The Environment: An Agricultural Perspective on What We Know and What We Need to Know

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The natural environment embraces agriculture and all its components-crops, animals, land, water, forestry and fisheries. It is the most important user of environmental resources, made more complex by the interactions of the various systems, biophysical elements and their implications. Increased food production, especially of animal protein supplies are unable to meet current and projected future needs for humans, including about 15 %of the world population being malnourished. Agriculture is currently waning, and a coordinated and concerted technologically-driven transformation is necessary. Poorly managed agriculture for example, can lead to serious environmental degradation and exacerbate poverty. Land and water are considered to be the most limiting factors in the future. Non- irrigated rainfed areas can be divided into high potential and low potential areas; the former offers considerable promise to expand food production. This paper argues for increased Research and Development (R&D) focus that can maximise improved natural resource management(NRM), and whether agricultural development can maximise productivity yields .Other opportunities include expanding crop–animal production systems in less favoured areas (LFAs), intensifying land use for silvopastoral systems in rainfed areas , and enhance carbon sequestration. Ruminants can be used as an entry point for the development of LFAs, and the presence of about 41.5% of the goat population found in the semi-arid/arid AEZs X provides good opportunities for expanding food security and human well-being. Community-based interdisciplinary and systems approaches are essential to provide the solutions. The legacy of continuing malnutrition and food insecurity must be overcome by effective development policy, multi-donor resource allocation, governance and political will that target food insecurity and poverty. The R&D agendas and resource allocations are compelling, but dedicated vision can lead the way for science-driven sustainable environment, efficiency in NRM, and self-reliance to the extent possible , in harmony with nature and the environment.

Key words: Climate change; animal-agriculture; food security; rainfed; natural resource management; sustainability; impacts; investments in R&D

The Association of South East Asian Nations (ASEAN) has shown that agricultural growth is the key to equitable economic development for generating employment, increasing exports, enhancing food security and energising domestic economies. Agricultural growth is particularly effective in reducing hunger and malnutrition, for which reason increased emphasis, is given to '*food insecurity*' rather than *'food security'*.

About 43% to 88% of the total human population depends on agriculture for their livelihoods, of which 12% to 93% of the people live in rainfed areas and 26% to 84% of the arable land. Some 5% to 41% of the agricultural output comes from these areas. Due to low productivity, the shares of total crop and livestock outputs coming from rainfed areas is much lower than the share of the total area under irrigation. Livestock contributes 10% to 45% to the agricultural Gross Domestic Product (GDP) in the developing world, and can be higher if the values of draught power are included in the calculation.

The Illustrated Oxford English dictionary (2013) defines *Environment* as "the totality of the physical conditions on the Earth or part of it". The New Penguin

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Thesaurus (2000) gives alternative words like "surroundings, conditions, circumstances, location and territory". Perhaps the most exacting and descriptive definition is that of the Department of International Development in the United Kingdom (DFID 2005) in *Livestock and Wealth Creation*. The book involved 105 contributors from 26 countries, of which 65 of the contributors were from developing countries and 37 from nine Africa countries. The popularity of the word has also let to the emergence of other difficult words like "Environmental conservation", "Environmental sustainability" and 'environ-mental degradation".

DFID`s definition of *Environment* states, "The natural environment can be conceptualised as a complex and dynamic entity, composed of a variety of interlinked ecological systems and cycles that are buffered against disturbance by their relative size and feedback loops, and are reasonably stable over time, within certain limits of tolerance". Livestock interact with and impact on their environment through activities, inputs, outputs and management practices. Direct interactions include respiration, drinking, feeding, gaseous emissions from digestion, excretion and movement (Bourn *et al.* 2005). These definitions suggest that perhaps a shorter and more comprehensive definition is wanting.

This paper presents a comprehensive account of the 'Environment' in perspective, definitions currently used to describe it, and provides some clarification on the links with agriculture, and the overwhelming interphases with food security, poverty, human health, and the justification for R&D to cope with the effects of climate change. Agriculture stands tall, due to its pivotal role in food production systems to keep pace with rapidly increasing human population and the need for efficient use of environmental resources, including water, soils and forests, alternative ways to increase food production. However, agriculture is at the crossroads of uncertain demonstrable capacity and response to the challenges for R&D to resolve food insecurity, investments to sustain agricultural growth concurrently, increased food production, as well as reduce poverty in the poor and landless.

The Biophysical Environment and the Context for Animal-agriculture

Closely associated with the environment are the many biophysical factors, agro-ecological zones (AEZs), ecosystems ,ecoregions, and rainfed areas. It is also important to keep in perspective the definitions of these terms. In a discussion on the relationship between agriculture and the environment, Kaosa-ard and Rerkasem (2000), referred to the environment in terms of 'onsite and offsite' aspects. Whereas, 'onsite' may have direct negative impacts on farm productivity offsite effects result in loss or damage. For instance, they estimate that the onsite cost of soil erosion in Java, Indonesia, the losses in agricultural were USD324 million equivalent to 3% of the agricultural GDP.

In this context, value chains are important to enable improved understanding of the various elements and stages from production to consumption systems . They include inter alia resource inputs, access to credits, supplies, production, handling, transportation and processing. More particularly, the assessment provides information and clear identification of those factors that need to be improved to benefit small farmers. Presently, there exists a diversity of supply and value chains, ranging from small links with individual small farmers who are dependent on unscrupulous middlemen, to more advanced capital intensive agri-business systems (Devendra 2016).

The biophysical environments refer to lands in terms of variability, agricultural potential, total rainfall, soils and slopes. Rainfall and temperature are the two key important variables, and these together determine to a very large extent the level of productivity. The Asian region is very diverse, with variable soil quality, crop growth, different types of livestock and potential. The biophysical components vary between-and within-individual countries and regions. Some 300 million small farmers and the landless depend on animals, and South Asia, South East and East Asia accounted for 59-60% of poor livestock keepers in mixed farms. The overwhelming emphasis is on mixed farming, from which a variety of crop residues, agro-industrial by-products (AIBP) and non-conventional feed resources (NCFR) are produced. Table 1 illustrates the patterns of farming systems in Asia, types of cropping systems and the varied types of crop residues that are produced and provide valuable feeds for animals.

The Daunting Challenges for Animal-agriculture from Environmental Components

(i) Agro-ecological zones (AEZs)

The AEZs refer to the biophysical characteristics, climate and geography of an area. Understanding these and their description rely heavily on in-digenous knowledge, traditional farming systems, experience, knowledge of

Table 1. Types of mixed farming systems in the different agro-ecological zones in Asia

System and agro-ecological zone (AEZ)	Length and growing period (days)	Type of crops and cropping systems	Species of animals	Mixed farming benefits
Rainfed temperate and tropical highlands (e.g., Bhutan and Nepal)	<110	Barley, millet, potatoes, fruits, mustard	Yak, cattle, sheep	Traction, transport, manure, reduced risk, survival
Rainfed humid and sub-humid uplands (e.g., Vietnam, Philippines)	180-270	Maize, rice, wheat, root crops, plantation crops	Cattle, pigs, chicken	Traction, transport, income, manure, crop residues
Rainfed humid and sub-humid lowlands (e.g. Indonesia)	180-300	Maize, rice, wheat, root crops, sugar cane, mung bean	Buffalo, cattle, pigs, chickens, ducks	Traction, transport, income, manure, crop residues
Irrigated humid/sub-humid lowlands (e.g. Malaysia)	180-365	Maize, rice, cassava, sweet potatoes	Buffalo, cattle, pigs, chickens, ducks	Traction, transport, income, manure, crop residues
Rainfed arid and semi-arid lowlands, unirrigated (e.g. Pakistan, Thailand)	60-120	Sorghum, millet, groundnut, soya beans, pigeon pea, cotton	Camels, donkeys, cattle, goats, sheep, chickens	Traction, transport, income, manure, reduced risk, survival
Irrigated arid/semi-arid lowlands (e.g. India)	75-180	Millet, groundwater, pigeon pea, cotton	Cattle, pigs, chickens	Income, manure, reduced risk, survival

the environment and the data base. In turn, these features provide good understanding of the types of farming systems practiced in individual areas, reasons for the choice, some data on yields, problems and constraints, and the potential for improvement.

(ii) Ecosystem

The term ecosystem referres to a complex of plant, animal, microorganism communities and their non-living environment interacting as a functional unit.

(iii) Ecoregion

The term 'Ecoregion' or 'ecoregional' refers to those regions that are delineated by socio-economic and AEZ characteristics. The term also refers to regional priorities. The priorities for South East Asia are the humid and sub-humid areas; including for South Asia, the semi-arid and arid AEZs, respectively (TAC 1994). Ecoregion promotes and builds synergies, enhances information exchange and technology application, enables more rapid germplasm exchange and promotes regional integration. Personal contacts among scientists and also through network arrangements can significantly accelerate new information.

(iv) Rainfed areas

Rainfed areas refer to all the lands outside of the irrigated, more favoured or high potential areas. They have been variously referred to as fragile, marginal, and dry, waste, problem, and threatened, range, less favoured, low potential lands, forests and woodlands, and include a reference to lowlands and uplands. Of these terms, 'less favoured areas' (LFAs), *low or high potential* are quite widely used and have been adopted in this paper.

The biophysical characteristics of rainfed areas include lands that are very variable, have low agricultural potential, low rainfall, poor soils and steep slopes. Key features about these areas are (Devendra 2013) are:

- These are the areas that have been by-passed by the Green Revolution.
- The poorest of the poor are found here due to the disparity with richer farmers who have benefitted from the Green Revolution.

- Poverty, low agricultural productivity and natural resource degradation are very common, with the poorest of the poor. These are exacerbated by vulnerability to high temperatures and survival. For example with decreased yields of rice (Peng *et al*. 2004), and decreased productivity from animals (Devendra 2015a).
- These same areas are also densely populated with particularly goats, sheep and camels; all of which are very adapted to the semi-arid and arid areas.

(v) Forestry

Another sector which in terms of the environment is very useful is forestry. The total land area of the country was 32.975 million hectares, and the total forested area 20.575 million hectares. The Global Forest Resources Association has estimated that there exists 62.4% proportion of forested land area in Malaysia in 2010. Permanent reserved forest accounted for 71.8% of total forested area in 2009. The National Forestry Act of 1984, revised in1992 provides functional classes of permanent reserved forest for soil potation, soil reclamation, flood control, water catchment, and sanctuary for wild life, virgin jungle, amenities, education and research (Forestry Department, Peninsular Malaysia 2009).

This natural resource is part of our ecosystem, and together with biodiversity therein, it is essential that forest conservation is taken very seriously to mitigate climate change. The forest areas are important carbon sinks. Conservation regulates climate change, have significant economic and ecological values, support biodiversity, soil stability and food security. In the more fragile LFEs where precipitation is low, unreliable, soils are poor and the length of the growing period is short, very careful management is necessary to avid biophysical deterioration , and ultimately a desert environment where no plants can grow.

(vi) Water

The availability of water supplies and use are critical factors in agriculture. The problem will be much more pronounced in the rainfed environments (Table 4) and drought-prone areas of especially northern parts of South Asia, northern China and in parts of the Mekong countries like Thailand, Cambodia and Vietnam. In these situations the problem will increasingly exacerbated by decreasing rainfall, reduced length of the growing period, reduced agricultural production especially of food staples and increased food insecurity While mitigation to climate threats need to be explored, increased ways to adaptation and resilience to climate change and global warming are more important. Excessive use of chemical pesticides and fertilisers contaminates underground water, and can be a serious way to pollute domestic water sources and cause ill health to humans.

Water shortages are very common during the long dry seasons in most parts of South Asia, Civil unrest is common, and mobs of people have to chase water trucks that come twice a week to supply the people. Associated with these is potential use of indigenous knowledge and traditional systems. These include methods of harvesting, harnessing, conservation and various uses in very complex and trying circumstance. ESCAP (2008) has suggested that greater attention to policy is also required concerning water conservation, water pricing, diversions from surplus to deficit areas, and establishing and restoring water management structures and institutions.

The unavailability of land and scarcity of water will become major limiting factors to agricultural development in the future. Agriculture will have to stand in competition with human and industrial needs. As it is, agriculture is being criticised for using too much water. At the International Rice Research Institute in the Philippines, it has been reported that to produce 1 kg of rice, 4,700 litres of water are required; which is a huge input (Lampe1996). Clearly, research has to find ways and means to breed rice varieties that consume less water and develop other water-conserving management practices.

Using the classifications of the TAC (1994), the rainfed AEZ's of relevance are as follows:

- Rainfed temperate and tropical highlands – mainly the Hindu-Kush/Himalayan region;

- Rainfed humid/sub-humid tropical systems – mainly countries in Indo-China, South East and East Asia, and the Pacific Islands, parts of South Asia to include Bangladesh and Sri Lanka; and
- Rainfed arid/semi-arid tropical systems – mainly countries in South Asia excluding Nepal and Bangladesh.

Within Region Situational Analysis

In the light of the terms used to discuss R&D, it is appropriate to focus on improved understanding of the distinctive characteristics between South Asia and South East Asia, including China. The biophysical environments within the Asian region are very diverse, with variable soil quality, crop growth and different types of livestock. The biophysical environments vary considerably between-and within-individual regions. Rainfall and temperature are the two key important variables, and these together determine to a very large extent the level of productivity.

There are overriding differences between South Asia and South East Asia and East Asia. Table 2 summarises the marked differences between the two sub-regions, especially with regards to the resource base, agricultural production systems and feed resources. In terms of animal genetic resources, the size and diversity of the animal populations are far much greater in South Asia. The number of indigenous breeds within-species is greater in South Asia. Moreover, the goat and sheep populations are found to be generally higher and are more concentrated in the drier AEZs such as Rajasthan.

Crop-animal Interactions

Efficient NRM is most essential for producing food and income, which in turn allows for improved livelihoods. Conversely, poorly managed agriculture, causes environmental degradation, depletion of natural resources, pollution and wastage with serious effects on food safety and human health.

Agricultural production is to a very large extent is a manifestation of crop-animal-soil-water interactions It is brought about by the interactions of system components which impact on the environment through production system, feed availability, various activities, use of various inputs and management practices. The interactions can be positive or negative, and their relative importance and impacts depend on the size of the result, extent and duration, and an assessment of the implications. In general, the positive results are economically beneficial, while the negative ones will be more problematical, and likely to require more R&D to seek a resolution.

There are a number of types of crop-animal interactions, involving both annual and perennial tree crops. Nevertheless, the extent of the interactions and their implications are more manifest with tree crops. On the animal side, both ruminants and non-ruminant are reared, and the presence of both animal and crop diversity provides a variety of crop-animal interactions and many benefits (Devendra & Thomas 2002), the effects of which are reflected in increased productivity, improved livelihoods of people and sustainable agriculture.

Examples of the nature of crop-animal interactions are reflected in integrated ruminants with various crop systems in different countries in Asia, as given in Table 3. 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. Namely, sheep are more suited for integration with rubber where light transmission is less and therefore biomass production, while goats are more selective in their feeding habits because they are browsers (Devendra 1996; 2007), and are therefore, only more suited when both browse and forage in available agroforestry and silvopastoral systems. Most importantly, an understanding of the significance and implications of soil-crop-animal interactions is essential in order to ensure that the resulting benefits are consistent with productivity enhancement, environmental integrity and sustainable development of rainfed areas.

More recently, there is increasing awareness of green energy plantation landscape. In this context, much attention is being given to the government-identified energy plants: jatropha (*Jatropha curcas*), kenaf (*Hibiscus cannabinus*) and Leucaena *(Leucaena leucocephala*); all of which are being considered as cash crops in large plantation. The first two are widely used in the production of biodiesel. Kenaf biomass is already widely used in agricultural industrial applications such as in paper pulp and thermoplastic. *Leucaena* is very widely cultivated for multipurpose use (animal feed, fuelwood and as a fence line) is also very common throughout the South East Asian region. The utilisation of *Leuceana* as a source of animal feed particularly for

Table 2. Situational analyses in the arid/semi-arid and sub-humid/humid AEZs in Asia

Themes	SOUTH ASIA Arid/semi-arid	SOUTH EAST ASIA Sub-humid/humid zone
Resource base	High demand for water resources	Adequate water resources
	Length of growing period 0-179 days	Length of growing period 180-270 days
	Salinity problems in soils under irrigation	
	Fragile environment with soils of low fertility	
	Land degradation associated with nomadism/ transhumance, tree removal and overgrazing	Natural resource management problems in upland areas
	Human population density low and incidence of poverty and food insecurity high	Human population density high, poverty and food insecurity high
	Adoption of improved livestock technologies variable and generally poor across countries	Adoption of improved livestock technologies variable and generally poor across countries
	Inadequate interdisciplinary research on natural resource management	Inadequate interdisciplinary research on improved natural resource management
Agricultural production systems	Annual and perennial crops grown under rainfed and/or irrigated conditions. Irrigation is advanced	Rice and wheat-based farming systems involving ruminants and non-ruminants, also fish in some places
	Crop-animal systems are important	Draught buffaloes and cattle, poultry and pig populations are increasing
	Relatively high populations of buffaloes and cattle	Dairy cattle and buffalo numbers marginally increasing
	Dairy buffaloes and small ruminant populations increasing, draught cattle decreasing.	Multiple cropping common, and manure is an important source of nutrients
	Development of market-oriented smallholder dairying due to co-operatives and infrastructural support	Variable integration of animals with cropping systems and intensification of crop-animal systems.
	Goats and sheep are mainly under pastoral systems interfacing with mixed farming	Market-oriented smallholder dairy less developed due to lack of marketing and infrastructure
		Animals commonly tethered or stall-fed
		Variable land areas under integrated animals – tree crop systems, mainly coconuts, oil palm and rubber and fruits. Small ruminants and cattle are usually used.

Source: Devendra (2007b)

Table 3. Distribution of land types by region

Region	Land type (% of total land)				Rural population living in favoured lands (%)
	Favoured	Marginal	Sparsely populated arid lands	Forest and woodlands	
Asia	16.6	30.0	18.5	34.6	37.0
Latin America and the Caribbean	9.6	20.3	8.1	61.9	34.0
Sub-Saharan Africa	8.5	23.1	24.6	43.7	27.0
Near East and N. America	7.8	22.6	65.8	3.9	24.0
Total(105countries)	10.7	24.0	25.9	39.4	35.0

Source: CGIAR/TAC 2000

ruminants also has the distinct advantage of increase carbon sequestration on account of the return of dung and urine, improve soil fertility and plant growth.

Along with the green energy concept, there is also the issue of alternative uses for these crops. R&D will need to evaluate and access the contrasting comparative advantages between these crops. The outcome of the evaluation of the individual crops remains to be seen, as also the realisation of the very concept of green energy.

Land Use and Animal Production Systems

Effective land use is a most important determinant of agricultural productivity. Of the factors affecting this productivity and the extent of supply of animal proteins, type of production system, biophysical environmental factors, and the availability and quality of feeds, are all very critical for the performance of ruminants. The last factor of feed availability and quality will determine the type of production system that is appropriate (Figure 1). Excluding goats and camels, it is very doubtful if cattle and sheep, can withstand the very high temperatures and heat stress that are found in the arid and semi-arid areas.

Crop-animal systems form the backbone of Asian agriculture, and have evolved and developed over many centuries. The principal determinants of the type of crop and animal systems that are found in a particular location are the agro-ecological conditions. Namely, climate, and to a lesser extent soils, affect the natural vegetation and determine what crops can be grown. These in turn determine the feed base and its types, quantity, quality and distribution. The feed base, together with the disease challenge, governs the development of potential animal production systems. Feed resources and their diversity provide a direct link between crops and animals and the

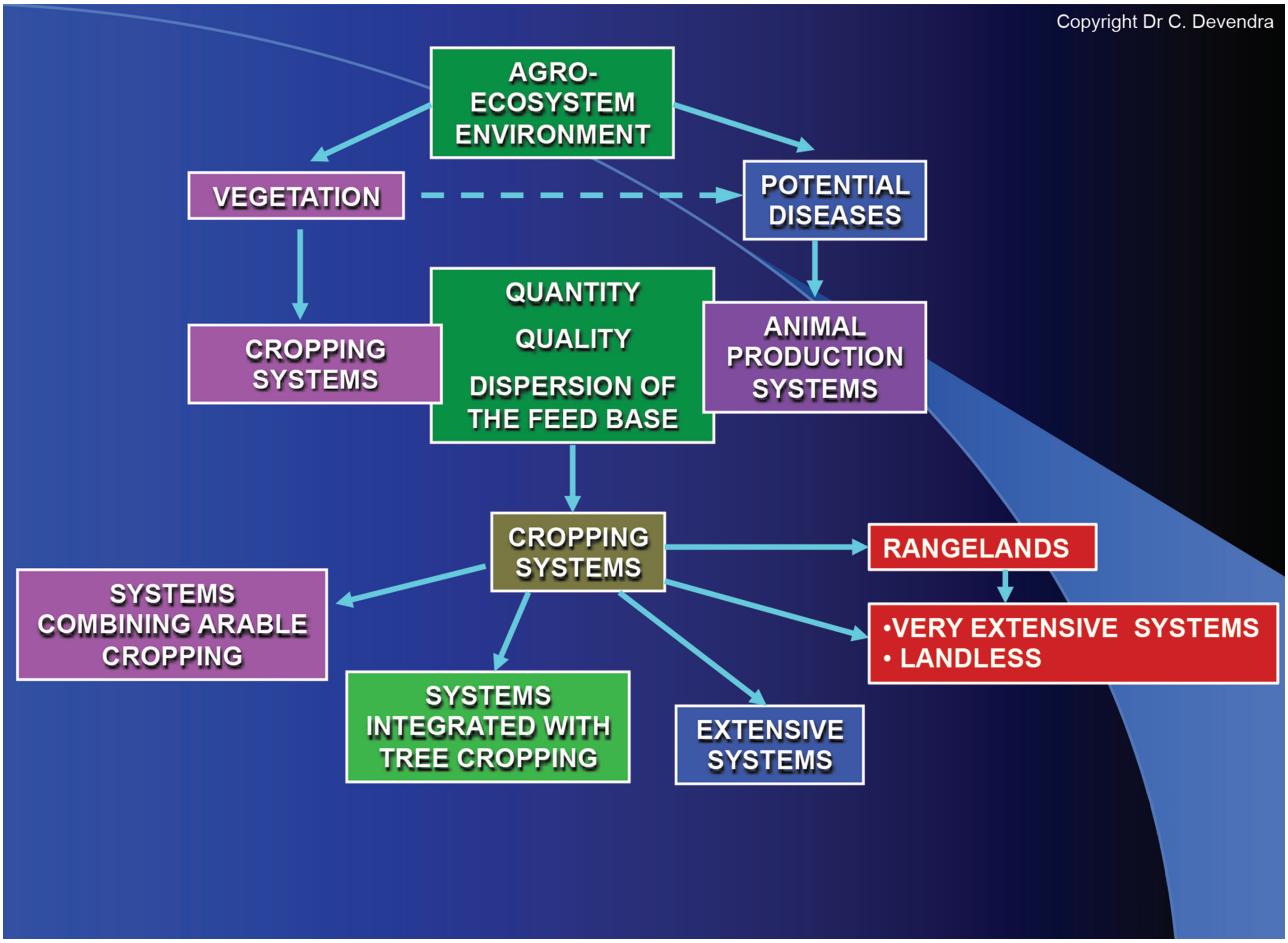

Figure 1. Genesis of Animal Production Systems in Asia

interaction of the two largely dictates the development, intensification of animal production systems and productivity from animals (Devendra *et al*. 2005).

Animal production systems are a function of the agro-ecological conditions and prevailing farming systems. The key AEZs include the arid and semi-arid, humid and sub-humid, and highland and temperate regions (Plate 1). On the other hand, climate, edaphic and biotic factors determine whether cropping is feasible, which in turn determines the link with animals through the quantity and quality of feeds produced (Devendra 2010). It is interesting to note that indigenous knowledge and community-based participation have also influenced the evolution and development of improved systems and system perspectives. Presently, the extensive systems dominate ruminant production systems.

The systems are also very dynamic, and respond well to improved productivity-inducing technologies. Community–based participation of farmers in the project from the beginning to the end has also the advantage of using traditional knowledge. Over time and good experience with effective NRM, specialisation follows. Such specialisation is not independent, but continues to be associated with diversification, spreading the production resources and reduce risks for the enterprises, for example using crops and animals, to seek efficiency, economic benefits and sustainable production even at the subsistence level. It has been suggested that

Plate 1. South China black goats in extensive grazing in Nanjiang Province, Yunnan, China

Plate 2. Nili-Ravi buffaloes used for intensive milk production in the Landhi milk colony in Pakistan

prevailing animal production systems are unlikely to change in the foreseeable future. The best strategy therefore is to ensure maximum use of the available feed resources and push the frontiers of production (Mahadevan & Devendra 1986).

The final step in this genesis is intensification of animal production systems, which is the process of modifying production practices to increase output per animal, per unit of land and per unit of labour (Nicholson *et al*. 1995) e.g. meat and milk. Intensification reduces production costs per unit of agricultural product output (Plate 2). The spectacular growth of the pig and poultry industries and self-sufficiency in poultry meat, pig meat and eggs in several countries in Asia is a good example of this process, followed by dairy development. However, intensification involves large capital and other resource inputs e.g. imported grains. More importantly, it responds well to the current increased demand for current and projected demand for animal proteins.

Consequently, the remarkable growth of the poultry and pig industries have brought with it useful structural changes, which are also very valuable for the ruminant industries. With ruminants, intensification lags behind, and will involve a shift from the extensive systems progressively to the more intensive systems that can be developed, provided the process is in close proximity and has accessibility to sizeable and constant supplies of feed resources, application of yield-inducing technologies, and an expanding market demand. In turn they will influence such other issues as C sequestration and GHG emission.

Currently, intensive production in ruminants is apparent mainly in dairy and beef production systems in developing countries. Moreover, revitalising agriculture will require very innovative ways to adapt to the prevailing biophysical environment and be resource efficient to promote development of sustainable agriculture. High temperatures make both crops and animals very vulnerable, as is the case with rice (Peng *et al*. 2004) and animal production (Devendra 2015).

Due to the overuse and decreasing availability of arable land, the justification for targeting rainfed areas for food production is urgent, and is linked to the following:

- Demand for agricultural land to meet human needs, e.g. housing, recreation and industrialisation;
- Limited arable land for the expansion of crop production to ceiling levels
- Increasing and very high animal densities;
- Increased resettlement schemes and use of arable land;
- Growing environmental concerns due to very intensive crop production e.g. acidification and salinisation with rice cultivation and human health risks due to expanding and often very intensive peril-urban poultry and pig production; and
- Urbanisation.

The notion of decreasing land availability due to reasons of industrialisation and urbanisation is serious, and is exacerbated by decreasing farm sizes due to population. This is reflected in the projected decrease from between 0.17 and 1.0 ha/person in 1988/90 to 0.05 and 0.30 ha/person by 2010 (FAO 1998). In China for example, the available arable land has decreased from 130.04 million hectares in 1996 to 130.03 million hectares in 2005. Associated with this, *per capita* arable land has fallen below 0.094 ha in 2004 (Qiu *et al.* 2008). Of equal concern is the loss of about 5.7 million hectares of arable land annually through soil degradation, and a further 1.5 million hectares as a result of water logging, salinisation and alkanisation (FAO 1999). If the process of land fragmentation continues without any consolidation, in the long term it is feasible that farmers will have to shift out of agriculture.

Given the fragility of LFAs, the efficiency of NRM will require innovative strategies for improved soil fertility to enhance crop cultivation, coping with low rainfall, water harvesting and conservation, use of traditional ecosystem practices, as well as improved animal production systems that together can benefit the livelihood of small farms and poor farmers (Devendra 2010). The occurrence of increased human-induced climate change with an anticipated harsher climate will push for extreme poverty and survival. Hence, there is a need for efficiency in the use of available natural resources, as well as defining the objectives of production more clearly in terms of potential outputs and profitability. In this context, listening to farmers about community knowledge, traditions and their experiences with NRM provide advantages for the success of a project (Devendra 2006). Furthermore, the significance and implications of soil-crop-animal interactions need to be understood so that the resulting benefits are consistent with productivity enhancement, environmental integrity and sustainable development of rainfed areas.

These issues together suggest the need for more resource efficiency in all available lands. Table 4 indicates the extent of rainfed agriculture and its importance in the different AEZs of the Asia- Pacific region (ADB 1989). Rainfed areas in the arid/semi-arid, sub-humid and humid AEZs were 38.8, 16.9 and 26.3 respectively, as percentage proportion in Asia respectively. Of particular importance in the table are also the sizes of human population dependent on rainfed agriculture.

Strategies for Animal Production to Cope with Climate Change

Animals have a very significant multifunctional role. These are as follows:

- Promotion of linkages between system components (land, crops and water)
- Diversification and reduction of socio-economic risks;
- Generation of value-added products (e.g. meat, milk and eggs) and draught power;
- Small animals empower women, nutritional and food security;
- Income generation, investment, insurance and economic security;
- Increased soil fertility through nutrient cycling (dung and urine); and
- Provide prestige in their ownership, social and recreational values, as well as the development of stable farm households.

Table 4. Types of crop-animal interactions in various countries in Asia

Country	Interactions
China	• Manure from dairy cattle for triticale and rice production in the Beijing municipality; • Manure from pigs for maize and rice production in the Hunan Province; • Manure from black goats for vegetable production in the Hunan Province; and • Buffaloes and cattle for draught in Hunan and Yunnan Provinces.
India	• Manure from small ruminant flocks folded on arable land in Gujarat and Rajasthan States; • Sorghum residues by cattle in the Andhra Pradesh State; • Cattle for draught power in rice–wheat production systems; and • Manure from large ruminants for cropping in Uttar Pradesh State.
Malaysia	• Buffaloes and cattle are used extensively for haulage and transportation of products such as fresh fruit bunches draught in oil palm estates; • Animals grazing the herbage control weeds; • There are reduced weeding costs (16 – 40%); • The effective utilisation of the feeds gives valuable animal products such as meat, milk and eggs; and • 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.
Nepal	• Manure for composting from cattle and buffalo in the mid-hills region; • Crop residues in the Terai region for what crop product or animal feed; and • Cattle and buffaloes for draught power in the Terai and mid-hill regions.
The Philippines	• Small ruminants for weed control under coconut in Southern Luzon; • Manure from cattle feedlots for pineapple production in northern Mindanao; and • Ducks in rice paddies to control golden snails (rice pests in Southern Luzon).
Sri Lanka	• Buffaloes for land preparation in rice production in the wet and intermediate zones; • Rice straw by cattle in the irrigated dry zone; and • Cattle for weed control and manure application under coconuts in the intermediate zone.
Thailand	• Rice straw for cattle and buffalo feed in the North-eastern Province; • Manure from stall-fed large ruminants for rice production in North-eastern Province; and • Buffaloes for draught power in rice production in Northeast Province.
Vietnam	• Buffaloes for draught power in rice production in Song be Province; • Crop residues in the Song Be Province; and • Ducks feed on weeds in ponds fertilised by pig manure in central and North-eastern areas.

Source: Devendra 2004

Two key factors that will affect animal performance are heat stress and feeding and nutrition. Nevertheless, the notion of heat stress must be kept to the barest minimum, and with efficient feeding and management. As such, the strategy will be to enable the animals to recover from the harsh impacts with high quality dietary feeds. Table 5 summarises the impact of climate change on animal production.

Strategies for ensuring adaptation and tolerance of animals to high temperatures, cope with climate change without loss in productivity, present major challenges to R&D. In this situation where the interactions are numerous between-components, it is essential to establish priorities for the R&D applications to cope with climate change, support the development of sustainable agriculture. These have been reviewed by Devendra (2012a; 2012b) and are summarised as follows:

1. Develop the LFAs in humid, sub-humid and arid and semi-arid AEZs;
2. Develop sustainable food production systems from a diminishing resource base with all possible alternatives;

Table 5. Major impacts of climate change in animal production

Major issue	Potential climate change impacts	Opportunities for R&D
1. Heat stress	• Physiology • Metabolic • Reduced feed intake • Reduced reproduction • Increased mortality • Low productivity	• Adaptation • Feed efficiency • Measures to increase intake • Supplementation • Improved management • Shade
2. Feed resources (Forages, crop residues , AIBP and NCFR)*	• Reduced quantities • Poorer nutritional quality • More fibrous • Decreased palatability • Reduced digestibility	• Use more heat tolerant plants • Food-feed systems • Use of multipurpose tree legumes • Conservation
3. Land use systems	• Shift to dry land agriculture • Droughts • Water scarcity • Diversification of agriculture • Sustainability	• Heat tolerant plants and animals • Development of food-feed systems • Emphasis on rainfed agriculture in LFAs • Maximising feed supply
4. Animal species and breeds	• Adaptation • Yield changes • Possible reduction in size • Loss of biodiversity • Loss of grazing land • Flooding in river deltas • Migratory systems	• Dynamics of nomadic and transhumant systems • Ensuring choice of AEZ • Understanding interactions with the environment • Vulnerability and survival of the poor and the ownership of animals
5. GHG emissions Enteric fermentation and manure, producing global warming	• Reduced crop growth and animal productivity • Poor C sequestration	• Improved use of grasses, legumes and agronomic practices • Use of dietary nitrates to reduce CH_4
6. Integrated NRM and holistic systems**	• R&D capacity	• Intensification • Interdisciplinary R&D
7. Semi-arid and arid AEZs, including rangelands	• Reduced feeds • Overstocking • Environmental damage • Landlessness • Water conservation	• Use of systems perspectives • C sequestration • Impacts • Control of numbers • Use of leguminous trees • Improved management • Water use efficiency

Note: *AIBP - Agro-industrial by-products; NCFR-Non-conventional feed resources;
** NRM- Natural resource management.

3. Promote innovation (for example, food–feed systems);
4. Ensure that high priority is given to R&D and farming systems research using systems perspectives and community-based participation with researchers and extension personnel;
5. Pursue new mitigation and adaptation R&D pathways; and
6. Develop systems approaches that focus on the biophysical environment and natural resource use and management and their interactions (Devendra 2013), and distil from these the best options for food production.

ADB (2009) studied the economics of climate change in South-east Asia (Thailand, the Philippines, Indonesia, Vietnam and Singapore) as a basis for formulating policies to include impact assessment, adaptation and mitigation analysis. The study indicated that agriculture-dependent economies could contract by as much as 6.7% annually. It reported that mitigation could potentially sequester carbon by 3.04 tCO_2/ha/yr, reduce CH_4 emissions by 0.02tCO_2-eq/ha/yr, and reduce N_2O emissions by 0.02–2.30 tCO_2-eq/ha/yr. Contrariwise, the presence of grazing ruminants will lead to emissions of more CH4 into the atmosphere. Thus, important adaptive options in agriculture have also been suggested (ADB 2009) In addition, there are several other options *inter alia*: adjustment of cropping calendars and patterns, changes in management and farming practices, use of heat-resistant varieties, development of more water efficient crops, diversified farming, intercropping, crop rotation and food–feed systems, use of the southern oscillation index (SOI) in designing cropping strategies, implementation of index-based insurance, development of early warning systems and improvement of irrigation efficiency Silvopastoral systems their potential importance and impacts of particularly integrated oil palm –ruminant systems have been reviewed (Devendra 2009).

This potential has not been adequately explored, and highlights the advantages, economic benefits and impacts resulting from the integration of ruminants with oil palm. Currently the only about 3% of the 4.7 million hectares of land under oil palm is used for integration, but hopefully this area can be rapidly expanded with increasing awareness and policy support from the government. The integration model offers application of the principles involved with other tree crops like coconuts in the Philippines, Sri Lanka and South Asia, rubber in Indonesia, and citrus in Thailand and Vietnam, and elsewhere in Africa, Latin America and the Caribbean. Such transformation has been referred to as 'ecological intensification' (UNCTAD 2013). The potential production options 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.

The economic benefits due to positive crop- animal-soil interactions based on a review of the existing information gave the following results with reference to the use of cattle:

1. **Increased animal production and income**

   This arises from increased productivity and meat offtake.

2. **Increased yield of FFB and income**

   The escalation is by about 30 % with measures of between 0.49 – 3.52 mt/ha/yr.

3. **Savings in weeding costs**

   The costs are lessened by about 47 – 60 %, equivalent to 21 – 62 RM/ha/yr.

4. **Internal Rate of Return (IRR)**

   The IRR of cattle under integration was 19% based on actual field data.

Several theoretical calculations approximate to this value are very useful and fairly well known (Cajas & Sinclair 2001). Nevertheless, they are underestimated and underutilised in developing countries, especially where tree plantations are abundant, such as oil palm in Indonesia, Malaysia and Colombia. Despite its potential economic advantages, the system has weak adoption rates. In addition, the system promotes stratification, which provides an important opportunity to intensify natural resources (Devendra 2007a; 2014).

Furthermore, the available methods are inadequately used for integrating ruminants with tree crops. Their two main advantages are using the forage biomass to economic advantage and, secondly, stratification provides several production options – breeding ruminants (buffalo, cattle, goats and sheep) for production systems; growing ruminants for meat production. However, much depends on the zero-grazing systems (feedlots, goats and sheep). In Latin America, the optimum carrying capacity is dependent on the configuration of trees as well as animal numbers, which in turn will enable the value of such interventions. Concerted development of integrated tree crops-ruminant systems is therefore potentially most important, and this opportunity should not be missed. Weak arguments against it, based on poor understanding of the system, non-innovative agricultural development and mere opinions, remain an academic exercise.

Of the factors limiting productivity from animals, feeding and nutrition is a major constraint. The application of feed-based yield inducing technologies therefore merits priority attention. There already exists a number of proven and potentially important productivity-enhancing technologies of which the replication can significantly increase productivity in animals, which include *inter alia*:

1. Three-strata forage system (Indonesia)
2. Food-feed inter-cropping (Philippines, Thailand, India)
3. Integration of ruminants with tree crops (Malaysia, Philippines and Indonesia)
4. Effective utilisation of crop by-products and non-conventional feed resources (Most countries)
5. Strategic supplementation (Most countries)
6. Rice-vegetable-ducks-fish integration (Indonesia, Philippines, Vietnam)
7. Sloping agriculture land technology (India, Nepal, Philippines)

A framework of national strategies for adapting to climate change and mitigation is required within which research will need to addresses climate-friendly productivity increases, and details of how the technologies developed appropriate to mixed farming conditions involving crops and animals. Identifying key mitigation options will be important which for South East

Asia has recently been reported (ADB 2009; Devendra 2012). The information relates to the type of practice, relative mitigation potential, challenges, opportunities, and co-benefits and contribution to sustainable development.

Figure 2 summarises the interconnectedness of the objectives and the many interactions that are involved in rainfed agriculture. Most importantly, the fundamental message here is that agriculture must provide access to and an abundance of reasonably priced food for a rapidly expanding human population, and reduce hunger and malnutrition.

All the new technologies identified are adapted to high temperature, and should therefore be welcomed in large parts of the tropics. Beyond these, it is suggested that the following areas also merit R&D: plant breeding for increased drought and flood tolerance and disease resistance, application of new technologies for water harvesting, conservation and recycling, nutrient management and soil fertility integration of animals with annual and tree crop systems, sustainable intensification of improved crop–animal systems, appropriate econo-mic incentives, subsidies, pricing and taxes and linking production to post-production systems and the international food supply. Furthermore, climate change could result in reduced arable land for food production for humans and reduced grazing area for ruminants. Second, and more importantly, a changing climate could push several million people further into poverty. Both these concerns need to be addressed by policies to support secure and sustained food supplies and improve livelihoods and sustainable animal-agriculture in the future (Devendra & Chantalakhana 2002).

The Relevance of System Perspectives and Methodologies

Systems perspectives, methodologies, together with FSR are fundamental in driving technological improvements and yield-enhancing strategies that improve NRM and agricultural productivity, resolve farmer`s problems and sustain food security for human welfare in Asia. ‘Systems’ is a relatively new discipline. Its systems perspectives and approaches are based on a concept of organised and essential steps that deal with several prerequisites, for instance in defining a programme that is needs-led and have institutional and structural

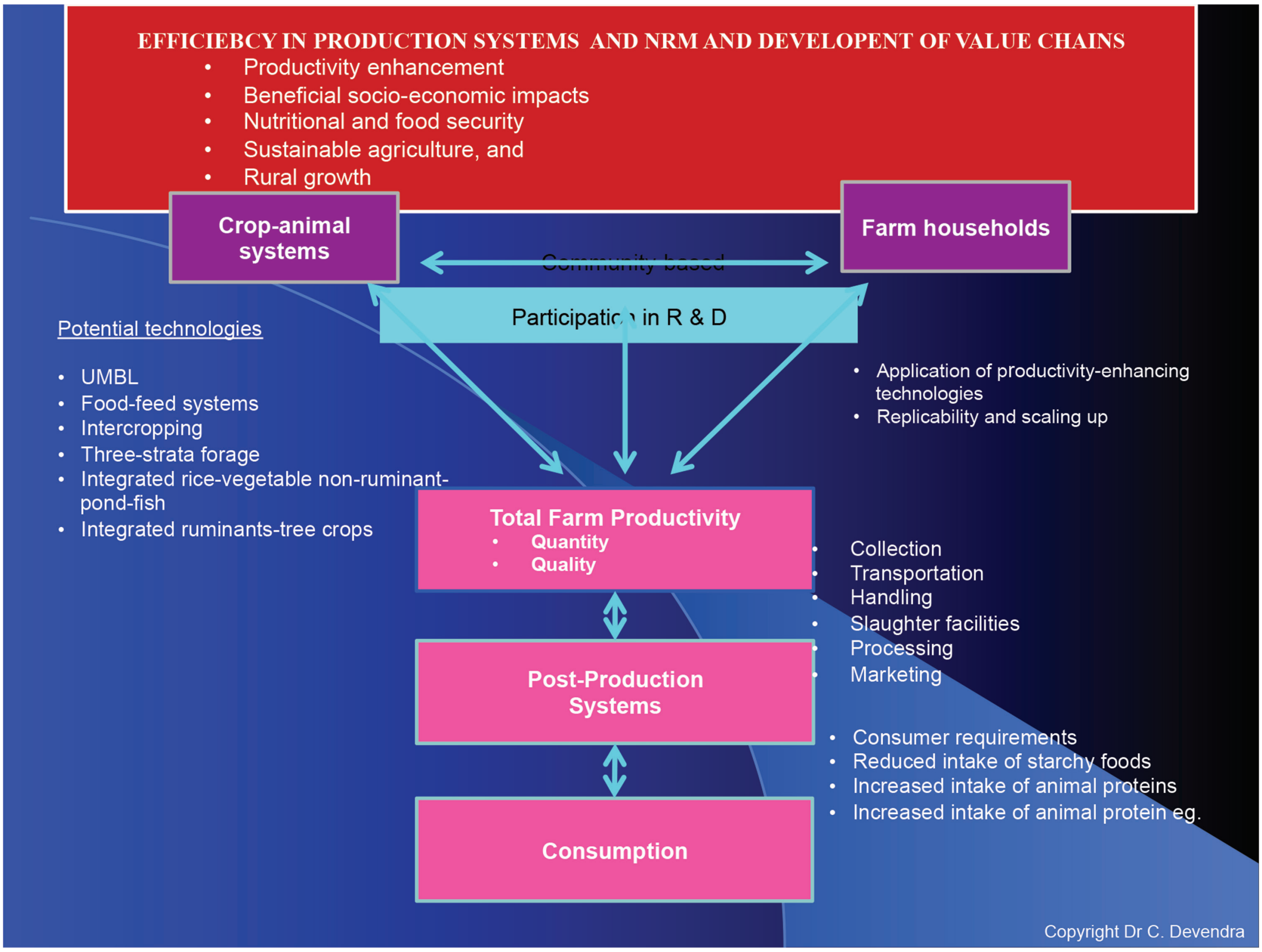

Figure 2. Whole farm production to consumption systems

commitment. In this context, agricultural education and technological change enable efficiency, build the capacity to manage and conserve the natural resource base, and promote technology-induced productivity gains (Devendra 2015c).

Nonetheless, while strong disciplinary training is essential, a detailed more rounded and holistic view is necessary to deal with the complex interactions of the diversity of crops and animals and traditional methods of farming The capacity to efficiently manage the natural resource base (land, crops, animals and water) and resolve farmers' problems through the integration of multiple R&D based on community participation is emphasised.

Methodology for Farming Systems Research

FSR is central to system perspectives and efficient NRM. The methodology is based on careful problem identification and their resolution. FSR owes its origin to cropping systems research and methodologies which were developed mainly in Asia and Latin America. It started with a focus in the early 1970s on agronomic management of rice, but shifted to combinations of crops (Zandstra *et al.* 1981). In 1984, the animal component was added to cropping systems research and named FSR to provide a good understanding of farming systems and the practices. The systems approach needs to be supported by a good understanding of farming systems research. Figure 3 illustrates the sequence of steps in the research process. These steps are distinctly sequential, and it is also emphasised that there needs to be continuous checks to assess the progress, as well as make changes for improvements. The following steps are critical in FSR:

1. Characterisation (Diagnosis)
   - Selection of benchmark sites;
   - Description of socio-economic conditions and biophysical factors;
   - Understand prevailing farming systems;

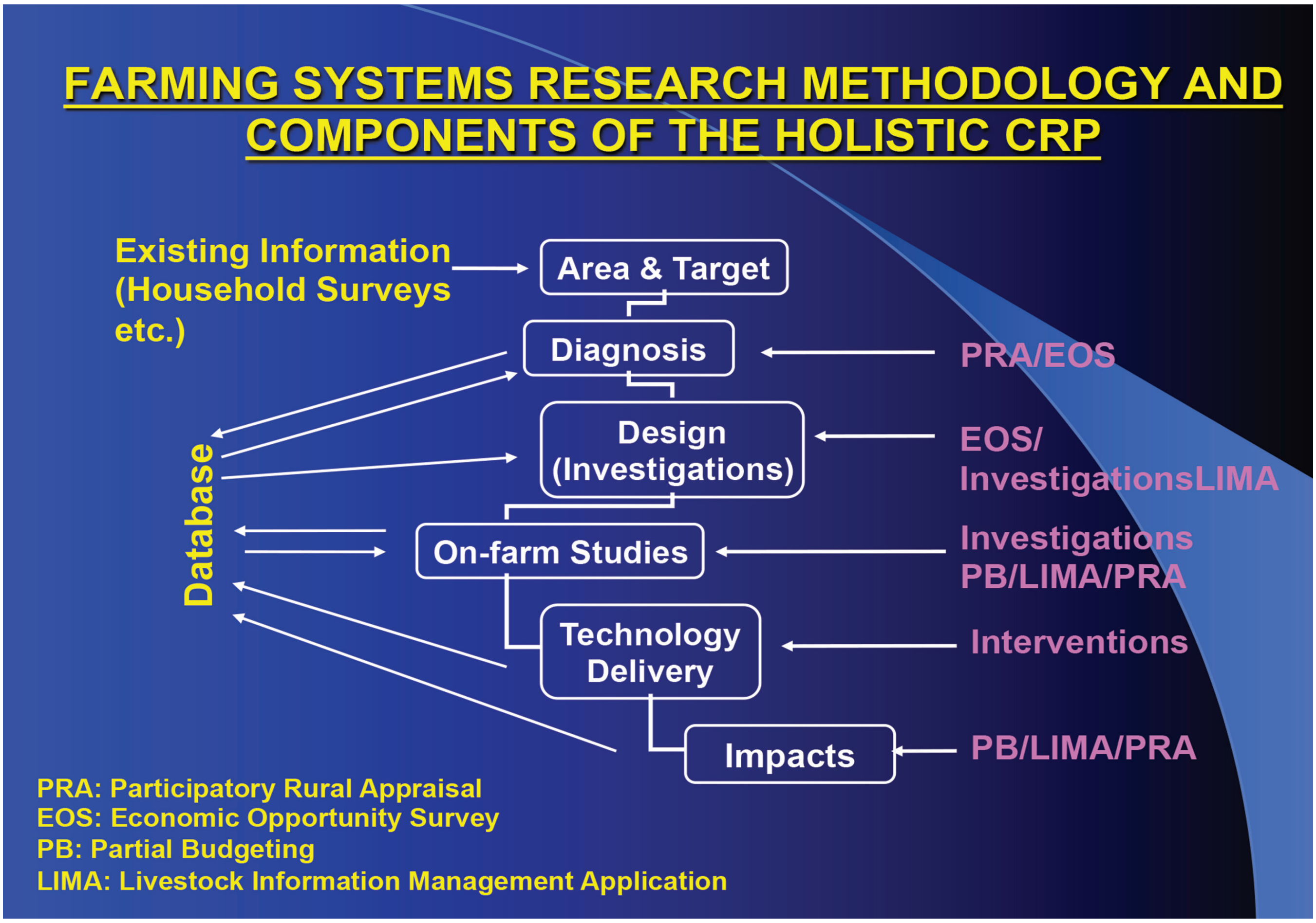

Figure 3. Methodology for farming systems research

- Analyses of constraints: on–farm and off-farm;
- Listening to farmers, municipal officials and key informants; and
- Regional: GIS maps, integration of geographic and socio-economic data.

2. Design
   - Analysis ex-ante: constraints and opportunities to improve the system;
   - Discussion of the results with the stakeholders;
   - Seek consensus on the findings; and
   - Refine the results.

3. Testing
   - Research on component technologies to improve systems;
   - Selection of cooperating and participatory farmers;
   - Agreement on interventions;
   - Implementation: on-farm testing and validation of alternatives;
   - Lessons learnt;
   - Monitoring and evaluation, and
   - Feedback.

4. Diffusion of results and impact assessment
   - Several methods can be used and include newsletter, persona; contact, publication, de-monstrations and field days. Interpersonal links, as well as network arrange-mentscan significantly promote knowledge, information, germplasm and visits.

Demonstrable Socio-economic Results

It is appropriate in the final sections of the review to present examples of projects that embody efficiency in NRM, economic production and demonstration of sustainable agriculture. Any new potentially important intervention or regime will be worthless and unlikely to be adopted if the cost of dietary feeds is not lower that than the value of the product response. This point is illustrated through two sets of excellent data, as shown below, one from Indonesia and the other from Malaysia.

The two examples are cited from the above success stories which have shown demonstrable impact. Both are complementary integrated systems, and provide a strategy and technical basis for development, combining animal production with annual and perennial cropping.

The Three-strata Forage System (TSFS) in Indonesia

The three-stratum forage system has been developed over nine-and-a half years to match the low rainfall environment (600–900mm annual rainfall and 4 to 8 months of dry season) in Bali, Indonesia. The concept integrates cash cropping and ruminant production (mainly cattle and goats) in a sustainable crop animal system, and enhances the efficient use of natural resources, especially for small farms. The TSFS is an integrated way of planting and harvesting forage so that a source of feed is available all year round. The core area is the centre of the plot where maize, soya bean and cassava are grown. The peripheral area consists of three strata. The first consists of grasses and legumes for use during the wet season; the second consists of shrub legumes for use during the middle of the dry season, and the third consists of fodder trees for producing feed for the late dry season(in Bali, Indonesia (Nitis *et al.* 1990).

The results were: (i) increased forage production, (ii) higher stocking rates (3.2 animal units/ha) and total live weight gains of 375 kg/ha/year, compared with 2.1 animal units and 122 kg/ha/year in the non-TSF system, (iii) 90% more live weight and reached market weight 13% quicker (iv) farmers benefitted a 31% increase in income. The introduction of forage legumes (v) resulted in a reduction in soil erosion by 57%, (vi) the presence of 200 shrubs and 112 trees produced 1.5 tons/year of firewood, which met 64% of farmers' annual needs, (vii) the integration of goats in addition to cattle further increased farmers' income, and (viii) the concept has been institutionalised. The system has much potential for replication in the semi-arid areas of Sub-Saharan Africa (Devendra 2010), East and West Africa, Latin America and the Caribbean.

Intensification of Integrated Ruminant – oil Palm Silvopastoral Systems (Malaysia)

Not surprisingly, the oil palm environment offers a number of conducive production attributes for integrating ruminants to enhance total factor productivity as follows:

- Forage dry matter availability: 2.99- 2.16 mt /ha for 3 and 5 year old palmsreducing 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;
- About 72- 93% of the forages are palatable and of value to ruminants;
- Kedah-Kelantan and Bali cattle 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 260-320g/day 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).

The second example relates to silvopastoral systems, which unfortunately are neglected, underestimated, and merit urgent development attention. The largest land areas under oil palm (8.4 million hectares) are found in Malaysia and Indonesia, who together own over 79% of the world planted area and produced about 87% of the total world output of palm oil. In Malaysia, the distribution and ownership of land areas under oil palm by the several groups, including government-linked companies (GLCs) are as follows:

- The largest owner of oil palm areas of about 60%, followed by the Federal Land Development authority (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; and

- Among the Government Linked Companies (GLC`s), FELDA was the largest owner of oil palm land.

The results of the two projects strongly emphasise the significance of nutrition on productivity in animals, which in turn has significantly contributed to improved livelihoods.

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4. Diffusion of results and impact assessment.

Carbon Sequestration

Carbon sequestration is defined as a process of increasing the carbon content of a reservoir rather than the atmosphere. It is an important pathway to stabilise the environment with minimum effects of climate change. Farming systems provide a non-compensated service to society by removing atmospheric carbon generated from fossil fuel combustion, feed production, land restoration, deforestation, biomass burning and drainage of wetlands.

Carbon is sequestered from the atmosphere by growing plants, trees and pastures and is stored in extensive root systems. The amount stored is influenced by several factors and includes biophysical factors, notably rainfall and temperature, type of plant or tree, density of plant and tree growth, soil fertility status and type of farming system. Farming systems thus provide a non-compensated service to society, removing atmospheric carbon generated by fossil fuel combustion, feed production, land restoration, deforestation, biomass burning and animal production. Strategies to maximise carbon sequestration through enhanced farming practices, particularly in crop–animal systems, are thus an important priority to reduce global warming. These pathways also respond to agricultural productivity in the multifaceted, less- favoured rainfed environments (Devendra 2015b).

The increase in global emissions of carbon is estimated at around 270 Gt, which is determined to be growing at a rate of 4 Bt year^{-1} (Lal 2009). With increasing attention and concerns about ways to increase carbon storage, producers and farmers can be paid on the basis of the net amount of carbon sequestered from the atmosphere.

There are potential possibilities for the accumulation of higher levels of C sequestration. In the Chiang Mai region of northern Thailand, researchers under the Royal Thai Organic Project have recorded a 5% increase in soil organic matter over 8 years, equal to 187.2 t of CO_2 ha^{-1} or 23.4 t of CO_2 ha^{-1} year^{-1}. If this were applied globally, it would sequester 114 Gt CO_2 year^{-1}, more than double the world's current GHG emission (Royal Thai Organic Project, Chiang Mai, Thailand: personal communication).

In Malaysia, about 86% of the total agricultural area of 6.9Mha in land in 2010 was under tree crops. Oil palm alone occupies 63.4%, of which about 49% is found in Sabah and Sarawak. The integration model with oil palm offers extension of the principles involved with other tree crops like coconuts in the Philippines, Sri Lanka and South Asia, rubber in Indonesia and citrus in Thailand.

The reference to the environment must constantly recognise the preponderance of small farm systems in Asia where mixed farming is the backbone of agriculture. In South East Asia, the main mixed farming operations occur in the humid-sub-humid areas, compared to the arid/semi-arid areas in South Asia. The AEZs in both regions are characterised by rampant poverty, malnutrition and major challenges for R &D to accelerate agricultural growth (Devendra 2010).

CONCLUSION

The word Environment is very widely used presently because of diminishing natural resources, resulting in the inability of the food systems to produce enough supplies. Environmental degradation is also apparent, threats and potential impacts of climate change exist especially on food insecurity, amidst the search for environmentally sustainable animal-agriculture. The environment interacts with all the system components and more, but the overwhelming stature of agriculture that stands out most is the term 'Systems'. 'Systems' is a relatively new discipline, whereas systems perspectives and approaches are based on a concept of organised and essential steps that deal with several prerequisites, Given the vast variations in biophysical elements, numerous interactions between NRM, crops and animals, resolution of the many problems can only be done by interdisciplinary R&D.

The potential impacts on animal production and especially on food insecurity are real and inevitable. Hence, several strategies exist that are potentially important and need to be pursued vigorously in interdisciplinary R&D terms to mitigate the impacts of climate change. Key themes that merit coordinated and concerted attention include the following:

- Development of the potential value of rainfed areas and improved use of LFAs in pro-poor initiatives;
- Breeding and conserving indigenous animal genetic resources as an important means of mitigating the impacts of climate change;
- Wider expansion and benefits of integrated tree crops-ruminant systems, including stratification and C sequestration ;
- Wider application of the finding that the use of nitrate salts potentially reduces methane production to minimal levels in ruminants, and

- Growing fast growing leguminous shrubs and multi-purpose leguminous trees to provide valuable feeds during the dry season as well as enhance the environment, and
- Research agendas must be participatory, community-based and have a holistic view of farming systems.

The opportunities and challenges are numerous. A key concern is whether there is adequate research capacity and a policy framework for the more efficient use of the natural resources to increase current supplies of animal proteins. Increased R&D focus that can maximise improved NRM and agricultural development that can maximise yields in environmentally sustainable production systems are important goals. There are other opportunities as well, and include expanding crop–animal production systems in less favoured areas (LFAs), intensifying land use for silvopastoral systems in rainfed areas, and pathways to enhance carbon sequestration. The LFAs remain totally neglected for various reasons, but interestingly, ruminants can be used as an entry point for the development of LFAs, and the presence of about 41.5% of the goat population found in the semi-arid/arid AEZs is significant. It provides good opportunities for expanding food security, support the preservation and improvement of the environment and human well-being.

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