement is for us a challenge and also an opportunity.

The environment movement can be a very strong political ally in the debate within the developed countries on the need to develop agriculture in developing countries. As you know, there is, particularly in this country, a strong farmers' lobby. Those groups that are organized on commodity lines are especially important, indeed, the most important and powerful in the United States. To a lesser extent they are also significant in Europe. They strongly oppose aid to developing countries, fearing the competition with developed countries' agricultural production. We need allies to oppose these forces.

The most important environmental issue facing the Bank's agricultural sector is deforestation in the humid tropics, in part because its consequence are so visible. The most enlightened members of the environment movement view this process as the result of demographic pressure which forces poor people to migrate to the forest for their survival. This element of the environment movement understands that there will not be any sustainable development and protection of forests unless viable production systems are developed elsewhere.

3) The third theme concerns biotechnology. Here again I think the need for professionalism has to be underlined. Much overselling has been done in this area. I think this morning's presentations on biotechnology were excellent in this regard because they were very balanced. They told us two things. First, a tremendous scientific revolution is underway. Second, this scientific revolution in biology has potentially dramatic repercussions for agricultural research. Agricultural research will not be done now and in the next decades in the same manner as it was ten or twenty years ago.

This scientific revolution may someday lead to a very broad technological revolution, analogous to the industrial revolution that took place in the nineteenth century. Perhaps instead of the mechanical sciences, the biological sciences will this time lead the way. But, and this is my second point, this will evolve over a long period. Historians may decide in the future that the biotechnology revolution was next century's revolution. But it is not as yet comparable, in my opinion, with the industrial revolution. Indeed, the analogy with the green revolution is particularly inappropriate, because developments in biotechnology as of
today do not yet constitute a technological revolution. That came out quite clearly from the presentations this morning.

Peter Dart was, in my view, quite right in urging that advantage be taken of progress in the biological sciences and of the tools that come from it. To do this requires that, for instance, a breeding program should be staffed by breeders, physiologists and agronomists, i.e., the whole array of disciplines that previously have been involved, but now a breeding program must also include molecular biologists, microbiologists, etc. New disciplines need to be brought in but breeding is not a whole new ball game. Of course this has implications for the way we in the Bank do our work, particularly in terms of our support to agricultural research.

This leads me to make several related points concerning the more general topic of agricultural research. As you know, the World Bank supports the CGIAR system -- $35 million plus per annum in the form of grants. We as an institution, however, do not have much leverage on the international centers. Maybe this is something we will need to re-examine at some point though I am reluctant to go very far in this direction because core support to the international centers is probably what gives them autonomy and the ability to be tremendous entrepreneurs.

A second means of Bank support to agricultural research is, of course, through agricultural loans to developing countries. However, the World Bank lends money to sovereign governments, which have their own priorities and ways of doing things. Indeed, national boundaries are more and more a constraint to effective Bank support for agricultural research; and I think the developments in biotechnology show this clearly. In many places in the world, particularly in Africa where there are many small countries, it is very difficult to build viable national research systems that are of high quality. So collaboration across borders is extremely important.

As far as biotechnologies are concerned, networking clearly will be extremely important -- networking between research units and between the public and private sectors in both developed countries and developing countries. Indeed, very complicated networks will have to be established and managed. This is a real challenge since all intervention tools are somewhat blunt. Nonetheless, highly refined institutional arrangements will have to be invented if future support for agricultural research is to be effective.

4) A brief word on the final theme of crop-livestock interactions. The purpose of the sessions on this topic was to look more closely at the technological base of agricultural projects. In that respect, I believe the symposium was quite successful. The discussion clearly indicated that new technologies are needed and that their adaptability and adequacy need to be studied. As you know, this is an area which AGR would like to explore further.

5) This leads me to some of the implications for our work as agriculturalists in the Bank. Let me place myself briefly in the perspective of my own Department, AGR. We feel several topics deserve to be emphasized and we intend to work on these. The first is the issue of
production technologies. We believe that this is extremely important and I believe the discussion here at the symposium reinforced our conviction. My assessment is that this institution, probably because of its recent attention to policy lending, may have slipped in the area of agricultural technologies. We lack a strategic vision of the technological issues and technological developments that confront agriculture. If we are serious as a development institution, we clearly have to be concerned with long-term considerations and we all know that technological change is one of the engines of growth, particularly of growth in our own sector. So this topic clearly deserves our attention.

The second area which I would like to expand in AGR is trade. What developed countries do obviously has tremendous implications for world markets and, in turn, for the fate of agriculture in developing countries. Although I, as an economist, am convinced that there are important gains to be reaped from trade and that the current situation is really doing a lot of damage to developing countries, I am also convinced that the developed countries are not going to fully liberalize their domestic agricultural policies. To work under the assumption that this will occur would, in my opinion, be very unrealistic. Therefore, it seems to me that what we should denounce the trade distorting practices of developed countries, particularly the use of export subsidies. But we have to be a little more sophisticated in our approach to this general topic than we have been in the past. All policies are not equally trade distorting. Campaigning for complete trade liberalization is futile. Instead we need to examine more closely the impact on various types of developing countries of a whole array of policy changes in developed countries.

The last topic that I want to touch upon is that of sustainability. I should first say one thing, however. As a Frenchman I find this word very strange; it cannot be translated into French; it cannot be translated into Spanish and when you look in an English dictionary, it cannot be found! This being said, if the term is not in the dictionary, this probably means that is being used to refer to something quite vague and not well thought out. We need to reflect, to conceptualize, and to specify what is actually meant by this 'catchall' word that we find so convenient to use. Achieving greater conceptual clarity with regard to this term is clearly on AGR's agenda.

In summary, we intend to develop our understanding of agricultural technology issues and the policy process which may lead to some degree of agricultural trade liberalization. We will also attempt to formulate more clearly the issues subsumed under the convenient but vague concept of sustainability. These new emphases will complement work already undertaken by AGR, our ultimate objective being to articulate as clearly as possible the issues raised by the promotion of agricultural growth and the fight against rural poverty, i.e., the two main objectives of our sector within the Bank.