



- Invited Review -
**Integrated Tree Crops-ruminants Systems in South East Asia:
Advances in Productivity Enhancement and
Environmental Sustainability**

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ABSTRACT : Improved efficiency in the use of natural resources, pragmatic production systems and environmental sustainability, justified by the need for improved land use systems and increased productivity, are discussed in the context of Asian integrated systems, diversification, and issues of sustainability. The importance of these are reflected by serious inadequate animal protein production throughout Asia, where available supplies cannot match current and projected human requirements up to 2050. Among the ruminant production systems, integrated tree crops-ruminant production systems are grossly underestimated and merit emphasis and expansion. As an example, integrated oil palm- based system is an important pathway for integration with ruminants (buffaloes, cattle, goats and sheep), and provides the entry point for development. The importance and benefits of integrated systems are discussed, involving animals with annual and perennial tree crops, integration with aquaculture, the significance of crop-animal interactions, stratification of the systems, production options, improved use of forages and legumes, potential for enhanced productivity, implications for improved livelihoods of the rural poor and the stability of farm households. The advances in research and development in South East Asia highlight demonstrable increased productivity from animals and meat offtakes, value addition to the oil palm crop, sustainable development, and distinct economic impacts. The results from 12 out of a total of 24 case studies concerning oil palm over the past three decades showed increased yield of 0.49-3.52 mt of fresh fruit bunches (FFB)/ha/yr; increased income by about 30%; savings in weeding costs by 47- 60% equivalent to 21-62 RM/ha/yr; and an internal rate of return of 19% based on actual field data. The results provide important socio-economic benefits for resource-poor small farmers. Potential increased offtakes and additional income exist with the integration of goats. Additionally, the potential for carbon sequestration with tree crops is an advantage. The reasons for low adoption of the systems are poor awareness of the potential of integrated systems, resistance by the crop- oriented plantation sector, and inadequate technology application. Promoting wider expansion and adoption of the systems in the future is linked directly with coherent policy, institutional commitment, increased investments, private sector involvement, and a stimulus package of incentives. (**Key Words :** Tree Crops, Integrated Systems, Crop-Ruminant-Interactions, Oil Palm, Carbon Sequestration, Economic Impacts, Sustainability, Environment, Constraints, Opportunities)

INTRODUCTION

Farming systems are the practices of agriculture in numerous ways in different locations and countries. The systems vary according to the type of agro-ecological zones (AEZ), biophysical environment, extent and quality of the natural resources available, and the level of poverty with resource-poor farmers. Success in agricultural development is dependent to a very large extent on the efficiency in the

use and management of the natural resources (land, crops, animals and water). In this context , increased efficiency in natural resource management (NRM), and environmental sustainability is justified by the need for improved land use systems and total factor productivity The latter is dictated by three principal factors:

- Defining the objectives clearly in terms of production and profitability
- Understanding the significance and implications of soil-crop- animal interactions, and
- Ensuring that the resulting benefits are consistent with

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productivity enhancement, environmental integrity and sustainable development.

With reference to animal production, there is increased emphasis and justification for improved production systems to accelerate the output of foods of animal origin in most countries in South East Asia. This is directly linked to the fact that current outputs of meat and milk from ruminants are relatively low, as are the levels of self-sufficiency in these products, which are exacerbated further by increasing imports at high cost. Increased costs can trigger higher commodity prices that can be associated with strong global demand. The latest OECD-FAO (2010) forecast is that average crop prices over the next 10 years will be 15-40% higher in real terms relative to 1997-2006.

This increased demand is associated with several demand-driven factors and includes inadequate animal protein supplies; rising incomes, which encourage people to diversify their diets in a variety of meats; eggs and dairy products, including the substitution of calories in livestock for low-priced starch calories. Equally awesome is the inadequacy of animal protein supplies to meet current and projected future requirements and spiralling costs. Improved animal production and productivity enhancement is therefore urgent in direct response to the need for more animal proteins. The major opportunities and challenges need to be thoroughly addressed to the extent possible (Devendra, 2007a; 2010a).

This paper is concerned with the significance and potential importance of integrated tree crop-ruminant systems and environmental sustainability. It emphasises their underutilisation, opportunities and unrealised economic benefits of integrated systems, status of advances in research and development (R and D) on the subject, relevance to other regions, ways of overcoming the major constraints and challenges associated with the environmental sustainability of the systems in the future. In



Plate 1. Integration and interaction of swamp buffalo with rice cultivation to provide draught power for land preparation, soil conservation and haulage operations are important functions in the Philippines and throughout South East Asia (C.Devendra).

view of the economic importance of the oil palm in South East Asia, the treatment of the paper will focus particular attention to integrated systems involving this crop.

INTEGRATION AND INTEGRATED SYSTEMS

It is important to keep in perspective the terms integration and integrated systems. Integration involves various components, namely crops, animals, land and water. Integrated systems refer to approaches that link the components to economic, social and ecological perspectives. The process is holistic, dynamic, interactive, multi-disciplinary and promotes efficiency in natural resource management (NRM). The integration of various crops and animals enables synergistic interactions, and result in a greater additive and total contribution than the sum of their individual effects (Edwards et al., 1988). Thus for example, swamp buffaloes in rice growing areas provide valuable draught power for land preparation, soil conservation and



Plate 2. Integration of crossbred goats with oil palm for meat production in Selangor, Malaysia (C. Devendra).



Plate 3. Integration of imported Hereford and Brahman cattle with oil palm in Sabah, Malaysia (C. Devendra).

haulage operations (Plate 1), and the integration of goats and beef cattle with oil palm results in value addition and increased FFB, palm oil and also beef production (Plates 2 and 3). Additionally, both ecological and economic sustainability are addressed in a mutually reinforcing manner.

Such integrated systems are especially well developed in East and South East Asia. An overview of their potential importance and relevance to small farms in Asia, and description of the distinctive characteristics has been reported (Devendra, 1995; 1996). The characteristic features include *inter alia* :

- Diversified and integrated use of the production resources, mainly crops and animals.
- Use of both ruminants (buffaloes, cattle, goats and sheep) and non-ruminants (chickens, ducks and pigs).
- Animals and crops play multi-purpose roles.
- The process is holistic, interactive, multi-disciplinary and promotes NRM.
- Crop-animal-soil interactions are varied and have socio-economic, ecological and environmental implications.
- Low inputs use, indigenous and traditional systems, and,
- Is associated with demonstrable sustainability and sustainable production systems.

In view of the various types of natural resources that are involved (land, crops, animals and water) and the numerous interactions both positive and negative, understanding their relevance, implications, priorities for their improvement and resolution, necessitates interdisciplinary and participatory R and D approaches. With respect to NRM, key disciplines that are involved include *inter alia* agronomy; soil, animal and veterinary science; sociology, economics and extension. The participatory approaches involve joint efforts by researchers, extension personnel and farmers.

An important feature of integration and integrated systems is the involvement of resource-poor small farmers and rural communities throughout Asia. The practice of integrated systems is the norm in the small farms which are diverse, complex, are found across all AEZs, and involved with various biological and livelihood diversification strategies. The latter are often associated with the significant participation and contribution of women to animal production (Devendra and Chantalakhana, 2002). A large proportion of the rural poor people are found in small farms, living in the shadow of poverty and hunger, with an enduring wish for improved and a more comfortable life tomorrow. In the developing countries, it has been reported that 50% of the estimated four billion rural poor are dependent on livestock to maintain basic quality of life. The resource poor small farmers are characterised by deprivation, subsistence, illiteracy, survival, and

vulnerability (Devendra, 2010b).

Integration and integrated systems are characterised by the following features, typical of the small farm scenario:

- Low input use
- Diversification of agriculture
- Extensive use of indigenous knowledge and traditional systems
- A high proportion of the land is used for food crops, mostly for home consumption and also food security
- Diversification and integration promotes feed security
- Cash crops are grown to generate income
- A mix of animals is present, but seldom are more than two species of ruminants reared together, and
- Poor access to market outlets and poor marketing arrangements.

ASIAN INTEGRATED SYSTEMS

Asian agriculture is characterised by mixed farming activities which form the backbone of farming systems. It is typified by a variety of systems in the various AEZs, involvement of the diversity of crops and animals, mainly small farm systems, small farmers and poor people (Devendra, 2007b). Mixed farming systems are synonymous with crop-animal systems, are varied and integrated with cropping in various ways. Mixed farming systems are widespread in all AEZs, and in South East Asia these systems mainly occur in the humid/sub-humid regions. With the increasing need for food in the future, these systems are likely to see important growth and continue to be dominant in the Asian region.

Both ruminants (buffaloes, cattle, goats and sheep) and non-ruminants (poultry, pigs and ducks) are involved, and the choice of one or more species is dependent on the biophysical environment, type of cropping system, the overriding influence of consumer preference, market dictates, potential to generate income, contribution to crop cultivation and livelihoods. Much will depend on the extent of the functional contribution of animals. Mixed farming provides a range of products, and enables farmers to diversify risk from a single commodity.

Mixed farming involves both annual and perennial crops. However, the decreased availability of arable land in many countries and the need for more food from animals could encourage further integration of ruminants with tree crops in the upland areas. Associations of tree crops and animals are established farm practice in many developing countries. The expansion and intensification of these systems is a realistic objective, given the extent of farmer experience, the periodic collapse of world prices for plantation commodities and the projected demands for animal products in the future. New technologies to intensify production and better scientific guidelines for managing the

components of silvo-pastoral systems are now available that can lead to higher farm incomes and a more protected environment. However, future development of these integrated systems will require policy support to encourage the introduction of ruminants and to increase their productivity.

Integration with aquaculture

The integration of crops and animals places less dependence on the natural resources base than if they are produced separately. Integration with aquaculture is quite feasible and has the potential to improve the sustainability and income generation of small farms, when it is fully integrated with other enterprises and household activities so as to allow farm families and communities to manage their natural resources effectively. Fish convert crop, livestock and household wastes into high quality protein and nutrient-rich pond mud that can replace fertiliser completely in small vegetable gardens. Between annual and perennial crops, integration with aquaculture is more common with annual crops throughout South East Asia rather than perennial crops, probably due to the increased availability of crop residues as feeds. Integration of tree crops and aquaculture systems which are less common, are found in the Philippines and Vietnam.

Aquaculture systems are especially advanced in China (Congyi and Yixian, 1995) and Vietnam (Thien et al., 1996) in terms of practice, efficiency and complementary management of the natural resources. On the other hand, despite some individual success stories, intensive aquaculture can do more to reduce poverty and malnutrition. Integrated farming systems that include semi-intensive aquaculture can be less risky because, when managed efficiently, they can benefit from synergism among enterprises, diversity in produce and environmental soundness. The Asian economic crisis clearly demonstrated that mixed farming systems are much more resilient than was imagined formerly. Farmers were able to survive mainly because of their use of local production resources and diversification.

In integrated crop-pig-aquaculture systems in South East Asia, pig manure is drained and the clear affluent applied as fertiliser to vegetable plots or to rice fields. The solid component is used for the production of biogas. In Vietnam, manure from intensive per-urban pig and poultry production around Ho Chi Minh City is applied to fish ponds. In irrigated rice-duck-aquaculture systems throughout South East Asia, duck excreta fertilises the rice crop and also provides food for fish. In poverty stricken small farm systems, these integrated systems provide a most important source of dietary animal proteins especially for the children, pregnant mothers and elders to improve the livelihoods of the poor and the stability of the rural

households. It follows that any improvements in productivity of the integrated systems will also improve the livelihoods of the poor. In perennial plantation crop systems, animals grazing the understorey vegetation provide manure to increase tree yields.

It is pertinent to note that in Asia, mixed farming provided 90% of the milk, 77% of the ruminant meat, 47% of pork and poultry meat, and 31% of the eggs. Past growth trends suggest (Steinfeld, 1999) that mixed farming systems grew half as fast (2.2% per year) compared to industrial systems (4.3% per year), and three times as fast as that of pastoral systems (0.7% per year). The data suggests that ruminant production in mixed farming systems will continue to be important, but more particularly that there needs to be increased development attention in the future.

Categories of integrated systems

Two broad categories of mixed farming systems can be identified:

i) Systems combining animals and annual cropping in which there are two further sub-types:

- Systems involving non-ruminants, ponds and fish eg. Vegetables-pigs-ducks-fish systems in Vietnam, Rice-maize-vegetables-sweet potatoes-pigs-dairy cattle (China)
- Systems involving ruminants eg. Maize-groundnuts/soya bean-goats systems (Indonesia), Rice-finger millet-rice-goats (Nepal).

ii) Systems combining animals and perennial cropping in which there are again two sub-types:

- Systems involving ruminants eg. Coconuts-sheep integration (Philippines), Oil palm-cattle integration (Malaysia)
- Systems involving non-ruminants eg. Oil palm-chickens integration (Malaysia).



Plate 4. Oil palm leaves being machine chopped for feeding to cattle and goats in feedlots in Sabah, Malaysia (C. Devendra).

Integrated tree crops-ruminant systems

Among the ruminant production systems, integrated systems involving tree crops (e.g. coconuts, oil palm, rubber) is least developed and underestimated (Plate 4). An estimated area of 210,000 million hectares are found under perennial tree crops in South East Asia (Alexandratos, 1995). The presence of a range of perennial tree crops in the uplands of many countries provides a common thread for the development of integrated systems involving ruminants. In this context, it is appropriate to also draw attention to the major tree crops that are potentially important from the standpoint of developing integrated systems and the main country locations where are to be found. Table 1 summarises the current opportunities in various parts of Asia. Many of these locations offer good opportunities for adaptive R and D for example sheep and citrus in the Philippines, and the development of sustainable integrated NRM.

Preferred animal options

Table 1 also gives an indication of preferred animal options that are appropriate for individual tree crops. Small ruminants appear to be favored in most cases. The fact remains that ruminants provide the entry point for the development of integrated tree crops-ruminant systems.

The production systems together are unlikely to change in the foreseeable future (Mahadevan and Devendra, 1986; Devendra, 1989). However, these systems will no doubt respond to changing demand and consumer preferences at varying levels through increasing intensification, specialisation and commercialisation, depending on resource endowments, supporting infrastructure, market potential and policy. In particular, there will be a shift from extensive to systems combining arable cropping, induced by population growth. The principal aim should therefore be improved feeding and nutrition, and maximum use of the available feed resources, notably crop residues and low quality roughages, and various leguminous forages as supplements- the oil palm environment provides opportunities for increasing productivity. Issues pertaining to feed resources in Asia, strategies for their efficient use,

and intensification, have very recently been discussed (Devendra and Leng, 2011).

AGRICULTURAL DIVERSIFICATION

Diversification is the process of spreading the production resources and enterprises for example crops and animals to reduce risks and losses to seek economic benefits and sustainable production. Agricultural diversification in small farms is directly associated with two key reasons- risks and seasonality. Both factors become more serious with decreasing quality of arable land. Diversification involves the addition of crops or animals or other enterprises at the farm level. The development of integrated tree crop- ruminant systems is a good example of diversification.

Apart from meeting the immediate needs of the household- mainly food and also traditional self-sufficiency, specialisation follows, in which income generation and market orientation become new driving forces. Diversification in terms of the use of the production resources sees expression in mixed farming activities in humid AEZs of South East Asia, and least in the more semi-arid and arid areas. The former involves a mix of crops and animals and possibly also aquaculture.

ISSUES OF SUSTAINABILITY

The concept of sustainability is an important element in the development of integrated systems. The MEA (2005) defined it as a characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generation or population in other locations to meet their needs.

The concept of agricultural sustainability initially focused environmental aspects, but has now been expanded to include broader socio-economic and political elements:

Ecological : focus on environmental protection to enhance ecosystem resources and preservation of biodiversity.

Table 1. Potentially important perennial crops for integrated systems and their locations in Asia

Crop	Location	Preferred animal species
1. Cashew	S.India, Vietnam	Small ruminants*
2. Citrus	India, Philippines, Thailand, Vietnam	Small ruminants
3. Cocoa	Malaysia, Papua New Guinea, Indonesia	Small ruminants
4. Coconuts	S.China, S.India, Indonesia, Philippines, Sri Lanka, Thailand	Large and small ruminants
5. Fruit trees e.g. Mango	N.India, Philippines, Thailand	Small ruminants
6. Oil palm	China, Indonesia, Malaysia, Papua New Guinea, Thailand	Large and small ruminants
7. Rubber	S.China, Indonesia, Philippines, Malaysia, Thailand	Small ruminants
8. Teak	Lao PDR, Myanmar	Large ruminants*

* Small ruminants - Goats and sheep. * Large ruminants - Buffaloes and cattle.

Socio-economic : concerns the value and management of the resources, their enhancement, socially acceptable technological improvements, farmers organizations and cooperatives, and improved livelihoods of poor farmers.

Figure 1 illustrates a conceptual framework for sustainable ruminant production systems. Given the AEZ's, small farm systems, biophysical and socio- economic environment, the major targets for development are efficiency in the management of the natural resources, income growth, poverty alleviation, food security, economic viability, minimum dependence on external non-renewable inputs, response to changing consumer preferences, rural growth, and self- reliance.

THE OIL PALM ENVIRONMENT

The oil palm is the premier tree crop in Malaysia. Oil palm cultivation was preferred over rubber and cocoa, which has led to rapid expansion of the crop. Over the period 1960 to 2005, the areas expanded annually by 10.1%, as did palm oil production. The current planted area is about 4.1 million hectares (MPOB, 2007). The oil palm is referred to as the golden crop and the oil a gift from nature and a gift

for life. The Malaysian palm oil industry is a highly organised sector, and has the potential to continue to make significant contributions to the national economy. Over the period 1990-2005 the land area has increased at the rate of 6.6%/yr. in comparison to negative growth for the other tree crops. The main reason for this is the replacement of these latter tree crops by oil palm (Table 2). Of the land area under oil palm, only 2.1% is currently used for integration with ruminants, emphasizing the enormous potential for expanding this system.

Some facts pertaining to the distribution and ownership of land areas under oil palm by the several groups, including government - linked companies (GLCs) as well as the private sector is as follows:

- Throughout Malaysia, the private sector was the largest owner of oil palm areas of about 60%, followed by FELDA (16%), and smallholders (11%) of 4.1 million hectares
- In East Malaysia. Sabah has an expanding land area under oil palm, 74% of which is owned by the private sector comparable to 78% in Sarawak.
- Among the GLC's FELDA was the largest owner of oil palm land.

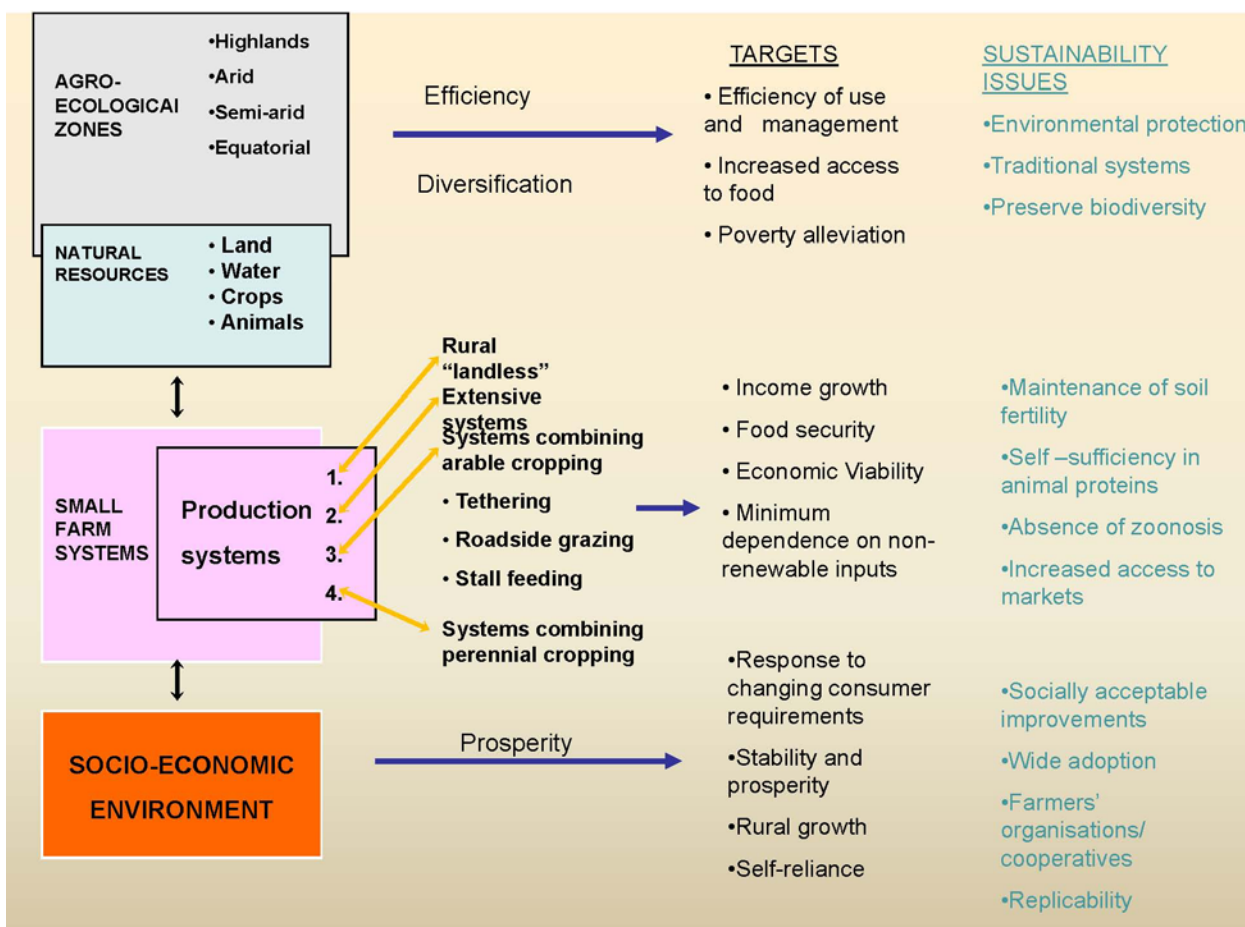


Figure 1. Sustainability of ruminant production systems (Devendra, 2010c).

Table 2. Land areas of selected plantation tree crops in Malaysia (Million Ha) (Adapted from MPOA, 2005)

Year	Oil palm	Rubber	Cocoa	Coconut	Total
1990	2.029	1.836	0.393	0.314	4.572
2000	3.377	1.431	0.076	0.159	5.043
2002	3.670	1.348	0.051	0.155	5.224
2003	3.802	1.320	0.045	0.153	5.320
2004	3.880	1.282	0.044	0.147	5.353
2005	4.049	1.250	0.033	0.180	5.512
% change per yr	6.6	- ve	- ve	- ve	1.4

The oil palm environment includes the natural vegetation produce valuable feeds, the former with mainly forages, and the latter with crop residues and agro-industrial by-products. The feeds that are produced are palm oil, and crop residues like palm kernel cake (PKC). Both categories of feeds provide the link with animals and the development of feeding systems. The income generating products are palm oil, some feeds like PKC, live animal as well as meat and milk. The manure that is produced is either returned to the land or is sold commercially.

Palm oil and available feeds from the oil palm

The principal product of significance for human nutrition and economic importance is palm oil. It is the leading edible oil in global terms, with Indonesia and Malaysia being the main producers. Associated with red palm oil is palm olein, the liquid fraction of palm oil. Both these products are important ingredients in food applications requiring solid fats without hydrogenation. Together with reports of lowered total cholesterol (TC) and low density lipoprotein cholesterol (LDL-C), both products are poised to continue their importance for human consumption worldwide (Kalyana Sundram, 1997). Additionally, the presence of various minor micronutrients in the crude oil, including carotenoids (some with Vitamin A activity) and Vitamin E 9 including a high concentration of tocotrienols) has resulted in palm oil becoming a global player in health initiatives (Khosla and Kalyana Sundram, 2011).

From an animal nutrition standpoint, crude red palm oil continues to be used widely in diets especially for non ruminants. Up to 5% dietary levels are commonly used in the diet formulations to augment the supply of Vitamins A and E, and also act as a binder. Palm oil has also been studied as a substitute for expensive important maize. Inclusion of between 5-30% crude red palm oil in isonitrogenous diets to pigs showed no treatment differences. The results suggested that the optimum level of inclusion was 5% (Devendra and Hew, 1977). Studies have also been made to include the oil to reduce the dustiness, increase the palatability and intake of sago-based diets. Pelleting the sago-based diets with added red palm oil

significantly improved the performance of the pigs.

Excluding palm oil, two categories of feeds are involved. One is the undergrowth under oil palm, consisting of grasses, shrubs and ferns. Among the available feeds in Malaysia, those from the oil palm are potentially and by far the most important, and are currently underutilised. This is associated with the very large land area of about four million hectares under oil palm in Malaysia. Table 3 presents the range of the feeds produced and the magnitude of production. The principal feeds from oil palm are palm oil, oil palm trunks (OPT) oil palm fronds (OPF), and palm kernel cake (PKC). The other feed is palm oil mill effluent (POME). Grazing the undergrowth and supplementary feeding with feeds such as PKC are economically feasible.

Research and development on the use of productivity-enhancing feeds

Very useful R and D progress has been made notably by the Malaysian Agricultural Research and Development Institute (MARDI) on various aspects of the feeds from the oil palm over the last three decades. The studies have focused on availability, production, nutritive value, utilisation and performance by animals, processing and engineering aspects, and enhanced value. The advances that have been made and available improvements and technologies emphasise the urgent need to utilise the research results at the plantation level.

One example of the use of oil palm by-products concerns the development of oil palm-based intensive and sustainable production systems *in situ*, is a comparison of a cut-and-carry feedlot system, a semi-feedlot system, and

Table 3. Available feeds from the oil palm

By-product	Yield (mt/ha/yr)
Edible	
1. Oil palm fronds	0.62
2. Palm kernel cake	0.96
3. Palm oil mill effluent	0.04
4. Palm press fibre	0.23
Non-edible	
1. Bunch trash	10.74
2. Palm nut shells	0.15

free grazing for beef cattle in Johore, Malaysia, where coffee was grown as an intercrop under coconuts. Stall-fed local Jersey yearling males were fed for 178 days, (Sukri and Dahlan, 1986) using rations consisted of coffee by-products (30%), palm kernel cake (37%), urea (2%) and mineral-vitamin premix (1%) and various native forage species (*Paspalum*, *Axonopus*, *Ottochloa*, *Ischaemum* and *Brachiaria*) for grazing. The animals under the feedlot system were confined and fed the feed ration *ad libitum*; the semi-feedlot treatment involved tethering and grazing on the native grasses for five hours daily before the animals received the same feed ration *ad libitum*; the free-grazing animals were tethered to graze the native grasses.

Average daily gains of the animals in the feedlot, semi-feed lot and free-grazing systems were 0.48, 0.37 and 0.15 kg respectively. The feedlot and semi-feedlot groups were extended for a further 116 days with average daily gains of 0.60 and 0.38 kg/animal respectively, demonstrating that the gross profit was higher for the feedlot animals than the semi-feedlot or grazing groups, emphasising that feedlot and semi-feedlot systems had great potential for increasing beef production in estate environments among smallholder farmers.

Despite the apparent benefits, there is inadequate attention to develop the alternative options in the estate environments, due to a combination of such factors as inadequate investments, lack application of technologies, resistance by the tree crop sector to integrate animals, and lack of policies that can enhance the development of the systems. Additionally, the system is also not viewed holistically to push development.

Production attributes

The oil palm environment offers a number of conducive production attributes for integrating ruminants to enhance total factor productivity albeit from both crops and animals. It is pertinent to enumerate these as follows:

- Forage dry matter availability : 2.99- 2.16 mt / ha for 3 and 5 year old palms reducing to 435-628 kg / ha for 10-29 year old palms (Chen et al., 1991).
- 60-70 forage species in young palms, which are reduced by about 66% in older palms
- Forage categories : 56-64% grasses, 18-23 dicotyledons, 3-19% legumes and 2-15% ferns for 3-10 year old palms, and 50% grasses, 13% dicotyledons, 2% legumes and 35% ferns (Wong and Chin, 1988).
- About 72-93% of the forages are palatable and of value to ruminants
- Kedah-Kelantan and Bali cattle breeds are well suited for integration with oil palm
- Carrying capacity : 3 steers/ha in 3-4 year old palms with average daily gain of about 260-320 g/d for a two year

cycle to 0.3-0.4 steers/ha with over 7 year old palms, and

- The under-storey forage cover presents an excellent area to breed cattle to produce numbers for intensive production systems, especially the use *in situ* of the many crop residues and by-products from oil palm (Devendra, 2009).

Types and benefits of ruminant-oil palm interactions

Crop-animal interactions are important in small farms, and contribute to the sustainability of mixed farming systems. There are many benefits of crop-animal-soil interactions (Devendra and Thomas, 2002). With oil palm, the following interactions are common, with resultant tangible benefits:

- Beneficial effects of shade and available feeds on livestock
- Draught animal power on land preparation and crop growth
- Dung and urine on soil fertility and crop growth
- Use of crop residues and agro-industrial by products from trees *in situ*. With oil palm this involves oil palm fronds, palm kernel cake, oil palm fibre, and palm oil mill effluent (Plate 5)
- Use of native vegetation and effects on cost of weed control, crop management and crop growth
- Type of animal production systems (extensive, systems combining arable cropping, and systems integrated with tree cropping), increased income and environmental integrity.

Table 4 gives an indication of the nature of crop-animal interactions in ruminant in oil palm systems. 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



Plate 5. Integration of crossbred Sindhi cattle with coconuts in Sabah, Malaysia (C. Devendra).

Table 4. Main crop- animal interactions in integrated systems with oil palm (Devendra, 2004)

No.	Crop production	Animal production
1	The natural herbage between inter-rows of oil palms provides a variety of feeds (grasses, legumes and shrubs) which can be used by ruminants. The average availability is 600 kg DM/ha.	Buffaloes and cattle are used extensively for haulage and transportation of products such as fresh fruit bunches.
2	The oil palm crop also provides many principal feeds (oil palm fronds and tree trunks) and by-products feeds (palm press fibre, palm oil mill effluent and palm kernel cake), all of which can be used by ruminants.	Animals grazing the herbage control weeds. There are reduced weeding costs (16-40%).
3	The crops also provide valuable shade for animals, which for imported cattle significantly reduces heat stress.	Ruminants and non-ruminants produce manure and urine for the maintenance and improvement of soil fertility.
4		The effective utilisation of the feeds from the oil palm gives valuable animal products such as meat, milk and eggs.
5		Animals provide an entry point for the introduction of improved grasses (e.g. Guinea grass) and legumes (e.g. Gliricidia) for productivity enhancement in animals with attendant benefits.
6		The sale of animals, animal products and hiring out of draught animals provide cash for the purchase of fertilizers and pesticides.
7		The integration of animals adds value to the oil palm crop, and can demonstrate total factor productivity.

light transmission is less and therefore biomass production. Goats are more selective in their feeding habits because they are browsers (Devendra, 1996), 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 10-15 cm above ground level (Kochpakdee, 1999). 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, the correct choice of species, control of grazing, and also the optimum age of trees when the leaf canopy is out of reach of the animal are important considerations.

On the negative side, inadequate control of grazing animals and overstocking can easily lead to damage of oil palm trees, with consequent low yields of fresh fruit bunches (FFB). With larger ruminants, soil compaction can also result from overstocking.

ADVANCES IN RESEARCH AND DEVELOPMENT ON RUMINANT-TREE CROPS SYSTEMS

There have been significant advances in the

understanding of the methodologies used, crop-animal-soil interactions, and resultant benefits in integrated systems with ruminants and tree crops. The main areas in which research has been undertaken include:

- Characterisation of environmental conditions within plantations.
- Measurements of forage availability and quality, as well as seasonality of production.
- Assessment of the availability of crop residues agro-industrial by-products (AIBP), evaluation of nutritive value and use.
- 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,
- Implications of climate change on heat stress, animal performance and productivity and
- Analyses of the economic benefits of integrated systems.

The first four areas are the most studied (Wong and Samiah, 1998), followed by limited work in the next two.

The remaining four items remain untouched and merit more attention. Future R and D efforts, backed by increased investments must therefore give increased emphasis to the last five areas. Long term animal production data for the different ruminant species are needed, as also information on the effects of grazing management and socio-economic analyses. These analyses are essential for presenting a convincing case for the wider adoption of the systems. The overall conclusion is that much more work 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. The looming effects of climate change which will be mediated through heat stress on animal performance and productivity remains largely unknown, and will need specific research effort.

Associated with the R and D efforts, Table 5 summarises the various results, involving 24 case studies from seven countries over the period (1984-2007), which includes 12 from Malaysia. Four observations about these reports are relevant:

- Distinct economic benefits were reported e.g. crop yields and savings on weeding costs
- Most of the reports deal with individual benefits and not the system as a whole
- Very few studies were concerned with quantitative animal productivity, and
- Issues of sustainability were not addressed and neglected.

POTENTIAL PRODUCTION OPTIONS FOR OIL PALM-BASED RUMINANT PRODUCTION

There exists a huge potential for developing integrated oil palm-based ruminant production which is presently underestimated. It embodies efficiency in NRM, sustainability, value addition, and total productivity returns. This production system involves buffaloes, cattle, goats and sheep. Among these, cattle and goats are the priority animals because of the high demand for their meats. The potential production options and combinations among these within oil palm plantations are as follows:

- Breeding ruminants (buffaloes, cattle, goats and sheep) for production systems
- Growing ruminants for meat production
- Zero grazing systems (beeflots, goats and sheep)
- Rearing ruminants to use the available oil palm by-products
- Rearing ruminants for grazing and controlling weeds
- Rearing ruminants for draught and haulage operations

- An entry point for development of integrated NRM and sustainable production systems
- Value addition and total productivity returns. and
- A hedge for possible reduction in the price of crude palm oil

CARBON SEQUESTRATION AND GREENHOUSE GASES

An area that has not been addressed in Malaysia concerns carbon sequestration, which is defined as the complex and secure storage of carbon that would otherwise be emitted or remain in the atmosphere (Watson et al., 2000). Notwithstanding the fact that animals emit methane from enteric fermentation and manure, the expanding land areas under oil palm provide good opportunities for carbon sequestration through more widespread use of grasses and tree legumes, and improved forage management practices, with resultant decreased carbon atmospheric emissions and global warming. Pretty et al. (2006) has calculated that in mixed farming systems, the carbon sequestered per hectare was 0.32 tC/ha/yr. The practical implication of this is that agronomic practices need to enhance these carbon sinks through enrichment of soil organic matter and the forage biomass under the oil palm.

Associated with above is the issue of greenhouse gas emissions (GHG), mainly CH₄, N₂O and CO₂ and their effects on climate change or global warming. Improved grass- legume pastures to feed grazing ruminants will have the beneficial effect of enhancing carbon sequestration and releasing more O₂ into the atmosphere (Plate 6). On the other hand, the presence of grazing ruminants will mean emissions of more CH₄ into the atmosphere, and their possible effects. In Brazil, Zebu cattle grazing tropical



Plate 6. Oil palm cultivation and integration with ruminants also enables improved forage production, soil fertility and carbon sequestration as is reflected in the setting from Sarawak, Malaysia (C. Devendra).

Table 5. Summary of results of the beneficial effects in integrated tree crops-ruminants systems in Asia

Type of crop-animal system	Country	Estimated profitability/net income	Reference
1. Coconuts – beef cattle pastures	W. Samoa	Net farm returns increased by 148-165% in marginal and small farms Income from native pastures: 21-41%	Reynolds (1995)
2. Improved beef cattle production systems based on local by-products	Malaysia	Free grazing: 0.21/d Semi-feed lot: 0.28/d Benefit: 33.3%	Sukri and Dhalan (1984)
3. Three-strata forage system	Indonesia	Without project: US \$106 With project: US \$186 Benefit: 75.5%	Nitis et al. (1990)
4. Oil palm - cattle – goats	Malaysia	With integration US \$110.8/ha/yr	Devendra (1991)
5. Oil palm - cattle integration	Malaysia	Increased yield of 0.49 mt FFB/ha	Samsuddin (1991)
6. Oil palm - cattle integration	Malaysia	Savings in weeding costs were RM 22/ha	Salim (2003)
7. Oil palm - cattle integration	Malaysia	Savings in weeding and herbicides costs were RM 30/ha	Fadzil Mohammad (2003)
8. Oil palm - goat integration	Malaysia	Increased income from milk	Awaludin and Othman (2003)
9. Coconuts - crops- animals	India	More profitable than coconuts alone	Das (1991)
10. Improved grass-legume pastures in coconut plantations integrated with cattle	Philippines	Net profit: US \$510	Deocareza and Deista (1993)
11. Coconuts - dairy cattle integration	Sri Lanka	Increased nut and copra yields by 17 and 11%. Reduced cost of fertiliser use by 69%	Liyanage et al. (1993)
12. Oil palm - cattle integration	Malaysia	Increased yield of fresh fruit bunches (FFB) by 30%	Chen et al. (1993)
13. Small ruminants under coconuts (1991-1994)	Philippines	Net income without and with project: Sheep: US \$25 (127) Goats: US \$35 (229)	PCARRD (1994)
14. Food crop- rubber-animals integration (1 cow, 3 goats, 11 chicken) i) Batumarta, S.Sumatera ii) Tulang Bawah Tengah, S.Sumatera iii) Manganayu, S.Sumatera	Indonesia	Net farm income Without project US \$ 168 With project US \$ 161 Without project US \$ 81 With project US \$ 138 Without project US \$ 24 With project US \$ 124	CRIFC(1995)
15. Integration of maize baby production and beef cattle production	Thailand	Economic gain of cattle fattening to farmers was on average US \$ 358,8/cow	Prucasri and Thanonwongwathana (1995)
16. Integration of leguminous hedgerows on steep slopes (sloping agriculture land technology)	Philippines	Net profits US \$ 865.8-1,940.1	Laquihon et al. (1997)
17. Rubber - sheep integration	Indonesia	Increased income by 20%	San NuNu and Deaton (1999)
18. Coconuts -dairy farming- poultry integration	India	Increased returns with livestock by 59%	Maheswarappa et al. (2001)
19. Oil palm - cattle integration	Malaysia	Reduced cost of weeding by 68.6%	Ongkah (2004)
20. Cash-crops-grasses-tree legumes-goats integration	Vietnam	Before project: 420 After project: 1,211 Increased income: 188%	Nguyen and Than (2005)
21. Oil palm - cattle integration	Malaysia	Savings in weeding costs (5-26%)	Khan (2007)
22. Oil palm - cattle integration	Malaysia	Savings in weeding costs (44-50%)	Nasir et al. (2007)
23. Oil palm - cattle integration	Malaysia	Savings of 30-40% field costs/yr	Zainudin (2007)
24. Oil palm - cattle integration	Malaysia	Savings in weeding costs (15-28%)	Kabul (2007)

pastures produced a larger methane loss of 27 g/kg compared to either Holstein or Nellore cattle fed sorghum silage-concentrate diets that averaged 22 g/kg. Holstein or Nellore cattle on *Bracharia* or *Panicum* pastures consuming sorghum had methane losses that were close to the temperate forage-based diet of 20 g/kg (Lima et al., 2004).

In response to possible effects on climate change, mitigation efforts have therefore concentrated on ways of reducing the CH₄ emissions in which a wide range of strategies to include enhanced feed quality, supplemental lipids, tannins, protozoal inhibitors with varying success (Johnson, Pongchompu and Wanapat, 2005). Of these, strategies to reduce GHG have largely focused on methanogen inhibitors and substrate levels, rather than at the feed quantity and quality end.

What is required is more understanding of the relative GHG emissions from improved grass-legume pastures, including the O₂ under oil palm trees compared to grazing ruminants. If the emissions are in favour of the former especially in respect of more O₂ into the atmosphere, the case for integrated systems and sustainable agriculture becomes even stronger. In practice, strategies will need to be developed that can have a balance between the two types of emissions which is consistent with minimal effects on climate change. These interrelated and complex issues justify the need for more vigorous research and development.

It is also pertinent to note that recent studies suggest that the fermentable nitrogen requirements of ruminants on diets based on low protein cellulosic materials can be met from nitrate salts (Trinh et al., 2009) and this potentially reduces methane production to minimal levels (Leng, 2008). Trinh et al. (2009) demonstrated that with adaptation, young goats given a diet of straw, tree foliage and molasses grew faster with nitrate as the fermentable N source as compared with urea. Further studies from the same group have shown that nitrate can be used as a fermentable N source for beef cattle fed treated straw (Nguyen Ngoc Anh et al., 2010). In a recent study (Nolan et al., 2010), sheep were fed oat hay and either potassium nitrate or urea (5.4 g N/kg hay), first in metabolism cages and then in respirations chambers. Methane production was reduced by feeding nitrate instead of urea but there were no effects on feed intake, DM digestibility or microbial protein synthesis in addition van Zijderveld et al. (2010a) have shown a 60% reduction in methane production by sheep fed nitrate in a corn silage based diet. The same group have shown persistent reduction of 16% methane in dairy cows supplemented with nitrate (see van Zijderveld et al., 2010b quoted by Hulshof et al., 2010) and a 32% reduction in methane production in beef cattle in Brazil when 2.2% nitrate replaced urea in a sugar cane/concentrate based diet (Hulshof et al., 2010). This is a

major step forward in ruminant nutrition and production.

ECONOMIC BENEFITS

The economic benefits due to positive crop- animal- soil interactions are especially significant. A review of the existing information (Devendra, 2007c) as well as from more recent information suggest the following results with reference to the use of cattle:

i) Increased animal production and income

This arises from increased productivity and meat offtakes

ii) Increased yield of FFB and income

By about 30% with measures of between 0.49-3.52 mt/ha/yr.

iii) Savings in weeding costs

By about 47-60%, equivalent to 21-62 RM/ha/yr.

iv) Internal rate of return

The IRR of cattle under integration was 19% based on actual field data. Several theoretical calculations approximate to this value.

Additionally, it is also interesting to note the benefits of using other ruminants such as goats and sheep. Haji Basir Ismail (2005) calculated the economic returns from four hectares of land under oil palm, inter-cropping as well as fodder cultivation for a seven year period. The RM 14, 562 is income from oil palm after seven years. The beneficial incomes generated as a percentage of total incomes in favour of integration for cattle, sheep and goats were 44.4%, 86.6% and 91.5% respectively. The income from goats was the highest as follows:

Cattle (cow-calf model): 14,562+11,690 (44.4%) = RM 26,342 (US \$7,141)

Sheep: 14,562+95,053 (86.6%) = RM 109,745 (US \$29,661)

Goats: 14,562+157,187 (91.5%) = RM 171,839 (US \$ 46,443).

An important biological advantage influencing productivity and income generation from goats' concerns fertility and the productive lifespan of goats. Goat production has a particular niche in these circumstances (Devendra, 2007d).

Relevance of the results to other regions

The work on tree crops-ruminant integration in Asia has much relevance to other parts of the developing world where tree crops are grown. With oil palm in particular, the advances in Malaysia will be of much interest as well as have relevance and application in other oil palm growing

countries. Notable in this regard are several countries in West Africa, Central and Latin America (Devendra and Pezo, 2004). The principles of integration will be much the same, but will vary with type of parent tree crop, animal species, herbage and feed availability, location specificity, knowledge of the biophysical environment, and capacity to use systems perspectives.

POTENTIAL PRODUCTION AND ENVIRONMENTAL SUSTAINABILITY

Considered together, the following key potential benefits provide major opportunities and challenges for production and environmental sustainability. Their realisation is dependent on a combination of policy support, greater awareness and understanding of the benefits of integration and efficiency in NRM, institutional commitment, and increased resource use can be brought to bear on expanded integrated systems in the future:

- Increased productivity from ruminants, mainly meat
- Value addition to the oil palm crop, and higher palm oil output
 - Improved forages and forage management in oil palm plantations can promote carbon sequestration and reduced possibilities of climate change
 - Enhance carbon sinks and enriched soil organic matter, and
 - Demonstrable sustainable agriculture.

Constraints to integration

Given the very low adoption of integrating ruminants with oil palm, it is relevant to ask what are the reasons for this situation. The reasons are many and are associated with the following:

- Poor awareness of the potential of integrated systems eg. oil palm and ruminants
- Resistance by the crop-oriented plantation sector
- Inadequate technology application
- High prices for crude palm oil
- Unattractive investment climate
- Weak inter-agency collaboration, and
- Absence of policies to encourage integrated systems.

OVERCOMING THE CHALLENGES AND CONSTRAINTS

There exist a number of opportunities to address the challenges and constraints with the primary purpose of more vigorously promoting and expanding integrated tree crops-ruminant integrated systems.

The key aspects of this strategy are as follows:

- i) Need for a definition of a coherent and clear policy on integration.
- ii) An awareness campaign is necessary through such approaches as publications, meetings, media and announcements.
- iii) Increased inter-agency coordination and collaboration in the activities to ensure efficient use of the resources as well as ensure more rapid progress and impacts.
- iv) Definition of a national breeding policy for cattle is necessary that includes choice and control of the imports of exotic cattle and the use of the oil palm areas for integration
- v) Increase the participation by the private sector and major stakeholders are necessary though awareness and dialogue, and
- vi) A stimulus package of incentives is necessary to promote the systems. These can include *inter alia* provision of animals, tax breaks for allocation of land for integration, tax exemptions, and interest free loans.

CONCLUSIONS

Integrated tree crops-ruminant systems are potentially very important, but are underestimated in South East Asia. The inclusion of animals provides the entry point for development, and has the twin advantages of increasing the supplies of animal proteins and also value addition in the oil palm. The benefits of integration are considerable and are mediated through positive crop-animal-soil interactions and merit expanded development. The key benefits are:

- Potential increased of animal protein supplies (mainly meat and milk) and draught power for haulage operations
- Increased yield of FFB and income
- Savings in weeding costs
- Integrated and efficient use of the natural resources
- Enhanced C sequestration
- Distinct economic impacts, and
- Development of intensive and sustainable production system

A combination of clear policy, increased technology application, more intensive production systems, increased investments and private sector participation can significantly accelerate the wider adoption of the systems and demonstrable environmental sustainability. These aspects constitute the challenges for the future.

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