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Conceptualizations of Environment and Technology in Food Systems

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CONCEPTUALIZATIONS OF ENVIRONMENT AND TECHNOLOGY IN FOOD SYSTEMS

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PREFACE

This paper was originally written as a background paper for the IIASA Food and Agriculture Program (FAP) Task Force Meeting of 29 January through 1 February, 1980. The Task-force was devoted to exploring options for FAP Task 2, a research task oriented toward systems analysis of resources, technology, and environment within agricultural systems.

The paper's original purpose was to expand the number of options available to FAP Task 2. Basically it is a statement of how I, given my mixed training in human ecology, agricultural economics, and system dynamics, would proceed if I were responsible for FAP Task 2.

As a consequence of the Task Force Meeting mentioned above, FAP Task 2 appears to be going to use a programming approach that is very different from the approach described herein. Given the time and data constraints, and previous work done by FAP, this is a reasonable choice.

Now that the Task Force Meeting is over this paper simply describes an option that was considered but not used. It may also serve as an overview of the global agricultural system from a human ecology perspective.

I would like to express my gratitude to Dr. Jaroslav Hirs of FAP for his support in writing this paper and his willingness to listen to viewpoints very different from his own.

CONCEPTUALIZATIONS OF ENVIRONMENT AND TECHNOLOGY IN FOOD SYSTEMS:

Jennifer Robinson

INTRODUCTION

This paper develops three alternative conceptualizations of the interrelationships between the environment, technology, and the food system as a basis for looking at the global dimensions of the food system in context of environmental and technological factors. The three conceptualizations are, respectively, a balance of trade oriented perspective, a human labor oriented perspective and a carrying capacity perspective. I intend these as alternative perspectives appropriate to different circumstances as shown in Table 1. I have tried to frame these conceptualizations in a way that suggests useful action; i.e., rather than simply describing the system and its problems, I have tried to define things in a way that leads to insight on how the system's available resources could be used to solve its problems.

The three conceptualizations are neither mutually exclusive nor exhaustive. Many systems in the world could usefully be viewed from all three perspectives simultaneously. For example, poor tropical countries with balance of trade problems, fragile environments, and serious employment problems. Some places might find a fourth, fifth or nth conceptualization useful; for example, in many European nations agricultural systems seem to be viewed mainly in terms of avoiding vulnerability and keeping rural incomes at a reasonable level. However, as shown in Figure 1, a large fraction of the earth's land surface is utilized in ways that can be fit into one or more of these conceptualizations.

The following text reviews the three conceptualizations one by one and then draws some generalizations from them. For each conceptualization I first present and describe the system's supply/demand interactions. Second I describe how resources and environment fit into the system; and third I

Table 1. Three conceptualizations.

Type	Circumstances	Example
Trade balance	temperate zone, industrial, oil importer	USA, much of Europe, Japan
Labor	poor, heavily populated	China, India. Indonesia
Carrying capacity	poor, fragile environment, often tribal	much of Africa and Latin America

describe where technology may effect the interaction of supply, demand, resources and environment. Thereafter I discuss the fact that the real world is a mosaic of interacting systems with different structures and speculate on the interaction of different system types. Lastly I offer some generalizations on representation of environment and technology in agricultural systems.

BALANCE OF TRADE

In the absence of serious domestic hunger problems or overt signs of environmental degradation, industrial countries often view agriculture from the question of "how can we use this sector to help solve other national problems?" In 1980 this often means "how can we use agriculture--either through decreasing imports or increasing imports--to help pay our fuel import bill.

In this conceptualization, as shown in Figure 2: Loop 1, increased production leads to increased domestic stocks, which permit increased exports and improves the balance of trade. If the balance of trade remains a problem which it seems likely to do due to long-term problems in the energy system, this stimulates policies designed to increase domestic production in order to increase production. The result is a negative feedback loop that directs its activity toward maintaining an acceptable balance of trade.

The difficulty of this loop is that it does not work so well if all the world is trying to use it. If all agricultural producers are simultaneously trying to increase agricultural production, world stocks increase and world agricultural prices are decreased. This means that: 1)

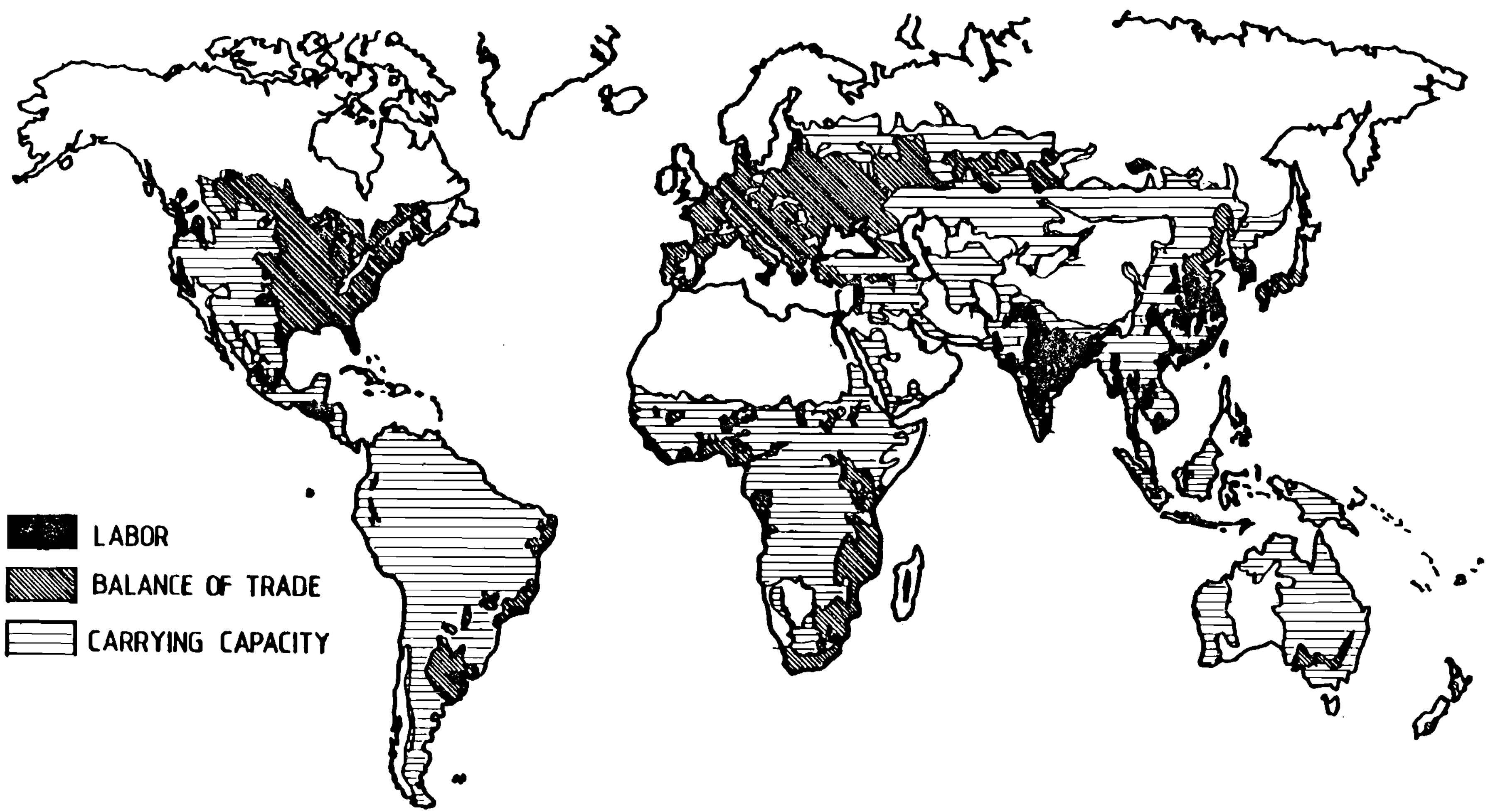

Figure 1: Distribution of the globe between three conceptualizations.

Note: Boundaries are only rough approximations. The idea that the system is a complex mosaic and does not follow national boundaries is to be stressed more than exace placement of boundaries.

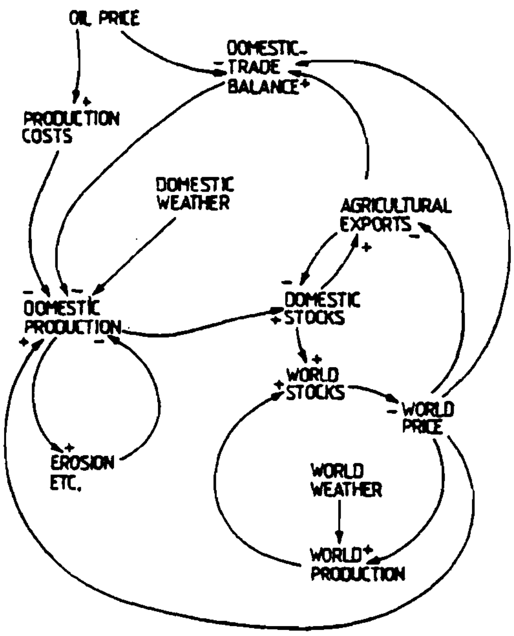

Figure 2

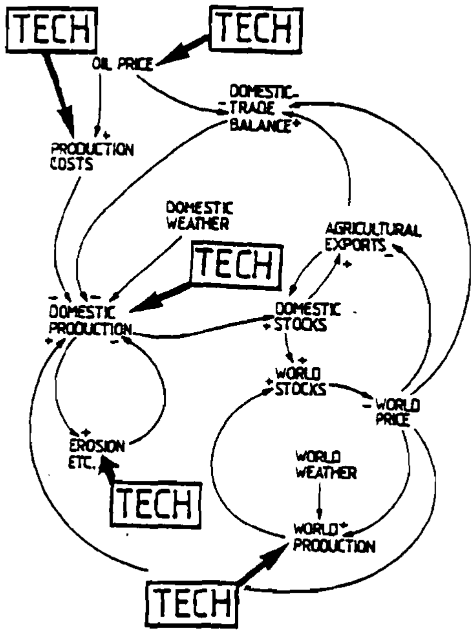

Figure 3

Figures 2 and 3: Patterns of causation in balance of trade conceptualization and places where technology influences the system

agricultural exports don't earn as much; 2) producer profits decrease and there is a disincentive to increase production, both domestically and abroad; and 3) there is a disincentive to export. These system tendencies create loops 2, 3, 4, and 5 in Figure 2.

The way this interaction works out in reality depends on multiple complex factors, including trade barriers, relative speeds of price response, relative elasticities of supply in different regions, and rates of demand growth. A full international trade model, such as that being developed in the IIASA Food and Agriculture Program's Task 1, would be appropriate for studying the details of this process.

Resources and Environment

Resources and environment fit into this picture in three ways: 1) The price of oil is a resource factor; it is outside the agricultural system, and it is putting pressure on the entire global agricultural system. 2) Domestic and foreign weather influence production. Weather may be considered a randomly varying factor, although if CO2 buildup continues weather effects may become a random variation superimposed on a definite trend, and the underlying long-term time trend may be linked to agriculturally related clearing of tropical forests and decay of soil organic matter. In Figure 2 weather is shown as an exogenous force influencing both domestic and world production. If one wanted to look at CO2, weather effects could be partially endogenized. 3) When production is expanded into marginal lands or when too little is expended on environmental maintenance, erosion and other forms of environmental degradation increase. This, as shown in Figure2:Loop 6, decreases production in the long term. This loop may describe other problems associated with industrialized agriculture--for example, monocultural practices that encourage pest epidemics or soil compaction caused by use of heavy tractors. The exact structure used should vary from representation to representation, because there is great difference between regions and between agricultural practices in the rapidity and severity of environmental degradation (some practices may even build up the resource base). There is also variation in the extent to which natural resources are self-renewing.

The way weather, erosion and oil price effect the system--and the problem of keeping desired trade balances under conditions of high oil prices--depends not only on domestic reactions to the situation but also to reactions around the globe, and the way they are transmitted through the global trade system. At first glance, the configuration suggests that reactions to high oil prices may eventually result in agricultural depression, as agricultural nations collectively increase agricultural production to attempt to increase their balances of trade. It also looks as though the pressure on domestic production will be likely to result in increased pressure on the natural environment, which may result in problems over the long term.

Technology

Technology, as shown in Figure 3, affects many of the relationships in this system. If oil prices increase, technology will tend to take energy saving forms; after the lapse of years or decades required for technological change to bring about significant energy savings, this will partially counteract the effects of oil price increases.

Production technologies may increase agricultural productivity, which may lead to high stocks and low prices. Choice of technology will also strongly influence the stresses placed by agricultural production on the environment. For example, cropping practices vary greatly in their tendencies to cause erosion, to lead to organic matter depletion (and carbon dioxide release) and to cause soil compaction. Technology, such as scientific inventory management, could also conceivably influence the way stocks are managed, and thereby influence the way that trade and price systems transmit supply changes.

LABOR

Poor countries tend to see agriculture as a way of producing food, and tend to see the agricultural problem in terms of fulfilling basic human needs. Poverty is generally associated with an abundance of human labor, a scarcity of capital, and a land base that is operating well below potential. From the orientation of using abundant resources to compensate for scarce ones, this situation leads to a conceptualization as shown in Figures 4 and 5.

The work force--human labor--is the most abundant resource. It has tended to be used directly in production as manual labor without heavy use of capital equipment; it may alternatively be used for producing capital equipment (agricultural or otherwise) or for resource conservation activities such as terracing, reforrestation and improvement of drainage systems. In all three cases, the direction of the effect is the same--increased labor leads to increased output. However, the manner and magnitude of influence varies greatly. Direct labor application requires little social and economic organization, leads to immediate effects, and yields low marginal returns. Use of labor for capital formation and conservation both tend to lead to relatively high marginal yields, but require relatively high levels of management skill and supportive social and political systems, and impose a delay of at least a few years before the fruit of people's labors can be harvested.

In whichever direction it is applied, work increases output; increased output leads to improved human and environmental health, thereby to increased labor and land productivity. It also leads to decreased infant mortality, thus over the long term to a larger working population. An increased supply of children (and eventually adults) along with increasing the workforce, also increases the amount of time and energy that must be devoted to childcare and the amount of food required to maintain health.

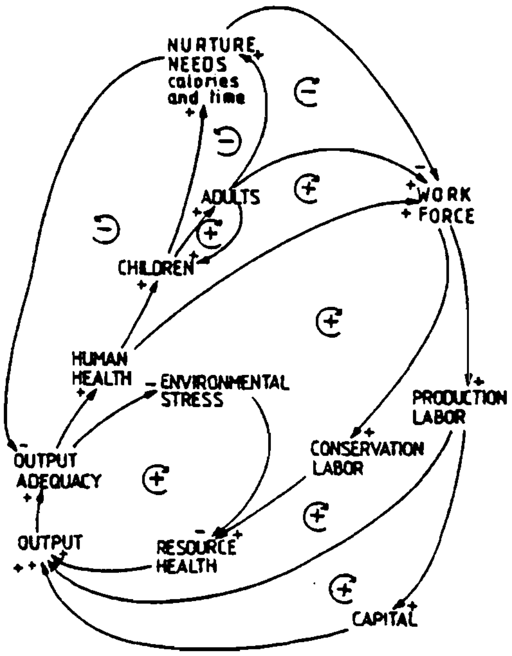

Figure 4

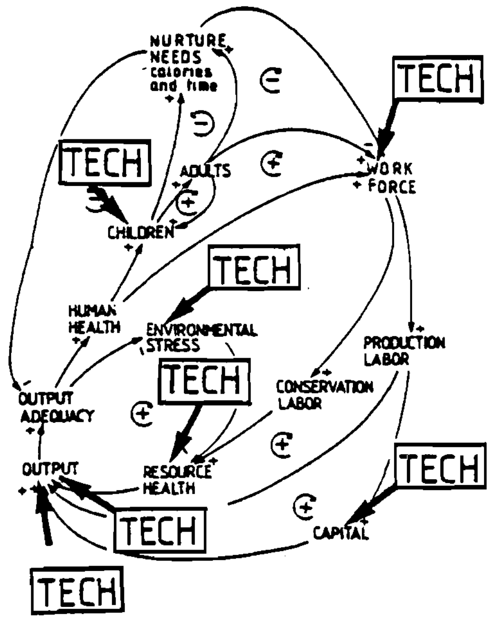

Figure 5

Figures 4 and 5: Main causal influence in laborforce conceptualization and places where technology may influence relationships.

The three basic processes in this configuration are shown in Figure 6; first, population creates the means of supporting people, as shown in the outermost loop. Second, people create more people, as shown in the innermost loop. Third as shown by the loops between the inner and outer loops, people create time and material needs. If these needs exceed supply--which they usually do--the system suffers stress and both labor and environmental productivity are reduced.

If welfare is to increase in a labor-based system, supply must expand faster than demand. This can be achieved both through rechanneling human labor to uses that bring

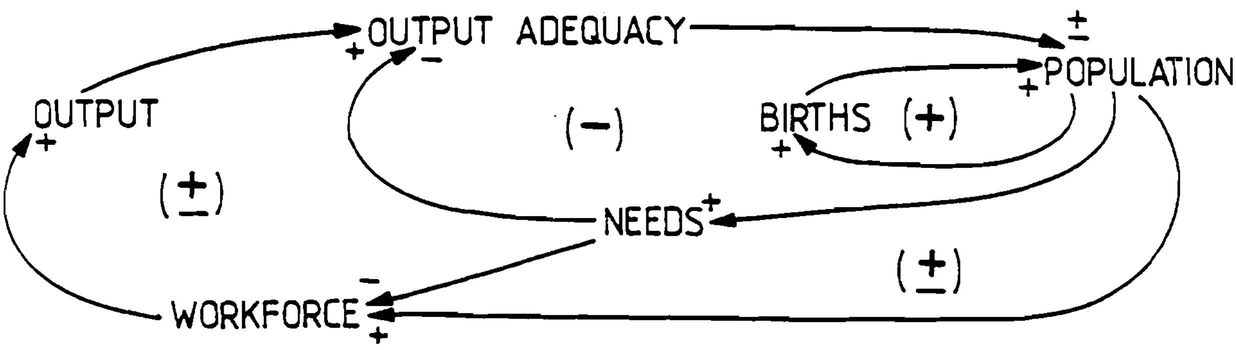

Figure 6: Simplified labor conceptualization.

higher output per person and/or by slowing population growth. Obviously population growth reduction coupled with redirecting labor (particularly female workforce) away from child rearing and toward productive activities will make a greater contribution to welfare than fertility reduction alone. This coupling is often observed; that is, where women can be employed at a decent wage they tend to move into productive activities and fertility tends to drop.

Resources and Environment

Resource and environmental questions come into labor-based systems in several ways. If the system has previously operated at a high level of environmental stress for a long time, present yields are probably depressed by depleted soil and other environmental conditions. Many land reclamation practices are labor intensive, therefore this configuration creates an opportunity to utilize the labor force to increase yields. If the system presently operates with a healthy environment, environmental conservation is an activity that requires labor allocation to protect the system from degradation.

Weather and climate also affect the system. Flooding or drought may cause drops in yields; these in turn may result in hunger, stress and soil degradation. Long term climatic trends could help or harm such systems depending on whether they made things better or worse for growing crops. Energy price may also affect the system by altering the cost relationships of different uses of human labor (e.g., increased energy costs may make it more efficient to use green manuring techniques than to purchase fertilizer) and by influencing peoples choice of heating and cooking fuels, thereby influencing deforestation rates or rates at which cow dung is substituted for other fuels.

Of course the above portrayal of environment is over-simplified, and like many formal models it undercounts institutional, political factors. Often conservation is not so much a matter of using labor as it is of changing habits;

for example, limiting the size of livestock herds so that they do not overgraze, destroy rangelands and upset natural balances. Even where conservation activities require large amounts of labor, as for example in reforrestation of watersheds and soil reclamation, there may be no effective social means of getting people to work for something that will benefit them only indirectly and only in the long term.

If and when formal modeling distracts us from the institutional factors of environmental management it confuses our understanding of the agricultural system more than it clarifies it. It is critical that any formalized investigation of environmental factors in poverty situations be coupled with investigation of the institutional factors creating the observed patterns of environmental management.

Technology

Technology, once again, influences many of the relationships in this conceptualization of the agricultural system. Starting at the top of Figure 5 (see page 6 above) and working down, technology influences all the following variables:

- Time required for nurture--for example, one food preparation technology may require that someone be present in the house almost around the clock while another only requires that someone be at home for a fraction of an hour before meals are served.

- Reproduction and death rates--medical technologies and birth control technologies. Medical technology may also influence the effectiveness of the workforce; for example, by eliminating endemic diseases such as balharzia, and hookworm.

- Environmental stress-crops and methods of cultivation vary greatly in their effects on the environment. Traditional paddy rice culture causes little or no erosion; hillside cultivation of corn may cause horrible sheet and gully erosion. Modification of either technique may increase or decrease erosion.

- Effectiveness of conservation labor in increasing resource health--e.g., a reforrestation team working with poor implements, poor organization and the wrong strain of trees may achieve little or no good.

- Effectiveness of production labor--e.g., a laborer may be able to move dirt and rocks twice as fast with a well designed wheelbarrow as with a poorly designed one; harvesting labor may similarly be reduced by well designed hand tools.

- Effectiveness of labor in producing production capital--rural electrification for example, may permit craftsmen to achieve much greater proficiency in making agricultural equipment, as may upgrading the tools with which they work.

As with resource questions, in the labor model many technological questions are at their core problems of institutional and social organization. For example, credit availability, absence or presence of mechanisms to promote cooperation where technological improvement requires it (e.g., cooperation of full villages is often required in applying technologies to eliminate endemic parasitic diseases, regularity of behavior is often required for increasing scales of production) and attitudes toward women or people of different races, tribes or other social groups are often more limiting to technological efficiency than technical factors. Once again it should be emphasized that if and when formal modeling techniques lead to ignoring these very real factors, formal modeling is contributing to misunderstanding of the problem.

CARRYING CAPACITY

Ecosystems vary in their resilience to stress. Abuse a rice paddy and you get less rice (presuming you don't destroy the irrigation system); abuse marginal wheat growing land or savanna under drought conditions and you are likely to end up with desert; abuse a rainforest and you get worthless scrub. In general, system resilience is lower in tropical and subtropical regions where temperatures are high, rates of chemical reaction are rapid and sun and rain fall on the earth with great intensity. For many such systems heavy stress leads to catastrophic declines in bioproductivity--a system in an eroded state may be reduced to 10 percent of its former life support capacity.

Under such conditions it may be most useful to conceptualize the agricultural system purely in terms of protecting its carrying capacity.

As shown in Figure 7, the carrying capacity problem begins with human and/or livestock populations whose birth rates are in excess of their death rates. This creates an exponentially growth configuration, as shown in Loop 1. The more populations grow, the less digestable organic matter the system produces per head, hence output adequacy decreases. As shown in Loop 2 this leads to a vicious circle in which inadequate output stresses the system, system stress reduces productivity, and reduced productivity leads to greater inadequacy of output and hence further system stress. This may set off a second vicious circle (Loop 3); when the resource base is too badly stressed it may become less capable of natural regeneration, thereby less able to counteract stress, and thereby more badly stressed.

For example, in a grazing system, overgrazing eliminates woody plants and begins destroying the soil's root and humus layers, thereby impairing the system's ability to retain moisture. This leads to lower forage production and causes grazers to do even more damage. It may simultaneously alter microclimate in a way that makes it difficult for natural forage to grow back. In a slash and burn system, when rotations become too frequent soil nutrients become permanently lost and soil structure be irreversibly damaged. This both decreases output and adds stress and impairs the system's capacity for natural regeneration.

The main factors countering the vicious circles just described are famine, disease and outmigration. Declining output per head harms human and livestock health. This may lead either to famine and elevated death rates or to rapid outmigration (which may end up stressing some other system....or leading to tribal warfare).

Four things should be noted about the carrying capacity conceptualization. First, it should be familiar to you if you have read Limits to Growth (Meadows et. al 1972) or related books, or if you know the Kiabob deer model, or if you have studied Garrett Hardin's essay "Tragedy of the Commons" (Hardin 1968). The same structure, an erodable carrying capacity supporting a growing population, is behind all these models, although World 3 is considerably more detailed and rich in its treatment of carrying capacity than the others.

Second, many people dislike this model intensely. I must say that in writing it up now I find I don't like the carrying capacity model very well either, for it is a model with no good opportunities. If I look at a system using a carrying capacity conceptualization, I will not find ways to use the system's abundant resources to compensate for its scarce ones. The model structure forces one to the conclusion that the system will not stabilize unless birth (or infant survival) rates are kept less than or equal to death rates. I believe that in many non-resilient ecosystems this is true and important.

Third, I would say that where a carrying capacity conceptualization pertains, field activity is more useful than model building. You don't need a model to tell you how the

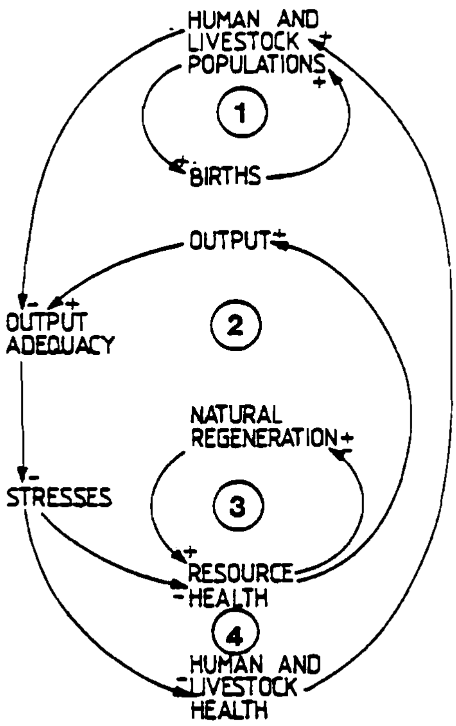

Figure 7

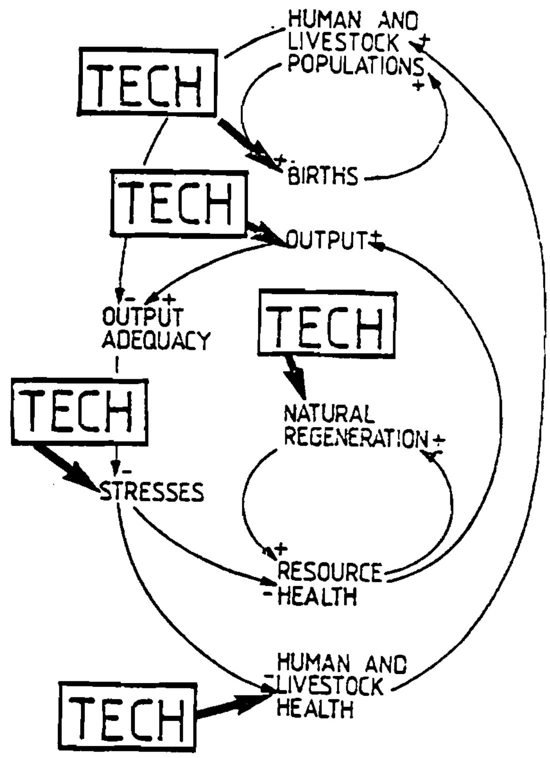

Figure 8

Figures 7 and 8: Basic causal loops in a carrying capacity system and ways in which technology may influence system relationships.

system will behave; it will overshoot its carrying capacity and collapse unless there are adequate controls on population. Thus more useful research activities include carefully measuring system parameters to learn what its capacity is and looking for ways to reduce stress, to increase resilience and to add feedback that will keep livestock and human populations below critical levels.

Fourth, the basic carrying capacity structure can be applied to all ecological systems, whether or not they contain human beings. A resilient carrying capacity model--i.e., one parameterized so that overexploitation depresses output but does not destroy environmental regenerative capacity--amounts to a sustainable yield conceptualization.

Such a conceptualization is appropriate to a large part of the earth's surface, including the oceans, the tundra, most temperate forests. The environmental loops described above in the balance of trade and the labor conceptualization are of such a form (when the system is sufficiently resilient one can safely reduce regeneration as an implicit form of land regeneration).

Environment

A carrying capacity model is a model of environment; it makes no distinction between economy, social systems and ecological systems, and it is dominated by ecological systems. A further environmental variable that can be added to such models is weather--a heavy drought added to a carrying capacity model may trigger the system to collapse sooner than it would of its own momentum. This observation leads to the conclusion: DON'T BLAME DROUGHT FOR SYSTEM INSTABILITY. Again this is a conclusion that you don't need a computer model to understand.

Technology

Technology, as shown if Figure 8 (page 12), influences carrying capacity systems in several ways. First, technology change may set the system into unstable behavior modes by improving human and livestock health and permitting populations to expand past carrying capacities. Second, technologies influence how much people need from the environment. For example, cultures that use burning technologies to get food out of grassland systems (a very large part of the African savanna system is so used) tend to stress their respective ecosystems much more than peoples who do not. Similarly, charcoal burning technologies tend to encourage deforestation in arid or semi-arid environments, and thus to hasten desertification. Third, technologies influence output. Indeed, transition to a completely new technological base, such as plow-based agriculture in a grazing system or export-oriented forest products industry in slash and burn systems, may be the most effective way of stabilizing an unstable carrying capacity system and increasing the standards of living of its inhabitants. Fourth, technology may influence system recovery from stress; for example, systematic afforestation technologies may be critical for undoing desertification.

ON RESOURCES AND ENVIRONMENT

The conceptualizations provided above are neither precise nor sophisticated. However, they demonstrate an approach that might be refined to be useful for further work. That is, the global system might be mapped out into different structural types according to their human-ecological relationships, prototype models might be built for each type, and work might proceed either toward parameterizing prototype models for specific regions or towards theoretical investigation of the action and interaction of structural types.

The overriding concept behind this approach is that environmental and resource questions form themselves along biogeochemical and demographic lines; that is, watersheds, climatic regimes, soil characteristics and settlement patterns determine the environmental and resource outlook for any specified piece of agricultural, grazing or forest land. This is to say, the political map, although it may be critical to managing the problem, is largely irrelevant to the problem's physical structure.

I believe that any work on resources and environment must come to grips with this problem. Work must proceed with reference to physical, bio- and economic geography. Soil scientists and geographers should be included and given prominent places in the research.

It might also be useful to shift some emphasis from mathematical modeling to map drawing and analysis. Many people who find normal computer output uninteresting or confusing find maps easy to relate to, and we are not bombarded in our daily lives with maps the way we are with facts, figures and verbal descriptions. Therefore maps tend to have great power for drawing and focusing attention.

Specifically, I see a need for explicit maps of the soil types most prone to erosion. These might usefully be coupled with photographic and descriptive material on early warning signs and timespans over which problems are likely to occur. I would also like to see some map-overlay study of the correspondence between potential agricultural productivity and present yields; I think this would be useful for improving people's images of where there is potential for further agricultural development. If this were coordinated with mappings of resilience/fragility it would be very useful for improving public and academic understanding of the possibilities and difficulties of opening new agricultural lands, as well as for directing further development toward areas with highest potential and least serious environmental problems.

ON TECHNOLOGY

After fitting technology into three conceptualizations of the food system, I would say the following about the general problem of fitting technology into representations:

A: Look at technological change in a systems context. Don't reduce technological change to change in the input-output relationships of production functions. Technological change has much broader effects. Over the long term, technology may influence the system more through its influence on demand (e.g., medical technology increasing population growth or medical knowlege influencing people's food tastes and preferences), on resource health (as in irrigation technologies leading to salinization or to depletion of ground water), on restoration of resource health (e.g., development of improved cover crops), on ability to absorb labor (e.g., "appropriate technology") and equitably distribute the benefits of labor, and dozens of other factors than through its direct influence on yields.

B: Do look for multiple effects of specific technologies. In particular, look what technologies do to the soil, to human health (eg. irrigation systems may lead to increased incidence of balharzia, drainage systems may help control malaria), to income distribution, and to use of time (including whether they encourage or discourage participation of women and/or children in production).

C: When looking for technological fixes (i.e., ways that technology can help get a system out of its problem) don't lock your attention onto the obvious factors (e.g., increasing productivity and decreasing fossil fuel inputs). Technology has powerful influences on demand, on information flows, on income distribution, on social values and on system resilience. In many cases these side effects may have greater leverage for changing system behavior than the more obvious technological means.

D: Do not expect to be able to model everything...and do not deceive yourself into believing that the things you can model are the most important things. Technological change is very deeply tied up with social and political change. Factors such as credit availability, ability to foster cooperation in large-scale projects, ability to motivate people to undertake actions with long-term external benefits, and degree to which people view their situation with a pragmatic, materialistic attitude are central to changes in agricultural technology. Allow yourself plenty of time to look at the variables you can't fit into a formal model, and don't forget them. I would say, leave at least half the research budget for non-modeling activities, and make sure these non-modeling activities feed into the modeling effort.

In light of the great extent to which technological change in agriculture is linked with social and political change, and in light of the large number of ways it effects agricultural systems, I would almost be tempted to say, forget the word "technology", let's just talk about change, let's just note ways in which any of the relationships in our model may vary.

A LARGER PICTURE: THE INTERACTION OF SYSTEMS

The actual global system does not fit any one of these conceptualizations; it is a mixture; and it contains important structural elements not included in any of the three conceptualizations described here. In the real system, different structures often exist side by side: rubber, cocoa, tea and coffee plantations, which loosely fit the balance of trade conceptualization, coexist in the tropics with both labor-based systems and with precariously balanced carrying capacity systems.

The conceptualization behind the conceptualization is how these various systems live together on the globe, how they push each other around, and how they can work together in mutually helpful fashions.

Very often now, carrying capacity and labor systems coexist in ways that tear each other apart. Inequitable land distribution in heavily populated systems often ends out with outmigration to forest or marginal lands. This can be the last straw, so to speak, for a non-resilient carrying capacity system. Similarly, the disintegration of a carrying capacity system may have unfortunate effects on labor-based systems, particularly when the latter are downstream from the former. For example, deforestation in the Himalayas leads to flooding and siltation of water systems in Bangladesh, India and Indochina.

Another common and unpleasant consequence of interaction between different sorts of agricultural systems is warfare. At least as I understand it, a large part of the tension between the peoples of Southeast Asia is mutual hatred between the labor-intensive valley peoples and land intensive (carrying capacity) jungle farmers.

Balance of trade systems are not immune to the mess either. If the very large part of the earth's dry crust that is cultivated by land-intensive carrying-capacity systems continues to eliminate its forest and grassland cover, it will make an immense contribution to atmospheric carbon dioxide levels, perhaps even more than industrial systems contribute by burning fossil fuels. On the other hand, balance of trade systems have exacerbated pressures on carrying capacity systems by giving them technologies that increase population growth rates while simultaneously taking land away from them and putting it into cultivation of commercial crops (or use as game refuges, or fenced-in pasture). The energy situation is likely to lead to further pressure on carrying-capacity systems by balance of trade systems for the equatorial regions, where tropical forest and grazing systems prevail, are potentially very good regions for solar energy collection. Both energy plantation systems and large scale desert lands solar collectors are likely in the 21st century.

There is much room for study of the way different human-ecological systems interact and how their interaction can be made to work better. If this is undertaken, it is important that more time be allocated to verbal exploration of the system, careful definition of problems, and communication activities than to modeling. The system is far too complex to allow precise, detailed modeling. Any ambitious modeling effort looking at this system is going to get all twisted around the system's complexity and is unlikely to get to the point of telling us anything about how the system operates and can be made to operate better.

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