Crop-Animal Production Systems in Tropical Regions[a] - Review -

C. Devendra*
International Livestock Research Institute, P.O. Box 30709, Nairobi, Kenya

ABSTRACT : Crop-animal systems which form the backbone of agriculture in the tropics are discussed with reference to their characteristics, economic importance of animals, genesis and types of crop-animal systems, relevance and potential importance, and priorities for research and development. These production systems are found across all agroecological zones: rain-fed temperate and highland systems, semi-arid and arid tropics, and sub-humid and humid tropics: the last four are priority areas in Asia. The potential importance of these systems in Asia is reflected in their advantages, synergism and complimentarity, economic benefits and contribution to sustainability. Illustrative case studies are cited which are appropriate to the two broad types of mixed farming systems: systems combining animals and annual cropping, and systems combining animals with perennial cropping with reference to Indonesia, Philippines, Malaysia, Sri Lanka, China and Nigeria. Priorities for research and development should address more complete use of the animal genetic resources, intensive utilisation of the feed resources, development-oriented utilisation of research results, minimizing animal diseases, and implementation of appropriate institutional and policy issues. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 2 : 265-276)*

Key Words : Crop-Animal Systems, Research Priorities, Economic Impact

INTRODUCTION

Crop-animal production systems constitute the backbone of agriculture throughout the tropical regions. They involve the natural resources (crops, animals, land and water) in which these sub-systems and their synergistic interactions have a significant positive and greater total effect than the sum of their individual effects (Edwards, Pullin and Gartner, 1988). The management and use of the natural resources in a mutually reinforcing manner, enables ecological and economic sustainability.

Crop-animal systems are varied in the tropics, and the systems have evolved in response to environmental dictates, notably temperature, rainfall and elevation, presence of type and intensity of animal production, and human intervention. Without exception, diversification is the rule, and the use of the available resources spreads the risks and provides stability to farming systems. Farmers consciously diversify the use of the resources to practice a mix of activities which are economically rewarding.

Crop-animal systems are characterised by a number distinctive features which are as follows (Devendra, 1993):

· Diversification in the use of production resources
· Reduction in, and spread of risks
· Preponderance of small farms
· Use of large populations of ruminants (buffaloes, cattle, goats, and sheep) and non-ruminants (chicken, ducks and pigs/animals)
· Integration of crops and animals
· Animals and crops play a multipurpose role
· Low input use and traditional systems
· Involves the three main agroecosystems (highlands, semi-arid and arid tropics, and sub- humid/ humid tropics).

RELEVANCE AND POTENTIAL IMPORTANCE

The relevance of crop-animal systems is associated with the characteristics of the systems, and the management and use of the production resources. In particular, the nature and extent of the crop-livestock interactions are especially important, in relation to the negative and positive benefits, effects on the environment and sustainable agriculture. The potential importance of the systems from a research and development perspective, is directly related to three considerations (Devendra, 1996):

· Increased productivity in the future through strategic interventions will involve the preponderance of small farm systems, which currently produce over 90% of food from livestock in Asia.
· Improved efficiency in the use of natural resources, and
· Development of sustainable agriculture that is consistent with poverty alleviation, food security, and environmental integrity.

* Address reprint request to C. Devendra. 130A Jalan Awan Jawa, 58200, Kuala Lumpur, Malaysia. Tel: +60-3-754-8277, Fax: +60-3-757-4493, E-mail: cdev@pc.jaring.my.

[a] This paper has been presented at Symposium X entitled "Efficient Animal Production System in Harsh Environments" of the 8th World Conference on Animal Production on June 30, in Seoul, Korea.

Examples of such demonstrable impact are:

- Sustainable crop-livestock systems that involve nutrient recycling efficiency, with no pollution.
- Development of food-feed systems that provide increased feeds for animals through the year, increased crop yields, and soil fertility.
- Improved livelihoods, promotion of stable household and self-reliance, and, increased economic output, and rural development.

ECONOMIC IMPORTANCE OF ANIMALS

The economic importance of animals within the mixed farming systems is considerable and is often underestimated. This value increases with a shift from subsistence agriculture to the more open market economies, to include specialisation and intensification of the production systems. Within mixed farming systems, the economic contribution of animals becomes even more significant in the contest of the following beneficial effects:

- Demonstration of low input integrated systems
- Nutrient recycling
- Positive environmental effects that have economic, ecological and sociological benefits
- Contribution to sustainability and development of sustainable systems, and
- Alleviation of rural poverty and improved food security.

It is pertinent to note that small farm systems contribute about 90% of the total production of meat and milk, to meet the demand of urban areas. These relate mostly to ruminant meats and milk, but also include pig and poultry meats.

TAC/CGIAR (1992) has reported that within the annual value of production from crops, livestock, poultry and fisheries in developing countries of US$ 638 millions, livestock accounted for 19% of this with in regions. Asia contributed about 52% of the total value. When the contribution is examined within agroecological zones, and especially to the priority ecoregional areas (semi-arid tropics and subtropics with summer rainfall, and warm humid, subhumid tropics and subtropics), this accounted for 43.4% of the total value. Within these, about 22.5% came from the warm humid, sub-humid tropics and sub-tropics within which mixed farming systems are traditional and predominant. The data may be underestimated, since these do not include the contribution of draught power and manure whose use in mixed farming operations is considerable.

In the best two years, the financial and economic crisis is several countries in South East Asia has placed greater emphasis on agriculture, and the efficiency of use of the national resources. In this context, the potential contribution from animals has come under even greater pressure. Much more concerted effort will need to be place therefore a research-based development approaches that can significantly increase productivity and contribution of animals.

GENESIS OF CROP-ANIMAL SYSTEMS

Crop-animal systems have evolved and developed over time. The principal determinants of the type of crop and animal systems which have developed at any particular location are the agroecological conditions (Duckham and Masefield, 1970; Spedding, 1975; Ruthenberg, 1980). Sere and Steinfeld (1996) have reported more detailed analyses of these systems. Climate, and to a lesser extent soil, affect the vegetation that develops and determines whether crops can be grown. These in turn determine the feed base, its quantity, quality and distribution. The feed base, together with the disease challenge, determines the potential animal production systems that may develop. The feed resources provide a direct link between crops and animals and the interactions of the two dictate, to a very large extent, the development of such systems. figure 1 provides an illustration of the phases in the development of crop-animal systems.

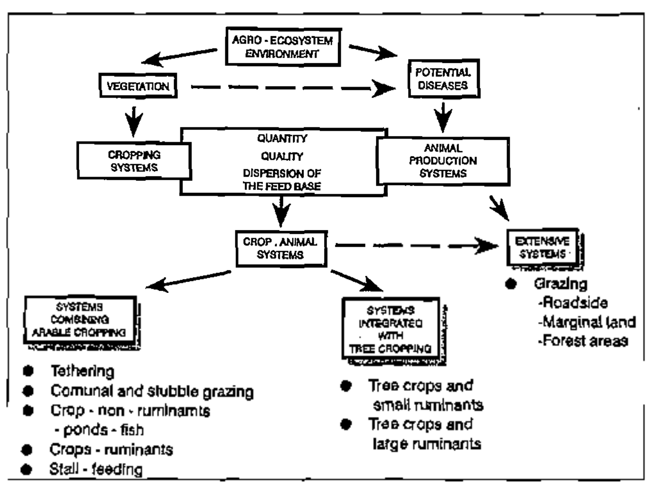

Figure 1. Genesis and types of animal production systems in Asia

ANIMAL PRODUCTION SYSTEMS

Animal production involves both non-ruminants and ruminants and a variety of systems that are integrated with crops. The systems vary in relation to type of agroecological zone, types of animals and size of their populations, and intensity of mixed farming operations. The development of these systems have considerable potential, and the benefits are associated with complimentary interactions of the sub-systems (e.g. crops, animal and fish) in which the products are additive. Two good examples of such integrated systems, their economic benefits, and contribution to sustainability are pig-ducks-fish-vegetables systems in the Mekong countries (Cambodia, Laos, Myanmar and Vietnam), Indonesia, and the Philippines, and small ruminant-tree cropping systems throughout South East Asia and the Pacific islands (Devendra, 1993).

Ruminant production systems are of three categories:

(i) Extensive systems
(ii) Systems combining arable cropping
- Roadside, communal and arable grazing systems
- Tethering
- Cut-and-carry feeding
(iii) Systems integrated with tree cropping

The production systems are unlikely to change in the foreseeable future. New proposed systems and returns from them would have to be demonstrably superior and supported by massive capital and other resources (Mahadevan and Devendra, 1986; Devendra, 1989). However, it is quite predictable that there will be increasing intensification and a shift within systems, especially from extensive to systems combining arable cropping, induced by population growth and the fact that population density and intensity of land use are positively correlated (Boserup, 1981). This situation is increasingly likely with decreasing availability of arable land in many parts of South East Asia. The principal aim should therefore be improved feeding and nutrition, in which the objective is maximum use of the available feed resources, notably crop residues and low quality roughages, and also various leguminous forages as supplements.

TYPES OF CROP-ANIMAL SYSTEMS

Two broad categories of crop-animal systems are identified:

1. Systems combining animals and annual cropping Within these two, further types are distinguishable

(i) Systems involving non-animals, ponds and fish
(ii) Systems involving ruminants

2. Systems combining animals and perennial cropping

Again two types are identifiable:

(i) Systems involving ruminants
(ii) Systems involving non-ruminants

These crop-animal systems are found across several agroecological zones (AEZ) in the tropics. In Asia for example, they involve five types of AEZ from the tropical highlands, semi-arid and arid, and sub-humid and humid regions. Table 1 describes the different types of crop-animal systems in the individual AEZ, including the kinds of crops and animals used in Asia.

Crop-animal systems are especially significant in South East Asia where annual crops (rice, wheat, maize, pulses and oilseeds) and perennial crops (coconuts, oil palm, rubber and fruits) are grown and both ruminants (buffalo, cattle, goats and sheep) and non-ruminants (pigs, poultry and ducks) are integrated into these systems. Examples are rice-chicken-fish-vegetables in Indonesia, vegetables-goats-pigs-ducks-fish in the Vietnam, and oilpalm-ruminants in Malaysia and coconuts-cattle in the Pacific islands. With annual crops, animals are integrated into a range of cropping systems.

Research priorities

Very recently, the International Livestock Research Institute (ILRI), with a global mandate that places emphasis on Asia, has completed detailed assessments of the major constraints and opportunities for improvement of crop-animal systems in nine countries in South East Asia and six in South Asia (Devendra et al., 1997; Devendra et al., 1999). Arising from these, priorities for research have been identified that give increased focus on rainfed areas, since these rainfed agricultural areas in Asia represent nearly two-thirds of the total arable land, and support over 50% of the human population, from 73 to 93% of which are resource poor small-holders (TAC, 1996). Significantly, higher productivity from crop-animal systems in the rainfed areas, along with improvements in the conservation and management of scarce resources, can meet as well as contribute to increased income, employment generation and food security for the rural poor.

The assessments in the two sub-regions indicates that feed resources and nutrition was the major constraint, followed by animal genetic resources, animal health, systems analysis, socio-economics and policy. These aspects thus constitute key priorities for research, which together with institutional support, provide for necessary interdisciplinary research on small farms throughout Asia.

IMPACT OF CROP-ANIMAL PRODUCTION SYSTEMS

The benefits of crop-animal interactions are signifi-

Table 1. Agroecological zones and types of mixed farming systems in Asia

Agroecological zone	Growing period (days)	Crops	Animals	Mixed farming benefits
Rainfed temperate and tropical highlands	<110	Barley, millet, mustard, potatoes, fruits	Yak, cattle, sheep	Traction, transport, manure (fuel and soil fertility), reduced risk, survival
Rainfed humid and sub-humid uplands	180-270	Maize, rice, wheat, root crops, plantation crops	Cattle, pigs, chickens	Traction, transport, income, manure (fuel and soil fertility), crop residues
Rainfed humid and sub-humid lowlands	180-300	Maize, rice, wheat, root crops, sugar cane, mungbean	Buffalo, cattle, pigs, chickens, ducks	Traction, transport, income, manure (fuel and soil fertility), crop residues
Irrigated humid/sub-humid lowlands	180-365	Maize, rice, cassava, sweet potatoes	Buffalo, cattle, pigs, chickens, ducks	Traction, transport, income, manure (fuel and soil fertility), crop residues
Rainfed arid and semi-arid lowlands, unirrigated	60-120	Sorghum, millet, groundnut, soya beans, pigeon pea, cotton	Camels, donkeys, cattle, goats, sheep, chickens	Traction, transport, income, manure (fuel and soil fertility), reduce risk, survival
Irrigated arid/semi-arid lowlands	75-180	Millet, groundnut, pigeon pea, cotton	Cattle, pigs and chickens	Income, manure (fuel and soil fertility), reduced risk, survival

cant, and the systems have therefore had an impact on the development of sustainable agriculture. However, data on this aspect is limited, due to inadequate experiments on crop-animal systems, the challenges imposed by the need for understanding of holistic systems, multidisciplinary research, on-farm testing, and systems methodology. Nevertheless, it is instructive to reflect the impact of such systems from the limited data available, in order to emphasise the benefits as well as concurrently emphasise, the need for more sustained research and development efforts on these systems. Specific case studies in Asia, and the beneficial results from them have been reviewed (Devendra, 1993, 1996). The examples below serve to highlight the impact of crop-animal systems.

1. Systems combining animals and annual cropping

1) Crop-animal systems (Philippines)

In the rainfed lowland areas of Pangasinan in the Philippines, the development of food-feed systems had two objectives: to increase the availability of animal feeds throughout the year, and promote sustainable rice production. Accordingly, rice-mungbean has replaced rice-fallow. Intercropping with siratro, and incorporation of the herbage as green manure from the last cutting two weeks before replanting into the soil, resulted in higher yields of the succeeding crop (table 2).

Table 2. Intercropping with Mungbean and Siratro in Pangasinan, Philippines

Cropping System	Rice Yield (MT/ha)	Mungbean Yield (MT/ha)
Rice-Fallow-Rice	3.0	-
Rice Mungbean-Rice	3.7	1~1.5
Rice-Mungbean+Siratro-Rice	4.5	1~1.5

In addition, cattle fed with rice straw as the basal food and strategic supplementation with forage legumes (siratro and mungbean), rice bran and urea showed that this was generally beneficial in stimulating live weight gain and reduced live weight loss. Farmers in this area have now widely adopted the use of systems for cattle for draught and meat. The benefits of this system are:

- Increased rice yield and farm income
- 50-70% reduced dependence, and cost of organic fertilisers
- Increased forage biomass
- Increased carrying capacity of cattle (1-6 cows)
- The ability of siratro to resist drought provides valuable feed for cattle calving at the end of the wet season (November) and onset of the dry

season (October) when feed deficits are a major constraint to production

- Development of all year round feeding systems, and
- Increased output from animals

2) Three-strata forage system (Indonesia)

In the more drier and low rainfall areas, a useful system has been developed that combines arable cropping and ruminant production in a sustainable crop-animal system. The three-strata forage systems (TSFS) is a way of producing and conserving the food requirement of cattle and goats, without any degradation of the environment. For dryland farming areas such as in eastern Indonesia and south Asia, the systems combines production of good crops (maize, groundnut, cassava and pigeon pea) with shrubs and trees to produce food for all year round feeding with outstanding results (Nitis et al., 1990). Major highlights of the system are:

- Increased forage production enabled higher stocking rates and live weight gains (3.2 animal unit equivalent to 375 kg/ha/yr in the TSFS compared to 2.1 animal unit or 122 kg/ha/yr in the non-TSFS
- Cattle in the TSFS gained 19% more live weight and reached market weight 13% faster farmers in the TSFS benefitted by a 31% increase in farm income
- The introduction of forage legumes into the TSFS reduced soil erosion by 57% in the TSFS compared to the non-TSFS, together with increased soil fertility
- The presence of 2000 shrubs and 112 trees logged twice a year produced 1.5 MT/yr of firewood, which met 64% of the farmers annual firewood requirements
- The integration of goats in addition to cattle into the system, further increased the income of farmers, and
- Institutionalisation of the concept and technology

3) Crop (Rice/Vegetable)-pigs-ducks-fish-integration

An excellent example of a crop-animal production system that involves water especially in ponds concerns the integration of rice or vegetable production with pigs, ducks and/or fish (figure 2). The system in especially common in China and humid South East Asia, in which non-ruminants are integrated in a bewildering variety of combinations. Examples of such systems (Devendra et al., 1997) are:

Indonesia: Rice-fish-duck-goats
Philippines: Rice-buffaloes-pigs-chickens-ducks-fruit trees-fish
South China: Rice-maize-pigs-vegetables-sweet potato-dairy cattle
Thailand: Rice-fish-pigs-ducks-vegetables
Vietnam: Pigs-ducks-vegetables-fruit trees-fish-goats

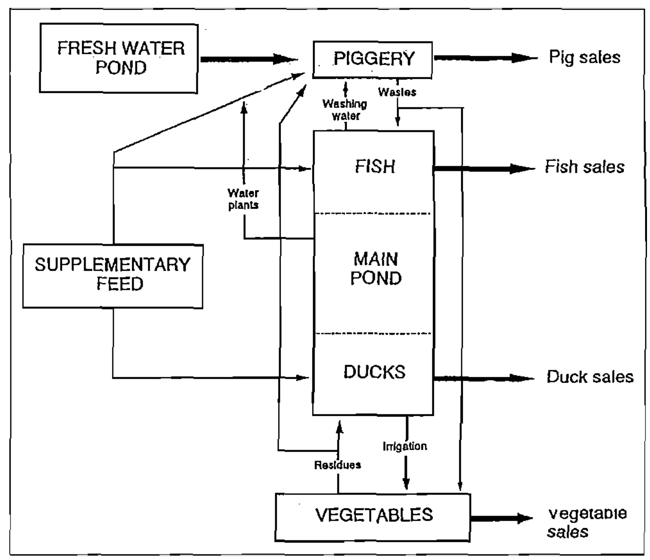

Figure 2. *Integrated pig-fish-duck-vegetable system*

Three examples of such successful systems are cited:

(a) Rice-fish-duck system (Indonesia)

The success and rapid expansion of the rice-fish system in particular, and the inclusion of ducks in Indonesia is a good example of efficiency in integrated natural resource use and its economic benefits. Table 3 shows that the net returns from the

Table 3. Economic returns between a rice-fish-duck system and rice monoculture per hectare for a one year operation at the Sukhamandi experiment station (Suriapermana et al., 1998)

Cropping pattern and integrated system	Production			Production costs (US$)	Value of output (US$)	Net returns (US$)
	Rice (Kg)	Duck eggs (No)	Fish (Kg)			
Rice-rice-fallow	11,268	-	-	812.5	1,762.3	949.8
(Rice+fish+ducks)-(Rice+ducks+fish)-ducks	11,708	17,031	185	1,632.6	3,692.3	2059.7

rice-fish-duck system was US$ 2,060/yr compared to US$ 1,950 from rice alone. The same study also revealed that the fish production of 185 kg/ha was much higher than the yield in traditional systems.

It is pertinent to note that the ratio of net returns on inputs per year in the rice-rice-fallow, rice-rice-fish, and (rice+fish) (rice+fish) fish patterns averaged 115-125 and 173% respectively (Yunus et al., 1992). The authors also reported that on average, the income from fish was able to meet 20-50% of the total cost of rice production in the rice-rice-fish and (rice+fish) fish patterns.

Similar economic benefits in integrated fish-duck-goat systems have been reported in the Philippines in the Philippines (Cruz and Shehadeh, 1990) Malaysia (Mukherjee et al., 1992), China (Chen, 1992), Vietnam (Le, 1992), Thailand (Little, Khalil and Taikaikaew, 1992) and Bangladesh (Huque, 1992).

(b) Rice-pig-fish system (Philippines)

In the Philippines, fish stocked at 10,000-20,000 fingerlings has been combined with 40-60 pigs/ha (average initial weight 20 kg). The best results were obtained with 60 pigs 20,000 fish/ha or 1.9 MT of fish/ha/90 days and 60 pigs weighing 3-4 MT. The total live weight gain of the 60 pigs as 2.2 MT/90 days. In three cycles of 90 days, the combined production reached 3.9 MT of fish and 6.7 MT of live weight gain in pigs (Cruz and Shehadeh, 1980).

Also in the Philippines, the integration of fish, azolla and ducks enhanced rice production significantly. The system demonstrates increased productivity from the land, especially of animal proteins and rice yields increased income for farmers, ecological and environmental sustainability. The major contributory issues to the benefits are associated with nutrient enhancement, feed availability and pest control. Table 4 shows interesting results in lowland irrigated rice fields during the dry season.

Table 4. Effects of integration with fish, azolla and duck production on rice production in the Philippines (Cagauon et al., 1996)

Type of system	Rice Production (kg/plot)	Rice Production (kg/ha)
Rice	79.2[ab]*	2934.6[b]
Rice-fish	63.4[aa]	211.4[a]
Rice-azolla	86.b[c]	3188.9[b]
Rice-ducks	78.3[ab]	2898.8[b]
Rice-fish-azolla	118.0[ab]	3934.4[cd]
Rice-fish-ducks	106.1[de]	3535.6[bc]
Rice-azolla-ducks	114.5[cd]	4241.9[cd]
Rice-fish-azolla-ducks	131.4[e]	4378.9[d]

* Data with the same suffix letters are not significantly different.

4) Rice-pigs-fish-ducks-vegetable system (Vietnam)

In Vietnam, extensive studies on rice-fish-pigs-vegetables-ducks integration clearly that this system yielded three times the benefits from the non-integrated system. Using pig manure for fish culture, the integrated system produced a harvest which was worth 35 to 40 millions Vietnam dong (VMD) compared to 10 million VMD with rice cultivation only (Thien et al., 1996).

Many of these systems are practiced at a traditional level in which most farmers are not fully acquainted with the management of the components, and more particularly, intensification of the systems to increase productivity. This process will however evolve. In this context, it is especially relevant to note the study of Congyi et al. (1993) who have reported clear evidence of the economic viability and sustainability of the system. The research involved comparison of the integrated crop-pigs-fish system with conventional fish culture, in which the latter involved three sub-systems: crops (barley and rapeseed cake to supply feeds for pigs and fish), fish (for food), and cultivated forage to supply feed for herbivorous fishes. Three types of systems (intensive, semi-intensive and extensive) were tested. The following results were achieved:

- The semi-intensive system had the highest net profit per unit input of money.
- The efficiency of energy and nitrogen utilisation were highest in the semi-intensive system.
- The output value was 2.6 times the production costs
- The positive interactions of the sub-systems, the recycling of nutrients, and economic viability of the integrated system was demonstrably sustainable.
- The integrated system is especially appropriate for resource-poor small farms, efficient use of low inputs and the development of sustainable agriculture.

2. Systems combining animals with perennial cropping

1) Tree crops-ruminants systems (Malaysia Philippines and Pacific islands)

The integration of tree cropping and ruminants is a production system that has not been adequately exploited, given the considerable benefits of such integration. The potential for this system is reflected in the presence of an estimated area of about 210 million hectares in South East Asia (Alexandratos, 1995) under forest and woodland, a high proportion of which involves tree crops like coconuts, oil palm and rubber. The economic benefit of the integrated system is shown in the data in table 5. The study involved the effect of grazing with cattle and goats compared to no grazing resulted in increased yields of between 2.2-5.2

Table 5. The effect of mixed cattle and goat grazing on the yield of fresh fruit bunches in oil palm cultivation in Malaysia (Devendra, 1991)

Year	Grazed area (Yield of fresh fruit bunches /ha/yr, MT)	Non-grazed area (Yield of fresh fruit bunches /ha/yr, MT)	Difference (Fresh fruit bunches /ha/yr, MT)
1980	30.55 (C)[+]	21.61	4.94
1981	17.69 (C)	15.87	1.82
1982	25.12 (C+G)[++]	22.97	2.15
1983	23.45 (C+G)	18.29	5.16
Mean	24.20	20.29	3.51

[+] C= Cattle; [++] C+G= Cattle+Goats.

Table 7. Present value gross margins from three alternative farming systems in Southwest Nigeria (Naira/ha/year) over a 9-year period (Reynolds and Jabbar, 1994)

	Traditional farming	Alley farming with fallow	Continuous alley farming
Cropping only	16,325	16,324	21,255
Cropping allowing for soil nutrient loss	16,176	16,204	21,070
Crops and livestock	16,176	18,794	23,749
Crops and livestock with terminal tree clearing costs	16,074	18,489	23,444

US$ = 25 Naira in 1998.

MT fresh fruit bunches/ha/yr. Considering the total land area under oil palm and the sale value of fresh fruit bunches per tonne, the economic advantage is substantial.

Increased yield of 30% have also been reported by Chen and Chee (1993). These authors have also reported 20-40% reduced weeding costs for cattle under oil palm, comparable to a savings of 16-35% using grazing sheep reported by Chee and Faiz (1991). Also in Malaysia, utilising buffaloes to transport oil palm fruit bunches from the field to collecting contres increased the farmers income by as much as 30% (Liang and Rahman, 1985).

In the Philippines, introduction of improved grasses or grass-legume pastures and cattle into coconut plantations resulted in total incomes ranging from US$ 608-809 compared to US$ 510 from coconuts alone (Deocareza and Diesta, 1993). By comparison, the integration of goats and sheep with coconuts over three years increased in the income of farmers by between US$ 127-229 (PCARRD, 1994).

Coconut plantation provide and important opportunity to integrate cattle. Reynolds (1988) has calculated that in Western Samoa, beef cattle production was an important source of secondary income. Based on data of liveweight gain and copra production, the contribution of beef to increased gross income increased from 21 to 41% for a farm with cattle on natural pastures, and from 42 to 71% with cattle an improved pastures. The farm without cattle suffered a reduction in gross farm income by 70%. Stur, Reynolds and Macfarlane (1994) have recently reviewed the available information on cattle production under coconuts, citing several examples in the Pacific islands, and concluded that the level of production in such systems with adapted forages, is comparable to that obtained in open systems.

2) Sloping agriculture land technology

The concept of sloping agriculture land technology (SALT) has been successfully developed in the Philippines on account of the presence of about 30 million hectares of uplands, of which 80% are considered slopelands. These land areas are relatively more steep and include slopes up to 18° . SALT is essentially a type of crop-animal system integrating the management and use of natural resources, and involving the integration of leguminous hedgerows to

Table 6. Average economic performance per year, per acre and per person of the farm activities of the three MLDC farms - 1985 - 1992 (de Jong et al., 1994)

Item	Half acre		One acre		Two acre	
	Rs/year	Rs/acre	Rs/year	Rs/acre	Rs/year	Rs/arce
Total revenue	55,483	110,966	39,780	39,780	70,455	35,227
Total direct cost	36,937	78,874	12,611	12,611	33,401	16,700
Total gross margin	18,546	37,092	27,169	27,169	37,054	18,527
In % of 0.5 acre farm	100	100	147	73	200	50
Gross margin/LU	8,243	(2.25 LU)	(2.5 LU)	(4.25 LU)		
Gross margin/(person)	12,364	(1.5 p)	18,113	(1.5 p)	21,174	(1.75 p)
In % of 0.5 acre farm	100		147		171	
Gross margin per Rs 1,000 investment	387		594		599	

reduce soil erosion, improve soil fertility and nutrients for the crops (e.g., maize and black pepper) grown between the hedgerows, and provision of precious fodder for goats in a zero grazing system. Among the forages tested, *Calliandro spp.*, *Leucaena diversifolia*, *Gliricidia sepium*, *Erythrina poepiggina*, and *Fleminga macrophylla* have been particularly promising. Implicit in this system is the objective of generating regular and adequate income.

Laquihon et al. (1997) has analysed the benefits of the system between 1991-1993, and concluded that the mean annual income was US$ 1,354 per 0.5 ha (Table 8). The mean internal rate of return was 38.7%. The mean annual income is 14 times higher than the mean annual income of US$ 120 per 0.5 ha in the Philippines (Villar, 1998).

Table 8. Cost and return analysis of SALT in Davao del Sur, Philippines between 1991-1993 US$ (Laquihon et al., 1997)

Components	1991	1992	1993
Cash Income			
- Crop+	154.6	130.0	128.5
- Goats++	3,351.5	3,505.4	3,178.4
- Value added items+++	1,516.8	1,516.8	1,516.8
Total returns	5,022.7	5,152.2	4,862.9
- Materials	2,402.6	1,381.7	1,593.0
- Non-cash items	1,754.3	1,830.5	2,014.9
Total costs	4,157.0	3,212.2	3,607.9
Net Profits	865.8	1,940.1	1,255.1
Returns on investments (%)	20.8	60.4	34.8

+ Maize, citrus, black pepper and miscellaneous crops.
++ Live animals, goat meat and goat milk.
+++ New births, replacements and goat dung.

The SALT model has now led to other variants: SALT 2 (simple agro-livestock technology), SALT 3 (sustainable agroforest land technology), SALT 4 (small agrofruit livelihood technology), and SUPER SALT (sloping agricultural land technology. This technology has been extended for use elsewhere in the region such as in India, Sri Lanka and Laos, and also into parts of Africa.

3) Crop-animal systems (Sri Lanka)

In the upland areas of the mid-country in Sri Lanka, crop production involves tree crops (coconuts and fruits), root crops and herbs in stratified layers. Animals are integrated into about 20% of these farms, mainly cattle for dairying, goat and poultry production.

Economic performance for the period 1985-1992 for three sizes of farmer-managed farms (0.5, 10 and 2 acres) showed that dairying contributed to most of the total gross profits of 31, 63 and 69% for the three types of farms respectively. Among the animals, dairy cattle and goats gave the greatest income returns (table 6). Animals also significantly contributed to the improvement of soil fertility through, manure and biogas production to replace domestic fuel needs (de Jong et al., 1994).

4) Alley farming and livestock production (Nigeria)

In many parts of Africa, uncertain weather conditions, especially low rainfall and other calamities impose much risk to farming systems. Strategies to overcome this risk are therefore essential , and one option that most farmers resort to is keeping livestock. This however, accentuates the situation if feeds are inadequate. Alley farming systems that use food or forage crops between hedges of multipurpose trees such as leucaena and gliricidia for mulch and/or forage provides an alternative, and has been successfully developed especially in Nigeria. It is a technology that improves soil fertility, improves crop yields and animal feed shortages as well as provide fuel for the household.

A review of the role of alley farming in African livestock production (Reynolds and Jabbar, 1994), gave the following highlights:

- Maize grain the most important single food crop in Africa gave linear response yields according to the level of *Leucaena* or *Gliricidia* applied, and up to 40% increases were recorded when all the tree prunnings were returned as mulch.
- Supplementation with *Leucaena* or *Gliricidia* increased the productivity (kg weaned/dam/year) of both West African Djallonke sheep and West African Dwarf goats.
- *Leucaena* forage supplementation gave increased milk production in early lactation especially in the dry season when the basal roughage diet is of poor quality.
- Economic analysis of livestock production showed that continuous alley farming was more profitable than alley farming with fallow, or conventional no-tree farming, even when the cost of clearing trees at the end of their useful life is included. Table 7 presents the results.

Beneficial impacts

Table 9 presents a summary of the positive and beneficial impacts resulting from the application of the available technologies. There are both socio-economic and environmental benefits, but more importantly, these together contribute to the development of sustainable agriculture.

Research and development

The opportunities for increasing productivity through research and development are enormous and merits high priority. However, a reorientation of programme focus and direction is necessary, involving multidisciplinary strengths to bear on target agroecological zones, to demonstrate sustainable production systems, increased productivity and environmental protection. The following issues merit research and development attention.

1) Research in crop-animal production systems

Research on farming systems involving crops and animals in holistic terms is weak. The inclusion of animals into cropping systems needs greater emphasis, to include the development of methodologies to understand the effects of interactions between the sub-systems (crops, animals, land and water). There is a need for wider application of crop-animal systems projects across various AEZ. The latter involves semi-arid regions, sub-humid and humid regions and the highlands.

Timon (1992) has suggested the following requirements in support of crop-livestock-tree systems in Asia: (a) baseline studies to quantify energy flows, (b) simulation studies to identify possible coefficient changes in the system, (c) field testing of possible interventions/new technologies, and (d) testing marketing proposed developments on representative sub-populations within the region. He further suggests that such studies need to be carried out across national boundaries within the ecoregion.

2) More complete utilisation of the animal genetic resources

More complete utilisation of the animal genetic resources is necessary to maximise productivity. Animal development programmes in most countries have largely tended to overemphasis one or two sectors. Dairy production for example, has received major attention in almost all countries without exception, mainly for reasons of the ability to generate quick income for poor people and produce precious animal proteins. In general, dairy development has varying degrees of success, been hampered by yield-reducing environmental stresses, inadequate food production and poor nutritional management, high capital costs, limited size of markets, low cost of imports, and product perishability. The investments on these programmes have been enormous, returns essentially short term, and the viability of such projects very doubtful. This has been associated with the inability to sustain breeding and maintenance of crossbred animals to support such programmes. Such massive use of resources has tended to divert attention from more balanced development and wider use especially of other species to increase protein production. Notable in this regard are beef cattle, swamp buffaloes, goats, sheep and ducks. Implicit in this observation is the fact that many potentially important breeds among these have never been adequately used, and in many cases are destined for extinction.

3) *Intensive utilisation of the feed resources*

Increased intensification and efficiency in the use of available feeds represents a most important strategy. It is the principal constraint among the non-genetic factors which affects productivity. With ruminants, the food resources are very much underutilised. Within

Table 9. Benefits of some technological options in crop-animal systems and demonstrable sustainable agriculture in Asia (Devendra, 1996)

Technology	Soil conservation	Soil fertility	Increased animal performance	Increased crop yields	Increased food security	Increased income/stable households
1. Supplementation			+		+	+
2. Draught animal power	+	+		+	+	+
3. Legumes (feed, green manure, hedges and in rice bunds)	+	+	+	+		+
4. Food-feed systems	+	+	+	+	+	+
5. Three strata foage system	+	+	+	+	+	+
6. Alley cropping	+	+	+	+		+
7. Sloping agriculture land technology (SALT)	+	+		+		+
8. Manure availability	+	+	+	+		
9. Rice-fish integration	+	+		+	+	+
10. Ruminants-tree crop integration	+	+	+	+	+	+

different ecosystems, different types and quality of feeds are variable, but the general principles of feeding and management are unchanged. The approach should be balanced feed supply, with balanced energy/protein ratios, and correcting any critical deficiencies with low- cost supplements.

4) Improved technologies and utilisation of research results

Inadequate, inappropriate, and inefficient use of available technologies is a major limitation to increased production from animals. Technology application at the farm level is particularly weak, and is related to a combination of poorly formulated development programmes that often preclude strong inter-disciplinary team effort and concerted on-farm application. The utilisation of research results therefore merits very high priority in research and development. Large-scale on-farm testing is implicit, involving a major shift to on-farm participatory development. Whole-farm production, and post-production to consumption systems should be addressed. Intensification and efficient resource use will determine the extent to which traditional systems can be improved to market-oriented situations with attendant benefits.

5) Increased investment for research in rain-fed areas

Investment in agricultural research has generally produced high rates of return. This is reflected in the benefits of high yielding cereal varieties. Parallel evidence for animal production systems are few and far between and this imbalance needs to be corrected through increased investments in research. Focusing research on commodities is no longer enough and now should be expanded to crop-animal systems especially in rain-fed areas. Because of the complexity of research and development in rain-fed lowland and upland areas which are generally were difficult, resource management will have to be more holistic. The costs are therefore higher, but the payoffs for the contribution of livestock are likely to be much more greater in the future.

6) Animal diseases

Animal diseases seriously reduce animal productivity and also cause major economic losses. The major infectious diseases in ruminants are foot and mouth, rinderpest, haemorrhagic septicaemia, blackleg and anthrax. With pigs and poultry, swine fever and Newcastle disease are serious constraints. Tick-borne diseases like the ileriosis, anaplasmosis, babesiosis also occur in Asia, but these are endemically stable in indigenous animals. They do however cause significant wastage and mortality in imported and improved livestock. It has been estimated that in India, tropical the ileriosis causes an estimated annual loss of US$ 800 million in improved cattle, and more that 200 million indigenous Zebu cattle are exposed to anaplamosis and babesiosis in South East Asia.

Other infectious and non-infectious diseases are also prevalent which reduce the level of animal productivity. These are mainly internal parasites e.g. *Fasciola gigantica* in all ages of buffaloes and cattle, and *Haemonchus contortus* and *Trichostrongylus spp.* in small ruminants. These also exists diseases of the reproductive tract e.g. brucellosis, contagious pneumonia and mineral deficiencies.

The ADB (1993) has reported that animal health accounts about 80% of Government support to the livestock sector, together with a substantial component of donor aid. It suggests that since the endemic diseases are under workable control and that the main role of government should be in vaccination and prevention of endemic diseases such as rinderpest. Training of farmers in basic animal hygiene is also suggested.

7) Institutional issues

Several institutional issues are necessary to enhance the new and more innovative animal production programmes in the region. Four key requirements are essential *inter alia*:

- Commitment to inter-disciplinarily, a systems approach and sustainable development. This is especially important for research and development of integrated systems in specific ecosystems.
- Formulation of research programmes that involve both production and post-production components, and community-based participation in response to the real needs of farmers.
- Institutional and structural commitment that are programmes-led, and the programmes are needs-led.
- Establishment of effective inter-institutional coordination and collaboration for decision making, management, dissemination of practical technical information, and resolution of feedback issues.

In general, institutional support for crop-animal systems research is very weak or non-existent, and research into such integrated systems involving the national resources will require much more commitment and support in the future.

8) Policy framework

Overriding policy support is necessary to realise the implementation and success of crop-animal systems projects. A reorientation of animal production programmes is required to deal with the more complex projects that are multisectoral and multidisciplinary, and can address natural resource management and use such as crop-animal interactions, economic and environment impacts, nutrient recycling, biodiversity, changing socio-economic and consumer preferences, and provide for environmentally sustainable development.

REFERENCES

ADB. 1991. Sector paper on livestock. Agriculture Department Staff Paper No. 4, Manila, Philippines, X. p. 225.

ADB. 1993. Policy and strategies for livestock development. Procedures of a Regional Seminar, Manila, Philippines, xii. p. 251.

Alexandratos, N. 1995. World Agriculture: Towards 2010. FAO and John Wailey and Sons, Rome, Italy. p. 488.

Boserup, E. 1981. Population and Technological Change: A study of Long Term Trends. Chicago University Press, Chicago, USA.

Cagauon, A. G, C. Van Hove, E. A. Orden, N. M. Ramito and R. Brankaert. 1996. Preliminary results of case study on integrated rice-fish-azolla-ducks production system in the Philippines. Proc. Symp. Integrated Systems of Anim. Prod., Chiba, Japan. pp. 35-62.

Chee, Y. K. and A. Faiz. 1991. Sheep raising reduces chemical weed control in rubber. In Forages for Plantation Crops (Ed. H. M. Shelton and W. W. Stur). ACIAR Proc. No. 32, ACIAR, Canberra, Australia. pp. 120-123.

Chen, C. P. and Y. K. Chee. 1993. Ecology of forages under rubber oil palm. In Advances in Sustainable Small Ruminant - Tree Cropping Integrated Systems (Ed. S. Sivarj, P. Agamuthu and T. K. Mukherjee), University of Malaya, Kuala Lumpur, Malaysia. pp. 9-18.

Chen, Y. C. 1992. Integrated livestock-fish production in China. FAO/IPT Int. Workshop on Integrated Livestock-Fish Prod. pp. 103-106.

Congyi, Y., Z. Quangji and Z. Jianchu. 1993. Comparing crop-hog-fish agroecosystem with conventional fish culturing in China. Ecological Engin. 2:231-242.

Cruz, E. M. and S. H. Shehadeh. 1990. Preliminary results of integrated pig-fish and duck-fish production tests. Proc. ICLARM, No. 4, pp. 225-238.

de Jong, R., L. G. Kuruppu, Q. W. Jayawardena and M. N. M. Ibrahim. 1994. Performance of small livestock crop demonstration cum training farms in Sri Lanka. Asian-Aus. J. Anim. Sci. 7:571-582.

Deocareza, A. G. and H. E. Diesta. 1993. Animal production under improved pasture under coconuts. Proc. Regional Working Group on Forages, Khon Kaen, Thailand. pp. 189-193.

Devendra, C. 1983. Small farm systems combining crops and animals. Proc. Vth. World Conf. Anim. Prod., Tokyo, Japan Vol. 1. pp. 173-191.

Devendra, C. 1989. Ruminant production systems in the developing countries: resource utilisation. In Feeding Strategies for Improved Productivity of Ruminant Livestock in Developing Countries, IAEA, Vienna, Austria. pp. 5-30.

Devendra, C. 1991. The potential for integration of small ruminants and tree cropping systems in South and South East Asia. Wrld. Anim. Rev. (FAO). 66:13-22.

Devendra, C. 1993. Sustainable Animal production from small farm systems in South East Asia. FAO Anim. Prod. Health Paper, No. 106, Rome, Italy, IX. p. 143.

Devendra, C. 1996. Overview of integrated animals-crops-fish production systems: achievements and future potential. Proc. Symp. Integrated Systems of Anim. Prod. in the Asian Region, Chiba, Japan. pp. 9-22.

Devendra, C., D. Thomas, M. A. Jabbar and H. Kudo. 1997. Improvement of Livestock Production in Crop- Animal Systems in the rainfed agro-ecological zones of South East Asia. International Livestock Research Institute Nairobi, Kenya. VII. p. 107.

Devendra, C., D. Thomas, M. A. Jabbar and E. Zebini. 1999. Improvement of Livestock Production in Crop-Animal Systems in Agro-ecological Zones of South Asia. International Livestock Research Institute, Nairobi, Kenya (In press.).

Duckham, A. M. and O. D. Masefield. 1970. Farming Systems of the World. Chatto and Windus, London, UK.

Edwards, P., R. S. V. Pullin and J. A. Gartner. 1988. Research and education for the development of crop-livestock-fish farming systems in the tropics. ICLARM Studies and Rev. No. 16. p. 53.

FAO. 1993. Production Yearbook. Vol. 47, Rome, Italy, XI. p. 254.

Huque, Q. M. E. 1992. Integrated livestock-fish farming: Bangladesh perspective. Proceeding FAO/PT Workshop on Integrated Livestock-Fish Production, Kuala Lumpur, Malaysia. pp. 118-121.

Laquihon, G. A., G. Suico and W. A. Laquihon. 1997. Intergration and SALT management of crop-livestock in slopeland areas: the case of "super" SALT (sloping agricultural land technology). Proc. Int. Workhop on Sustainable crop-livestock integration in sloping lands of Asia. Davao, Philippines. (Mimeograph). pp. 1-21.

Le Hong Man. 1992. Duck-fish integration in Vietnam. Proc. FAO/IPT Int. Workshop on Integrated Livestock Fish Production, Kuala Lumpur, Malaysia. pp. 101-102.

Liang, J. B. and S. Rahman. 1985. Dual purpose (drought-meat) buffalo: the last resort to save the dying species in Malaysia. Proc. Ist. World Buffalo Cong. Cairo, Egypt. pp. 926-928.

Leng, R. A. and C. Devendra. 1995. Priorities and direction for research for more effective use of feed resources by livestock in Asia. In Global Agenda for Livestock Research. Proc. Consultation for the South East Asia Region (Ed. C. Devendra and P. Gardiner). ILRI, Nairobi, Kenya. pp. 25-44.

Little, D. A., Khalil and P. Taibaikaew. 1992. Development of duck-fish integrated systems on North East Thailand. Proc. VI Asian-Aust. Anim. Sci. Cong. Vol. II. pp. 93-106.

Mahadevan, P. and C. Devendra. 1986. Present and projected ruminant production systems of South East Asia and the South Pacific. In forages in South East Asia and the Pacific, ACIAR Proc. No. 12, pp. 1-6.

Mukherjee, T. K., S. Geeta, A. Rohani and S. M. Phang. 1992. A study on integrated duck-fish and goat-fish production systems. Proc. FAO/IPT Int. Workshop on Integrated Livestock-Fish Production, Kuala Lumpur, Malaysia. pp. 41-48.

Nitis, I. M., K. Lana, W. Sukanten, M. Suarna and S. Putra.

1990. The concept and development of the three strata forage system. In Shrubs and Tree Fodders for Farm Animals (Ed. C. Devendra). International Development Research Centre, IDRC-276e, Ottawa, Canada. pp. 92-102.

PCARRD. 1994. Philippines recommends for Sustainable Integrated Small Ruminants - Coconut systems. PCARRD Philippines Series No. 77, PCARRD, Los Ba os, Philippines. p. 57.

Reynolds, L. and M. A. Jabbar. 1994. The role of alley farming in African livestock production. Outlook on Agri. 23. pp. 106-114.

Reynolds, S. G. 1988. Pastures and cattle under coconuts. FAO Plant Prod. and Protection Paper No. 91. p. 33.

Ruthernberg, H. 1980. Farming Systems in the Tropics. 2nd Edn. Clarendon Press, Oxford, UK. p. 424.

Spedding, C. R. W. 1975. The Biology of Agricultural Systems. Academic Press, London, UK. p. 261.

Sere, C. and H. Steinfield. 1966. World livestock production systems: current status, issues and trends. Anim. Prod. and Health Paper No. 127, FAO, Rome, Italy. p. 82.

Stur, W. W., S. G. Reynolds and D. C. Macfarlane. 1994. Cattle production under coconuts. Proc. Agroforestry and Animal Production for Human Welfare. (Ed. J. W. Copland, A. D. Djajanegara and M. Sabrani), ACIAR, Canberra, Australia. pp. 106-114.

Suriapernama, S., T. Syamsiah, A. M. Fagi and Atunadja 1988. Optimase daya dukung lahan dengan ristem minapadi- itek pada lahan dengan ristem minapadi-itek pda lahan saevah beririgasi. Simposium Tananam Pangan 11, Bogor, Indonesia. pp. 21-23.

Technical Advisory Committee/CGIAR. 1992. Review of CGIAR priorities and strategies Part 1, TAC Secretariat, FAO, Rome, Italy. p. 250.

Thien, N., N. Cong Quoc, D. Xuan Tuyen and M. Sasaki. 1996. Rice-fish-duck-pig production in Vietnam. Proc. Symp. n Integrated Systems of Animal Prod. in the Asian region, Chiba, Japan. pp. 63-76.

Timon, V. M. 1992. Advancement of animal agriculture in Asia: issues and suggestions for CGIAR consideration. TAC working document, Rome, Italy. p. 74.

Yunus, M., A. Hardjamulia, I. Syamsiah and S. Suriapermana. 1992. Evaluation of rice-fish production in Indonesia. Proc. Rice-Fish Farming Res. And Dev. Workshop (Eds. C. R. dela Cruz, C. Lightfoot, C. B. A. Costa Pierce, V. B. Carangal and M. A. P. Bumbao). ICLARM, Manila, Philippines. pp. 131-138.

Villar, E. C. 1998. Dynamics of crop-livestock integration in slopelands areas. Proc. Workshop on Sustainable Crop-Livestock Integration in Slopelands ASPAC/FFTC, Ho Chi Minh City, Vietnam. pp. 13-29.