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LOW INPUT TECHNOLOGIES AND FARMING SYSTEMS:

THE NEPAL CASE

Background Papers
Richard R. Harwood

IMPROVING NEPAL'S HILL FARMS: THE IMPORTANCE OF FARM STRUCTURE ^{1/}

The existing capability for farming systems research in Nepal

A much-used conceptual model of hill farms shows their complex structural relationships (Fig. 1). ^{2/} The outline given in this Rockefeller Foundation study was used as a basis for the ICP-sponsored cropping systems project. That project was organized according to the evolving on-farm methods being developed by the Asian Cropping Systems Working Group. At the time of inception of the Nepal ICP the input from that working group was direct and effective. The Nepal project quickly became a lead program in use of state-of-the-art farming systems methods and established a clear lead in carrying the on-farm approach into pre-production testing and then production block efforts.

An assessment of the state-of-the-art in farming systems research would reveal that on-farm research methodologies are well developed. Nepalese scientists and their cropping systems project are using these approaches quite well. A start has been made in several countries to identify "cropping system determinants," the major physical and socioeconomic factors which determine cropping systems potential. Much more needs to be done in this area, but the approaches suggested in recent research papers give general guidelines for selecting "uniform" zones for testing and outreach extrapolation. These methods now need to be simplified and made more operational. They must be further applied to Nepal's variable hill environments.

A crucial area of weakness in available methods on a worldwide scale is in farming systems design. Few workers have approached the conceptual framework needed for effective design of systems. This cutting edge research area will be pivotal to the success of the production and resource stabilization efforts in the hills of Nepal. The ultimate success or failure of the ARP project depends not only on its strengthening of institutions, but on its proposed solutions to hill farm problems. The most probable approach to those problems is through farm development. Considerable effort could be made in landscape design which could conceivably arrive at structural solutions. These would, in turn, be difficult to implement because of discontinuities with the overwhelmingly dominant factor in hill agriculture, the small farm enterprise and the sociopolitical system built around it. It makes far more sense to approach the problem through that farm enterprise from the outset. It is suggested that this ARP project do just that.

The Structure of Hill Farms

The component pieces of hill farms have close links as shown in figure 1. Since most such farms are in remote locations where inputs are both scarce and expensive, circular flows and self-containment are crucial. A reminder of a few of the key links is useful at this point.

^{1/} An analysis by IADS as articulation of the conceptual basis for the proposed interventions in Nepalese hill farms.

^{2/} A Study of Hill Agriculture in Nepal. The Rockefeller Foundation. 1975. p. 97.

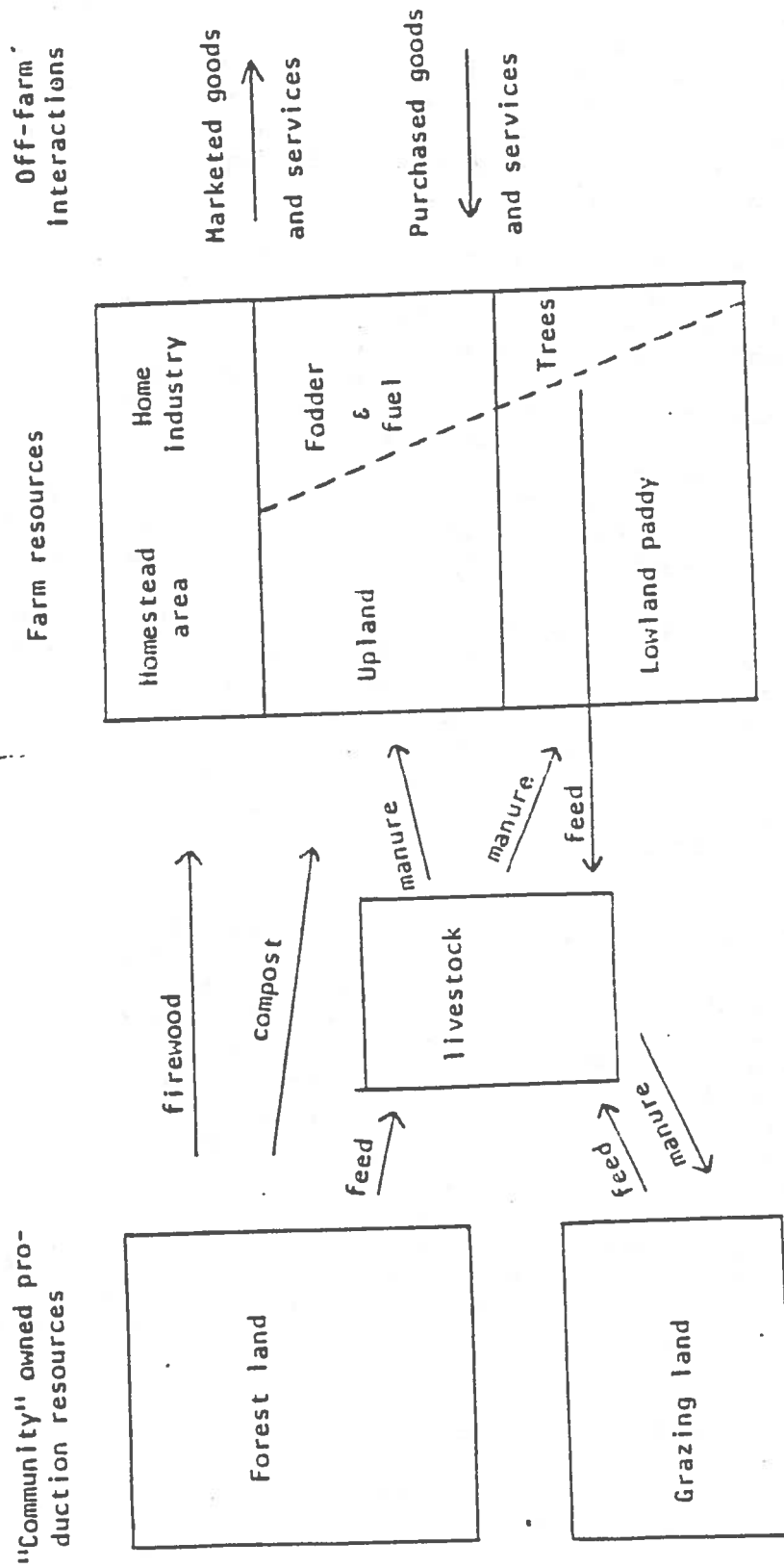


Figure 1. Conceptual model of a Nepalese hill farm production system.
 Source: The Rockefeller Foundation; 1974. A study of Hill Agriculture in Nepal, p. 96a.

As hill farms and their physical environment have come under increasing population pressure through the last one to two decades, resource use has become increasingly exploitive in that long-term production potential is depleted by intensification and resultant erosion. A key factor has been the requirement for firewood coupled with a need to bring all arable land under cultivation.

The effective farming systems in the hills have two physical boundaries, an inner and an outer (Fig. 2). The outer boundary is roughly coincident with the Panchayat (or ward) land area. The outer boundary defines the common area of pasture and forest, and has the inner farm, under private management, within it. The privately managed farm land occupies, for the most part, the arable land of the Panchayat. The productivity of arable land, in the absence or short supply of fertilizer nutrients, is dependent on the nutrient flows, the flow of animal feed, and the energy flows between the inner and outer areas as well as on the efficiency of flow within the inner farm. This is shown conceptually in Fig. 3, which is a modified version of the more well-known Fig. 1.

In an integrated system the "structure" of the system (the component pieces, the enterprise combinations and how they are linked) are crucial to its efficiency. The flows of nutrients, energy and materials within the system become the dominant factors. Unless additional resources are applied from outside in the form of energy or nutrients, any disruption of links without replacement with more efficient ones causes an overall decline in productivity of the system. Resource use imbalances can, to some extent, be corrected by changing the component mix of the farming system.

Of the flows in the large (Panchayat-level) farm system, that of firewood energy is central. Cooking and heating fuel from plant biomass has, as its energy source, carbon fixed through photosynthesis. As woody fuel becomes more scarce, villagers resort to burning plant residues, materials which have a lower heat yield and contain higher levels of nitrogen. This nitrogen is then lost to the atmosphere. Fixed carbon is highly important to other elements of the system. In various forms it serves as an energy source for soil micro fauna and flora. It is the energy source for livestock. Plant residues and their decayed form, soil organic matter, serve as the major holding form for short- and intermediate-term release of soil nutrients for crop growth. As fixed carbon levels in the large system, and ultimately the inner or on-farm system, "wind down" over time, as they are being observed to do in the hills, the energy levels and levels of available nutrients show corresponding decline. Crop yields then drop.

Interventions which are theoretically possible would be to provide a supplemental energy source such as coal, which is used in the People's Republic of China, and/or major inputs of crop nutrients. The latter option, even if it was economically feasible for the hills, could be expected to lead to nutrient environmental contamination if the farm system was not structured so as to hold nutrients. The knowledge of such flows is, at present, quite sketchy, but a beginning has been made of research into them. (1,2). Again, fixed carbon retention, in the form of crop residues and eventually of soil organic matter, plays a critical role in nutrient retention and release to crops.

Outer (Panchayat) farming system boundary

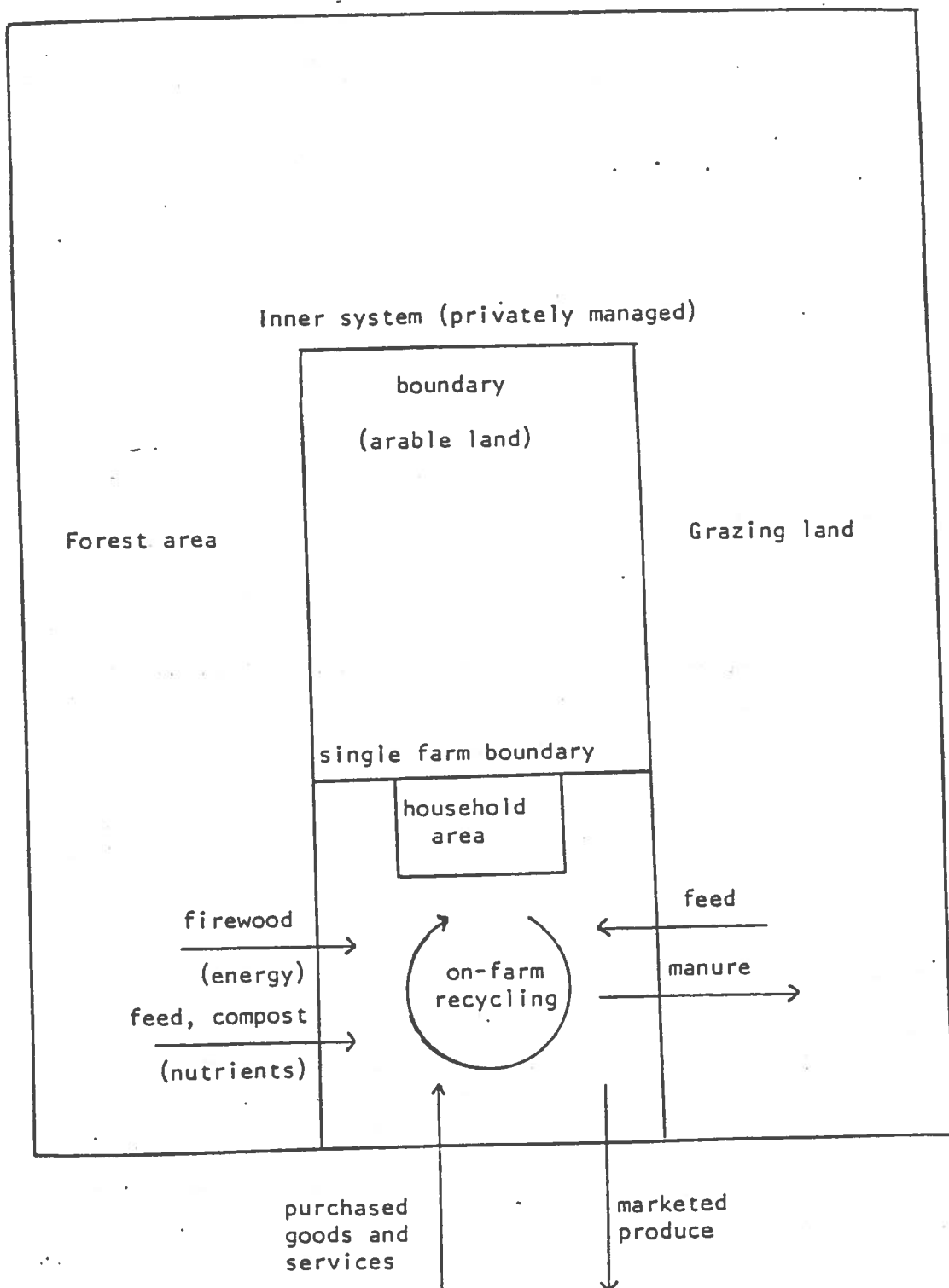
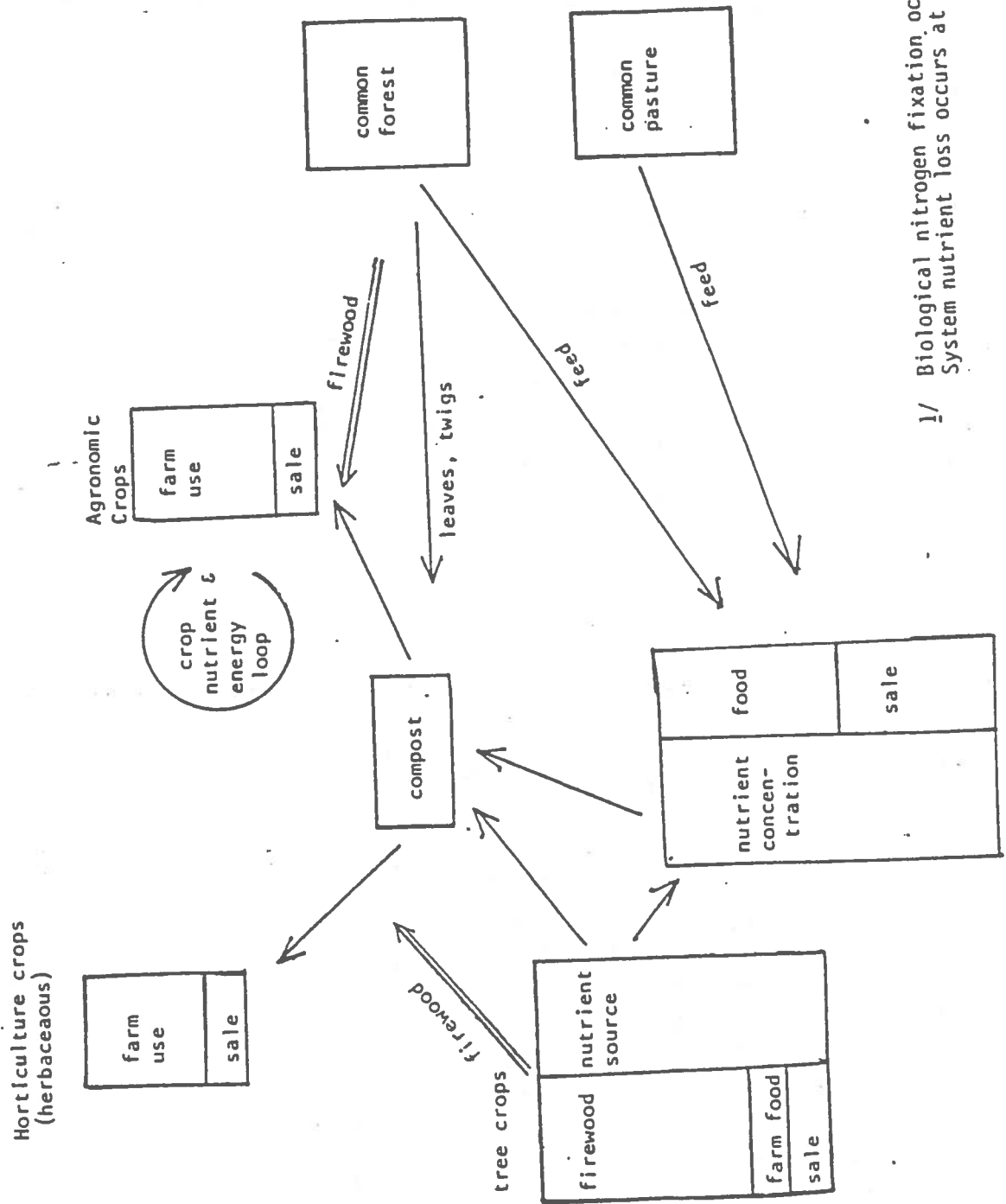


Figure 2. Conceptual model of Nepalese hill farm boundaries.



1/ Biological nitrogen fixation occurs at several points
System nutrient loss occurs at several points

Figure 3. Managed nutrient flows in a Nepalese Farm (partial representation) 1/

Summary

The farming systems of Nepal's hills are not increasing in productivity in spite of improvement in crop varieties, gradual intensification of crop patterns and the addition of more animals. Crop nutrients and, in particular, nitrogen are increasingly limiting. The nutrient cycling efficiencies of former years are decreasing as Panchayat and farm tree plantings are overcut to meet short-term fuel needs. There is a decreasing amount of nitrogen fixed in the systems with few legumes being grown.

1/Harwood, R.R., A. Borowski and W. Liebhardt. 1984. Managing nitrogen in Diversified Farming Systems. Presented at the symposium: Agricultural Policy and the Small Farm Sector. American Association for the Advancement of Science, New York, May 28, 1984.

2/Harwood, R.R. 1985. The Integration Efficiencies of Cropping Systems. In: Sustainable Agriculture and Integrated Farming Systems. Michigan State University.

RESOURCE USE EFFICIENCIES OF FARMING SYSTEMS

RICHARD R. HARWOOD

INTERNATIONAL AGRICULTURAL DEVELOPMENT SERVICE

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Fact: Most farmers in second and third world countries face resource limitations which are now reducing the agricultural production of their farms to levels well below the potential defined by their physical environment. That physical environment is defined by:

Farm size
Land farm, soil type
Temperature, water availability, light

Fact: We are probably on the "downhill" side of the ability to provide major sources of capital for massive schemes to improve these physical resources. There will continue to be investment in medium to smaller scale schemes.

Fact: Output from most farms can be significantly increased by making available at reasonable cost industrially-derived or processed production inputs such as fertilizer, pesticide or mechanization. The cost of these inputs will probably continue to increase with the cost of energy and as environmental safeguard costs are increasingly factored into them. These inputs require significant infrastructure and fit best into a high product-flow agriculture. Such a model is increasingly costly in the many very remote, low-resource areas.

Hypothesis: That farm structure can be a partial substitute for inputs in that component interactions can, in some economic environments, promote significantly higher efficiency of resource use and of farm output.

Assumptions for purposes of this discussion:

1. Most tropical farms will have a water limitation for at least part of the year, with high and unpredictable variability.
2. Land will be limiting (small farm size with an underdeveloped farmer management capability).
3. Capital will be scarce.
4. Inputs will be expensive, with supply often uncertain.
5. Farmer goals include:
 - A degree of self-reliance.
 - The need for cash income.
 - A requirement for economic stability.
6. "Societal" goals for those farmers include:
 - Higher production
 - Preservation of the production resource
 - Environmental protection
 - Productive employment for a wide range of ages of both sexes.

Farm System Structure

The structure of a farming system is defined by its crop (including trees) and animal mix component pieces, the extent of each, their use of farm resources, the interactions between them, the flow of energy,

nutrients and other factors through them and their individual contribution to total farm productivity.
The Effects of Structuring:

If farm systems are carefully structured (with the type of structuring dependant on the environment and on the resource mix) significant efficiencies of resource use can be achieved. There has been considerable interest in recent years in the lower energy inputs of the so-called organic farms in the United States. Organic farms in the midwestern U.S. have been reported to have a 60% reduction in energy input per dollar of produce 1/. A controlled experiment at the Rodale Research Center in Pennsylvania has shown similar results when rotations were established and biological nitrogen fixation was included in the system 2/. In the first crop system, hay, corn, wheat and soybeans were rotated under the assumption that animals would be fed and the manure returned. In the second crop system, corn, soybeans and wheat were rotated with fall and spring-sown legume cover crops. This was a cash grain rotation with no hay. In both of these rotations no chemical or fertilizer inputs were used. In the third system, corn and soybeans were rotated, with chemical inputs used as needed for optimum yields. An analysis of the energy inputs required for corn or soybeans was compared across all rotations (Table 1).

Table 1. Energy requirements of corn and soybeans in organic and conventional systems (Rodale Conversion Experiment: 1981 base).¹

Crop	Treatment ²	Fuel (l/ha)		Energy (K CAL/ha)		Total Energy	
		gas	diesel	fertilisers	herbicides	K CAL/ha	MJ/ha
Corn grain ³	1	42.5	136.5			1.99×10^6	8.27×10^3
	2	25.7	117.8			1.60×10^6	6.67×10^3
	3	25.7	58.0	2.7×10^6	1.95×10^5	3.80×10^6	15.8×10^3
Soybeans	1	32.3	61.7			1.03×10^6	4.30×10^3
	2	32.3	61.7			1.03×10^6	4.30×10^3
	3	36.1	55.2		1.75×10^5	1.17×10^6	4.89×10^3
Corn silage	1	42.5	117.8			1.77×10^6	7.39×10^3
	2	25.7	99.1			1.35×10^6	7.39×10^3
	3	25.7	39.3	2.7×10^6	1.95×10^5	3.61×10^6	15.0×10^3

¹ Analysis by Stephen Kaffka.

² 1 = With animals (hay rotation and manure)

2 = Without animals (legume cover crops only - cash grain rotation)

3 = Conventional management (corn-soybean rotation)

³ The costs of replanting in 1981 are assumed to be atypical and are thus ignored.

Rotations 1 and 2, with a higher degree of internal "structuring" required about half the energy. Yields were 10% lower in the hay rotation and 30% lower in the cash grain rotation in the first year,

1/ Lockeretz, 1980. In: D. Pimentel (ed), A Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Florida

2/ Harwood, R.R. 1985. The Integration Efficiencies of Cropping Systems in: T.C. Edens, C. Fridgen and S.L. Battenfield eds. Sustainable Agriculture and Integrated Farming Systems. Michigan State University Press, East Lansing, Michigan.

but are the same as the corn-soybean rotation yields now after four years. The major interactions accounting for these reductions are noted below.

Crop Rotation Efficiencies

Seven interaction effects have been noted in crop rotation structuring ^{3/}. The most significant is that of efficiency of nutrient flow. Rotation effects (in temperate zones at least) include:

1. An altered vertical movement of nutrients in the soil. With effective rotations, use of low-solubility nutrient sources and an altered tillage, an actual upward movement can be achieved, with accumulation in the upper horizons.
 2. The form of organic matter in the soil seems to be altered. A higher portion of total organic matter can be maintained in the labile phase. Turnover rates are higher. It appears that soil nutrients can enter and be released from soil organic matter at significantly higher rates under certain structural conditions.
- Both of these factors contribute to significantly higher efficiencies of nutrient retention and recycling.

Secondly, weed population shifts in the field are significantly altered by rotation, tillage and chemical management. Some rotation patterns in temperate zones make use of a phenomenon called counter-cyclical shifts. Here warm season and cold season crops are rotated. With warm season crops such as corn and soybeans the weed pattern rapidly shifts toward warm season annuals, with broadleaves predominant in the absence of herbicide use. After two or three years of that shift, fall-sown wheat or other small grains are sown. There will be a nearly complete absence of cool season weeds to compete with these cereals for a year or two until the weed population shifts in response. This "counter-cyclical" shifting significantly reduces weed control costs. Included in these weed effects are crop competition effect, allelopathy and the selective effects of tillage or chemicals.

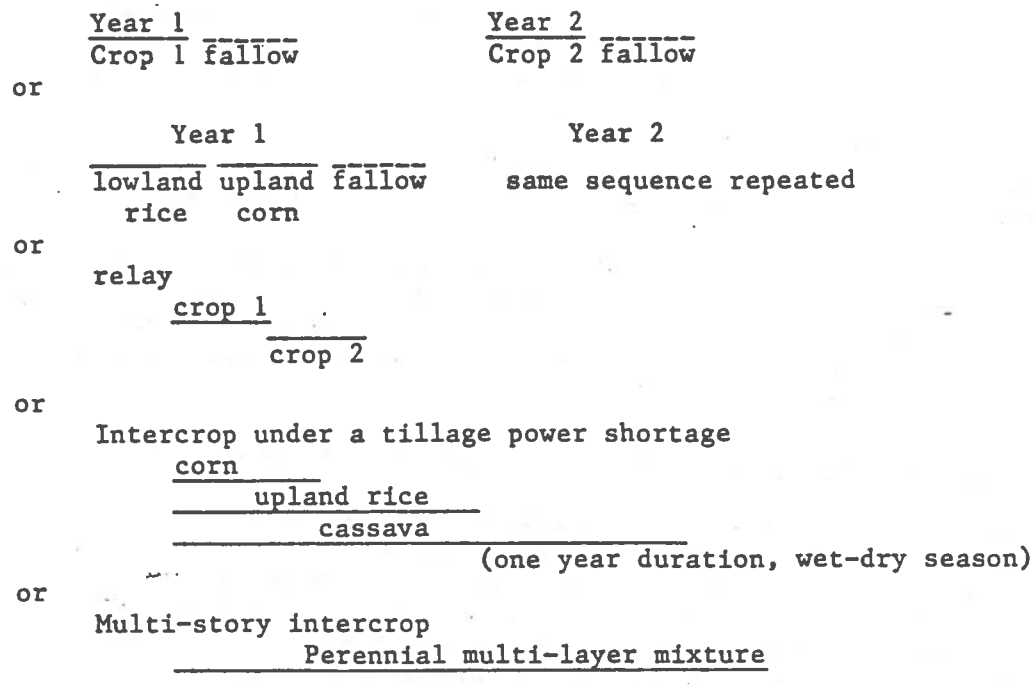
Another significant effect of structuring is the effect on insect and disease stability. This is complex, but often extremely effective in reducing pest buildup and the subsequent control costs.

Horizontal Dimensions of Crop Integration

Crop and animal systems can be integrated with other biological organisms of the farm in several ways. It is useful to think of that integration (or structuring) as having two dimensions. Horizontal structuring is that which occurs within a production system (production enterprise) over time. Crop rotation or intercrop effects are an example of this type. Time sequence interactions of crops may be shown as follows:

^{3/} Harwood, R.R. op. cit.

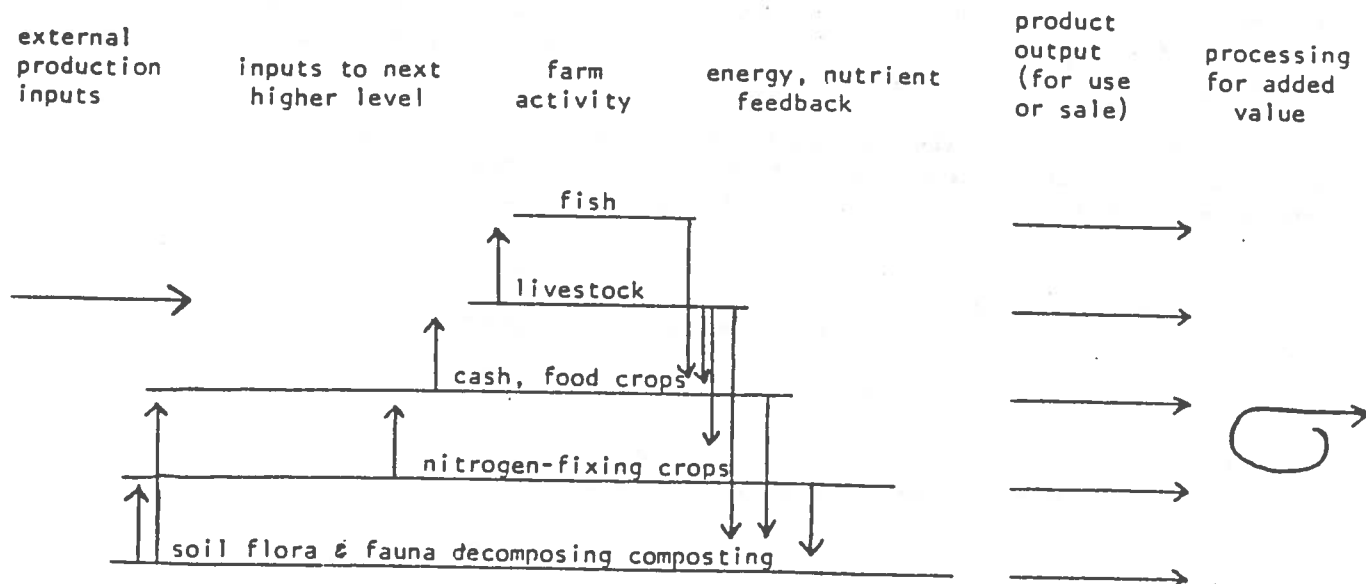
Simple rotations:



Many different integration efficiencies have been reported for these mixes and combinations. We need not repeat them here.

Vertical biological integration - the pyramiding of production enterprises. A concepted model of "vertical" integration is seen in the following figure:

Figure 1. Vertical integration of a farm system.



The value of any single production enterprise (crop, livestock,) is, in this system not only the value of the product output minus the value of the external inputs plus the capital cost of the production resource, but it includes the value of its outputs to other components of the system. With such vertical integration there are also the efficiencies of flow mentioned briefly above. The end result of this intensive structure is higher productivity, greater biological stability and more efficient use of resources (more efficient nutrient and energy flows) as compared to unstructured (or less-structured) systems.

But structuring is not free. There is a considerable increase in management time and information. The labor and energy inputs do not necessarily increase but there are more component pieces to manage. The "management stability" of the system may increase or decrease, depending on the type of system.

Socioeconomic Determinants of type and degree of structuring:

The appropriate level of farm structure depends on the cost and availability of inputs, on the farm size/management intensity, the type of labor and mechanization which is available and the degree of concern or cost of environmental impact of the farming system. Unstructured systems (for example continuous corn) fit where farm size is large, input costs low, biological stability is not a serious factor and there is little concern for the environment. The interaction of several of these factors is shown in figure 2. Each of the factor gradients moves left or right depending on the particular resource combination of the farm in question. An example of high structuring - a Nepali hill farm:

Nepal's hill farms are resource-limiting as shown by the location of farm "A" of figure 2. They have many production components and complex nutrient and energy flows. The extent of the efficiencies and interactions is unknown but is schematically represented in figure 3. The productivity of these farms has stagnated. A key to increased output is the insertion of high yielding, improved varieties and the increase of nutrients flowing through the system. Nitrogen seems to be particularly limiting.

In Nepal's hills external inputs are extremely limited and will continue so for the foreseeable future. The conditions for high structuring will continue to exist as far as can be predicted. Development strategies include:

1. Making available a ready supply of improved seed.
2. Increasing biological nitrogen supply through:
 - a. Woody legumes
 - b. Leguminous forages
 - c. Improved pulse crops
3. Increased production of animal feed.
4. Maintaining or increasing farm structural integrity.

Figure 2 Factor relationships which determine the optimal structuring of a farming system

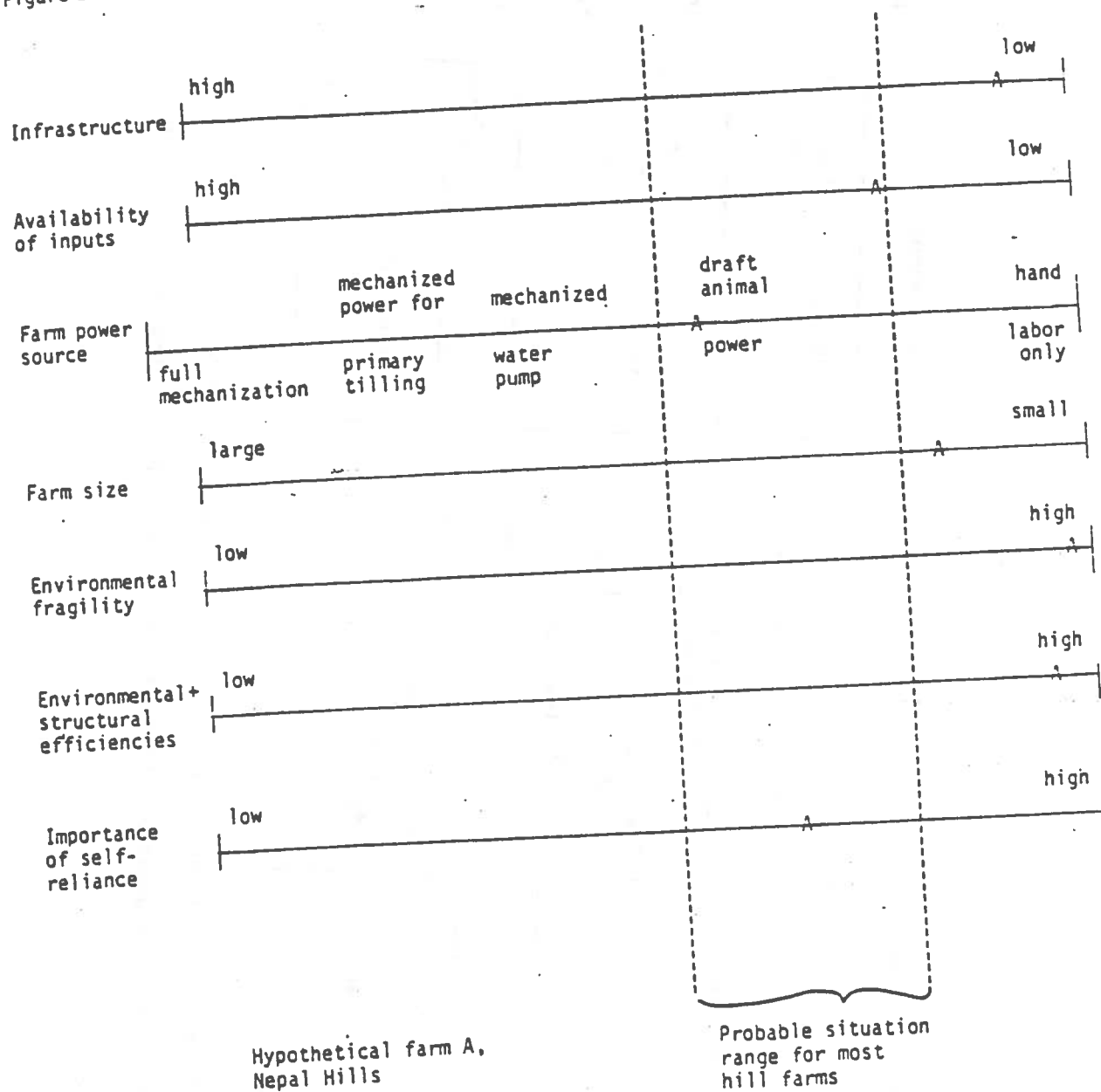


Figure 3

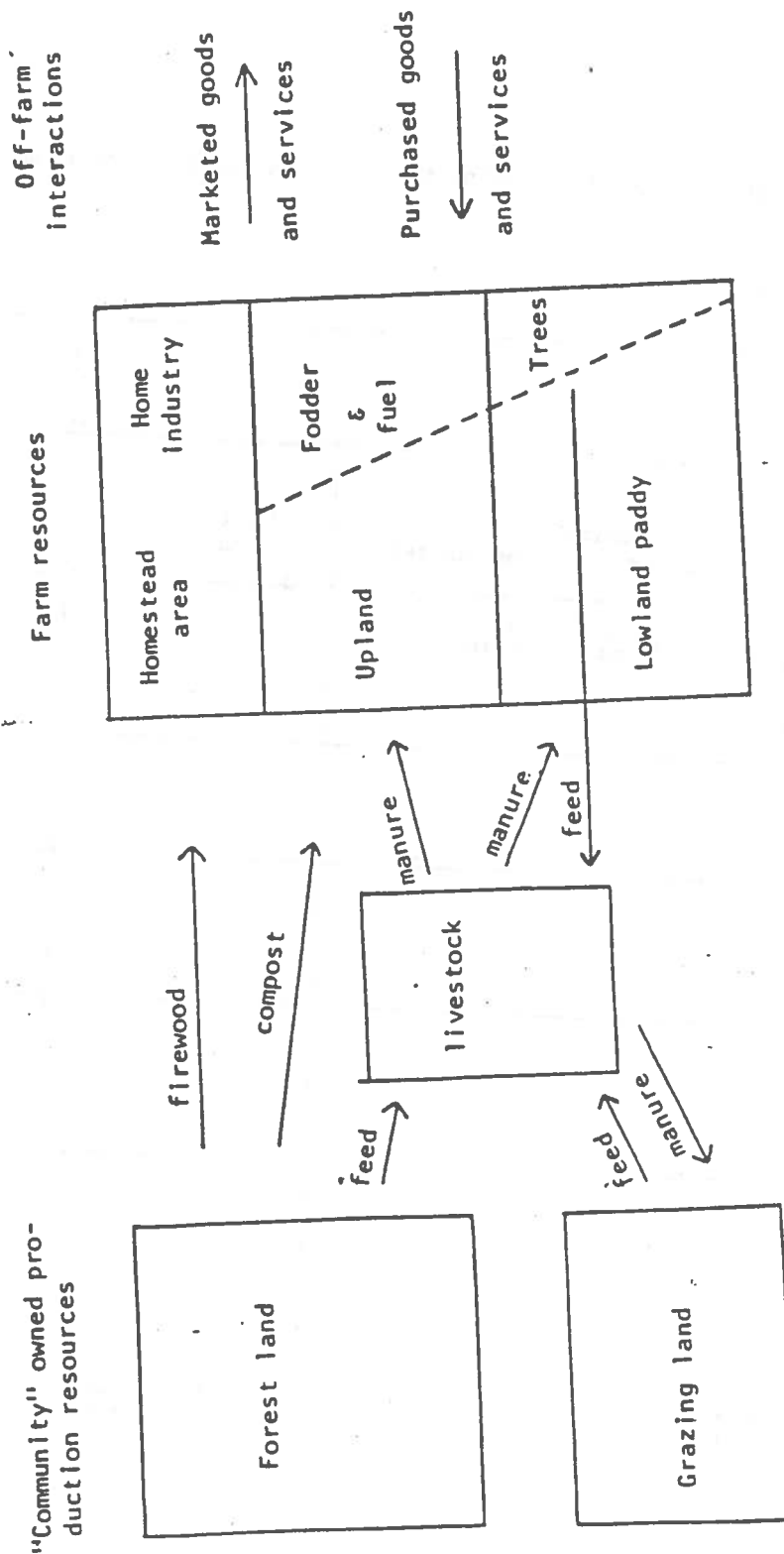


Figure A-1. Conceptual model of a Nepali hill farm production system.

Source: The Rockefeller Foundation; 1974. A study of Hill Agriculture in Nepal, p. 96a.

Other authors have stated these concepts in somewhat different terms:

"An ecosystem approach implies that an agronomic unit is perceived as being comprised of interacting components that form a whole which has system-level properties. The logical extension is that to understand behavior of system components (crops, livestock, pests, etc); one must know something of the way a component is connected within an ecosystem.

Agroecosystems may have extensive dependence and impact on externals. - They are then essentially economic in nature.

They may be ecological systems under a high degree of socioeconomic control, or they may be socioeconomic systems with varying levels of ecological control." ^{4/}

The "fit" of intensive structure to socioeconomic gradients

A conceptual matrix for third world farming systems shows very general relationships between rural population pressure, rural infrastructure and supply of inputs (figure 4). The most intensive structuring occurs on the low infrastructure and high population pressure sides of the intensive cash crop or crop/livestock systems. The purposeful structuring for nutrient flow efficiency typically occurs toward the upper left corner of the matrix. Hill systems of Nepal clearly fall in this area.

In determining development direction and the impact points for intervention, it is extremely important to understand where target farmers are with respect to this matrix. Farmers will not invest the required management in greater structure if inputs are cheap and readily available. Likewise, they will not move from horizontal structuring to the more complex horizontal/vertical combinations until economic pressures to do so are substantial. In non-mechanized agriculture the complex forms of structure where nutrients are "harvested" and moved from field to field seem to fit only under extreme conditions of small farm size, high labor availability and extreme scarcity of input. In mechanized agriculture, such structuring fits on the intermediate to small sized farms where crops and livestock are integrated or in proximity to an external nutrient source. U.S. alternative or organic agriculture fits this latter pattern.

In summary, there is a marked shift in farm development strategies toward rational design of integrated farm systems. Improved component technologies are then essential to the change process. A basic difference with respect to environmental protection is that now, with effective systems design, ecological and environmental safeguards are built into the production system. Components are assembled which balance each other to minimize adverse environmental impact rather than depending on expensive and seldom used add-on remedies to problems created by a narrow,

^{4/} Lowrance, R., B.R. Stimmer and G.J. House. eds. 1984. Agricultural Ecosystems: Unifying Concepts. Wiley, 233 p.

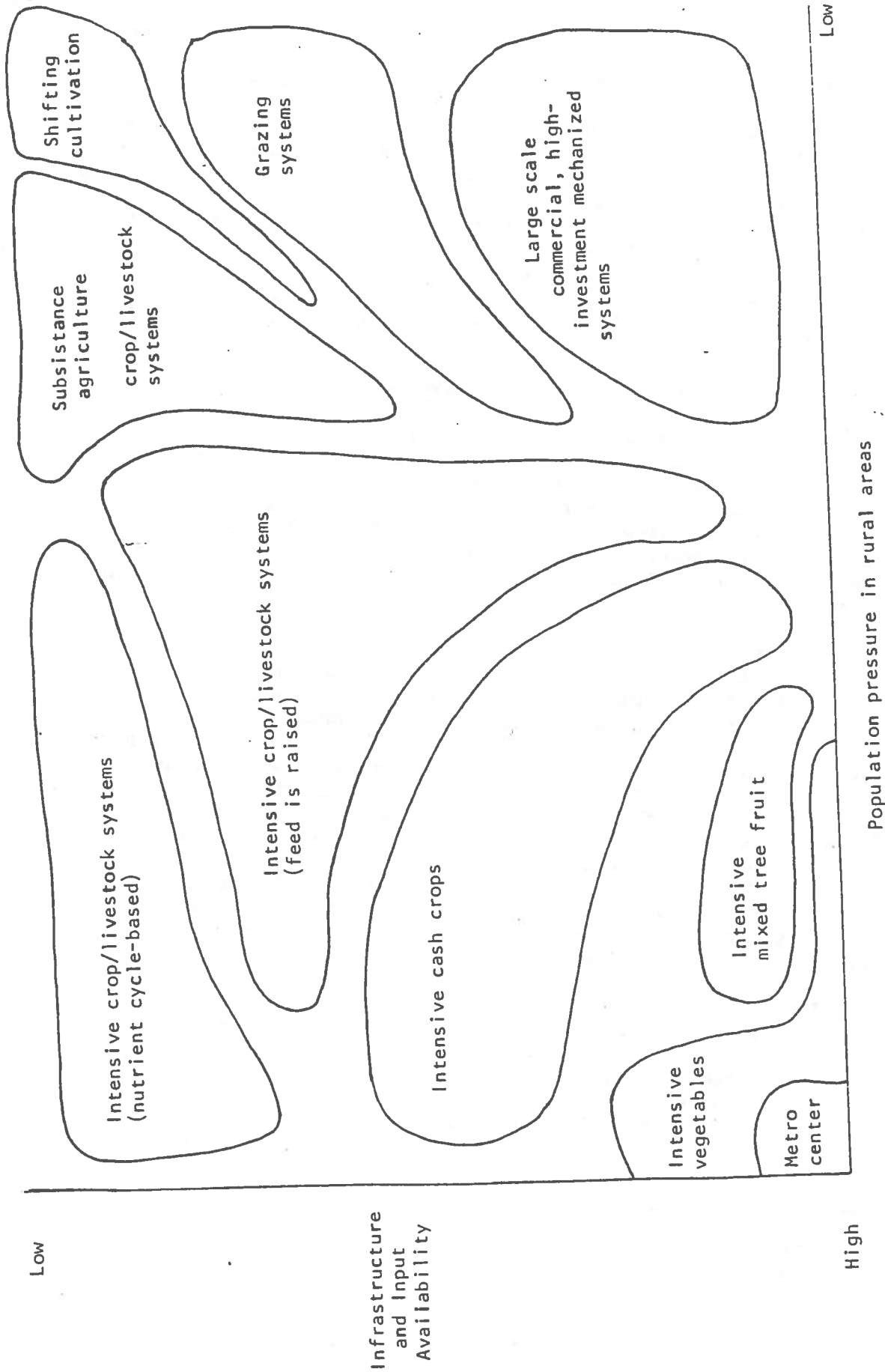


Figure 4. The relationship among infrastructure, population pressure and farming system type.

single factor approach such as "increased rice yield". Mixed farm development with crop, animal and agroforestry components represent the cutting edge of new strategies and direction. This new strategy is sometimes referred to as "agricultural ecology" (Conway, 1984). ^{5/} For many environments and systems, available nitrogen is becoming the single most limiting factor to increased farm productivity. The amount of fixed nitrogen in the farm system is closely limited to the total amount of fixed carbon. The productivity of the system depends on the total amount of both. As their levels are drawn down by burning or "exploitive" pressure on the farm system, yields and total productivity decline. Soil erosion increases, accelerating the process of decline. Under conditions of high input cost or of scarcity, the integration of systems components is the only economical way to improve the system.

I have discussed a few of the basic principles of system integration. The "art" is now poorly developed and largely conceptual, yet it can provide a framework for guiding development change. Hopefully, the "science" of systems design will follow rapidly. That "science" will come from your programs in the field. It will depend on those rare individuals that you must identify for your programs. I can only encourage you to seek them out carefully, and once identified, use them to their fullest.

^{5/} Conway, G.R. 1984. Rural Resource Conflicts in the U.K. and Third World - Issues for Research Policy. Imperial College of Science and Technology, University of London, 35 p.