SYSTEMS ANALYSIS IN CROP-LIVESTOCK INTEGRATION

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INTRODUCTION

A system is a conceptual artifice that includes a collection of interdependent and interactive elements that act together to accomplish a given task. The interactions with, and influence upon, elements outside the system may be either weakly or strongly connected to any intrinsic feedback mechanism of the system. A farming system is a unique and reasonably stable arrangement of farming enterprises that a household manages according to well-defined practices in response to physical, biological, and socioeconomic factors and in accordance with household goals, preferences, and resources (Van Der Veen, 1986). All the above factors influence the production methods used by the household and the output that is achieved.

Within the farming system are the household, crop, animal, soil, weed, insect, and other subsystems. The household, crop, and animal subsystems are integrated and interdependent. The household provides labor and management, crops provide feed, and the animals generate power, manure, meat, milk, and capital. The farming system is part of a larger agroecosystem composed of non-agricultural systems, market and credit systems, and other farming systems.

However, although there is widespread interest in, and a large amount of published literature on, the topic of Farming Systems Research (FSR), these researches concentrated on improving the crop component of a variety of farming systems. In the present state of Asian mixed farming systems, its animal component has been neglected. As a result, yields of rice and wheat have increased dramatically but animal productivity has remained unchanged. Among the reasons for the neglect of animal research directed toward small farms are the high cost of on-farm research, the marketing constraints on increased production, and the popular belief that only commercial animal production is profitable. Presently, it is clearly recognized that new technologies must be found for the small farm, which comprises the majority of the agricultural sector in most developing countries. Any realistic strategy for improving conditions of the small farm must be directed toward increasing the productivity of the crop and animal components simultaneously.

THE SLOPELAND FARMING SYSTEMS APPROACH

Systems Characterization and Interrelations

Southeast Asia, one of the world's most densely populated regions, covers: Myanmar, Vietnam, Thailand, Laos, Cambodia, Malaysia, Indonesia, and the Philippines. While the core areas, the lowlands, have profound significance in terms of staple food production (rice), they represent only a small proportion of the total area of the region (Garrity and Sajise, 1993). The hinterlands or upland areas encompass from 84 to 98% of the total land area of each country. The difference in the ecological conditions of the core areas and the hinterlands (Table 1) has some implications on the strategy for agricultural agenda (Fujisaka and Sajise 1986).

Because of these contrasting characteristics, agricultural development strategies essentially differ between the core and hinterland areas. The uplands or hinterland areas exhibit high heterogeneity and high degradation of natural resources. This is particularly true with the soil component that affects much of the system productivity and livelihood of upland farmers. The nutrient loss and gain is pictured in Figure 1 below. To sustain the upland farming system requires a diverse set of programs that fit the varied micro-patches and sub-systems such as the sub-system of livestock production. Since the hinterlands are remote, highly diverse and rapidly changing, strategies should be adaptive, flexible and sustainable.

There is a need to hasten the transfer of sustainable upland development technologies and strategies to the Southeast Asian region to arrest the most alarming problems in SEA agriculture today - soil erosion, resource degradation, and on increasing population of the "poorest of the poor". Slopelands will be a destabilizing force in the pace and security of countries if environmental and socioeconomic conditions are not improved.

Slopeland farming systems are often characterized by three dimensions, namely; food sufficiency, environmental stewardship and socio-economic dimensions.

Food sufficiency is the ability of agricultural systems to produce food in sufficient quantities to meet the demand of the population over the long term. According to this interpretation, estimating future demands for food and the potential for increased food production can be used to access sustainability of the system.

System sustainability has been increasingly associated with the maintenance of environmental quality both on and off the farm (Smit and Smithers, 1993). Maintenance of environmental quality essentially means preservation of the productive capacity of the land resource.

Economic and social concerns can be addressed as maintenance of community systems by food efficiency, fair distribution of benefits, institutional support and stewardship values; and inter- and intra-generational equity. Some necessary characteristics of a sustainable slopeland farming system can be summarized as follows :

Social aspects

1. Democratization
2. Socialization with the urban area
3. Community Organization

Technical aspects

1. Democratization of knowledge
2. Construction of knowledge
3. Specialization of technology
4. Appropriation of knowledge
5. Satisfaction of the needs of animals and plants

Cultural aspects

1. Self-esteem and identity
2. Rescue and change of values
3. Self-reliance

Economic aspects

1. Diversification of products
2. Decrease in the costs of production
3. Regularity of income
4. Increase in income

To achieve this sustainable development concept, the income generation need of local communities must be balanced by the objective of conservation. This could be done through improved resource use, transformation and marketing of natural resources. The rising demand for natural resources is to a large extent being serviced by small rural enterprises, with considerable environmental consequences on both conservation (off-take) and household economy (income generation). In that context, the livestock component and its relationships with other components in the small scale farms would be a reliant solution for the sustainable development.

Methods of Analysis

There is increased awareness of the important role of livestock in Asian economies. Different livestock species are used to cultivate land, transport goods and people in rural areas, provide manure for fuel and crop production, utilize marginal lands and crop residues, and provide a form of insurance for the farm household (Table 2). Thus livestock makes many important contributions to the welfare of the people beyond the production of meat, milk, eggs, skins, and hides.

There are many interactions between crops and farm animals. At times, livestock may be the only way farmers can benefit from community resources, such as grazing lands or forests. Livestock provide an alternative market for crops by use of low-quality roughages and poor-quality grains. In addition, livestock ownership provides a safe investment that can be stored and which produces increased returns through reproduction and gain in body weight. This flexibility in marketing and savings adds to the sustainability of farm enterprises and protects against natural calamities.

However, livestock do compete with food crops for land and labor. Forages may occupy land or can be intercropped with food crops, planted in hedgerows, or confined to land types that are difficult to manage. Livestock definitely competes for farm labor, which is needed to feed and care for the animals and process the resulting products.

Because of the small number of animals on farms, high cost, and close emotional ties between the farm family and its animals, on-farm experimentation with animals becomes more difficult than with crops. Failure of a treatment, or even animals' adjustment to new feed sources, may lead to a drop in milk-production, loss in weight, or listlessness. Disease can have more serious repercussions for livestock researchers than will reduced grain yield in a farm.

For these reasons, the emphasis on the *ex ante* analysis of biological and economic feasibility of new production methods should be greater in animal production than in cropping systems research. Modifying the animal production system, with multiple products and a complex set of difficult-to-cost crop by-products, labor, and agricultural inputs, can make analysis difficult. Because of such complexities, animal scientists have been slow to adopt on-farm research strategies. This has prevented crop scientists such as production-oriented agronomists and economists from incorporating livestock component in their analysis.

Experience of on-farm animal production experiments is needed and is expected to increase rapidly. This is believed to contribute to better understanding and communication among scientists, and thus be an important stimulus to further development of the methods. Some characteristics of livestock production systems have special implications for designing, testing, and evaluating technology as Bernsten *et al.* (1983) describe in Table 3.

In recent years, the Farming Systems Research approach to livestock production improvement has gained considerable attention from researchers. This approach seeks to understand the animal component as it interacts with and relates to other parts of the farm system, and is often studied through analytical models. These models consider the whole farm perspective. As seen in Table 3, livestock are an important component of many farming systems. In addition to providing society with quality food, livestock also provide numerous other goods and services. In fact, the monetary value of non-food products probably equals or even exceeds the value of food goods (McDowell, 1977). Not only is it necessary to recognize all the products and services provided by animals, it is also important to be aware of all the purposes for which a farmer keeps animals. This is because the reason for keeping livestock affects the management practices used by a producer. In Vietnam, to solve some difficulty, a pig can be sold to generate necessary cash, and therefore a minimum of capital is invested in keeping pigs.

SYSTEMS ANALYSIS, MODELS, AND SIMULATIONS

The Interaction of three Sub-systems

In agroforestry systems, the interaction of three components: perennial trees, annual crops and livestock, is modified by the closed links among themselves. To represent these links, several agroforestry systems have been named (Fig. 2).

The interaction among the subsystems has also been plotted (Fig. 3). Usually it is studied from the whole farm perspective and through analytical models to analyze new technology options at the farm level. These are also applied directly to the problems of small farms under the umbrella of Farming System Research in several Asian countries.

This approach has its own advantages and disadvantages, as follows:

Advantages

1. The long-term effects of any crop changes on animals can easily be studied.
2. When funds are limited, development of livestock component under the umbrella of cropping systems allows for cost sharing,
3. The effects of the new technology on livestock can be viewed holistically.
4. All the farming system components can be considered simultaneously by the farmers for decision making.

Disadvantages

1. It is recently new,
2. It requires farmers' knowledge and skills in animal husbandry,
3. It is not easy to work as part of an interdisciplinary team to adequately address the livestock component.
4. It is complicated for the team to monitor and evaluate the implemented activities on livestock, and may lead to team conflicts.

Recently, there has been a great concern on the role of legumes in several sub-systems of the farming system. In order to emphasize the integration between livestock and crop, these coherent factors should be recognized to strengthen the sub-system capability.

The Role of Forage Tree Legumes in Cropping and Grazing Systems

Legumes have been used in agriculture since ancient times. Legume seeds or pulses were among the first sources of human food, and their domestication and cultivation in many areas occurred at the same time as that of the major cereals. Nutritionally they are two or three times richer in protein than cereal grains, and many also contain oil. Leguminous mulches have always been used as a source of nutrient-rich organic matter and nitrogen for crops. In more recent times, legumes have become important as high quality forages for livestock, both in cultivated pastures and in naturally occurring associations.

Of all plants used by man, only grasses are more important than legumes, but it is the legumes that show the most promise for future exploitation and development.

Legumes in Agriculture

Nitrogen (N) is the most limiting element in agricultural production, and deficiency reduces the productivity of crops, pastures and animals. There are several potential sources of nitrogen to overcome this shortfall, namely:

- N from the mineralization of soil organic matter,
- N from artificial fertilisers,
- N from biological nitrogen fixation in legumes, *and*
- N from organisms associated with tropical grasses.

Of these, N from soil is often insufficient for plant growth, especially in most tropical soils which are low in organic matter. N from organisms associated with grasses is a minor source. Fertilizer N and N fixed by legumes are the largest potential sources, with the latter being the cheapest source. Biologically-fixed N is transformed into leguminous protein and this may be consumed directly by animals to meet their protein requirements. The excess is returned to the soil via animal wastes. Alternatively, N may be returned directly to the soil as an organic mulch.

Since few other plant families include species with a nitrogen fixing ability, legumes produce most biologically-fixed nitrogen and are therefore crucial to maintaining the N-balance in nature. In Australia, Steele and Vallis (1988) estimated that there is annual use of 35,000 mt of artificial fertilizer N on pastures, compared with 1.2 mt of N derived from biological nitrogen fixation. Very high yielding leguminous crops can add up to 500 kg of nitrogen to the soil per hectare per year (NAS 1979) although inputs of 100-300 kg N/ha/year from good quality legume-based pasture would be a more realistic expectation (Steele and Vallis 1988). Legume associations are therefore vital to sustaining soil nitrogen fertility over long periods. The practice of shifting cultivation, traditional in many countries, is heavily dependent on the leguminous component of the primary and secondary forest cover for fertility restoration.

Another advantage of legumes is their high quality for animal production. The nutritive value of legumes is measured in terms of the potential intake of digestible dry herbage and in general, legumes have both higher digestibility and higher intake than grasses. Their nutritive value tends to remain high as plants mature.

Until recently, tree legumes were largely neglected by researchers because their utilization and management fell between the disciplines of forestry and pasture agronomy. They are now receiving increased research attention, because of their multipurpose value and some distinctive features which set them apart from herbaceous legumes. Their special characteristics may be summarized as follows:

- They thrive for long periods with low maintenance, and therefore enhance the sustainability of farming systems.
- They provide high-quality forage for feeding of livestock.
- They stabilize sloping lands against erosion because of their deep-rooted habit.
- They supply N-rich mulch for cropping systems.
- They can be used to colonize and rehabilitate adverse environments, e.g. saline or arid areas.
- They provide a source of timber and firewood for either domestic or industrial use.
- They can be used in farming systems as living fences, as shade trees for plantation crops, and as living trellises for climbing crops
- They can be a source of fruit and vegetables for human consumption

Tree legumes can therefore be regarded as truly multipurpose trees for agriculture.

Tree Legumes as Forage for Animals

Trees and shrubs have provided valuable forage to man's herbivorous animals, probably since the time of their domestication (Robinson 1985). At least 75% of the shrubs and trees of Africa serve as browse plants, and many of these are leguminous (Skerman 1977). The overall importance of browse was summarized in the Commonwealth Agricultural Bureaux statement (1947).

> "more animals feed on shrubs and trees or on associations in which shrubs and trees play an important role than on true grasslands".

McKell (1980) pointed out that shrubs and trees are the most visible plant forms in many landscapes, yet have been neglected in most scientific research. Much research effort has concentrated on methods for their eradication. In some arid and semiarid climates, livestock would not exist without browse species to supply feed.

Browse has been defined as the leaves, shoots and sprouts, including tender twigs and stems, of woody plants which are cropped to a varying extent by domestic and wild animals. The definition should be extended to include the fruit, pods and seeds, which provide valuable feed, especially if the tree is deciduous.

Many tree legume species have evolved in semiarid regions alongside herbivorous animals, and therefore have developed means of protection against browsing or grazing. Among the protective devices are thorns, toxins, fibrous foliage and height of tree crowns (Brewbaker 1986). Thorns characterize many woody legumes, and are particularly prevalent on juvenile plants. Toxins are of two general types, those which deter feeding and those which poison the animal. The nutritional quality of tree legumes varies from excellent (*Leucaena leucocephala*) to quite poor (most Australian Acacia species). Poor quality can be due to tannins, which reduce the digestibility of both herbage and protein. The presence of tannins is often evident as brownish, reddish tinges in juvenile growth. Another reason for poor quality is that some species have phyllode* leaves which are very high in fiber and therefore of low digestibility, e.g. the Australian acacias.

Forage from tree legumes is often used as a buffer to overcome feed gaps that arise from seasonal fluctuations in the productivity of other feed sources. For example, grasses and other herbs may die when upper soil layers lose their moisture, but the deep-rooted trees exploit moisture at depth and continue to grow. During the dry season or in times of drought, trees provide green forage rich in protein, minerals and vitamins while the herbaceous cover provides only poor quality straw.

The use of naturally occurring browse species is a vital component of livestock production systems in many regions of the world. In the Sahelian savannahs in Africa, from Senegal to the Sudan, *Faidherbia albida* is a native leguminous species which is extremely important both in providing forage for livestock and in enhancing soil fertility for crops. *Prosopis* species provide forage for the sheep and cattle industries of the arid subtropical plains of Brazil, Argentina, Uruguay and Northern Chile. *Prosopis chilensis* contributes regular cattle feed in northwest Argentina and Central Chile, while *P. tamarugo*, a native of Chile's northern plateau, is the only tree that survives on the arid salt flats and produces the only available forage, timber and fuelwood in that region. In Southwestern Queensland and Northern New South Wales, mulga (*Acacia aneura*) occurs naturally, often in monospecific stands, and is used as a drought reserve for grazing sheep.

Under natural conditions, a large proportion of the foliage of tree species will be out of reach of grazing animal so utilisation can be manipulated by cutting or lopping to make it available when needed. Sometimes natural leaf fall through senescence is an important day-to-day component of the diet of some grazing animals. In Africa, goats thrive on the leaf fall of *Acacia melliflora* (Dougall and Bogden 1958).

Tree Legumes as Planted Forage in Cropping and Grazing Systems

Tree legumes are often planted specifically for forage both in extensive grazing systems and in association with crops.

In many of the more intensive agricultural areas of Asia and Africa, where livestock are raised in small numbers by smallholder farmers, tree legumes are planted as "forage banks" on unused land along field borders or fence lines, on rice paddy bunds or in home gardens. These areas are usually harvested under a "cut-and-carry" system and are a principal source of high-quality forage used to supplement low-quality roughages such as crop residues. Productivity from these areas can be quite high. In the Batangas region of the Philippines, a 2 ha area of *Leucaena leucocephala* grown in association with the fruit tree *Annona squamosa* (sweetsop) was able to supply the forage requirements of 20 growing cattle over a 6 month period (Moog 1985). At Ibadan in Nigeria, Reynolds and Atta-Krah (1986) suggested that the surplus foliage produced over a year from 1 ha of *Leucaena leucocephala* and *Gliricidia sepium* planted at 4 m intervals in an alley cropping system could be used as a supplement to provide half the daily forage requirements for 29 goats.

In many of these intensive cropping areas, tree legumes are planted not only for their forage but also for firewood, green manure and other uses.

In the more extensive grazing area of Australia, Southern Africa and South America, tree legumes are increasingly being planted in association with improved grasses to increase carrying capacity and productivity of grazing cattle. In central Queensland, over 20,000 ha have been sown in *Leucaena leucocephala* in the past 10 years. The leucaena is sown in wide spaced rows 4-10m apart. Improved grasses such as Green Panic (*Panicum maximum* var. *tricoglume*), Rhodes grass (*Chloris gayana*), Buffel grass (*Cenchrus ciliaris*) or Signal grass (*Brachiaria decumbens*) are sown between the leucaena rows. A high stocking rate (up to 3-4 animals/ha) and liveweight gain (up to 1 kg/head/day) can be achieved with this system. A record liveweight gain of 1,442 kg/ha for cattle grazing a grass/legume pasture was achieved on an irrigated leucaena/Pangola grass mixture in the Ord River District of Northwestern Australia (Jones 1986).

Other tree legume species that are being investigated for use in extensive grazing systems include *Calliandra calothyrsus, Albizzia chinensis, Cajanus cajan, Gliricidia sepium, Sesbania grandiflora, S. sesban* and *Indigofera teysmanii.*

Quantitative Decisions Based on the Models

There are physical and mathematical relationships between the level of inputs used and output received in a production process. Generally, given a level of fixed resources, higher levels of output can only be obtained by adding more variable resources. It is thus important to be able to identify the profitable levels of inputs to combine with a given level of fixed resources (Tan *et al.,* 1980).

In a production process, several inputs (factors of production) are used and ultimately transformed into the final output (product) or outputs. The farmer must choose the levels of each input — seed, fertilizer, feeds — that will, when transformed by the production process, produce the quantities and qualities of outputs that best satisfy the farmer's goals. This relationship between factors of production and output can be expressed as:

$$Y = f(X1,X2,X3, ..., Xn),$$

where Y is the output that is obtained as a result of using inputs X1, X2, etc. In the above equation, Y is used to denote a quantify of output, such as bushels of grain, pounds of meat, or dozens of eggs, while Xi represents units of specific inputs, such as pounds of fertilizer or tons of hay.

The quantities X and Y are called variables because variations in one of these quantities are associated with variations in the other. The expression $Y = f(X)$ means that Y is a function of X (that X affects Y). The production function is a mathematical statement about the relationship

* Phyllode: Flat leafstalk which functions as a leaf

between X and Y once these two variables are defined.

There are three basic relationships in the production process:

- Factor-product relationship: Output is related to a single variable production input (factor) given a set of fixed inputs and it can be expressed as Y = f(X1 / X2, X3 ...Xn)
- Factor-factor relationship: Output is related to two or more variable production inputs (factors)
- Product-product relationship: The relative quantity of two or more outputs (products) is related to a fixed quantity of inputs (factors).

These economic concepts can be used for analyzing the results of livestock and crop integration, particularly for farmers' decision making, such as what animal system a farmer should have or what feed supplements should be used. When applied to real-life farming situations, production economics can help farmers achieve maximum productivity. Although relationships on the small farm can be analyzed by using basic economic principles, care should be taken when making broad recommendations based on case studies or a field trial. In addition to the economic analysis of a new technology, close attention must also be paid to the farmer's response to the new technology and acceptance of it. If a technology is not being accepted by a particular group of farmers, something fundamental may have been missed in the initial analysis. When determining costs, it is important to find out whether the farmer agrees with the cost assessment and the values assigned to benefits. The key to any economic analysis is not to miss the big picture or the primary costs and benefits.

SUMMARY

To improve technology that relates to the livestock-crop system of a small farm, it requires a systematic analysis of the farm problems, household goals and aspirations, existing crop and livestock enterprises, market potential and government policy. Though there are several analysis methods, Farming System Research (FSR) has recently gained acceptance because of its concepts which emphasize on the animal research at the farm level. Based on the discussions on the several sub-system analysis, the interaction of those sub-systems is concerned to emphasize the important role of livestock component in improving the farmerís livelihood, generating income and then solving the long term environmental concern. Lastly, mathematical models are introduced to strengthen the farmer's decision making on livestock component.

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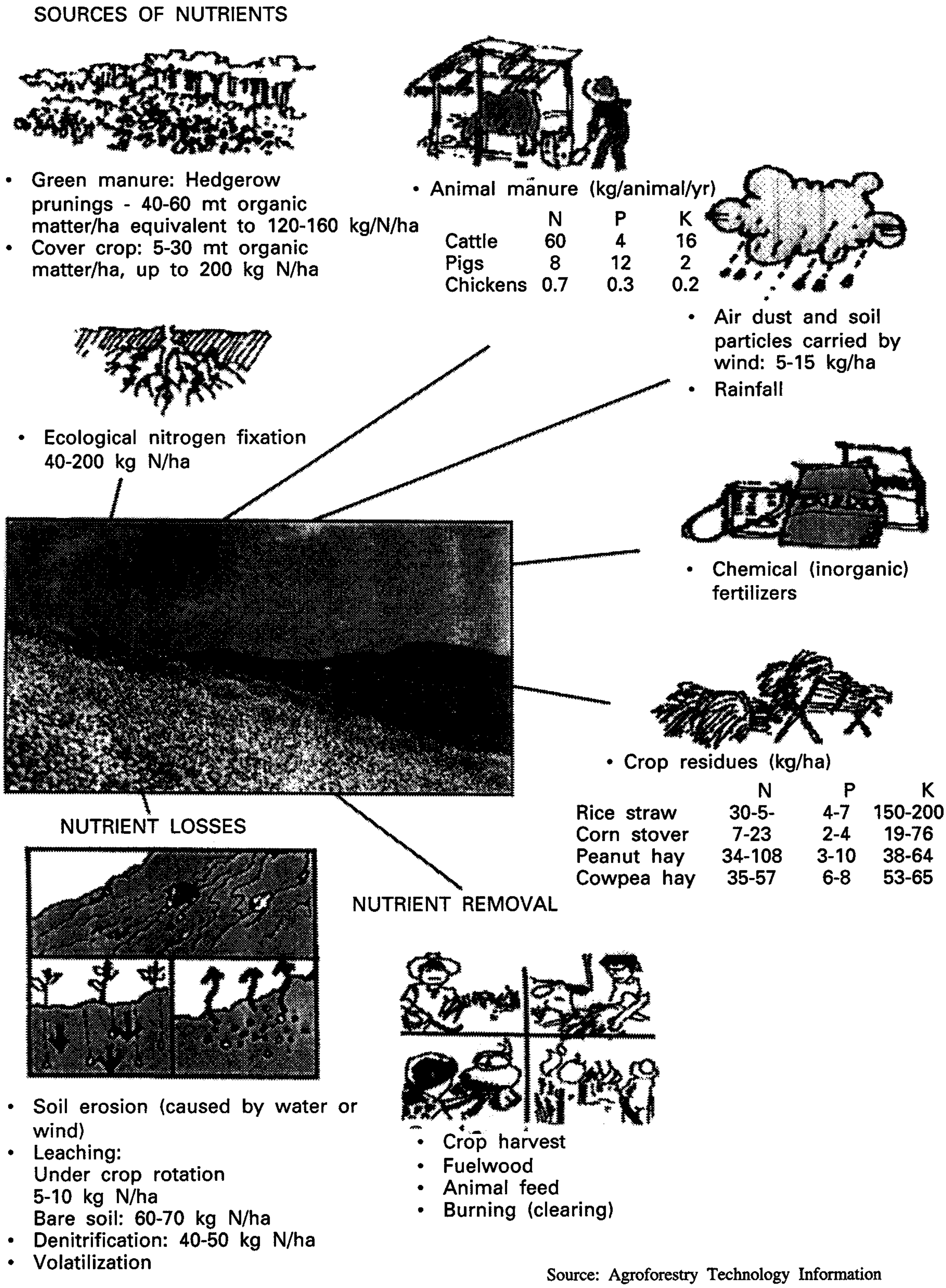

Source: Agroforestry Technology Information Kit (DENR/IIRR in the Philippines)

Fig. 1. Nutrient flows in upland farms

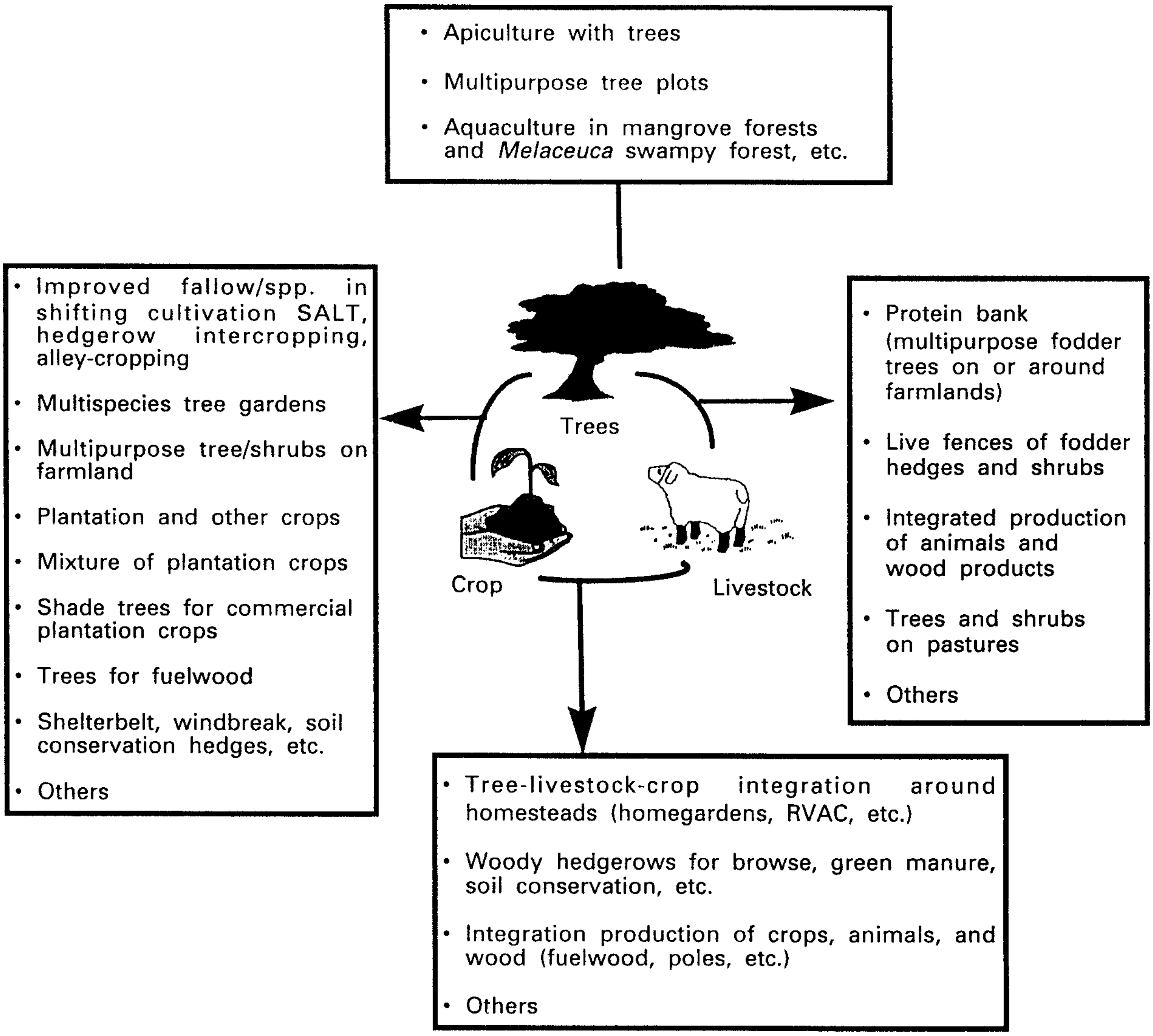

Fig. 2. The interaction of the three sub-systems under an agroforestry system

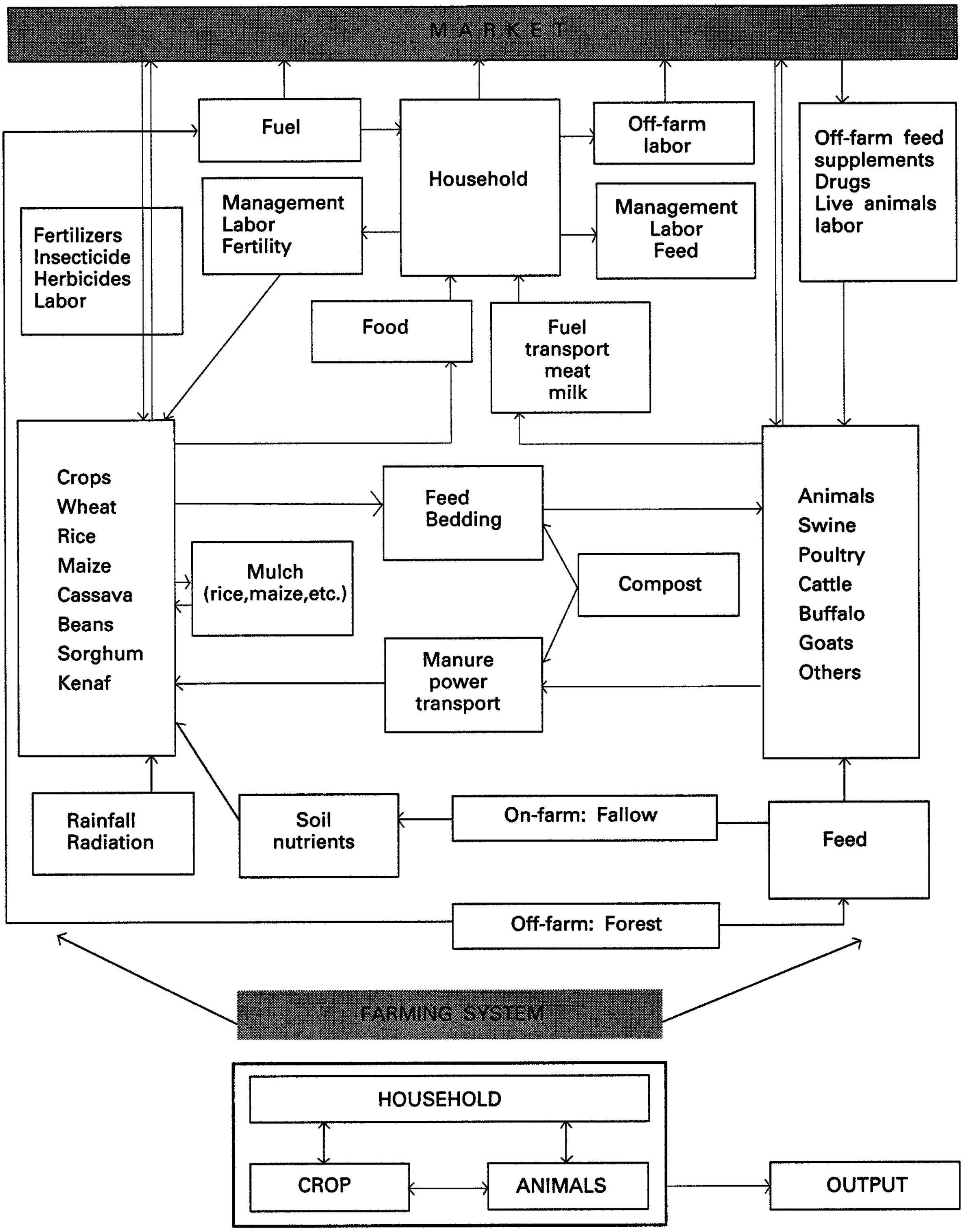

Fig. 3. The interdependent elements of a farming system and their connection with other elements within the agrosystem

Table 1. Upland and lowland technology generation

Characterisitic	Lowlands	Uplands
Variability	Relatively homogenous; some micro-environmental Variations	Very heterogenous
Baseline data	Considerable; available	Very little
Obtaining information for design of appropriate technology	Standard survey, extension agents, research stations	Adaptive ethnographic method, Rapid Rural Appraisal (RRA), *Ex ante* Analysis (EA)
Technology generation	Research stations	Heavily based on indigenous knowledge
Technology	"Packaged"	"Menu" type

Source: Fujisaka and Sajise 1986

Table 2. Livestock contributions to the economy

Food:	Meat, milk, eggs
Fiber and skins:	Wool, hair, hides, and pelts
Traction:	Power for land preparation, crop production, irrigation pumping, threshing, and transport
Animal wastes:	Fertilizer, heating fuel, methane gas, feed, construction material
Storage:	Storage of food supply or capital and seasonal excess of feeds
Weed control:	Biological control of brush, plants, and weeds along roadsides and waterways
Socioeconomic:	Security and self-esteem, revered symbols, a form of insurance for the farm household
Environment:	Utilize degraded (marginal) lands and crop residues
Sports/recreation:	Competition, exhibition, hunting, and companion animals

Table 3. Comparison of characteristics of crops and animals and implications for using livestock for on-farm testing

Characteristics	Crops	Livestock	Implications for using livestock
Mobility	Stationary	Mobile	Difficult to measure and control nonexperimental factors
Life cycle duration	Generally less than 4 months	Generally over 1 year	Increased costs, likelihood of losing experiment units
Life cycle synchronization	All units synchronized	Units seldom synchronized	Difficult to find comparable units
Multiple outputs	Only grain/tubers and residues	Multiple outputs: meat, hides, milk, manure, power	Difficult to measure value, treatment effect
Nonmarket inputs and outputs	Few	Many	Difficult to value inputs and outputs
Size of experimental unit	Small, divisible	Large, indivisible	Increased cost, risk to cooperator
Producer attitudes	Impersonal	Personal taboos	Difficult to cull, castrate
Management variability	Low	High	Difficult to isolate treatment effect
Number of observation units	Many	Few	Large statistical variability
Variability of observations	Low	High	Large statistical variability

Source: Bernsten, R., H.A. Fitzhugh, and H. Knipscheer. 1983.