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RESOURCE USE EFFICIENCIES OF FARMING SYSTEMS

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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]

		Fuel (l/ha)		Energy (K CAL/ha)		Total Energy	
Crop	Treatment[2]	gas	diesel	fertilizers	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 broadleafs predominant in the absence of herbicide use. After two or three years of that shift, fall-sown wheat or other small 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:

Year 1		Year 2	
Crop 1	fallow	Crop 2	fallow

or

Year 1			Year 2
lowland rice	upland corn	fallow	same sequence repeated

or

relay

crop 1

crop 2

or

Intercrop under a tillage power shortage

corn

upland rice

cassava

(one year duration, wet-dry season)

or

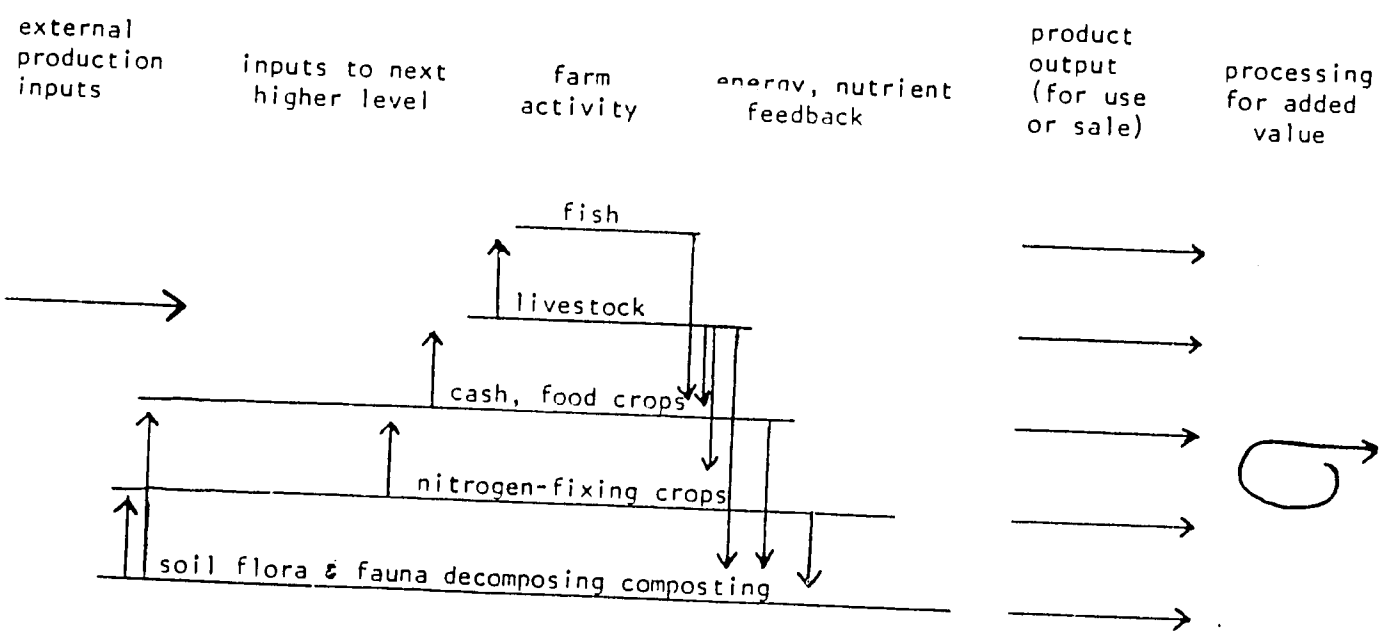
Multi-story intercrop

Perennial multi-layer mixture

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.

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

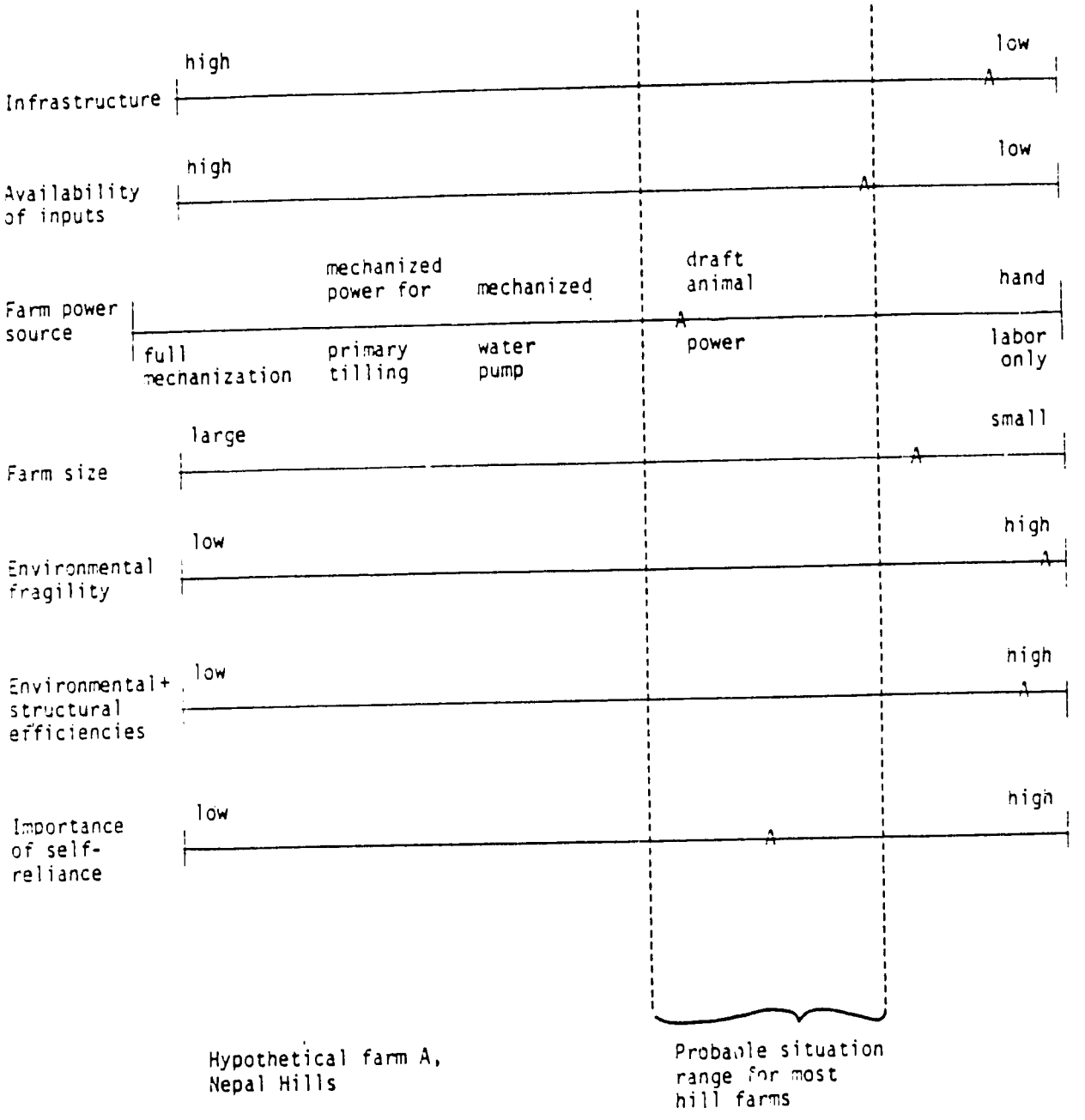

Figure 3

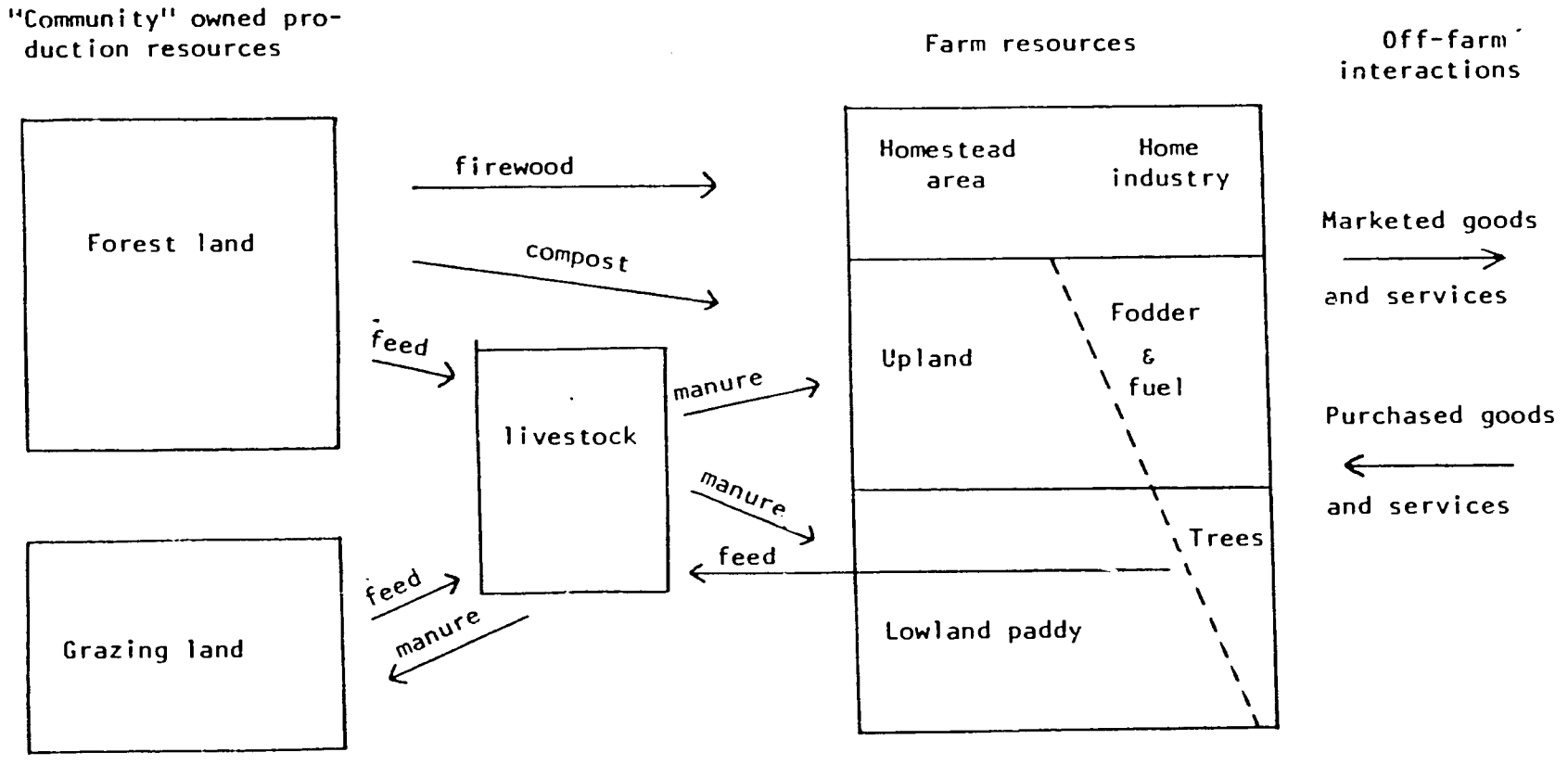

Figure A-1. Conceptual model of a Nepali hill farm production system.

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,

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

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.