Annals of Arid Zone 38(3&4): 399-414, 1999

The Relevance and Implications of Livestock-tree Interactions in Agroforestry Systems in Developing Countries

C. Devendra*
International Livestock Research Institute, Nairobi, Kenya

Abstract: Livestock-based agroforestry systems present important opportunities for increasing food production from farm animals. This is reflected in the widening gap between production and consumption, and the inability of domestic supplies to meet projected demand for foods of animal origin up to year 2020. Increasing productivity from animals thus necessitates assessment of all possible avenues of food production, including agroforestry systems. In South-east Asia alone, this concerns an estimated 210 million hectares under permanent tree crops and forests. The livestock-tree interactions include animal draught power for land cultivation and crop growth; effects of dung and urine on soil fertility and crop growth; use of crop residues and agro-industrial by-products; use of native vegetation on cost of weed control; effects of integrating livestock with trees, and that of the shade of trees on animal performance; and type of production systems on crop performance and environmental protection. Case studies are presented, data from which clearly demonstrate positive benefits, economic and ecological impacts. Areas for research include characterization of livestock-based agroforestry systems in target agro-ecological zones; compatibility between livestock and trees; appropriate choice of livestock species, production systems, and optimum age of trees for integration with livestock; effects of dung and urine and nutrient recycling on soil fertility and crop yields; efficient use of crop residues and agro-industrial by-products *in situ*; and assessment of the nature, extent and implications of the interactions. Increased resource use and concerted research focus on livestock-based agroforestry systems can provide for demonstrable improved efficiency in the management of natural resources, sustainable production systems, and increased productivity from the land in the future.

Key words: Livestock, trees, agroforestry systems, integration, interactions, nutrient recycling, impacts, interdisciplinary research, sustainable agriculture.

In recent years, the search for efficiency in the management and use of natural resources has become a particularly challenging task because of the overwhelming disparity between available supplies and human requirements for foods of animal origin. Recent assessments of forecasts of ruminants and non-ruminant meat production and consumption to the year 2010 indicate a widening gap between production and consumption in most selected countries studied (Vercoe *et al.*, 1997). With rare exceptions, the indications are that domestic production will be unable to meet the demand. More recently, projected demands of meat and milk production are expected to grow at rates of 2.8 and 3.2% annually up to year 2020 (Delgado *et al.*, 1999), which will put enormous pressure on the management of the natural resources.

*Corresponding Address: 130A Jalan Awan Jawa, 58200 Kuala Lumpur, Malaysia.

The importance of ensuring continuing productivity is seen in South-east Asia in the light of the recent Asian economic crisis and the impact on livestock production. Small farms were especially hard hit, with increased cost of production inputs and dislocated marketing systems. However, in Indonesia, one of the countries hard hit by the crisis, it is the agricultural sector that was able to show a small, but positive economic growth during difficult times in which animal production on small farms was especially valuable.

In these circumstances, the importance of maximizing productivity from the livestock resources through all available avenues of food production is therefore a compelling task. These approaches must necessarily ensure, however, that increased productivity and improved livelihoods are consistent with the sustainable use of the natural resources and environmental protection.

Agroforestry systems, including the role of livestock within these, provide an important research and development opportunity to increase the contribution of livestock. In simple terms, agroforestry systems refer to the use of trees in farming systems in which these are integrated with annual crops, livestock and fish. The International Centre for Research on Agroforestry (ICRAF) defines agroforestry as "a collective name for land use systems and technologies where woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between components".

This paper focuses on the relevance and implications of livestock-tree interactions, highlighting the nature and extent of these, as well as major examples that demonstrate ecological and economic benefits, in the developing countries.

Types of Livestock-tree Interactions

The following types of livestock-tree interactions are common:

- Beneficial effects of shade and available feeds on livestock performance
- Draught animal power for land preparation and crop growth
- Dung and urine on soil fertility and crop growth and reduced use of purchased fertilizers
- Use of crop residues, agro-industrial by-products (AIBP), and non-conventional feed resources (NCFR) from trees *in situ*
- Use of native vegetation and the effects on cost of weed control, crop management and crop growth
- Type of animal production systems (grazing, semi-intensive and stall- feeding or zero grazing) on the yield of tree crops, increased income and environmental integrity

The interactions can be positive or negative, depending on the type of livestock and trees, age of trees, and management systems. Among ruminants, cattle and sheep are well suited to integration with tree crops such as coconuts and oil palm. Sheep are more suited for integration with rubber where

light transmission is less. Goats are more selective in their feeding habits because they are browsers (Devendra, 1999), and are therefore only more suited when both browse and forages are available in agroforestry systems. In Queensland, Australia, goats caused 75% mortality in a stand of *Sesbania sesban* trees by ringbarking the stems 10 to 15 cm above ground level (Kochapakdee, 1991). However, sheep, cattle and buffaloes can all damage trees, especially the bark of rubber. Cattle are unsuited to rubber plantations as they can disturb the latex collecting cups. To ensure compatibility between livestock and trees, appropriate choice of species, control of grazing, and also the optimum age of trees when the canopy is out of reach of the animal, are important considerations.

Agroforestry systems, on account of the reduced temperature and shade, provide ameliorative environments compared to open sunlight (Ovalle and Avendano, 1988; Marai and Habeeb, 1998), and are conducive for good animal performance. The performance becomes more significant for exotic livestock in tropical climates. Daly (1984) reported a 0.9% reduced calving rate for every 0.1°C increase above 30.0°C in the rectal-temperature of cows. Calving rate depressions in British breeds and Brahman crossbreds were 10% and 10 to 25%, respectively. Stressed cows also gave birth to lighter calves. Milk production differences are also apparent, with Davison *et al.* (1988) reporting increased mean yields of 2 kg per cow compared to animals without shade, concurrent with a reduced rectal temperature of 39.4°C compared with 40.0°C for animals in open sunlight. In Latin America, decreased lamb mortality and better protection of sheared sheep (Peneloza and Harve, 1984) have been recorded as benefits of grazing under *Pinus*.

Of the three main tree crops (coconuts, oil palm and rubber), coconuts offer a particularly unique opportunity for integration with cattle or goats or sheep, with attendant economic benefits, mainly because of the constant light and long life of the crop of approximately 70 years. The available native vegetation, together with other introduced grasses, can then be grazed on a semi-permanent basis. Table 1 presents a summary of the responses by cattle. The variation in animal production was directly related to type of feed biomass available, soil fertility, fertilizer strategy and light transmission.

Draught animal power is a good example of the interaction between livestock and trees. Ploughing, harrowing, cultivation and haulage are key elements and are reflected throughout Asia. In South-east Asia for example, in coconut and oil palm plantations, draught animal power from buffaloes and cattle is used for various farm operations, such as tillage and haulage by small farmers who cannot afford more expensive tractor power and costs of maintenance.

The relevance and implications of livestock-tree interactions, especially the benefits, are highlighted in the results of long-term case studies in Asia and elsewhere. These benefits relate to improved soil fertility, increased income and development of potentially important sustainable systems. Aside from these examples, other examples of the integration of trees and especially small ruminants, with complementary advantages, include

Table 1. Cattle production from grazing experiments under coconut (Shelton, 1991; Stur et al., 1994)

Country	Pasture	Light transmission (%)	Live weight gain (kg ha^{-1} y^{-1})	Avg. daily gain (kg ha^{-1} d^{-1})	Stocking rate (cattle ha^{-1})	Reference
Indonesia (1700 mm y^{-1})	Improved	79	288-505	0.22-0.29	2.7-6.3	Rika *et al.*, 1981
Philippines (>2000 mm y^{-1})	Improved	n.a.	170-315	0.43--0.47	1-2	Moog *et al.* 1993
	Improved	n.a.	130-158	0.14-0.36	1-3	Deocareza and Diesta, 1991
	Improved	n.a.	137-306	0.20-0.37	1-3	
	Natural	n.a.	51	0.14	1	Deocareza and Diesta, 1991
	Improved	n.a.	91-146	0.20-0.25	1-2	
Solomon Island (2900 mm y^{-1})	Natural	60	235-345	0.27-0.40	1.5-3.5	Watson and Whiteman, 1981
	Improved	60	227-348	0.27-0.40	1.5-3.5	
	Natural	62	219-332	0.26-0.40	1.5-3.5	Smith and Whiteman, 1985
	Improved	62	206-309	0.23-0.35	1.5-3.5	
Thailand (1600 mm y^{-1})	Natural	n.a.	44	0.12	1.0	Manidol, 1984
	Improved	n.a.	94-142	0.16-0.26	1.0-2.5	
Vanuatu (>1500 mm y^{-1})	Improved	n.a.	175	0.32	1.5	Macfarlane and Shelton, 1986
	Natural	n.a.	250-285	0.26	2.6-3.0	Evans *et al.*, 1992
	Improved	n.a.	550	0.50	3.0	
Western Samoa (2900 mm y^{-1})	Natural	50	148	0.22	1.8	Reynolds, 1981
	Improved	50	225-306	0.33-0.47	1.8-2.2	
	Natural	70-84	127	0.14	2.5	
	Improved	70-84	273-396	0.30-0.43	2.5	
	Natural	70-84	401-466	0.27-0.32	4.0	Robinson, 1981
	Improved	70-84	421-744	0.29-0.51	4.0	

goats or sheep under cashewnut, cocoa, citrus, mangoes, jackfruit, kapok, tamarind, or teak in many parts of South and South-east Asia and Africa. In parts of sub-tropical South China and also in Vietnam, a variation to ruminant-tree crop interactions is the presence of ponds under coconuts or fruit trees which further enable the integration of fish, vegetable, pigs and ducks. This diversification and effective use of the

available natural resources presents the most important means to sustain livelihoods of small farmers, as well as maximize farm productivity.

Overview of Research on Tree Crops and Ruminants

Agroforestry systems potentially involve the management and use of 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 *et al.*, 1988). The management and use of the natural resources in a mutually reinforcing manner, enables ecological and economic sustainability. The greatest challenge is to identify improved and integrated management of natural resources with increased productivity in which whole farm systems are driven by market-oriented access.

Between ruminants integrated with annual and perennial crops, more research has been undertaken in the latter system. Several countries in South-east Asia (Devendra *et al.*, 1997) have been active in this regard, notably Indonesia, Malaysia and the Philippines. Attention is drawn to recent publications on small ruminants in tree crops (Iniquez and Sanchez, 1991; Sivaraj *et al.*, 1993; Mullen and Shelton, 1995); and the reviews of research over the past 20 years on integrated tree crop systems by Chen *et al.* (1996) and Reynolds (1993) for cattle in coconut plantations. More recently, a critical assessment of crop-animal systems and research priorities in South-east Asia, led to the conclusion that the integration of animals with tree crops was a priority research project (Devendra *et al.*, 1997).

The main areas in which research has been undertaken include:

- Characterisation of environmental conditions within plantations
- Measurements of forage, and availability of crop residues and agro-industrial by-products (AIBP) and quality, as well as seasonality of production
- Evaluation and selection of grasses and legumes for environmental adaptation and increased herbage production
- Measurements of animal performance under different nutritional and management regimes
- Measurements of soil compaction and tree damage resulting from the introduction of ruminants
- Measurements of tree crop yields in integrated systems
- Management of animals under tree crops
- Analyses of the economic benefits of integrated systems.

The first three areas are the most studied. In contrast, long term animal production data for the different ruminant species are limited, like the data on the effects of grazing management, and socio-economic analyses. Yet, these analyses are essential for presenting a convincing case for the wider adoption of the systems. The overall conclusion is that, much more concerted interdisciplinary research is required in developing methodologies for the process of integrating ruminant species with tree crops, as well as studies on the nature (positive and negative), extent and impact of crop and animal interactions on environmental indicators.

Table 2. 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^{-1} y^{-1}, MT)	Non-grazed area (Yield of fresh fruit bunches ha^{-1} y^{-1}, MT)	Difference (Fresh fruit bunches/ ha^{-1} y^{-1}, MT)
1980	30.55 (C)+	21.61	9.94
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.

Case Studies

The following case studies demonstrate good examples of the benefits and impact of livestock-tree interactions in agroforestry systems. In all cases without exception, the benefits were associated with economic and ecological impacts.

Tree crops-ruminants system (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 forests and woodlands, a high proportion of which involves tree crops like coconuts, oil palm and rubber. The study involved the effect of grazing with cattle and goats with oil palm, compared to no grazing resulted in increased yields of between 2.2 to 5.2 MT fresh fruit bunches ha^{-1} y^{-1}. Considering the total land area under oil palm and the sale value of fresh fruit bunches per tonne, the economic advantage is substantial (Table 2).

Increased 30% yield in oil palm plantations have also been reported by Chen *et al.* (1993) due to grazing. These authors have also reported 20 to 40% reduced weeding costs for cattle under oil palm, comparable to a savings of 16 to 35% using grazing sheep reported by Chee and Faiz (1991). Also in Malaysia, utilizing buffaloes to transport oil palm fruit bunches from the field to collecting centres 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 the income of farmers by between US$ 127-229 (PCARRD, 1994).

Coconut plantations provide an important opportunity to integrate cattle. Reynolds (1988) has calculated that beef cattle production was an important source of secondary income in Western Samoa. Based on data of live weight gain and copra production, the contribution of beef to increased gross income increased from 21 to 41% for a farm with cattle on natural

Table 3. Cost and return analysis of SALT in Davo 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 ++	3351.5	3505.4	3178.4
Value added items +++	1516.8	1516.8	1516.8
Total returns	5022.7	5152.2	4862.9
Materials	2402.6	1381.7	1593.0
Non-cash items	1754.3	1830.5	2014.9
Total costs	4157.0	3212.2	3607.9
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.

pastures, and from 42 to 71% with cattle on improved pastures. The farms without cattle suffered a reduction in gross farm income by 70%. Stur *et al.* (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.

In southern India, Das (1991) has reported from an evaluation of various coconut-based farming systems, that it is more profitable to integrate a number of subsidiary crops and animals than to grow coconuts as a monocrop. In this same zone, studies by Chinnusamy *et al.* (1994) between 1988-1993 on a one-hectare model farm integrating crops (grain and fodder), silvopasture (trees and grass) and goat-rearing indicated that soil physical and chemical characteristics were all improved, along with the socio-economic conditions of the farmer. In Sri Lanka, the integration under coconuts of a mixed pasture based on *Brachiaria miliformis/Pueraria phaseoloides* and the multipurpose trees *Gliricidia sepium* and *Leucaena leucocephala* resulted in increases of 17% and 11%, respectively, in nut and copra yields (Liyanage de Silva *et al.*, 1993). The nutrients returned from 73 kg of fresh manure and the application of 30 litres urine/palm/year reduced the cost of fertilizing the coconuts by 69%. The system produced sufficient forage to maintain growth and milk yields in the Jersey crossbred animals.

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 reduce soil erosion, improve soil fertility and nutrients for the crops (maize and black pepper) grown between the hedgerows, and provision of precious fodder for goats in

Table 4. Average economic performance per year, per acre and per person of the farm activities of the three MLDC farms - 1985-1992 (Jong et al., 1994)

Item	Half acre		One acre		Two acre	
	Rs./year	Rs./acre	Rs./year	Rs./acre	Rs./year	Rs./acre
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 (2.25 LU)	147	73	200	50
Gross margin/LU	8,243	(1.5p)	(2.5 LU)	(4.25 LU)		
Gross margin/(person)	12,364		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	

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) have analyzed the benefits of the system between 1991-1993, and concluded that the mean annual income was US$ 1354 per 0.5 ha (Table 3). The mean internal rate of return was 38.7%. The mean annual income was 14 times higher than the mean annual income of US$ 120 per 0.5 ha in the Philippines (Villar, 1998).

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.

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 to 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 4). Animals also significantly contributed to the improvement of soil fertility through, manure and biogas production to replace domestic fuel needs (Jong *et al.*, 1994).

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

Table 5. Present value gross margins from three alternative farming systems in Southwest Nigeria (Naira ha^{-1} y^{-1}) 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.

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 recent 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 5).

Studies in Africa and Latin America

Outside of the Asian region, limited studies have been undertaken on the integration of ruminants with trees in Africa and Latin America. Data on the implications of livestock-tree interactions is therefore limited. Nevertheless, grazing cattle under coconuts and cashew is common along the coastal areas of Tanzania and Kenya, as also in parts of West Africa where there are permanent tree crops such as oil palm and rubber. In all these situations, ruminants are variously grazed with a view of utilizing to advantage the available native vegetation, mainly grasses and browse plants.

In humid Central America, there are two good examples of livestock-based agroforestry systems. In Costa Rica, Somarriba and Lega (1991) have described a system involving *Pinus caribaea* for pulp and

Table 7. Benefits of some technological options in crop-animal systems and demonstrable sustainable agricutlrue in Asia (Devendra, 1996)

Technology	Soil conservation	Soil fertility	Increased animal performance	Increased crop yields	Increased food security	Increased income/stable households
Supplementation			+		+	+
Draught animal power	+	+		+	+	+
Legumes (feed, green manure, hedges and in rice bunds)	+	+	+	+		+
Food-feed systems	+	+	+	+	+	+
Three strata forage system	+	+	+	+	+	+
Alley cropping	+	+	+	+		+
Sloping agriculture land technology (SALT)	+	+		+		+
Manure availability	+	+	+	+		
Rice-fish integration	+	+		+	+	+
Ruminants-tree crop integration	+	+	+	+	+	+

fertilizer use. The economic and ecological benefits of such tree crop-animal interactions, in terms of hard data are limited, but beneficial evidence is apparent, supported also by the practice of such systems, especially by small farmers.

Beneficial Impacts

Table 7 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.

Areas for Research

The foregoing review and discussion of livestock-based agroforestry systems in general, and livestock-tree interactions in particular, clearly suggest that research on holistic systems is generally weak. Associated with this is sparse information on livestock-tree interactions. The opportunities for research to redress this situation offer exciting possibilities for integrated natural resource management. The following research areas *inter alia* merit attention:

- Detailed characterization and systems analysis of individual environments that favor livestock-based agroforestry systems, e.g., in uplands.

- Assessment of the nature and extent of livestock-tree-soil interactions, both negative and positive, effects of integrating animals on trees and of trees on animal performance, economic and environmental impacts.

- The effects of dung and urine on soil fertility, savings in the use of inorganic

fertilizers, and effects on crop yields, as well as nutrient recycling.

- The efficient use of available feed resources (grasses, crop residues, AIBP and NCFR) in the development of more controlled and zero grazing systems.
- Development of sustainable livestock-based agroforestry systems.
- Socio-economic impact on poverty alleviation and food security.

An essential prerequisite for the research is the need for a strong systems approach that is interdisciplinary and has a holistic focus. Such approaches should be needs-based in order to ensure that the contributions can benefit whole farm systems.

Conclusions

Livestock-tree-crop interactions in agroforestry systems are potentially very important, but have not been adequately developed. The nature of livestock-tree interactions are variable, and the extent, especially of the more positive effects, economic and environmental impacts, are inadequately understood. The systems involve mainly cattle, goats and sheep, but also buffaloes integrated in a variety of perennial tree cops. Most of the research has been undertaken in South-east Asia with demonstration of successful benefits; however, much more information is necessary about the impacts of the interactions. Elsewhere in South China and Vietnam, the ruminant-tree crops model is further extended to include ponds and the integration of fish, vegetables, pigs and ducks. Limited case studies indicate that with increased resource use and more focused research, integrated livestock-tree-crops systems provide an important opportunity to develop and demonstrate efficiency in the management of natural resources and sustainable agroforestry systems.

References

Alexandratos, N. 1995. *World Agriculture. Towards 2010.* FAO, Rome, Italy, 488 p.

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

Chen, C.P., Tajuddin, I. and Chong, D.T. 1996. Strategies for the entrepreneurship of livestock integration in plantation systems. In *New Perspectives in Animal Production* (Eds. H. Sharif, C.C. Wong, J.B. Liang, W.E. Won Khadijah and I. Zulfikli), pp. 101-117. MARDI, Serdang, Malaysia..

Chinnusamy, C., Sivasankaran, D. and Rangasamy, A. 1994. Sustainable integrated farming systems for rainfed upland farms in southern Peninsular India. In *Proceedings of the Third Asian Farming Systems Symposium.* University of the Philippines, 7-10 November 1994, Los Banos, Philippines (Mimeograph).

Daly, J.J. 1984. Cattle need shade trees. *Queensland Agricultural Journal* 110: 21-24.

Dalzell, R. 1978. A case study on the utilisation on palm oil mill effluent by cattle and buffaloes. In *Proceeding of the Feeding stuffs for Livestock in South East Asia, Malaysian*, pp. 132-141. Society of Animal Production, K. Lumpur, Malaysia.

Das, P.K. 1991. Economic viability of coconut-based farming systems in India. *Journal of Plantation Crops* 19: 191-202.

Davison, T.M., Silver, B.A., Lisle, A.T. and Orr, W.N. 1988. The influence of shade on milk production of Holstein-Friesian cows in a tropical upland environment. *Australian Journal of Experimental Agriculture* 28: 149-154.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S. and Courbois, C. 1999. *Livestock to 2020: The Next Food Revolution.* International Food Policy Research Institute, Washington, D.C., USA, 72 p.

Deocareza. A.G. and Diesta, H.E. 1991. Utilisation of native forages under coconuts in Bicol region. In *Utilisation of Native Forages for Animal Production. Proceedings of Second Meeting of the Regional Working Group on Grazing and Feed Resources of Southeast Asia* (Ed. A.C. De la Viña), pp. 155-160. 26 February-5 March 1991. University of the Philippines, Los Banos, Philippines.

Deocareza, A.G. and Diesta, H.E. 1993. Animal production on improved pasture crops under coconuts. In *Strategies for Sustainable Forage Based Livestock Production in Southeast Asia. Proceedings of the Third Meeting of Regional Working Group on Grazing and Feed Resources of Southeast Asia* (Eds. C.P. Chen and C. Satjipanon), pp. 189-193. January 31-February 6, 1993. Khon Kaen, Thailand.

Devendra, C. 1989. The nutrition of and feeding strategies for sheep in Asia. In *Proceedings Sheep Production in Asia* (Eds. C. Devendra and P.S. Faylon), pp. 21-42. Philippines Council for Agriculture Research and Development Resources Book Series No. 80.

Devendra, C. 1991. The potential for integration of small ruminants and tree cropping in South-East Asia. *World Animal Review* 66: 13-22.

Devendra, C. 1993. Sustainable Animal Production from Small Farm Systems in South-East Asia. *FAO Animal Production and Health Paper No. 106*. FAO, Rome, Italy. 143 p.

Devendra, C. 1996. Overview of integrated animals-crops-fish production systems: achievements and future potential. In *Proceedings of the Symposium on Integrated Systems of Animal Production in the Asian Region*. Eighth Asian-Australian Animal Science Congress, Tokyo, Japan. pp. 9-22.

Devendra, C. 1998. Improvement of small ruminant production systems in rainfed agro-ecological zones of Asia. *Annals of Arid Zone* 37: 215-232.

Devendra, C. 1999. Goats: Challenges for increased productivity and improved livelihoods. *Outlook on Agriculture* 28: 215-226.

Devendra, C., Thomas, D., Jabbar, M.A. and Kudo, H. 1997. Improvement of Livestock Production in Rainfed Agro-ecological Zones of South-East Asia, ILRI, Nairobi, Kenya, 107 p.

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

Evans, T.R., Macfarlane, D. and Mullen, B. 1992. Sustainable commercial beef production in Vanuatu. *Vanuatu Pasture Improvement Project Bulletin No. 4*, Technical and Department of Agriculture Livestock and Horticulture, Port Vila, Vanuatu, 68 p.

Iniquez. L.C. and Sanchez, M.D. (Eds.). 1991. Integrated tree cropping and small ruminant production systems. *Proceedings of a Workshop, Medan*, 9-14 September 1990. Medan, S.R.-CRSP, 329 p.

Jong, R. de, Kuruppa, L.G., Jayawardena, Q.W. and Ibrahim, M.N. 1994. Performance of small-scale livestock/crop demonstration-cum-training farm in Sri Lanka. *Asian-Australasian Journal of Animal Science* 7: 571-582.

Kochapakbdee, S. 1991. An evaluation of browse trees in the grazing management of breeding does and kids. *M. Agr. Sci. Thesis*. The University of Queensland, Australia.

Laquihon, G.A., Suico, G. and Laquihon, W.A. 1997. Integration and SALT management of crop-livestock in solpeland areas: The case of "super" SALT (sloping agricultural land technology). In *International Workshop on Sustainable Crop-livestock Integration in Sloping Lands of Asia*. Davao, Philippines (Mimeograph, 21 pp).

Liang, J.B. and Rahman, S. 1985. Dual-purpose (drought-meat) buffalo: the last resort to save the dying species in Malaysia. In *Proceedings of the 1st World Buffalo Congress*, pp. 926-928. Cairo, Egypt.

Liyanage de Silva, M., Jaysundera, H.P.S., Fernando, D.N.S. and Fernando, M.T.N. 1993. Integration of legume-based pasture and cattle into coconut growing systems in Sri Lanka. *Journal of Asian Farming Systems Association* 1: 579-588.

Macfarlane, D.C. and Shelton, H.M. 1986. Pastures in Vanuatu. Canberra, Australia: *ACIAR Technical Reports*, No. 2, 32 p.

Manidol, C. 1984. Pastures under coconut in Thailand. In *Asian Pastures: Recent Advances in Pasture Research in Southeast Asia*, pp. 204-214. Taiwan, FFTC, No. 52.

Marai, I.F.M. and Habeeb, A.A.M. 1998. Adaptability of *Bos taurus* cattle under hot arid conditions. *Annals of Arid Zone* 37: 253-281.

Moog, F.A., Deocareza, A.G. and Diesta, H.E. 1993. Demonstration trials on improved pastures under coconuts in Bicol region. In *Strategies for Sustainable Forage-based Livestock Production in Southeast Asia* (Eds. C.P. Chen and C. Satjipanon), pp. 43-48. Proceedings of the Third Meeting of Regional Working Group on Grazing and Feed Resources of Southeast Asia, January 31- February 6, 1993, Khon Kaen, Thailand, pp. 43-48.

Mullen, B.F. and Shelton, H.M. (Eds.) 1995. Integration of ruminants into plantation systems in South East Asia. *ACIAR Proceedings No. 64*, Canberra. Australia, 115 p.

Nitis, I.M., Lana, K., Sukanten, W., Suarna, M. and Putra, S. 1990. The concept and development of the three-strata forage system. In *Shrubs and Tree Fodders for Farm Animals* (Ed. C. Devendra), pp. 92-102. IDRC, Ottawa Canada.

Ovalle, C. and Avendano, J. 1988. Interactions de la strate ligneuse avec le strate herbacee dans les formations d'Acacia caven (Mol) Hook et Arn. au Chili II. Influence de 'arbrc sur guelques dements der milien: Microclimat et sol. *Oecologia Plantarum* 9: 113-134.

PCARRD, 1994. Philippines Recommends for Sustainable Integrated Small Ruminants-Coconut systems. *PCARRD Philippines Series No. 77*, PCARRD, Los Banos, Philippines, 57 p.

Peneloza, R. and Harve, M. 1984. *Pastoreo permanente de ovinozen plantaciones forestales en pa Decina region. Proxima Decada*, Chile 24, pp. 16-21.

Reynolds, L. and Jabbar, M. 1994. The role of alley farming in African livestock production. *Outlook on Agriculture* 23: 106-114.

Reynolds, S.G. 1981. Grazing trials under coconuts in western Samoa. *Tropical Grasslands* 15: 3-10.

Reynolds, S.G. 1988. Pastures and Cattle Under Coconuts. *FAO Plant Production and Protection Paper No. 91*, 33 p.

Reynolds, S.G. 1993. Pastures and livestock under tree crops: present situation and possible future development. In *Sustainable Beef Production from Small holder and Plantation Farming Systems in the South Pacific. Proceedings of a Workshop* (Eds. T.R. Evans, D.C. Macfarlane and B.F. Mullen), pp. 77-117. Port Vila and Luganville, Vanuatu, 2-12 August 1993, Brisbane, Australia.

Rika, I.K., Nitis, I.M. and Humphreys, L.R. 1981. Effects of stocking rate on cattle growth, pasture production and coconut yield in Bali. *Tropical Grasslands* 15: 149-157.

Robinson, A.C. 1981. *End of Assignment Report.* UNDP/FAO Animal Health and Production Project SAM/76/003.

Shelton, H.M. 1991. Productivity of cattle under coconuts. In *Forages for Plantation Crops. Proceedings of a Workshop* (Eds. H.M. Shelton, and W.W. Stür), pp. 92-96. Sanur Beach, Bali, Indonesia, 27-29 June 1990. ACIAR Proceedings No. 32, Canberra, Australia, pp. 92-96.

Sivaraj, S., Agamuthu, P. and Mukherjee, T.K. (Eds.). 1993. *Advances in Sustainable Small Ruminant-Tree Cropping Integrated Systems.* University of Malaya, Kuala Lumpur, Malaysia, 243 p.

Smith, M.A. and Whiteman, P.C. 1985. Animal production from rotationally grazed natural and sown pasture under coconuts at three stocking rates in the Soloman Islands. *Journal of Agricultural Science, Cambridge* 104: 173-180.

Somarriba, E. 1985. *Arbales de guayaba (Psidium guayaba l) en pastizales, i. Produccion de fruita y potential de dispersion de semillas. Turrialba* 35: 289-295.

Somarriba, E. and Lega, F. 1991. Cattle grazing under *Pinus caribeae*. i. Evaluation of farm historical data on stand age and animal stocking rate. *Agroforestry Systems* 13: 177-185.

Stür, W.W., Reynolds, S.G. and Macfarlane, D.C. 1994. Cattle production under coconuts. In *Proceedings of the International Symposium on Agroforestry and Animal Production for Human Welfare* (Eds. J.W. Copland, A.D. Djajanegara and M. Sabrani). ACIAR, Canberra, Australia, pp. 106-114.

Sukri, M.I. and Dahlan, I. 1986. Feedlot and semi-feedlot systems for beef cattle fattening among small holders. *Proceedings of the 8th Annual Conference, Malaysian Society of Animal Production*, Genting Highlands, Malaysia, pp. 74-78.

Vercoe, J., Coffey, S., Farrell, D.J., Rutherford, D. and Winter, W.H. 1997. ILRI in Asia: An

assessment of priorities for livestock research and development. International Livestock Research Institute, Nairobi, Kenya, 62 pp.

Villar, E.C. 1998. Dynamics of crop-livestock integration in slopeland areas. In *Proceedings International Workshop on Sustainable Crop-livestock Integration in Slopelands*. pp. 13-29. ASPAC/FFTC, Ho Chi Min City, Vietnam.

Watson, S.E. and Whiteman, P.C. 1981. Animal production from naturalised and sown pastures at three stocking rates under coconuts in the Solomon Islands. *Journal of Agricultural Science Cambridge* 97: 669-676.