

**Is There a Doctor
on the Farm?**

*Managing Agroecosystems
for
Better Human Health*

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Managing Agroecosystems for Better Human Health

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The interests of our partners in developing countries demand that new research create synergy between agricultural practice and health practice, rather than merely preventing the two from getting in each other's way.

1. INTRODUCTION

An old adage says “you are what you eat.” It is generally taken as an admonition to avoid junk food or, more positively, to adopt healthy eating habits. But there may be another nugget of wisdom lurking in the words of that deceptively simple saying: We human beings are intimately bound, even biologically, to our food-producing environment, to the natural resources around us. So, we cannot pretend, as we have often done in the past, to be dispassionate observers of the global agroecosystem, as if it were a goldfish bowl. And we should no longer think of ourselves as distant, disconnected consumers of its products. We, like soil and water, plants and animals, bacteria and fungi, are integral and dynamic components.

It stands to reason, then, that our production and consumption practices, not just our eating habits, bear strongly on human health. And, to stretch the logic a bit, human health and human production methods – to generate food, fuel, fodder and fiber – influence each other profoundly, as well as the health of the natural environment. Thus, we not only are what we eat; the image of our species is also reflected in how we produce it. True poverty arises when people lack natural and other resources necessary to maintain good health, that is, the capacity to enable themselves and their descendants to realize fulfilling lives.

Health Promotion versus Risk Reduction: A Portfolio of Projects

This discussion paper sets out the rationale for a more holistic approach to two, normally separate domains of research – human health and agriculture. The latter is meant to include the natural resource management (NRM) practices of farmers, fishers, foresters and other land users. We also present evidence for a simple but potentially far-reaching hypothesis: good management of agroecosystems has the potential not only to reduce human health risks but also to intentionally, actively, and cost-effectively promote well-being.

The paper draws on the experience and results of several research projects supported by Canada's International Development Research Centre (IDRC) and carried out by various CGIAR and non-CGIAR centers. The projects, several of which feed into larger initiatives funded by other donors, are diverse and, we believe, innovative. They represent a range of countries, agroecosystems, research methods and health/agriculture interactions.

The information presented here is, in part, a summary and logical extension of a four-day international consultation¹ that brought together participants from universities, NGOs, international agencies and national governments to discuss ecosystem approaches to understanding and improving human health. The consultation and scientific presentations were wide-ranging. The participants, many of them researchers involved in on-going projects, explored the human health elements of not only agricultural environments, but also urban and coastal ecosystems. This paper focuses on ecosystems stressed by intensified agriculture.

IDRC recently decided to systematically assess the on-going health/agroecosystem projects it now supports. The evaluation results, we hope, will stimulate further interest in, and integrated research on, the links among human health, agriculture and natural resources. This paper, as a first attempt to synthesize concepts and results to date, is expected to serve as one of several reference points for the evaluation and for a forthcoming international electronic forum on the topic². While the main text largely reflects an initial IDRC interpretation of progress to date across the spectrum of projects, it draws on the thinking of many individual researchers. In addition, the 11 appended project summaries reflect the input of those scientists closest to the methodologies and results.

Getting under the skin of the health/agroecosystem continuum

Past agricultural research has, of course, sometimes included human health components. Studies of the nutritional content of food, pathogens in fresh and stored farm products, and the harmful effects of pesticide overuse are a few examples. Similarly, health research, especially in toxicology, occupational health and epidemiology, has sometimes been agriculture-specific. However, these investigations have scratched only the outer skin of the health-agroecosystem continuum. Many other connections – biophysical, but also social, economic and policy-related – need to be investigated and better understood. Without such knowledge, we scientists and development promoters, mandated to alleviate poverty through information and technology, risk doing harm as well as good. What is the value of, say, boosting crop production for improved food security if the end result is to undermine other aspects of the health of the very people who were supposed to benefit?

Agroecosystems and their interactions with human health are intricate and rarely amenable to simple linear analysis. In fact, they are sometimes said to be unpredictable, which suggests that the idea of “agroecosystem management” may be an oxymoron. Nevertheless, it is our hope that, far from scaring off potential contributors, this inherent complexity will arouse scientific curiosity, challenge researchers in developing countries and stimulate international collaboration. The world needs bold hypotheses, ideas that lead to new tools, methods and transdisciplinary

¹ IDRC/UNEP consultation on *Ecosystem Disruption and Human Health* as part of the Canadian Conference on International Health, 14 to 17 November 1999, Hull, Canada.

² This e-conference will take place in late 2000 or early 2001. Information will be available from IDRC.

innovations. The interests of our partners in developing countries demand that new research create synergy between agricultural practice and health practice, rather than merely preventing the two from getting in each other's way.

2. ECOHEALTH: AN EMERGING PARADIGM

Agroecosystems Defined

Among the world's varied ecosystems, agricultural ecosystems occupy a dominant position. They cover 30% of the world's land mass, and farmers, the primary stewards of agroecosystems, manage more area than any other group of people.

An agroecosystem can be defined as a geographically and functionally coherent domain of agricultural activity, including all living and non-living components and the interactions among them. Determining its precise physical boundaries is rather arbitrary and depends on the purpose of the analysis. The system may be a single farm, a rural community or microwatershed composed of many farms, or a major watershed. Or it may be an entire region broadly defined by climate, vegetation, and other ecological traits – as in the case of tropical forest margins or savannas.

Agroecosystems interact strongly with each other and as such are not closed systems. People migrate into and out of agroecosystems. Purchased inputs like seed and fertilizer are brought in from other areas. Trade in commodities means that food enters and leaves the system. Soil erodes off hillsides, washing downstream into neighboring ecosystems, sometimes with disruptive consequences for water supply and navigation. Human and plant pathogens, in some cases vectored by insects, may invade from outside regions causing an epidemic of disease and then fade. Or they may be seasonal, in step with temperature and water cycles.

Parallel Paths to Holism

The ecosystem approach to human health is deeply rooted in the events, innovations and debates of the last century that eventually led to the powerful but sometimes still elusive notion of sustainable development. The compartmentalization of agricultural sciences into discrete specialties focusing on narrowly defined production problems made the Green Revolution possible. Exploitation of the world's biological and energy resources, in the form of germplasm, soil organic matter and chemical fertilizers, triggered a global production boom and averted widespread famine. The overall benefits, however, were unevenly shared by the world's regions. And then, of course, the initially unforeseen but now well-known consequences of this success began to take their toll. Degradation of soil and water resources became widespread, biodiversity in many areas dwindled, and excessive use of agrochemicals became commonplace, especially with the development of pathogen and vector resistance to pesticides. The expansion of farming into vulnerable lands simply added to these mounting environmental pressures.

These trends led scientists and nonscientists alike to rethink approaches to agricultural development. Farmers, researchers, governments and development workers now face the double task of continually boosting food production to meet growing demand, while reversing the damage done to the natural resource base that current and future production depends on. Recognition of the immense challenge ahead has led, over the past two decades, to more holistic thinking about the interconnections between production and natural resource use and conservation.

The evolution of human health research and practice followed a pattern rather similar to that of agricultural research. Advances in sanitation, health education, nutrition, immunization and drug therapy drastically reduced the incidence of infectious diseases during the 20th century in industrialized countries. The eradication of smallpox is among the most widely recognized of these achievements. Much of the progress depended on specialized applications of medical science, often centering on diagnosis and prescription in a clinical setting. That approach, based on a somewhat restricted set of specialist disciplines, tended to isolate people from the physical environment of their daily lives. Despite the notable progress, the benefits have not been shared equally among countries and social groupings. And, globally speaking, infectious and communicable diseases are still the most common cause of death. In sub-Saharan Africa they account for 70% of the burden of illness.

As with the problem of pesticide abuse and pest resistance in farming, the health sector faces the challenge of growing resistance of disease vectors and pathogenic organisms to pesticides and antibiotic drugs. Examples include pesticide-resistant mosquitoes, chloroquine-resistant malaria, and drug-resistant tuberculosis, the latter often associated with the spread of HIV. Climate change and inadequate child nutrition are other factors now seen as undermining the otherwise positive advances made in global health care over the years.

Increasingly, the limitations of clinical medicine have been balanced with preventative public health care concepts. There has been a shift to a more holistic view of human health – one that goes beyond the biology and chemistry of people and medication, to take account of the human living conditions and ecosystems that influence health. This trend parallels the development of IPM. Pushing this trend is the fact that most developing countries cannot afford expensive health technologies, especially drugs, and are therefore looking for cost-effective alternatives to promote public health. Here, ecosystem management has much to offer.

There has thus been a parallel emergence of holistic thinking in the traditionally separate domains of agricultural sciences and health sciences. Each has come to recognize that the sustainability of its enterprise depends on understanding the complex interactions between the behavior of people and the ecosystem in which they live.

IDRC is not alone in calling attention to the interplay between environmental and human health. It is one of several agencies that have attempted, over the past decade or more, to grasp how human health is imbedded in the complex dynamics of ecosystems and conditioned by the poverty that is accentuated by stresses on those ecosystems.

The publication in 1987 of *Our Common Future*, the report of the Brundtland Commission, was like a shot heard round the world. It firmly placed in the international limelight the issue of sustainable development, a subject which until then had been debated mainly by scientists and environmentalists. A new publication by IDRC traces the importance of the event, and its follow-up at the 1992 Earth Summit in Brazil, for the evolution of “ecohealth” thinking:

“While the Brundtland commission’s mandate did not refer specifically to human health, the report identified clearly the role that human beings play in changing the environment, and it established unequivocally the impact that environmental changes in turn have on human health and well-being. This theme was taken up again by [UNCED, 1992]. In its report it noted that health and development are intimately related. In the first place, underdevelopment is directly associated with poverty, which is a major determinant of health. Secondly, inappropriate development leads to overconsumption of resources and degradation of ecosystems. These two findings, coupled with a growing world population, have the potential of causing severe environmental health problems not only in developing countries but also in those of the industrialized world. Agenda 21, the action plan for sustainable development proposed by UNCED, espoused the idea that the essential health needs of the world’s people must be urgently addressed. What is more, the document recognized that in order to meet these basic needs, more attention would have to be paid to the links between health and improvement of the physical and socioeconomic environment.”

Agenda 21 subsequently became a focal point for IDRC thinking and research-support work. The Centre’s Ecosystem Approaches to Human Health (Ecohealth) Program Initiative, under which the eight CGIAR-led projects reported here are funded, took an important cue from the UNCED action plan. Specific parts of Agenda 21 make direct reference to the need to pay more attention to links between agroecosystem management and human health. For example, the action plan³ recommends that agricultural water management plans be developed within a comprehensive set of policies for health, food production and environmental protection.

Here it is important to distinguish between the more traditional environmental health approach to research and the “ecohealth” approach taken by IDRC’s program initiative. At its most basic level, the former has to do with identifying interactions between a specific human health indicator, such as incidence of cancer, and a contaminant in the environment, such as dioxin. An ecohealth perspective, in contrast, is transdisciplinary and recognizes system complexity and multiple determinants of health.

Major international agencies have likewise contributed to more holistic thinking on health, poverty and sustainable development. The United Nations Development Programme (UNDP), for example, through its Human Development Report and human poverty index, has placed increasing emphasis on non-economic indicators of poverty, particularly health, social and environmental factors. These include shortness of life, lack of basic education, and lack of access

³ Page 78, chapter 3, Agenda 21, Edited Popular version by Daniel Sitarz.

to proper nutrition, safe water and health services. As the CGIAR is explicitly committed to reducing poverty, it would seem logical to systematically examine the health/agroecosystem interface, given the close connections between health and poverty that major development actors like UNDP now explicitly recognize.

Similarly, the World Health Organization's Panel of Experts on Environmental Management for Vector Control (PEEM) has been actively working with international centers of the CGIAR to promote health research in the context of agriculture. In recent years, WHO has also placed greater emphasis on understanding the links between human health and a range of pollutants in the air, water, soil and food. And a recent publication by the Canadian Commission for UNESCO⁴ also stressed the health-agroecosystem link: "About 70% of the global water harvest goes to farming needs, especially irrigation. Yet nearly half a billion people do not have access to safe drinking water and more than 15 million die each year because of lack of safe water. Thus, neither political nor research decisions should be taken in isolation by one sector [agriculture or health] or another."

Issues for Research in Transition

The international R&D community is clearly moving towards transdisciplinary research to integrate health, NRM and agricultural production issues in an ecosystem framework. But with any paradigm change, there is necessarily a transitional, adaptive period in which logistical and other problems must be solved. In the concluding paragraphs of this section, we mention just a few of the issues now facing holistic ecohealth research by CG centers and other organizations.

Methodology

A major challenge for transdisciplinary research is to harmonize scientific methodologies, data collection and analysis across component disciplines. Methods are also needed to integrate the various results in such a way that the second-order outputs yield new knowledge and insights that no single discipline could provide on its own.

Funding

Research-supporting agencies need to review funding policies and project criteria to ensure that integrated and transdisciplinary science for solving ecohealth problems is not unnecessarily fragmented or stifled by outmoded regulations. Some ecohealth projects will be large and complex, requiring far more coordination and flexibility among multiple donors and executing agencies than in the past.

⁴ Toward a New Contract between Science and Society: Report of the November 1998 North American Preparatory Meeting for the 1999 World Conference on Science.

Scientific culture and education

Despite the potential rewards from more holistic approaches, most scientists have been trained along classic disciplinary lines. Working in multidisciplinary teams is not easy because of differences in scientific language and outlook. While the value of teamwork is increasingly recognized, universities continue to put significant emphasis on individual student achievement and evaluation of that achievement. Transforming scientific culture so that it is amenable to transdisciplinary work will be a slow process and a potential source of conflict.

Participation and organizational complexity

Apart from the extra collaboration required between donors and recipient research institutions, the involvement of NGOs, local authorities, community organizations and farm families poses organizational problems for ecohealth research. The authority of participating government health, agricultural or water agencies (along fixed administrative boundaries, for example) may not match the geographical boundaries of the agroecosystem targeted for health-related NRM interventions. This can lead to jurisdictional problems. Similarly, with multiple participants, conflicts of interest may arise. What is perceived as a health benefit for one group (for example, altering water flows to cut the transmission of malaria) may not be perceived that way by others more dependent on the water supply.

Public awareness

Holistic ecohealth research, by its very nature, attempts to make sense of inherently complex systems. Results may not be expressible as “scientific breakthroughs” or discrete steps toward improved health in developing countries. Scientific communicators such as journalists and research center information staff may need special training and guidance in the reporting of ecosystem-level interventions, outcomes and impact.

Ethical requirements

Ecohealth research necessarily deals with confidential and highly sensitive information, such as medical records and data on family nutrition and personal hygiene. The need to share some information among research team members and other project participants increases the requirements for ethical reviews and enforcement of guidelines for scientific conduct. While agricultural scientists may have little experience with this, collaborating health professionals can be called on to provide guidance.

3. RESULTS AND LESSONS FROM PROJECTS WITH IARCS

Health in International Agricultural Research

Agricultural professionals, whether scientists or farmers, today devote much attention to promoting healthy livestock, healthy crops, and healthy agroecosystems for production of these

commodities. Arguably, these people are in a health care profession, but one in which non-human species are the direct beneficiaries. This newer model of “the agriculturalist as doctor” contrasts with the often prevailing view that agriculture’s mission is simply to produce more and better food and to make sure it is readily available in times of need.

With the growing interest in integrated pest management following the Green Revolution, agricultural “medicine” has shifted even further, from an emphasis on curative use of chemicals to the adoption of multiple preventative interventions — a situation not unlike what is happening in public health. Yet within the context of mainstream agricultural research, human health continues to simmer away on a back burner. For the most part, efforts are directed toward mitigating the negative impact of intensified agriculture on people while advancing plant and animal husbandry to maintain crop and livestock production. Little thought has gone into the design of methods for explicitly harnessing the power of agroecosystem management to actually promote human health. As the primary steward of the agroecosystems that sustain most human life, the agricultural profession nevertheless has the opportunity and responsibility to do so.

Human health has emerged as a development objective in several international IARCs and their collaborating partner institutions. This is a positive trend. The main appendix of this paper summarizes 11 ongoing and proposed research activities in which IDRC has had some involvement. There are, of course, other important activities going on in this area of research, carried out by both CG centers and non-CG organizations with support from other donors.

While each of the described activities can stand alone as a unique and important contribution to R&D for the developing nations, when viewed together they yield a bigger and more intricate mosaic of the interactions between health and ecosystem management.

Let us look briefly at differences in the scope and scale of these projects, as well as some of their key similarities.

- The projects cover several regions and countries and in all but one instance involve CG or CG-affiliated centers: in Asia, Thailand (ICRAF) and Sri Lanka (IWMI); in Africa, Ethiopia (ILRI), Kenya (ICRPE), Uganda (ILRI and ISNAR in separate projects), Côte d’Ivoire and Mali (WARDA), and Malawi and Tanzania (ISNAR); in Latin America, Brazil (non-CG organizations with recent expression of interest from CIAT), Ecuador (CIP), and Peru (CIAT). One project focuses on sub-Saharan Africa generally (ICRISAT).
- The geographic scales of the research range from very localized communities, such as rice-producing villages in central Kenya, to the Amazon Basin in the case of slash-and-burn agriculture, to the quasi-continental scale in the case of efforts to help sub-African agriculture cope with the impact of HIV/AIDS.
- The many agroecosystem-based determinants of human health examined by the projects include food availability and nutrition; exposure to mycotoxins, pesticides and natural mercury; seasonal changes in and access to natural resources; human migratory patterns; disease vectors such as tsetse flies and mosquitoes; and the introduction of irrigation systems. The breakdown of

social capital and order and the influence of external economic forces are also considered. The consequences of structural adjustment and globalization may be implicated in vulnerability to HIV.

- The human health problems encountered in the research include kwashiorkor, vitamin A and iron deficiency, cancers, human immune system suppression, tuberculosis, neurological degeneration, impaired vision, teratogenesis, suicide, malaria, Japanese encephalitis, sleeping sickness, intestinal parasites, diarrhea, and the myriad interactions among these.
- The R&D partnerships formed under these projects bring together various mixes of IARCs, NARS, NGOs, diverse southern and northern universities, government health agencies, women's and community organizations, and most important, local farmers and other individuals.
- The research draws on professional expertise from many disciplines, among them ecology, hydrology, geography, geology, information sciences (mostly GIS-related), engineering, epidemiology, parasitology, entomology, toxicology, veterinary sciences, agronomy, aquatic biology, forestry and agroforestry sciences, social sciences such as economics, sociology, anthropology and management, as well as clinical medicine and nutrition sciences.

These research efforts thus vary considerably in the scale of their geographical coverage and institutional partnerships and in the scope of health problems and scientific expertise directed to their solution. Yet, as outlined below, there are strong similarities between individual projects and, for a few characteristics, among all the projects.

Health as a local priority

An overarching goal of much agricultural research is to protect natural resources, especially by halting human-induced soil degradation, replenishing soil fertility, and conserving biodiversity. Despite the profound importance of these issues as the basis for sustainable agriculture, they often take a backstage to the pressing daily concerns of local people. Rural families' immediate preoccupations commonly include food security, cash income, and human health rather than more abstract concepts like soil fertility and biodiversity.

The case study of mercury exposure in the eastern Amazon and CIAT's project on health, biodiversity and NRM use in the western Amazon's forest margins demonstrate the catalytic effect of tying agricultural objectives to health improvement. In both cases, increased understanding of the health implications of local NRM helped sustain local interest in the research work. Evidence from many projects shows that the rural poor demand immediate payoff from research efforts. Indeed, the value they place on fulfilling short-term needs, especially good health, outweighs the value they assign to the promise of longer-term benefits from agricultural development.

Transdisciplinarity

To varying degrees, the researchers have stretched their minds beyond the traditional boundaries of their disciplines to embrace a new, more holistic paradigm centering on the complex ecosystem within which human health thrives or atrophies. They are attempting to balance integrative thinking with the continued need for reductionist inquiry. For example, efforts in Thailand to find sustainable soil management systems and to understand the health status of rural children in shifting-cultivation communities relied on traditional soil science and medical methodologies. The soil study results suggested that fallowing for as little as five years, a current practice among some hill tribe farmers, is sufficient for sustainable rice-based cropping. However, from a human health perspective, this agroecosystem may not be fully sustainable. As the researchers note, diets with little food-type variety may not provide the nutrients required to enable children to grow, develop and realize their full potential in life. To obtain adequate nutrition, people may need secure access to more land than that suggested by a narrow analysis of upland rice production systems alone. Bringing soil sciences and land tenure issues together with child health research requires a new integrative understanding of the agroecosystem that no single discipline could achieve on its own.

In Ethiopia, national and ILRI researchers integrated information on market economics, nutrition, and NRM to create a transdisciplinary model that quantifies the tradeoffs among soil conservation, food security and income-generating land management strategies. In the lower Amazon, Brazilian researchers integrated knowledge on fisheries, aquatic ecology, toxicology, slash-and-burn agriculture, and human health and nutrition to develop a more holistic understanding of the complex interplay of ecosystem management and human health. This learning process is going on in many settings around the world. As researchers gain insights into the dynamics of human health within an agroecosystem context, they are revealing new ways by which better NRM can be explicitly used to deliver improved health to the rural poor.

Participatory methodologies

An agroecosystem approach to NRM and human health quickly recognizes that local people are simultaneously both the subject of study and key decision makers and actors who must eventually buy into any recommended interventions. All of the on-going projects considered in this review sought greater involvement of local people – through participation in setting research priorities, as cooperating subjects of study, as partners in the conduct of field research, as decision makers choosing appropriate local interventions, or in negotiating shared responsibility for NRM with various levels of government. Including health objectives in the research clearly motivated people in the Amazon to take greater interest in NRM research objectives.

Gender and social grouping

All the research activities recognized that women, men and children, and indeed various socially distinct subclasses, occupy different life spaces or ecological niches within their respective agroecosystems. For example, CIP demonstrated that while men are often more exposed to toxic chemicals during spraying, women are at greater risk from washing farm laborers' contaminated

clothing. Because women make up the majority of the rural poor, South African research suggests that they are more at risk from diets highly contaminated by mycotoxins. Gender differences in roles of rice farmers can lead to increased bilharzia in those in contact with parasite-laden irrigation water. Researchers from WARDA noted that increasing irrigated rice crops to two annually from one may result in reduced food security for women farmers.

In many cases, competition and power struggles over access to land and other natural resources aggravate the disparities among different groups. The health of vulnerable groups in particular suffers most from the negative impacts of agriculture. Because the poor have few livelihood options, their ability to carry on productive NRM, agriculture and other activities quickly diminishes with an increased burden of illness. For example, the marginalized hill tribes of Southeast Asia have lost access to traditional land and, with shorter fallow periods, rely on less substantive and diverse diets. Heavy reliance on rice may end up undermining the sustainability of community livelihoods.

Agroecosystem-related health risks often place a greater burden on women than men. In many cultures, women are responsible for family health care, but men have decision-making power when it comes to the use of land and other natural resources, whether it be for agriculture or other purposes. IWMI's research demonstrates that men, who have the mandate to manage irrigation, often overlook women's need for reliable and safe supplies of domestic water. Yet when women function as heads of households, their actions are more likely to reflect the need to maintain family health. Nevertheless, in some instances men are at greater risk than women, as in the case of Amazonian fishers exposed to mercury and Ecuadorian potato farmers in close contact with dangerous pesticides during preparation and spraying.

Subclinical and non-specific symptoms of poor health

Exposure to mercury in the Amazon, to the insecticide carbofuran in the Andean highlands, and to mycotoxins in Africa reveals the potential impact of health risks that generate previously unrecognized and often non-specific symptoms of declining population health. In all three cases, there is growing evidence that rural poor people in particular suffer from degeneration of their nervous systems and from a range of other conditions such as cancer, birth defects and immunosuppression. Apart from these studies, literature shows that schistosomiasis and malnutrition also contribute to immune system suppression. Immunosuppression caused by agroecosystem-based factors may well be a significant factor in the high morbidity and mortality rates associated with the infectious diseases in sub-Saharan Africa, South Asia and tropical America.

Ecosystem uniqueness, spatial variability, levels of NRM

The research projects demonstrated the unique character of each study area or ecosystem. Sites differ in terms of their history, heterogeneity, biodiversity, soil fertility, climate, seasonality, availability of water, human ecology, and the degree and means by which they are affected by human-made and natural forces, whether local, regional or global. Conclusions from one system may not be applicable elsewhere even where two ecosystems have a superficial resemblance.

A clear example arises from the three studies that consider irrigated rice production and malaria. In the West African Sahel, evidence suggests that under certain conditions, the introduction of irrigation, while increasing anopheline mosquito populations, does not increase malaria transmission, but in Kenya and Sri Lanka, researchers believe the reverse is true. In the Peruvian Amazon, the high Andes of Ecuador, the irrigated rice systems of West Africa and the tsetse-prone areas of eastern Uganda, researchers emphasize the importance of understanding spatial and seasonal variation in the impact and management of ecosystem-based determinants of human health. There is growing recognition that excessively centralized or top-down NRM should be balanced with regional flexibility in decision making. Otherwise, decisions may interfere with time-tested traditional or ecologically sound natural resource use, thus threatening human health and promoting rather than alleviating poverty. For example, in both Thailand and Peru, researchers observed the vulnerability that marginalized tribes face when exposed to external demands that restrict their access to traditional land and natural resources.

Tradeoff analysis

When ecosystem management objectives are incompatible or at least not fully complementary, tough choices must be made. If the local development agenda includes better human health, higher agricultural production, increased cash income, and sustaining the ecosystem's capacity to deliver produce and ecological services, then decision makers, including farmers, must be able to analyze the tradeoffs.

Fortunately, there are modeling tools for this type of evaluation. In the highlands of Ethiopia, research indicates that, with available knowledge, inputs and technology, the land cannot provide sufficient calories to maintain people while simultaneously safeguarding and replenishing soil fertility. A viable strategy may be to produce high-valued agricultural products for the market and use the earned cash to buy inputs such as fertilizer, as well as nutritionally adequate food for family consumption. The investigators from Ethiopia and ILRI question the tradition of depending on manure for fuel. While other alternatives are not readily available, this strategy prevents nutrient recycling, leading to further soil degradation, food insecurity, malnutrition and declining human health.

In another example, researchers question the wisdom of having the rural poor apply pesticides to potato crops. Their work substantiates studies on irrigated rice systems that suggest that, under some conditions, the value of the production lost by not using pesticides is outweighed by the health costs that are avoided. Often, different groups of people do not equally share the costs and benefits of increased production or changes in health and the environment. This inequity can lead to advantages for the powerful that override economically sound agroecosystem management. The need thus arises for policy interventions to balance the tradeoff between health and food production and to ensure that the well-being of poor farmers and farm laborers is not jeopardized.

Impact of health on farm productivity

Most of the research examined in this paper focuses on the health impact of agroecosystem management. ISNAR's proposed study on HIV/AIDS in Africa, however, also highlights the devastating effects of ill health on rural people's livelihoods, particularly labor-intensive farming and natural resource use. Sick people cannot work nearly as well as healthy people. And even healthy people must care for the sick and dying, organize and attend funerals, and care for orphans. The financial toll exacted by health care and burials puts enormous stress on families who have already seen a decline in household income. The loss of educated or otherwise knowledgeable people also undermines the transfer of know-how, further reducing human productivity.

The specter of HIV/AIDS snatches more than loved ones, local wisdom and savings. It also takes away the simple human dignity of looking to the future with hope, the luxury of long-term planning. Concern for the future health of the natural resource base gives way to immediate and often desperate needs for cash and food. HIV's impact on Africa makes it unmistakably clear that "health" cannot be usefully understood as the mere absence of disease. Rather, it must be seen from a wider angle, in a more positive light, as the optimal capacity for people to lead full and rewarding lives.

Apart from HIV, other aspects of poor health undermine agricultural productivity. Malnutrition, the subject of several studies, reduces vigor and the human capacity to learn, thereby thwarting a community's ability to transform natural resources into food and other products. Studies of potato cultivation in Ecuador indicate that long-term exposure to pesticides actually decreases farmers' individual productivity.

Agroecological basis of human health issues

To remain healthy, people need a varied diet. For rural people in developing countries, the natural resources that surround them are the main and sometimes sole source of that variety, a luxury that supermarket-dependent consumers in northern countries take for granted. Yet relatively few people working in NRM or agriculture have also had formal training in human health and nutrition. Even fewer people trained in medicine and public health acquire formal skills in natural resource sciences.

While reductionist science may produce specific high-quality products – for example, plants with enhanced protein or beta-carotene⁵ (a building block for vitamin A) – research rarely considers the total range of food products seasonally available within an agroecosystem. And rarely is the menu of available food sources matched with gender- and age-specific requirements. Similarly, relatively reductionist environmental health research has tended to focus on one-to-one links between a particular health hazard and a very limited set of health indicators. To varying degrees, all the research projects discussed in this paper have attempted to

⁵ Work of Ingo Potrykus of Switzerland, cover story, *Time Magazine*, 31 July 2000.

move beyond this traditional approach to nutritional and environmental health research. They have pursued lines of inquiry intended to help uncover the complex structure of their respective ecosystems and to develop a more holistic understanding of the multiple ecological determinants of human health.

Targeting human health improvement through NRM interventions is a clear trend emerging from agroecological research in the CGIAR and like-minded research organizations. Agroforestry, for example, is now seen as one means to improve dietary diversity, cutting over-reliance on staple carbohydrates like upland rice. Agroforestry may also help reverse mercury contamination of aquatic food chains over the long term by controlling soil erosion. And, as an immediate solution, researchers from the State of Pará, Brazil, and from Montreal, Canada, are working with local communities to modify fishing practices to reduce human exposure to this heavy metal.

ILRI now believes that better NRM targeted on livestock may reduce the scourge of sleeping sickness in Uganda. In two highlands settings – ILRI's project in Ethiopia and ICRAF's in Thailand – livestock are also seen as key contributors to enhanced nutrient recycling to maintain higher levels of food production. Animal products, in addition, provide essential nutrients such as Vitamins A and B12 that are often lacking in people who are forced into a vegetarian diet composed mostly of carbohydrates.

WARDA, ICIPE and IWMI are experimenting with modified management of livestock, vegetation and irrigation schemes to help control malaria and other vector-borne diseases. And ISNAR, with a view to reducing HIV transmission, is looking at the promotion of agroecosystem-based opportunities in people's home areas to discourage labor migration. ICRISAT and researchers from Canada's Carleton University and the South African Medical Research Council are attempting to improve soil and crop management as a way to reduce human exposure to aflatoxins and fumonisins. For example, restoring soil fertility may make host plants less susceptible to invasion by mycotoxin-producing fungi.

Integrating Research on NRM, Poverty and Human Health

The similarities and differences among the research projects and results described above exemplify the profound interdependence of human health, poverty and agroecosystem management. What is needed is a common framework to clarify the complementary roles that NRM and health researchers can play.

Consider the pyramid of human health (Figure 1). In any human population, and for many health problems, a small number of individuals exhibit acute clinical symptoms. These are the problems that most medical professionals attempt to heal. When they fail, many patients continue to suffer and some die. However, a much larger number of people suffer from early subclinical changes and exhibit nonspecific symptoms. These are rarely reported and are often untreatable by the health care system. They require preventative approaches that go beyond the current domain of most public health agencies.

Conventional curative medical services are expensive to deliver and focus on the needs of the minority, namely those who have clinical signs of illness and access to medical care. There is growing evidence that further investment in curative health care may actually lower health standards by diverting resources away from the preventative non-medical measures that are better able to deal with widespread non-clinical threats to human health.

In future, we can expect that health delivery will no longer be the monopoly of classic “western style” health professionals. Many preventative interventions are needed to promote better health among the majority of the population represented by the lower half of the pyramid. Recognition of this creates an important role for agricultural professionals. Agroecosystems contain most of the fundamental determinants of human health particularly that affect the rural poor. While agricultural institutions and their personnel often make significant contributions to improving human health, ignorance of the human health consequences of NRM can undermine or conceal those gains. However, better understanding of the complex nature of human health within agroecosystems can pave the way for active delivery of preventative NRM and agricultural interventions that help achieve consciously formulated human health objectives.

The rural poor in southern countries depend heavily on agriculture and local natural resources for their livelihoods and well-being. Thus, health, poverty levels, and the sustainability and productivity of the agroecosystem are inseparably linked (Figure 2). Poor health is largely the

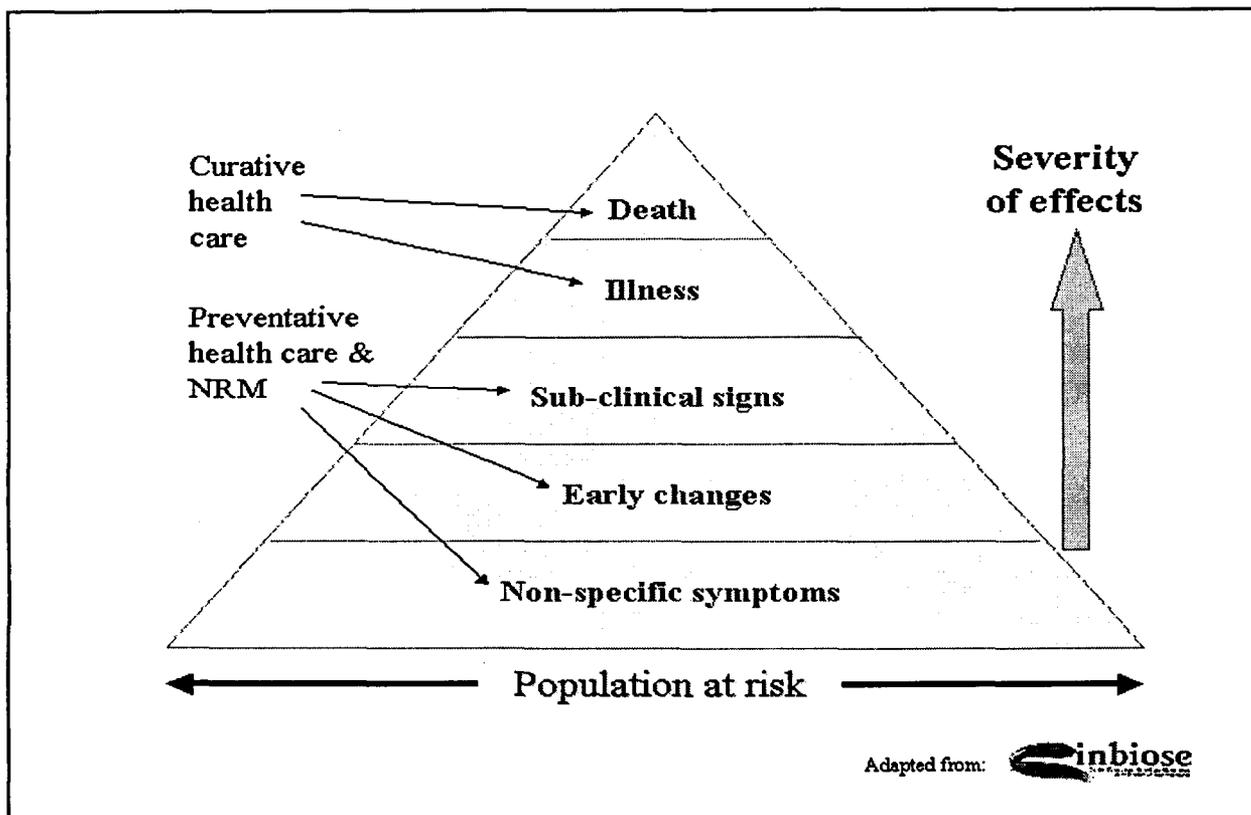


Figure 1. Pyramid of health demonstrating importance of preventative NRM and public health interventions in addressing population health.

outcome of unfavorable agroecosystem-based factors such as poor water quality, insufficient and nutritionally inadequate food supplies, inadequate housing, and exposure to pesticides, mycotoxins, vector-borne diseases and natural contaminants such as mercury. Individually, people with either acute clinical illness or non-specific symptoms of poor health are less capable of sustained management, harvesting and processing of agricultural and other natural resources. Collectively, an unhealthy community must divert more of its time and resources to dealing with illness and its social consequences. And its members are forced to reduce their investment of labor and cash in agriculture. The direct result of poor health is lower productivity, the adoption of less sustainable NRM practices, and a downward spiral of poverty.

More than lack of cash, to be poor means to suffer several or many deprivations at once — lack of access to health care, natural resources, credit, farm inputs, safe housing, knowledge, information, education, quality food and labor. Global economic policies such as structural adjustment programs can aggravate the impact of poverty by reducing the purchasing power of people's limited cash assets. Poverty leads many people to migrate in search of employment. This can expose them to additional health risks and contributes to the breakdown of social capital. To maximize cash income for immediate needs, poor and often marginalized farmers tend to forgo investments for long-term maintenance of soil productivity. They put added pressure on common property resources such as grazing areas and woodlands. They frequently sell the highest-quality produce, leaving their families to depend on nutritionally inadequate food

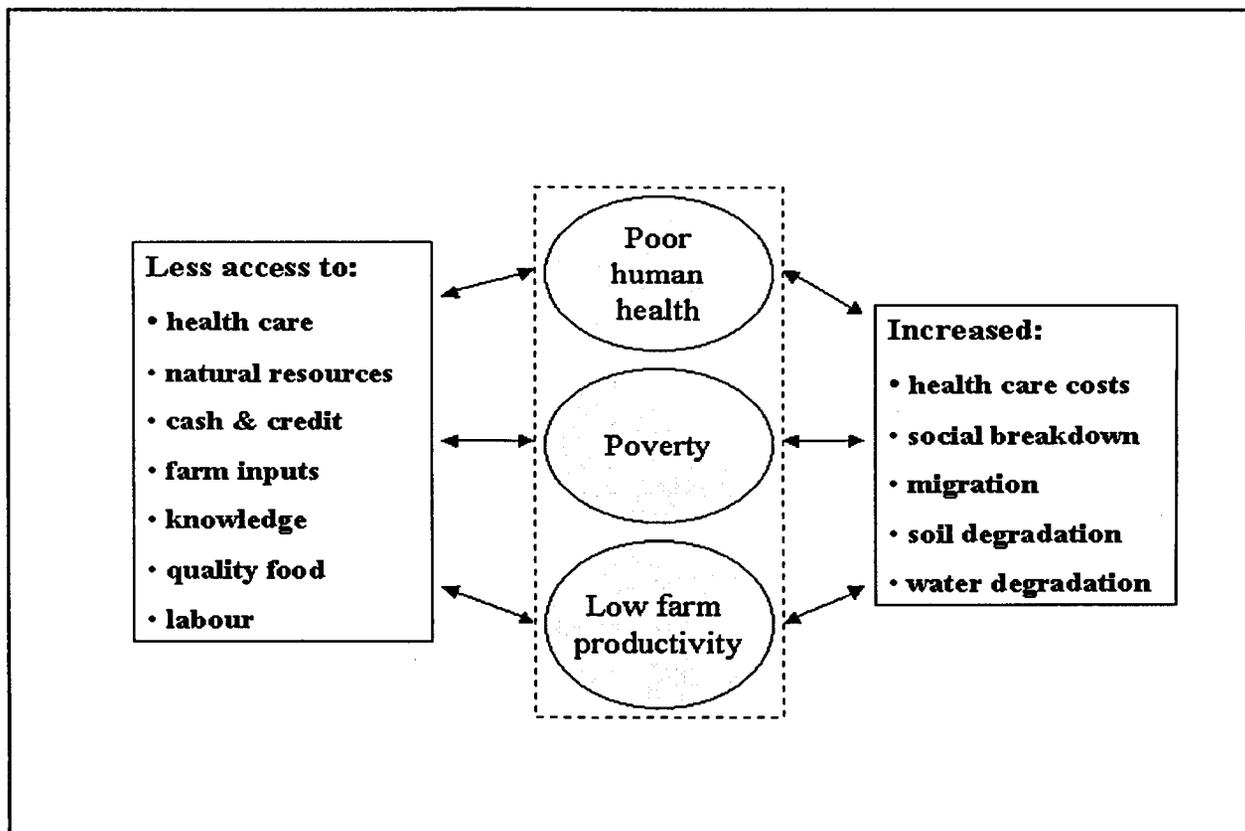


Figure 2. Human health, poverty and agroecosystem productivity are inseparable.

that may also be contaminated. The poor are typically marginalized on the basis of their gender, education, or ethnicity, which may further restrict their traditional access to essential natural resources. In addition, because marginalized people are “out of sight and out of mind”, they are at greater risk from externalities generated by more powerful producers and consumers of natural resources. For example, in efforts to increase food security in Southeast Asia, increased rice production is promoted. Consequently, the hill tribes now frequently suffer some of the most severe malnutrition in the region because they have lost access to diverse dietary resources that gave them a nutritionally balanced diet.

The low farm productivity and unsustainable land management practices that emerge from poverty and poor health reinforce the factors that compromised human well-being in the first place. The momentum of the poverty cycle is thus maintained. To break that cycle in poor rural communities of developing countries requires a multipronged attack on ecosystem degradation and related threats to human health.

4. WHERE DO WE GO FROM HERE?

More than 50 research and development institutions and many more individual researchers contributed to the synthesis exercise that UNEP and IDRC initiated in late 1999. Collectively they have demonstrated that agroecosystem-linked human health is a broad-based research theme actively pursued within the CGIAR and its network of affiliated partners. Other institutions, including investors, are also addressing the issue and deserve mention. For example, consider IRRI’s research on pesticides and health or IFPRI’s documentation of human nutrition in relation to the global pattern of agroecoregional productivity. It is important that they share their experiences and views.

The connections among NRM, human health and poverty are inseparable, and this paper scratches only the surface of existing knowledge. Individually, the projects described here could easily be overlooked by policy makers and others charged with improving the lives of large numbers of people. Together, however, they convey a more persuasive message to policy makers that expanded inquiry into additional causal linkages between human health and agroecosystem management could significantly alleviate rural poverty around the world.

Where, then, do we go from here?

Is there sufficient mutual interest in exchanging methods, insights, results and concepts related to the web of health-agroecosystem-poverty relationships to warrant creating a coherent, integrated global mechanism for this purpose? Would researchers’ wider sharing of knowledge across diverse agroecosystems enhance the effectiveness and impact of their individual research activities? Is there a need to build a more solid theoretical foundation by which better NRM, along with traditional health interventions, can contribute to improving people’s health? IDRC believes that the answer to these three questions is “yes”.

IDRC proposes further consultation to determine whether increased investment in research on

agroecosystem management for human health is needed, desired and feasible and what the likely outcome might be. However, such a consultation must reach beyond the narrow spectrum of activities in which IDRC has so far been involved. It must also give greater weight to the issues of concern to southern partners, particularly the ultimate beneficiaries, the rural poor.

Initially, IDRC proposes an electronic consultation. While this can help answer the following questions, other suggestions are encouraged:

- Besides the health-poverty-agroecosystem linkages touched on in this paper, what other key issues are currently being addressed, or should be addressed, under the umbrella of international agricultural and NRM research?
- What are the views of researchers, policy makers, farmers, and other stakeholders given their local, national and international roles, mandates and concerns?
- Apart from traditional partners in NRM and agricultural research, which additional collaborators are needed at the local, national and international levels?
- What innovative institutional arrangements would facilitate collaboration among partners who have little experience working jointly to improve human health through better agroecosystem management?
- How can traditional preventative and curative human health care systems be integrated with agroecosystem management so that together the two approaches more effectively and efficiently improve human lives and reduce poverty?
- Given the shortage of funds available for traditional agricultural and NRM research, what are the prospects of obtaining extra funding from investors whose priority is better human health?

IDRC's experience has generated initial answers to some of these questions. To dwell on them now would likely cut off fresh thinking. IDRC therefore invites responses to the ideas raised in this paper and to the questions posed for the electronic consultation. We also welcome expressions of interest in supporting, managing and participating in the consultative process. During the next few months in late 2000 or early 2001, IDRC will share these initial responses and, in collaboration with willing partners, take the consultation forward. If consensus emerges that future investment in agroecosystem approaches to human health is desirable, we look forward to collaborating with you to make this happen.

Appendix

Selected Summaries of Ongoing and Proposed Research on Agroecosystem and Human Health in International Agricultural Research

Facilitating Institution	Location and Title	Page
ICRAF	<i>Thailand: Shifting Cultivation and Health Conditions of Karen Hill Tribe Families</i>	22
ILRI	<i>Ethiopia: Enhanced Human Well-Being through Improved Livestock and Natural Resource Management in the East African Highlands</i>	24
ICIPE	<i>Kenya: Agroecosystem Management for Community-Based Malaria Control</i>	27
ILRI	<i>Uganda: Sleeping Sickness and Natural Resource Endowments and Use</i>	29
ISNAR	<i>Eastern and Southern Africa: AIDS and Food Security (research proposal)</i>	31
ICRISAT & SA MRC	<i>Sub-Saharan Africa: Ecology of Mycotoxins in Maize and Groundnuts</i>	33
CIAT	<i>Peru: Health, Biodiversity and Natural Resource Use on the Amazon Frontier</i>	35
Univ. of Para & UQAM	<i>Brazil: Mercury Poisoning in the Amazon</i>	39
CIP	<i>Ecuador: Pesticides, Health and Changes in Potato Technology</i>	42
IWMI	<i>Sri Lanka: Agroecosystem Management for Human Health in the Uda Walawe Irrigation Scheme</i>	44
WARDA	<i>West Africa: Irrigation, Water Management and Vector-Borne Diseases in Rice Farming</i>	47

Based on weight-for-age, nearly all the Karen children examined were classified as malnourished, though not severely. More than half had parasitic infections.

Thailand: Shifting Cultivation and Health Conditions of Karen Hill Tribe Families

Health / agroecosystem links

How do shortened fallow periods in shifting cultivation affect soil fertility, rice productivity, food supply and consumption? What is the link between management of this agroecosystem and farm families' nutritional status?

Research organizations

International Centre for Research in Agroforestry (linked to the CGIAR Alternatives to Slash and Burn Initiative); Chiang Mai University Department of Pediatrics, Thailand; University of British Columbia Department of Forest Sciences, Canada.

Background

The Karen and Lua hill tribe farmers of northern Thailand have practised shifting cultivation for centuries. They clear forest plots by slashing and burning, plant crops like upland rice for a year or two, then abandon the land. Traditionally, the fallow period was a decade or more, which allowed the land to regain fertility. In recent decades, though, population growth, natural resource policies, and changing land tenure have resulted in a drastic shortening of the fallow period – in some instances to less than six years. There are fears that the new production cycle threatens soil fertility, upland rice productivity and food supplies. In 1992, local Thai authorities reported, for example, that only about 50% of minority hill tribe families in Mae Chem District had a sufficient rice supply. Switching from slash-and-burn to permanent (fixed-field) rice paddy farming also presents problems. These include environmental and health hazards from using agrochemicals, increased production costs, and potential loss of the plant biodiversity found in fallow fields.

Project description

The project is investigating links between ecosystem management under shorter-fallow production and the health of the Karen farmers in the village of Mae Hae Tai, Mae Chaem District, in northern Thailand. The 4,000 square kilometer watershed of Mae Chaem is a benchmark site for the CGIAR's System-Wide Alternatives to Slash and Burn Initiative. The researchers are examining rice productivity, food supply and consumption (taking into account the special role of women as gardeners, food collectors and preparers), as well as the link between rice productivity and soil fertility. Health workers are assessing the nutritional status of local families, who in turn will participate in data review and help design interventions to solve health and ecological problems. Children are the main target of nutritional assessment. Resulting indicators of health and ecological status will allow researchers to assess and compare conditions in other communities, including those involved in long-fallow and permanent (as opposed to shifting) agriculture. Their findings will support Thai policy making in the areas of land use transformation and health promotion in the country's northern watersheds.

Results to date, preliminary conclusions and future directions*

The three-year project is in its early phases. Under the health component, a Thai researcher assessed between 51 and 53 Karen children, the exact number depending on the test being conducted. The assessment of vitamin A status using the Simplified Dietary Assessment (SDA) and Helen Keller International (HKI) methods revealed that all of the study children were at risk of having vitamin A deficiency. They usually consumed foods low in vitamin A. The prevalence of anemia was 15% but this was not due to vitamin B12 and folic acid deficiencies, nutritional factors often associated with anemia. (Vitamin B12 deficiency is common in vegetarians; the children in the study group, however, were all non-vegetarians.) Low iron reserve was observed in 63% of the children. Based on weight-for-age, nearly all the Karen children examined were classified as malnourished, though not severely. In addition, more than half had parasitic infections. Among the 49 Karen adults assessed, only a few were obese, whereas about one-fifth, mostly women, were underweight. Assessment results have been reported to local authorities.

Ecological field studies of crop productivity and the role of nutrients in forest-fallow shifting cultivation revealed an average upland rice yield of about 1 ton per hectare for the 1999 cropping season. Rice productivity, however, is subject to year-to-year fluctuations due to the spatial variability of soil fertility in shifting cultivation fields and to local climate. During the six-year rotation (one year of cropping, followed by five years of fallow), soil changes included an increase in soil organic matter and total nitrogen due to addition of litterfall, but a decline in pH, available phosphorus, extractable potassium, calcium and magnesium due to the diminishing effects of ash. Standing tree, shrub and herb biomass increased gradually over the fallow period. The second-year rice experiment with fertilizer trials revealed that nitrogen and phosphorus were the two most deficient nutrients in the system.

The current fallow period of five years appears long enough to maintain annual rice yields, but any further reduction could pose a threat to soil fertility and therefore to the relative sustainability of the system. The reduced duration of fallow (compared with a fallow period twice as long in some neighboring systems of shifting cultivation) has resulted in a substantial drop in the biomass of fallow fields. It also threatens the survival of some tree species found in the late stages of longer fallows.

The results show shifting cultivation has provided stable rice production over the years. However, rice is low in protein and the observed malnutrition among Karen children may be due to insufficient consumption from other food groups. It is a common hypothesis among development workers that longer fallows supply non-rice products that may be nutritionally important.

A next step for the researchers to determine rice deficiency/sufficiency by assessing consumption at the household level. They will also examine whether malnutrition is worse under short- versus long-cycle systems and whether major shifts in food sources have resulted from this change in production. Other local food sources, such as wild and domestic animals and plants, will be studied to determine their nutritional contribution to the diets of people in the study village.

** Health-related results are unpublished data from the ECONUT Project, Chiang Mai, Thailand.*

Bioeconomic modeling suggests that new production and resource management technologies could, over 12 years, increase farm cash income tenfold from the current low base and cut soil erosion by 20%. Farm outputs would still be enough to supply 2,000 calories per adult per day.

Ethiopia: Enhanced Human Well-Being through Improved Livestock and Natural Resource Management in the East African Highlands

Health / agroecosystem links

How can livestock production and related natural resource management strategies improve food security and human health?

Research organizations and partners

International Livestock Research Institute (ILRI); International Centre for Research in Agroforestry (ICRAF) via the African Highlands Initiative; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); Ethiopian Agricultural Research Organization (EARO); Ethiopian Health and Nutrition Research Institute (EHNRI); Addis Ababa University, Ethiopia; University of Guelph, Canada; University of Florida, USA; University of Manchester, UK; FARM-Africa, Ethiopia; Metcha Catholic Mission, Ginchi, Ethiopia; Dendi Wereda Bureau of Agriculture, Ethiopia.

Background

The East African highlands, covering about 3.5 million square kilometers, are one of the most densely populated regions of the world. Agricultural production, usually a mix of crops and livestock, has become highly intensive and pressure on natural resources, especially soil, is severe. Malnutrition and severe poverty are widespread, particularly in Ethiopia which accounts for 60% of the highlands area.

Deforestation, declining pastures and soil nutrient depletion are common in Ethiopia's highlands, half of whose arable area is moderately to severely eroded. Grain yields are low, less than 2 tons per hectare, in part because farmers can't afford high-production inputs such as chemical fertilizer. Livestock raising is central to the agroecosystems of this region and in Ethiopia accounts for up to 40% of agricultural gross domestic product. Animals provide income (from meat, wool and hides), food, draft power and social status. Manure is used as both fuel and fertilizer. As a capital investment, livestock provide a flexible reserve, convertible to cash in times of family crisis such as crop failure.

It is widely recognized that livestock, if properly managed, have the potential to boost highland agricultural production, alleviate poverty and malnutrition, and contribute to resource conservation. But animal productivity remains well below its potential mainly because of animal diseases (transmitted by tsetse flies and ticks) and low-quality feed. Consumption of even small quantities of meat and milk can improve human nutrition and is especially important for the health of women and children. Animal products are rich in micronutrients, such as vitamins A and B12 and iron – essential for the development of children's cognitive and motor skills. Health education programs, however, are needed to take advantage of any future gains in the region's livestock production since farmers' understanding of nutrition is low.

Research on individual components of the highland agroecosystems has led to new and adapted technologies, but these piecemeal innovations have had minimal impact on the region. Several years ago a global consultation on livestock, the environment and human needs, which brought together participants from 86 countries, concluded that a more holistic approach to R&D was needed. This means systematically taking into account the links between many aspects of the agroecosystem: land use, especially for production of food crops, forage and livestock; management of natural resources like soil, manure and water; biodiversity; family income; gender-related roles; human health and nutrition; and animal health and nutrition. However, the development of new frameworks for assessing sustainability in light of multiple development goals is still in its infancy.

Project description

The three-year project is testing the “agroecosystem health paradigm” as a framework for holistic, participatory assessment of the sustainability of current and alternative crop-livestock production systems in the East African Highlands. The overall aim is to improve human health and nutrition through better management of livestock and natural resources.

Research centers on the community of Ginchi, in Ethiopia’s Awash watershed, which already serves as a benchmark site for the CGIAR’s African Highlands Initiative. Findings will eventually be extrapolated to other regions. Following a 1998 workshop to refine the project methodology and identify gaps in data, researchers gathered detailed biophysical and socioeconomic information on the Ginchi microwatershed. They used a variety of methods, such as on-farm trials, site surveys, and participatory rural appraisal. Together with members of the target community, project staff defined indicators of agroecosystem health, related to factors like household food security, disease incidence, gender-related equity, soil erosion and biodiversity.

A bioeconomic model, comprising both static and dynamic versions, was designed for *ex ante* assessment of the impact of natural resource management strategies on economic, ecological and food-production sustainability. It is based on field data from the Ginchi microwatershed. The dynamic version allows researchers to evaluate both short- and long-term impacts (up to 12 years) of technology and policy interventions, thus providing a more complete picture of sustainability than is possible with the static version. In essence, the model quantifies the tradeoffs involved when farmers attempt to increase or maximize one of three factors: their income, their food self-sufficiency, or the sustainability of their farming system (by reducing soil erosion).

Other component studies of the project examined several topics: farmer adoption of multipurpose trees used mainly as an animal feed supplement; the impact of grazing pressure and manure droppings on biodiversity, biomass production, soil moisture and soil loss; the advantages of minimum tillage and early planting of crops in rows; gender roles and child nutrition in livestock production systems of developing countries; the impact of crossbred cow production on human nutrition and health; and community water supplies, for both households and livestock, and their links with human health.

Results to date

Results of bioeconomic modeling reveal that the practice of agroforestry and zero grazing demands a longer planning horizon, which is only feasible if farmers have more secure land tenure than at present. Livestock play a major role in reducing the negative effects of soil erosion, but proper pasture management, including removal of animals from certain vulnerable areas in some years, is required. Application of the model demonstrates strong tradeoffs between the attainment of food self-sufficiency, high income and reduction in soil erosion. For example, with the application of fertilizer to teff and wheat

in an otherwise traditional production system, farmers' cash incomes would rise by 50% from a currently low base, but annual soil losses would be 31 tons per hectare, which is still higher than the permissible level for the highlands. Under a scenario involving the introduction of a set of new technologies, such as higher-yielding crop varieties, agroforestry methods, and techniques to reduce soil waterlogging methods, the modeling results are quite different. Over 12 years, it would be possible to increase cash income tenfold and decrease aggregate soil erosion by 20%. However, farmers would be increasingly dependent on livestock for manure, draft power, milk and cash flow. Under this scenario, farm outputs would also be sufficient to provide a minimum daily intake of 2,000 calories per adult. The outcomes of the model are being shared with farmers in the watershed and district extension agencies as an aid to decision making for better use of resources.

The adoption study regarding multipurpose trees showed that farmer-to-farmer diffusion through seed sharing – a good indicator of potential for further adoption – has been occurring. The species selected by farmers varied with biophysical factors such as altitude and rainfall. Most farmers were using the trees for fencing, fuel and construction.

Results from the study of grazing pressure suggest that a no-grazing strategy does not help conserve biodiversity and improve soil quality. Recycling nutrients through manure ensures sufficient biomass production for regulated grazing and provides soil with a protective cover. Using dung for fuel aggravates the negative nutrient balance in the soil and depresses biomass production.

Tillage and planting tests during the onset of the main rains (end of June) showed that the time required to establish a crop using minimum tillage techniques was about one-third the time needed with traditional methods. Row planting, via a seeder attached to an animal-drawn Broadbed Maker, resulted in a large saving in seeds. It required only 90 to 110 kilograms of seed per hectare, as compared with 150 to 250 kilograms for traditional broadcasting.

A study of the households that raise crossbred cows and use better feeding techniques confirmed the hypothesis that the adoption of market-oriented dairy technology significantly reduces poverty and improves the nutritional status of the rural poor, particularly women and children.

Farm-level strategies for managing water and livestock have the potential to lessen human exposure to malaria-transmitting anopheline mosquitoes while making the ecosystem more sustainable.

Kenya: Agroecosystem Management for Community-Based Malaria Control

Health / agroecosystem links

How does rice irrigation affect human health? What are its links with domestic water supply and sanitation? Can new options for water and livestock management reduce the transmission of malaria? Which types of intervention are socioeconomically feasible?

Research organizations and partners

International Centre of Insect Physiology and Ecology (ICIPE); International Water Management Institute (IWMI); World Health Organization Panel of Experts on Environmental Management for Vector Control (PEEM); College of Agriculture and Veterinary Sciences, University of Nairobi, Kenya; Kenya Agricultural Research Institute (KARI); Division of Vector-Borne Disease (DVBD), Ministry of Health, Kenya; National Irrigation Board (NIB), Kenya; Kenya Medical Research Institute (KEMRI).

Background

Every year, malaria kills around two million people worldwide, 90% of them in Africa. About three-quarters of Africans live in areas of highly endemic but stable transmission. Another 18% inhabit areas where malaria transmission is seasonal and unstable. The latter areas are particularly vulnerable to deadly epidemics.

Malaria control has centered on two strategies: first, treating sick people with drugs that target the plasmodium parasite; second, using insecticides to eliminate the vector mosquitoes. These methods are not only very expensive, especially given the scarce economic resources of most African countries, but also increasingly ineffective as mosquitoes and malaria parasites continue to build resistance to insecticides and drugs respectively. The risk of environmental damage from insecticides is also a growing concern among the public, policymakers and scientists.

As demand for rice grows in Africa, so does the proportion of cultivated land brought under irrigation. These schemes provide a favorable breeding habitat for malaria-bearing anopheline mosquitoes. In a recent survey to assess the knowledge and perceptions of farmers in a rice irrigation scheme, all 104 families interviewed ranked malaria as their main health problem.

The deteriorating malaria situation in many African communities urgently demands new lines of attack to complement existing control measures. Farm-level strategies for managing water and livestock have the potential to lessen human exposure to malaria-transmitting anopheline mosquitoes while making the ecosystem more sustainable.

Project description

This newly launched 1½-year project aims to improve the health and economic well-being of communities in irrigation schemes. It will do this through the design of improved agroecosystem management practices that also reduce malaria and other health risks. The research will contribute to the development of an agroecosystem intervention model that can also be used in other parts of Africa.

The research results will feed into the design of farm-based malaria control measures which will be assessed for their social and economic feasibility before being promoted and applied. The measures focus on two strategies: water management (for example, intermittent irrigation), and the use of livestock (particularly cattle) to divert blood-seeking mosquitoes away from people. Cattle are dead-end hosts for malaria parasites. However, since opinions differ about the exact role of livestock in malaria transmission, the researchers will first attempt to clarify this link.

Researchers are conducting their core studies within the Mwea Rice Irrigation Scheme, about 100 kilometers northeast of Nairobi, Kenya. Nearly half of the settlement's 13,640 hectares is used for paddy farming, while the rest is devoted to subsistence farming, grazing and communal activities. The tenant population, dispersed in 36 villages, comprises 3,100 families. Malaria transmission in this area is low but stable, with a parasite prevalence of less than 20%.

Researchers have begun the work with a health risk assessment aimed initially at determining whether rice irrigation increases or decreases health risks. This study takes into account a variety of socioeconomic, environmental and institutional factors. The main ones are age, sex, education, occupation, income, religious and cultural affiliation, family size, nutritional status, water management practices, location, and the role and effectiveness of agencies responsible for public health. In parallel, the researchers are documenting and assessing the mixed crop and livestock production systems of the Mwea Scheme. Their aim is to identify opportunities for enhancing nutrition and income generation. Malnutrition generally lowers people's immunity to disease, including malaria. In the Mwea region, the staple diet of cereals is rich in calories but deficient in essential micronutrients which are available in livestock products, grain legumes, vegetables and fruits.

Optimal productivity of both crops and animals in Mwea could be achieved through more efficient use of local resources. Thus, besides the growing of rice, a further integration of livestock and crop production would increase both short-term benefits and longer-term sustainability of the farming system. An enhanced crop/livestock production system yields a mix of consumables and services that provide cash, subsistence and inputs (draught power and manure) to the farm enterprise. Having cattle near households may therefore not only help divert mosquitoes away from people and provide animal protein but also contribute significantly to an increase in home-garden production.

Mwea villagers will contribute to all phases of the research, from data gathering and analysis, to design and implementation of action plans. Participatory rural appraisal methods will be used throughout the project. Women in developing countries are often more vulnerable to environmental hazards than men, yet have less decision-making power over the domestic environment. Much of the research project's data gathering and analysis will therefore be gender specific. This will help ensure that agroecosystem strategies are designed to promote equity and to take gender differences into account.

*Changes in natural resource management
can be planned and integrated to enhance sustainable
crop-livestock production and the control of human
and animal trypanosomiasis.*

Uganda: Sleeping Sickness and Natural Resource Endowments and Use

Health / agroecosystem links

What are the links between natural resource endowment and use, agricultural practices, and the risk and control of human trypanosomiasis? How can communities manage disease risk as part of an overall strategy for managing and using natural resources? Which community organizations and institutions are important for effective natural resource management (NRM)? What kinds of economic incentives promote good NRM and public health management?

Research organizations

International Livestock Research Institute; Livestock Health Research Institute (LIRI) of the National Agricultural Research Organization (NARO), Uganda; Co-ordinating Office for the Control of Trypanosomiasis in Uganda (COCTU); Makerere University, Uganda; University of Edinburgh, UK; University of Guelph, Canada.

Background

Human trypanosomiasis in Africa has two principal forms: gambiensis, found mainly in West and Central Africa, and rhodesiense, mainly in Eastern and Southern Africa. At the turn of the 20th century, sleeping sickness killed one million people in a major outbreak. The disease was gradually brought under control in the first half of the century, with very few cases reported in the 1960s despite substantial surveillance efforts. Over the last 20 years, there has been both a resurgence of sleeping sickness and a marked decrease in surveillance. In 1999, 45,000 cases were confirmed; however, the World Health Organization (WHO) estimates that approximately 500,000 people are affected. Transmitted by tsetse flies, the disease also afflicts cattle and other animals and can be transmitted between people and livestock.

The rhodesiense sleeping sickness area of southeastern Uganda covers 7,000 square kilometers. Major outbreaks occurred in 1976-82 and 1984-89. In the past 10 years, there have been approximately 1,000 cases per year. The human population is a little over 2 million people, more than half of whom earn less than US\$1 a day. Small-scale crop-livestock farms predominate. The population of indigenous zebu cattle, which provide rural people with milk, meat, traction and savings, stands at about 500,000.

Because poor rural Africans depend almost entirely on natural resources for their survival, better NRM is their main option for building sustainable livelihoods. Yet people's natural resource endowments and how they manage them are closely intertwined with the health risks posed by infectious diseases like sleeping sickness and with patterns of poverty. Changes in NRM can be planned and integrated into multiple, interlocking strategies for the control of human and animal trypanosomiasis. Some of these measures can be designed and managed by the affected communities themselves, to improve the health of those most at risk while at the same time conserving the natural resource base.

Project description

The goal of this newly launched three-year project is to improve human health through a mix of NRM, public health, social and policy interventions for the control of trypanosomiasis. The target area is southeastern Uganda, an area populated largely by smallholder farmers at risk of riverine-transmitted rhodesiense sleeping sickness. The research is participatory and transdisciplinary, drawing on expertise from agroecosystem health research, epidemiology, ecology, GIS and systems analysis. It combines the practical problem-solving approach of rural Africans with the best of systems analysis tools developed by researchers.

Using participatory and other methods, the researchers will work jointly with six high-risk target communities to design indicators of natural resource management, poverty, disease risk and the impact of disease. These will then be assessed to determine which are location-specific and which can be applied across communities and regions.

Using GIS and participatory methods, the research team will work with farmers to map current levels of disease risk, NRM practices and poverty, and analyze the relationships among them as a means of identifying causal pathways. These factors will also be examined from an historical perspective, again with community input. The research team will conduct spatial and temporal analyses of trends over the past 40 years, based on existing data (such as disease records and aerial photographs) and oral histories. In parallel, simple models for simulating poverty distribution, disease risk and NRM strategies such as land-use change will be developed to help target trypanosomiasis control strategies and other interventions.

The various research results and products will support community-based design, implementation and monitoring of local action plans – the project's main output. The researchers will give special attention to gender differences, since some of the repercussions of sleeping sickness (for example, the need to provide nursing care) are gender-specific.

The project builds on, and integrates with, other past and current studies by ILRI and LIRI. For example, under a project funded by the UK's Department for International Development, researchers are carrying out molecular characterization of trypanosome isolates from cattle, other livestock and people. By distinguishing different strains of the parasite, this research will help define more precisely the transmission between livestock and people within and between geographic areas. Similarly, the current project draws on LIRI's ongoing work to collect field data on natural resources, animal and human disease risk and control options. This is funded under the EU-supported Farming in Tsetse Control Areas (FITCA) project. Additional funding has been obtained from the CGIAR's Collective Action and Property Rights Initiative (CAPRI) to investigate the economic incentives that enhance collective action in communities.

Initial project work has highlighted the importance of natural resource changes and cattle movements in sleeping sickness outbreaks. A new outbreak in Soroti district, beginning in January 1999, has been definitively linked to the purchase of cattle from endemic sleeping sickness areas. Recently re-established settlements in bushy areas have been most affected. This work has important implications for large-scale cattle re-stocking and re-settlement programs throughout northern Uganda.

Diversification of livelihood opportunities in and around agriculture may help reduce vulnerability to HIV infection. Conversely, agricultural production and development that induce people to migrate may inadvertently increase this vulnerability.

Eastern and Southern Africa: AIDS and Food Security (research proposal)

Health / agroecosystem links

How does HIV/AIDS affect food production and security, agricultural labor patterns, and agroecosystem management in African countries hit hardest by the epidemic? How and where is food insecurity leading to further spread of HIV infection? What importance should national agricultural R&D institutions accord to the links – in both directions – between HIV/AIDS and agriculture? In which types of agroecosystems are people's livelihoods most at risk? What can R&D institutions do to support local responses to the emerging threats?

Research organizations

International Service for National Agricultural Research (ISNAR); Institute of Tropical Medicine, Belgium; agricultural R&D organizations and public health organizations in Malawi, Tanzania and Uganda; other selected research institutions within and outside the region.

Background

There is growing evidence that, without decisive action, HIV/AIDS will reverse human development gains achieved in recent decades in parts of sub-Saharan Africa. Infection rates are increasing faster than expected just a few years ago. In at least seven countries – Botswana, Lesotho, Namibia, South Africa, Swaziland, Zambia and Zimbabwe – 20 percent or more of adults are now infected with HIV. Once concentrated in towns and cities, infection is now widespread in rural areas and more prevalent among African women than men. AIDS and its associated diseases, especially tuberculosis, are now the leading causes of both adult and child deaths in Africa.

AIDS affects many aspects of rural life. In severely hit agricultural areas, there is evidence of declining labor availability as people fall ill and die and as family members, particularly women, devote more time to caring for persons with HIV/AIDS. Family finances are under severe pressure since assets often have to be liquidated to pay for medical and funeral expenses. And as sick family members return to villages from the cities to be cared for by their families, there is an added burden on rural households. In some cases, children are removed from school to make up for labor shortages on family farms.

AIDS degrades agricultural systems, impoverishes those whose livelihoods depend on them, erodes the agricultural knowledge base, and shifts survivors' farming behavior to shorter-term objectives. The epidemic's spread is exacerbated by food insecurity and by the inability of rural people to make a living where they live. One common response is migration in search of work, whether seasonally or for longer periods. Particularly when they move alone, migrants are often at increased risk of HIV infection. Once infected, they may in turn increase the risk for others in the areas into which they move. Chronic rural unemployment and insecurity may also contribute to attitudes that favor risky sexual behavior. Diversification of livelihood opportunities in and around agriculture may help reduce vulnerability to

HIV infection. Conversely, agricultural production and development that induce people to migrate may inadvertently increase this vulnerability.

AIDS is now widely proclaimed a developmental crisis, yet the capacity to act lags behind. A few organizations have supported the coping strategies of AIDS-affected households – for example, by providing lighter farm implements that can be handled by women and children, reduced tillage methods, better-adapted varieties of roots and tubers, and new postharvest processing options to generate income. However, most agricultural R&D organizations in the region, both state and non-state, have been slow to respond. Most still see HIV/AIDS as a health problem and are unable to relate it to their core concerns. The toll that AIDS is taking on the organizations' own staff and their families further limits their responses.

Project objectives and methodology

The overall aim is to prevent and mitigate the impact of AIDS on agricultural systems and on the livelihoods of those who depend on those systems, by supporting innovation of at-risk and affected households and communities. More specifically, the 3½-year project will help fill critical gaps in current knowledge of the reciprocal links between HIV/AIDS and agricultural development and how agricultural R&D institutions are responding to the problem. It will enable such institutions to set and act on realistic priorities for response, in collaboration with communities and other supporting agencies.

The research strategy is based on a layered framework of analysis that supports research priority setting at three levels, in increasing level of detail. The project results should help agricultural research organizations address a number of interrelated questions: Is the actual or potential impact of AIDS within the institution's mandated area sufficiently great to warrant taking AIDS into account in the first place? If so, what level of resources should be allocated to the problem? In light of local disease prevalence and risk factors, vulnerability of farming livelihoods, and sheer numbers of people affected, which specific agricultural systems should be targeted for priority assistance? What exactly can research institutions do to help prevent or mitigate the impact of AIDS?

In the face of a crisis as big as HIV/AIDS, no single institution can expect to solve these problems on its own. At the central level, sectoral organizations and ministries must align their policies and plans – for example, ensuring that investment decisions take account of the understanding of risk and vulnerability emerging from research. They must also support operational coordination which is often best negotiated at district or local levels. Sharing of information and, where necessary, skills among organizations of different types (e.g., agencies working in public health and agriculture, socioeconomic research institutions, and field-level NGOs) will be essential in these areas where experience is sparse. "Platforms" for such coordination are emerging but require support.

The project will focus initially on three severely affected countries: Malawi, Tanzania and Uganda. Country teams, drawn from key agricultural R&D and public health institutions, will conduct research (literature reviews and field studies) to characterize and analyze the impact and response aspects of AIDS. They will then work with concerned agricultural R&D institutions in the participating countries to transform the findings into priorities for action. The teams will share information and lessons. A group of experts from within and outside the region, working in agricultural and public health research and in R&D planning and management, will support the teams.

*Freedom from mycotoxins in food ... is an indicator
of sustainable development (UN 1996).*

Sub-Saharan Africa: Ecology of Mycotoxins in Maize and Groundnuts

Health / agroecosystem links

How does aflatoxin and fumonisin exposure affect human health and poverty, particularly in rural households dependent on subsistence agriculture in sub-Saharan Africa? What social, economic and ecological factors contribute to mycotoxin exposure? What policies, technologies and behavioral changes are needed to reduce the risk of exposure to mycotoxins?

Research organizations

International Institute for Tropical Agriculture (IITA); International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); South African Medical Research Council; Carleton University, Canada.

Background

At least two potent mycotoxins (pathogens produced by fungi) commonly contaminate maize and groundnuts in sub-Saharan Africa. The best known are aflatoxins produced by *Aspergillus flavus*. More recently, fumonisins, released by *Fusarium verticillioides*, were discovered in maize in Southern Africa. These mycotoxins may occur simultaneously, and the interaction between them is not understood.

Animal and human exposure to both aflatoxins and fumonisin poses multiple health risks, proven and probable.* Because of limited past research on humans, concern about mycotoxin exposure is partly derived from studies on animal health. Aflatoxin is a known human carcinogen and, in combination with hepatitis B and C, raises tenfold the risk of liver cancer. Acute aflatoxicosis occurs in poultry, swine, cattle and people. At lower but chronic exposures, aflatoxin may damage the liver, lower appetite, promote diarrhea, inhibit growth, and suppress the immune system. It generally increases morbidity and may result in death. Aflatoxin is genotoxic and also thought to aggravate vitamin A deficiency and kwashiorkor (malnutrition from protein deficiency). The effect of fumonisins on human health is less well understood, but evidence suggests they are promoters of esophageal cancer and birth defects and suppress the immune system.

Little is known of the social and environmental factors contributing to human exposure to mycotoxins. Improper storage, though, is understood to enhance mycotoxin concentrations in maize and groundnuts. Evidence suggests that in sub-Saharan agroecosystems, mycotoxin-producing fungi in the soil invade plant roots, particularly when the host is stressed by short-term drought. Soil degradation, inappropriate farming practices and choices of crop varieties may affect the quality of the subsequent crop. There are indications that poor rural people who consume stored homegrown maize and groundnuts are among the most affected. Crops handled by government agencies, though, may be better inspected and thus safer for consumption. In some cases, farmers sell their high-quality produce, keeping mycotoxin-contaminated food for their own consumption. Because the poor rarely have the luxury of diversifying their diets, their exposure to mycotoxin-laden crops is often greater.

For centuries, farmers in Central America reduced their exposure to aflatoxin, knowingly or unknowingly, by treating their maize with lye. Unfortunately, this procedure was not taken to Africa with the original crop.

Project concepts

Several emerging areas of research require urgent action:

- Observing human diets in high-risk communities, to assess levels, seasons and sources of exposure to mycotoxins
- Evaluating health impacts of mycotoxins, particularly in food-insecure communities that depend on degraded soils for sustenance
- Defining social structures that differentially expose one or more subgroups to mycotoxin exposure
- Understanding soil ecology with a view to preventing mycotoxin-producing fungi from invading crop roots.

** Cardwell, K.F. 1999. Improving Human Nutrition through Agriculture: The Role of International Agricultural Research. Washington, D.C.: International Food Policy Research Institute.*

*The impact on community involvement
of having mothers, fathers and children view
their own parasites through a microscope far surpassed
the information value of stool sample analysis.*

Peru: Health, Biodiversity and Natural Resource Use on the Amazon Frontier

Health / agroecosystem links

How do the hydrological cycle, market access, ethnicity and the use of natural resources in slash-and-burn farming, fishing, cattle ranching, oil palm production, hunting and gathering influence food availability, disease levels, and the nutritional status of local people?

Research organizations and partners

International Center for Tropical Agriculture (CIAT); Ucayali Ministry of Health, Peru; Universidad Nacional de Ucayali (UNU), Peru; Instituto de Investigaciones de la Amazonia Peruana (IIAP), Peru; Asociación de Mujeres Campesinas de Ucayali (AMUCAU), Peru; Federación de las Comunidades Nativas de Ucayali (FECONAU), Peru; Organización de Mujeres Indígenas de la Amazonia Peruana (OMIAP), Peru; Ministry of Fisheries (DIREPE), Peru; Universidad Peruana Cayetano Heredia (UPCH), Peru; Instituto de Investigación Nutricional (IIN), Peru; British Institute of Tropical Medicine, University of Liverpool, UK; Programme for Appropriate Technology in Health (PATH Canada); University of Guelph, Canada; University of Waterloo, Canada.

Background

The Ucayali Region of the Peruvian Amazon is home to 370,000 people and covers 100,000 square kilometers. In the 1940s a road was built between Lima and the city of Pucallpa on the Ucayali River, a major tributary of the Amazon. This hastened settlement of the region. Now, about 80% of the population lives either in Pucallpa or along the road to the capital.

Despite Ucayali's rich biological diversity and fertility, remote communities struggle to meet basic needs. They also face a barrage of nutritional and health problems. With an estimated two-thirds of rural households living in absolute poverty, human deprivation is the norm here, not the exception. Chronic malnutrition affects over half of rural children under 5. Anemia and vitamin A deficiency are widespread and cases of malaria, dengue fever and persistent diarrhea are on the rise. People in the region make a living from a mix of enterprises: cropping, fishing, logging, ranching, plantation operations, hunting and gathering. While it is widely accepted that slash-and-burn farming and unregulated logging accelerate deforestation, it still isn't clear how these diverse livelihood strategies affect household health and income, or whether health and earnings are related. Yet, answers to these questions underpin the design of viable development options for the people of this vast region of forest margins.

Until the late 1990s, analyses of land use in Ucayali focused on small-scale cattle ranchers attempting to maintain productivity in the face of declining soil fertility. Although this research provided important insights into farm-level production and ecological constraints, it failed to link these processes with other

natural forces, resource sectors, actors and regional and national policies. In particular, earlier studies did not look at the role of seasonal flooding, a factor that strongly influences most aspects of life in the region. They were therefore not able to address issues of ecological adaptability and its relationship to health and nutrition. Although the international research agenda in the Peruvian Amazon has evolved to include integrated research on natural resource management, the evaluation of production strategies and land use technologies continues to be confined to their contribution to income. Human health and nutrition are ignored.

Project description

As a benchmark site for the CGIAR's Alternatives to Slash and Burn Initiative, Ucayali represents a valuable opportunity to understand a complex natural and human environment from an agroecosystem perspective. Research findings here may also have useful applications in other forest margin areas of the tropical world. The research is participatory and interdisciplinary, drawing on local knowledge as well as scientific expertise in nutrition, health, anthropology, agronomy, natural resource management, fisheries, forestry, ecology, rural planning and economics. The underlying conceptual framework, developed during earlier studies in Ucayali, is referred to as the adaptive methodology for ecosystem sustainability and health, or AMESH for short.

The project team used spatial mapping techniques to chart the mix of ecological resources available to the rural population and conducted household surveys to define food production, consumption and family income patterns. In addition, basic mortality and morbidity rates were measured, including field tests for anemia, parasitic infections and water quality. The work has involved 345 families in eight Ucayali communities representing a cross-section of production strategies, ethnicity, ecosystem types and market accessibility. The research was timed to capture seasonal variations in production and food availability determined by the annual hydrological cycle and the 8 to 15 meter rise in river levels. Using three time periods and data sets, researchers analyzed the cycles of food production and availability, disease outbreaks and nutrient intake. This helped identify critical periods of food scarcity and disease prevalence, allowing for more targeted and effective interventions.

Using participatory methods, the research team also explored the role of local beliefs and knowledge in the selection of food and treatment of illnesses and identified community health priorities. This information was used to formulate local definitions and indicators of health that aided the development of community action plans and the evaluation of the Ministry of Health's rural health programs.

Results to date, conclusions and interventions

Based on 18 months of fieldwork and initial data analysis, the researchers reached the following conclusions. First, health is multidimensional. Ecological factors, diversity of resources and soil fertility influence natural resource use patterns; these in turn affect nutrition and food security. Changes in vector habitats and water quality affect cycles of disease and the dynamics of disease transmission. Economic factors such as labor supply, distance from markets, and access to credit influence income and access to health and educational services. Cultural differences among colonists migrating from other parts of Peru affect social cohesion in young settlements, and lack of appropriate local knowledge undermines these colonists' ability to make use of the diverse resources available to them. Further analysis will allow the researchers to determine which factors, or combination of factors, are most important to human health, and under what circumstances.

Second, the ever-changing ecology of the floodplain and upland terraces dictates patterns of resource use, nutrition, food security and disease. Resource use follows the rhythm of the rivers as they flood and later

recede. Similarly, nutrient intake varies throughout the year as diets change in response to resource-use patterns. The movement of people across the landscape is also in step with floodplain dynamics. Local migration allows families to exploit the greater diversity of ecological resources made available by the flooding cycle. For example, at low water the commercially important seed- and fruit-eating fish inhabit the river channels and lakes, fasting, yet avoiding predators. Once rivers rise, these fish disperse into the flooded forest seeking food and the protective cover of trees. This fish migration pattern results in periods of abundance, in the dry months, followed by scarcity, when the rains come and fish are difficult to catch and expensive to purchase. Animals exhibit similar migratory patterns which, in turn, influence hunting patterns and food availability. Agricultural cycles likewise follow the rise and fall of the rivers. During the dry season, fertile alluvial banks are available for annual crops, particularly rice, maize and plantain. Interventions aimed at promoting more sustainable resource use for better human health and nutrition should focus on taking advantage of the annual floods rather than being drowned economically by them.

Third, the inclusion of a wide range of stakeholders demonstrated that the issues facing different groups vary considerably. For example, families living in the floodplain benefit from an abundant supply of fish and animals, yet their health is undermined by frequent parasitic infections due to poor water quality and sanitation caused by flooding. Food security and nutrition are therefore less of an issue than poor health status. In the upland terraces, high fish prices, scarce animal resources, and longer cropping periods to obtain a harvest lead to predictable and seasonal food insecurity each year. Development initiatives need to be flexible in order to accommodate the different needs of different groups in this ecosystem.

Finally, extensive and diversified patterns of resource use, although recommended, will eventually fail if there is no landscape-level mechanism for regulating and monitoring common-pool resources. On the Amazon frontier, the absence of government and nonexistent or precarious land ownership result in an institutional and political vacuum. In addition, physical demarcation of land on the floodplain is often impossible as lands appear and disappear with ever-changing river configurations. To maintain human health and the ecosystems that support people, an institutional, political and legal framework is needed – one that avoids narrow sectoral approaches and top-down management. This framework should be designed to encourage local involvement in decision making and meaningful dialogue between the policy and scientific communities. Community-based management offers one alternative whereby different users of shared resources together negotiate long-term plans for resource use.

The project team is now working with communities and health officials to design local action plans. These center on interventions such as health and nutrition education programs, testing inhabitants for parasites and anemia, water purification, small-scale food production projects, and the introduction of improved hygiene and sanitation practices.

In addition to generating useful data, the participatory methods used by the researchers stimulated community involvement in health improvements. For example, the impact of having mothers, fathers and children view their own parasites through a microscope far surpassed the information value of stool sample analysis. Parasites were no longer an abstract concept discussed only by Ministry of Health professionals; they became real aspects of villagers' daily experience with poor water quality and diarrhea. In each community, villagers were immediately mobilized and sought solutions to reduce water contamination and parasite transmission.

At the regional level, the project is helping the Ministry of Health to adjust its health and nutrition programs, based on the results of the field studies. An interdisciplinary course on ecosystem approaches to human health is also being designed for the National University of Ucayali.

The research is increasing various stakeholders' awareness of how the annual hydrological cycle affects human health and nutrition. This should eventually translate into ecologically sound adaptive strategies for improved health rather than policies that assume a static ecosystem of conventional agriculture and forestry. By mapping food sources, researchers can also determine the size and diversity of the ecosystem needed to maintain the human population at its current levels. This will support policies for the protection of natural areas to sustain human health.

*Deforestation and the whole process of soil erosion
have led to the transfer of high mercury loads
from the land to the aquatic ecosystems.*

Brazil: Mercury Poisoning in the Amazon

Health / agroecosystem links

What role do gold mining, crop-related deforestation and soil erosion play in methylmercury contamination of fish in the Brazilian Amazon and poisoning of the local people who eat the fish? At what level of contamination do people's motor and visual skills become impaired? Can impairment be reversed by reducing exposure? What can fishers and other fish consumers do to avoid mercury contamination, especially with regard to their fishing and dietary habits? What ecosystem management practices might reduce overall levels of mercury in the environment over the longer term?

Research organizations and partners

Université du Québec à Montréal (UQAM), Canada; Federal University of Pará, Brazil; Federal University of Rio de Janeiro, Brazil; the Grupo de Defesa da Amazônia, Brazil; the Biodôme de Montréal, Canada.

Background

The presence of mercury in the food chain and its absorption by people is universally recognized as a health hazard. Once mercury is released into rivers, lakes and other aquatic environments, bacteria can transform the mercury into its organic form, highly toxic methylmercury. In this form it can be absorbed by aquatic fauna, increasing in concentration (biomagnifying) as it moves up the food chain to fish and then to humans.

One of the best-known cases of methylmercury poisoning was discovered in 1956 in communities near Minamata Bay, Japan, where mercury discharged from a chemical plant accumulated in fish. Thousands of people who lived in the area and ate fish and shellfish from the bay developed what came to be known as Minamata Disease.

A number of studies have reported that fish in some rivers of the Amazon region are contaminated with mercury. Likewise, people who live along those rivers and depend on fish for a major part of their diet have relatively high levels of mercury in their hair, an indicator of mercury exposure. For years, the use of mercury to extract gold from river sediment and soil, a method still in use, was thought to be the cause of the widespread contamination.

Project description and results

Concerned about the effects of mercury on human health in the Amazon, scientists from the Federal University of Pará in Belém and UQAM teamed up in 1994 to explore the problem further. Their focus was Brazil's Tapajós River, where thousands of miners have panned for gold over the last 30 years. The subsequent six-year period led to increased understanding of the behaviour and toxicity of mercury in

Amazonian ecosystems. Now, researchers increasingly turn their attention toward appropriate ecosystemic approaches to reducing exposure to this heavy metal.

To determine mercury levels, the team collected and analyzed water, river sediment and soil at intervals along the river, starting at gold mining sites and ending hundreds of kilometers away. They also analyzed hair, blood and urine samples from fish-consuming villagers who live near the river and conducted simple coordination and vision tests on them to determine the impact on health.

The researchers expected mercury levels to drop as distance increased from gold mining operations. Instead, the concentrations were relatively constant along the Tapajós River, even hundreds of kilometers downstream from the mining sites. Moreover, there was essentially no difference in mercury exposure levels between villagers living 100 kilometers downstream and those 300 kilometers away from the gold mining sites. Thus, the scientists suspected there must be a major source of mercury other than mining.

Analysis of riverbed sediments, sampled in half-centimeter increments, showed the most recent layers contained 1.5 to 3 times more mercury than layers deposited 40 years ago. This was true even of sediments 400 kilometers downstream of the gold-mining sites. Sampling and analysis of nearby soils revealed high mercury concentrations throughout the soil profiles, down to a depth of 1 meter. The researchers concluded that deforestation had allowed rain to erode the surface layers of the watershed's soil, followed later by erosion of deeper strata. Indeed, in some areas along the Tapajós River, up to 15 centimeters of soil have been lost. Further study revealed that subsurface leaching of mercury from the land to the river also contributes to mercury accumulation in the aquatic environment. Deforestation and the whole process of erosion have led to the transfer of high mercury loads from the land to the aquatic ecosystems. Finally, the researchers now suspect that large mats of floating macrophytes are key sites of transformation of inorganic mercury into the toxic methylated form.

The explanation of mercury contamination based on deforestation and soil erosion is consistent with the recent history of the Tapajós River basin. Some 40 years ago, immigrants from northern Brazil had begun to colonize the area adjacent to the river where they slashed and burned the trees in preparation for cropping and other activities.

Hair samples from adults in the village of Brasília Legal contained an average of 15.9 parts per million (ppm), well below the threshold considered safe by the World Health Organization. The WHO threshold of 50 ppm is based on the lowest level at which previous studies have reported the first clinical signs of mercury poisoning in adults. Further tests on the villagers showed, however, that they had experienced declines in coordination, manual dexterity and certain visual functions. The researchers concluded that mercury can damage human health even at levels well below accepted international safety standards. Testing also revealed that the mercury levels in people were highest during the rainy season when large carnivorous fish were abundantly available.

These research results serve as an early warning sign that more serious neurological problems could develop among the region's population. Currently, researchers are working with local people, including a women's group in Brasília Legal, to design and implement intervention strategies. One set of activities, which includes further study of the links between fish diet and mercury content of hair, aims to reduce the consumption of fish with high mercury content (see box). For example, there are a number of species of edible herbivorous fish that could be promoted for human consumption. Other work focuses on identifying possible sites and mechanisms of mercury methylation in the Tapajós River. Limiting the proliferation of patches of floating macrophytes, through riparian forest conservation and restoration, is one strategy under investigation.

Future directions

Over the longer term, the project team hopes to scale up both research and interventions to the regional level. Proposed activity aims to shift family agricultural practices toward better land management as a way to protect and restore these important Amazonian ecosystems and improve the quality of life of the region's poor farmers. Local-level behavioral and technical interventions along with enabling policies will be needed. The project will be organized around a model that takes an ecosystems approach. Research and intervention activities will be conducted to generate data and clarify the relationships between components of the model, thus permitting it to be further refined. The area covered by the project will be the watershed of the Lower Rio Tapajós. This is an active colonization front where agricultural activities are leading to massive deforestation. The project will benefit from the creation of a network of key Amazonian institutions. Links with the International Center for Tropical Agriculture (CIAT) will foster greater integration of research on slash-and-burn agriculture, fisheries management and human health.

“Eat fish that don't eat other fish”

Since 1994, villagers from the town of Brasilia Legal have actively participated in the IDRC-funded study of mercury on the Tapajós River. In 1995, about 100 people provided hair samples for mercury analysis and underwent testing for nervous system functions. Although hair mercury levels were below those considered “safe”, results showed dose-effect relations, with fine motor movements and vision decreasing with increasing mercury levels.

After a workshop and discussion, the villagers agreed on a short-term solution. People would alter their diets to reduce mercury absorption but still maintain fish consumption. “Eat fish that don't eat other fish” became the slogan since mercury levels are lowest at the bottom of the food chain.

The village midwife has played key role in raising awareness about mercury and coordinating the activities of 30 village women. Every day over 14 months, the participants wrote down a list of all the foodstuffs and medication they had ingested. When asked after eight months whether they were tired of recording this information, the women responded: ‘No, we are learning about the relation between food and health and are much more aware of what we eat.’

In 2000, hair samples provided by 45 people from the original 1995 group were analyzed for mercury. The results showed a significant decrease in hair mercury levels, from 17.6 parts per million to 11.1 ppm.

*Farmers would be both healthier and more productive
if use of the pesticide carbofuran were reduced;
productivity gains from improved health outweigh
losses from reduced pesticide use.*

Ecuador: Pesticides, Health and Changes in Potato Technology

Health / agroecosystem links

How do pesticides affect the health of farm families who grow and consume potatoes? What are the health effects of pesticide-related household behaviors? Can health be improved and agricultural productivity maintained by training farmers in safer methods for handling pesticides and in methods of integrated pest and disease management?

Research organizations

Instituto Nacional Autónomo de Investigaciones Agropecuarias (INIAP), Ecuador; International Potato Center (CIP); McMaster Institute of Environment and Health, Canada; Programme for Appropriate Technology in Health (PATH-Canada); University of Montana, USA.

Background

In the Andean valleys of Ecuador's Carchi Province, just north of the equator, about 8,000 mostly commercial growers account for 40% of national potato production. These farmers, many of whom operate mixed potato-and-dairy systems, are also among the country's heaviest pesticide consumers. Using backpack sprayers, they apply the insecticides methamidophos and carbofuran to control foliage-damaging insects and the tuber-damaging larvae of Andean weevils (*Premnotrypes vorax*). Two fungicides, maneb and mancozeb, are widely used to combat late blight (*Phytophthora infestans*). Earlier Canadian research, directly related to the current project, revealed that pesticides were applied an average of seven times during the crop growth period. It also showed that farm people had significantly more nervous-system disorders (such as impaired motor skills) than non-farmers. Skin disorders were also common. The pesticide poisoning rate of 171 per 100,000 population was similar to the highest rates recorded elsewhere in the developing world. Direct skin contact with pesticides during mixing, leaky sprayers and lack of protective clothing clearly explain some of the health problems seen among farm workers who actually apply the pesticides. However, other factors may account for ill health among members of the farming community. These include contamination from pesticide residues on potatoes prepared and eaten in the home, as well as from storing pesticides and washing clothes in the household. Micronutrient deficiencies from unbalanced daily diets (unrelated to pesticides) may also be involved.

Project description

This research covers the health component of a major ecoregional project by CIP, INIAP and the University of Montana. That project has developed and tested a multidisciplinary model, based on Andean potato farming, for integrated assessment of the sustainability of agricultural production systems. Field-based surveys – for example, on crop production, household practices, poverty levels, dietary habits and nutritional status of farm family members – were essential to generate the information needed for the model. The model quantifies how farmers' methods and decisions (such as those related to pesticide use) affect crop productivity, farm incomes, the environment and human health. Then, using statistical

techniques, it aggregates those effects at the regional level so that they are useful in policy analysis – for example, to decide on pesticide subsidies or disincentives, or to formulate extension strategies. The project’s conceptual framework makes it possible to link results from individual disciplines, thereby producing a “second level” result from the combined analysis.

The health component of the research focuses on 40 farm families in two microwatersheds of Carchi, taking into account gender differences. It attempts to answer three questions: First, do differences in food preparation methods, diets and other household practices affect neurobehavioral function? Second, can participatory programs for men and women members of farm families change potato production and household management methods in a way that decreases pesticide exposure, thereby improving health? Third, what are the tradeoffs between human health, agricultural production and environmental protection in the broader region? And how would safer use of pesticides and integrated pest/disease management, as promoted by INIAP and CIP, affect those tradeoffs?

Results and conclusions to date

Exposure to pesticides has serious adverse effects – neurological and skin-related – on the health of Carchi’s rural population. In turn, health disorders undermine farmers’ ability to make efficient farming decisions. Farmers with higher neurobehavioral scores had lower production costs per hectare and thus higher productivity, consistent with better managerial capacity. Farmers would be both healthier and more productive if use of the pesticide carbofuran were reduced; productivity gains from improved health outweigh losses from reduced pesticide use.

For males, the principal exposure pathway is preparation and application of pesticides in the farm field. For women, exposure occurs mainly in and around the home where pesticides are often stored and where work clothes impregnated with pesticides are washed. Exposure of children is mostly accidental – for example, when they help parents with work or have chance encounters with pesticides. Children age 5 and younger are the age group with the highest number of hospital-treated cases of pesticide intoxication. Pesticides are also used frequently by other household members in suicide attempts. As pathways of pesticide exposure differ according to gender and age, the project has developed individual protection strategies for the various at-risk groups.

Tradeoff analysis suggests that safer pesticide handling and use of IPM to cut carbofuran use could reduce the pesticide’s adverse health effects by 50% or more without reducing potato production. A key policy implication is that related education and extension programs are less expensive than taxes on pesticides as a way to reduce the health burden of pesticide use and make the ecosystem more sustainable.

There was little evidence of carbofuran or other pesticide leaching from farmers’ fields in amounts that threaten human health. Thus, any policy to ban carbofuran would appear unjustifiable on purely environmental grounds. However, not all pathways and impacts of potential contamination by leaching were studied. For example, possible contamination of water supplies from mixing pesticides near water points was not investigated.

The research results show that economic, environmental and human health tradeoffs are spatially variable. And the larger the time and space scales, the more complex the analysis of sustainability tradeoffs.

Irrigation policies and practices that neglect the key role of rural women in water use and management may pose unnecessary risks to overall family health and place a disproportionately large burden of illness on women and children.

Sri Lanka: Agroecosystem Management for Human Health in the Uda Walawe Irrigation Scheme

Health / agroecosystem links

How do changes in agricultural water management and cropping patterns affect the breeding of disease-bearing mosquitoes, the availability of water for domestic uses, and the need for agrochemicals? What water management options can make the use of water for agriculture more efficient while protecting human health and the environment, including downstream ecosystems?

Research organizations and partners

International Water Management Institute (IWMI); Mahaweli Economic Agency, Sri Lanka; Regional Agricultural Research Center, Department of Agriculture, Sri Lanka; Anti-malaria Campaign (AMC), Sri Lanka; University of Peradeniya, Sri Lanka; Brace Centre for Water Resources Management, McGill University, Canada.

Background

Past research on health aspects of irrigation has tended to concentrate on the negative impact of irrigation schemes on people's well-being. But as emphasis in the irrigation sector shifts from building large new schemes to rehabilitating existing ones, there are opportunities to design changes in irrigation management that promote both human health and sustainable food production.

In many developing countries, especially those whose economies depend heavily on agriculture, water has become the object of intense competition among multiple users and uses. On the one hand, huge amounts of water are being harnessed for irrigation. This is because crop agriculture, especially paddy rice production in Asia, is intensifying in response to the food needs of large and still expanding populations. On the other hand, families also need reliable and convenient supplies of clean water for domestic purposes like drinking, cooking and bathing.

Ironically, the use of irrigation to produce enough food for basic human health and nutrition has often intensified other threats to health. These include increased transmission of malaria, Japanese encephalitis and schistosomiasis. In many irrigated areas, pesticide poisoning is a big problem because of high use without the necessary safety precautions. The availability of drinking water can also be affected when irrigation systems are rehabilitated. For example, when canals are lined, there is often less recharge of shallow wells and this leads to an increase in gastrointestinal diseases. Irrigation schemes can also affect regional water balances and sometimes have unintended ecological repercussions downstream, such as destruction of wetland biodiversity.

At the same time, irrigation development can help improve health. In many parts of the world, including Sri Lanka, irrigation canals and hydraulic structures are important sites for bathing and doing laundry, thus enhancing hygiene. Rehabilitation offers the opportunity to include adaptations to the infrastructure to facilitate multiple uses of water.

Women are the main providers and managers of domestic water in most rural areas of the developing world and play a major role in agriculture. However, irrigation still tends to be a male-dominated activity. Irrigation policies and practices that neglect the key role of rural women in water use and management may pose unnecessary risks to overall family health and place a disproportionately large burden of illness on women and children.

In 1963, the Sri Lankan government launched the Uda Walawe Irrigation Scheme in the country's south to boost food production and support colonization of the Walawe River basin. About 10,000 hectares on one side of the river and 5,000 on the other side have been developed. A key aim of the Mahaweli Authority of Sri Lanka (MASL), which controls the scheme, is to use water more efficiently so that a further 6,000 hectares can be brought under irrigation. The strategy centers on rehabilitating canals, managing water better and introducing non-rice field crops that need less water.

Recognizing the need for a broad perspective on ecosystem management, MASL asked IWMI in 1997 to help assess options for better water management at three levels: farm, irrigation system and basin. With support from the Japanese Bank for International Cooperation and the Council of Agriculture and Irrigation Associations of Taiwan, IWMI began research on drip irrigation for bananas, alternate wet and dry irrigation (AWDI) technology for rice, and the water balance at the basin level.

While crop diversification and intensified production through irrigation can alleviate poverty, environmental and human health problems also need to be addressed. For example, the resurgence of malaria (reaching epidemic levels in Uda Walawe in 1998) and numerous cases of pesticide poisoning have alarmed both community members and public health officials in recent years. Japanese encephalitis is also endemic in this area and the mosquitoes that transmit it typically breed in irrigated rice fields. These problems have raised serious questions about the sustainability of the whole irrigation enterprise. With IDRC support, the research project is therefore also examining health and environmental issues to identify options for improving human health in the Uda Walawe Irrigation Scheme.

Project description

The hypothesis of this three-year health research component of the overall project is that irrigation management can be altered to improve human health, with minimal impact on agricultural performance. AWDI technology, for instance, can help control mosquito breeding in rice fields while conserving water. Similarly, integrated pest management (IPM) could lessen farmers' dependence on pesticides. This might not only improve agricultural productivity and alleviate groundwater pollution, but also cut the number of suicides related to easy access to toxic substances.

The project methodology centers on four activities: investigating mosquito ecology and disease transmission; establishing the link between irrigation water management and groundwater quality and availability in shallow wells; estimating the need for agrochemical inputs for alternative crops and water management methods; and evaluating the potential for using IPM methods. The research draws on expertise from several disciplines: epidemiology, irrigation engineering, agricultural economics, agronomy, and anthropology and gender relations. The work is broadly participatory in that researchers are working closely with local communities, water user associations, women, NGOs, universities, and government authorities responsible for public health, irrigation and agriculture.

The data and related tools needed to analyze ecosystem management options for improved health come from several sources. A geographic information system (GIS) is being used to map malaria incidence. The information is broken down by environmental factors such as the extent of irrigation, other land uses, soil moisture and vegetative cover. At the same time, agrochemical usage is being recorded and analyzed, based on existing sales data as well as farmer surveys carried out by the research team. The researchers are also conducting field experiments to determine water inflows, outflows, groundwater levels, and the biological and chemical quality of surface water as well as deep and shallow groundwater, in relation to water management and cropping patterns.

The analytical results will be integrated to generate a basin-level estimate of changes in vector breeding, agrochemical use, and groundwater fluctuations under different scenarios of irrigation water management. Throughout the processes of data collection and analysis, the researchers are giving special attention to the role of women in water management and to the effects of policies and practices on them.

Rice irrigation in the West African Sahel substantially boosts anopheline mosquito populations. However, the larger number of vectors does not appear to result in higher transmission of malaria in that region.

West Africa: Irrigation, Water Management and Vector-Borne Diseases in Rice Farming

Health / agroecosystem links

Does expansion of irrigation and other water management strategies for rice production increase malaria transmission and the associated burden of disease in rural communities?

Research organizations

West Africa Rice Development Association (WARDA); Institut d'Économie Rurale (IER), Mali; École Nationale de Médecine et de Pharmacie, Mali; Institut National de Recherches en Santé Publique, Mali; Institut Pierre Richet – Organisation de Coordination pour la Lutte contre les Grandes Énimies (OCCGE), Côte d'Ivoire; Centre Universitaire de Formation en Entomologie Médicale et Vétérinaire, Côte d'Ivoire.

Background

Rice production and consumption have gone up rapidly in West Africa in recent decades. Furthermore, growth in consumer demand is likely to remain above 5% a year. Evidence suggests that rice availability and prices are a major influence on the welfare of the region's poor. Rice in West Africa is no longer the luxury it once was; it is now a staple food, especially for the urban poor. Yet, the Asian rice imported to meet growing demand consumes scarce foreign currency. Within the region, expansion in the cultivated area of irrigated rice is the main source of production increases. The "upland/inland swamp continuum" environment of the forest and savanna zones accounts for about 80% of the cultivated rice area of West Africa and 75% of production. This environment includes both rainfed and irrigated rice systems, while the more northerly Sahelian systems are irrigated.

Overall production trends have raised serious questions as to whether environmental degradation, particularly in fragile upland ecosystems of the savanna, and malaria transmission will accelerate. (The vast majority of the world's annual clinical cases of malaria and related mortality occur in sub-Saharan Africa, with West Africa being particularly susceptible.) On the environmental side, WARDA concluded some time ago that, in the effort to meet regional food requirements, lowland rice cultivation should be promoted to protect vulnerable upland areas. If agroecosystem management strategies are also to contribute to prevention and control of diseases like malaria and schistosomiasis, more information is needed on the socioeconomic, ecological and environmental aspects of the differing rice-growing systems, as well as on the epidemiology of these diseases.

Project description

The project focuses on the Sahelian and savanna/forest regions where rice is grown, with Côte d'Ivoire and Mali serving as the venues of research. Institutions in these two countries are major scientific partners. Key objectives are as follows: to characterize the irrigated rice agroecosystems of the Sahel, as well as the rainfed and irrigated lowland-valley rice systems of the upland/inland swamp continuum (savanna/forest), in relation to health risks; to identify social, biological and other factors affecting the



potential of agroecosystem management as a means of vector control; and to assess health risks posed by malaria and schistosomiasis in different ecological zones along a north-south transect through Mali and Côte d'Ivoire. The research is expected to increase awareness of various groups regarding the links between rice farming and health. These groups include rural communities, donor representatives, policy makers, and health and agriculture specialists.

Results to date and preliminary conclusions

Rice irrigation in the West African Sahel substantially boosts anopheline mosquito populations. However, the larger number of vectors does not appear to result in higher transmission of malaria in that region. Although malaria transmission and incidence during the dry season (rice-growing cycle) is higher in the irrigated zone than the unirrigated zone, rainy season (and consequently annual) transmission and incidence is much higher in the unirrigated zone. Relatively few of the abundant anopheline mosquitoes are infective in the irrigated zone. This is most likely because few mosquitoes live long enough to allow the malaria parasite to mature. In addition, the high biting rate on alternative hosts such as cattle probably reduces the chances of malaria parasites being transmitted to people. Very high bed net use (virtually 100% year-round) in the irrigated zone, stimulated by the high number of nuisance bites, may also play a crucial role. Attempts to control mosquito populations could reduce nuisance levels and, consequently, bed net use, which could have the unintended effect of increasing malaria transmission. Promotion of insecticide-impregnated bed nets could substantially reduce malaria, especially in the unirrigated zone.

In the savanna zone, irrigation leads to a higher anopheline population and to a second period of malaria transmission associated with rice production. Despite this, malaria transmission to children is similar in villages either having no irrigated rice or having two crops per year. Strangely, malaria transmission is lower in those communities having only one rice crop annually. These observations suggest that irrigation may, not in itself, be a cause of increased malaria transmission. Some other factors likely explain reduced malaria in areas with one only annual crop. The explanation does not appear to be highly related to use anti-malarial drugs and prophylactics. Socioeconomic factors are probably more important. The researchers observed that introducing cultivation of irrigated rice had strong impacts on social organization, economic status of households and intra-households relations (the distribution of roles and responsibilities between men and women) that affect the capacity of farmers to recognize and react to early symptoms of malaria, or to adopt protective measures.

Surprisingly, social sciences data indicate that, despite the increase in rice production, less food is available to people in villages with two rice crops than in those with only one. People complain that they find it more difficult to feed their families with food that they have produced themselves. This may be linked to increased difficulty of transporting food products from the uplands to the lowlands, to a transfer of the responsibility to feed the family from men to women (which forces them to sell some of their rice production to face a number of expenses previously assumed by men), and to better care of food crops in single cropping environments.