



- Invited Review -  
**Feed Resources for Animals in Asia:  
Issues, Strategies for Use, Intensification and  
Integration for Increased Productivity**

C. Devendra<sup>1,\*</sup> and R. A. Leng<sup>2</sup>

<sup>1</sup> Consulting Tropical Animal Production Systems Specialist at 130A Jalan Awan Jawa,  
58200 Kuala Lumpur, Malaysia

<sup>2</sup> University of New England, Armidale, NSW, Australia

---

**ABSTRACT :** The availability and efficient use of the feed resources in Asia are the primary drivers of performance to maximise productivity from animals. Feed security is fundamental to the management, extent of use, conservation and intensification for productivity enhancement. The awesome reality is that current supplies of animal proteins are inadequate to meet human requirements in the face of rapidly depleting resources: arable land, water, fossil fuels, nitrogenous and other fertilisers, and decreased supplies of cereal grains. The contribution of the ruminant sector lags well behind that of non-ruminant pigs and poultry. It is compelling therefore to shift priority for the development of ruminants (buffaloes, cattle, goats and sheep) in key agro-ecological zones (AEZs), making intensive use of the available biomass from the forage resources, crop residues, agro-industrial by-products (AIBP) and other non-conventional feed resources (NCFR). Definitions are given of successful and failed projects on feed resource use. These were used to analyse 12 case studies, which indicated the value of strong participatory efforts with farmers, empowerment, and the benefits from animals of productivity-enhancing technologies and integrated natural resource management (NRM). However, wider replication and scaling up were inadequate in project formulation, including systems methodologies that promoted technology adoption. There was overwhelming emphasis on component technology applications that were duplicated across countries, often wasteful, the results and relevance of which were not clear. Technology delivery via the traditional model of research-extension linkage was also inadequate, and needs to be expanded to participatory research-extension-farmer linkages to accelerate diffusion of technologies, wider adoption and impacts. Other major limitations concerned with feed resource use are failure to view this issue from a farming systems perspective, strong disciplinary bias, and poor links to real farm situations. It is suggested that improved efficiency in feed resource use and increased productivity from animals in the future needs to be cognisant of nine strategies. These include priorities for feed resource use; promoting intensive use of crop residues; intensification of integrated ruminant-oil palm systems and use of oil palm by-products; priority for urgent, wider technology application, adoption and scaling up; rigorous application of systems methodologies; development of adaptation and mitigation options for the effects of climate change on feed resources; strengthening research-extension-farmer linkages; development of year round feeding systems; and striving for sustainability of integrated farming systems. These strategies together form the challenges for the future. (**Key Words :** Feed Resources, Feed Security, Intensification, Case Studies, Integrated Systems, Systems Methodologies Perspectives, Technology Application, Research -extension- Farmer Linkages, Strategies, Asia)

---

## INTRODUCTION

Feed resources are the central components and drivers of production systems, whose efficient use dictates to a very large extent economic animal production in Asia. The efficiency of use of the available feed resources is

especially important as it is the primary determinant of animal performance and productivity. The justification for efficiency and intensive utilisation of the available feed resources is associated with two critical factors. Firstly, the production of foods of animal origin, and especially that from ruminants lags well behind the projected human requirements. The disparity relates to a two to three fold need for increased supply up to 2050 in most countries in Asia without exception. Secondly, feeding and nutrition

---

\* Corresponding Author: C. Devendra. Tel: +603-79879917, Fax: +603-79837935, E-mail: cdev@pc.jaring.my

have been consistently reported to be the major constraint to ruminant production in both South East Asia (Devendra et al., 1997) and South Asia (Devendra et al., 1999). Careful attention to this factor alone can significantly increase the contribution from animals.

A discussion on the available feeds and feed security is therefore timely, in the face of rapidly depleting resources - arable land, water, fossil fuels, nitrogen fertilisers that are produced from fossil fuels, phosphatic and other fertilisers that are mined. The crisis is compounded by looming climate change, spiralling food costs and financial crises, each of which is likely to be crucial (Leng, 2009a; Nellesmann et al., 2009). Decreasing land for crop cultivation for example, has been constrained by human population pressure and urbanisation, and exacerbated further by reduced crop yields. With food prices, at the beginning of 2008 (IMF, 2008), these were 150% higher than they had been in 2000 and, although these have decreased, they are still above the historic levels and pose a constant threat.

In the past, inexpensive grain, feed energy and protein enabled the economic development of intensive meat and milk production systems including grain-based dairy and beef production. With poultry and pig production these have developed into highly capital-intensive industrial, systems usually in peri-urban areas. However, with various limitations in the production resources for example with increased price of cereal grains, it is unlikely that the impressive growth and productivity rates of the past in the non-ruminant sector can be sustained in the future. They may even decline if the price of grain rise above a critical level, increases the cost of production, and possibly even become uneconomic. Additionally, these issues can also be exacerbated by increasing competition for arable land for food, feed and biofuel production.

It is suggested therefore that attention must shift to priority development of ruminants (buffaloes, cattle, goats and sheep) in key agro-ecological zones (AEZs), using to the extent possible more intensive use of the available biomass from the forage resources, crop residues as well as agro-industrial by-products (AIBP) and other non-conventional feed resources (NCFR). The justification for this priority focus rests directly with the potential multifunctional contribution in general, and especially their capacity for meat and milk production. The availability and rising fuel costs is also likely to see the re-emergence of animal draught power, particularly by small farmers. Concerted development can also benefit the weak ruminant sector in most countries, and more importantly the high concentration of cattle, goats and sheep that are very common in the neglected rainfed areas (non-irrigated marginal/less favoured+semi-arid and arid+forests and woodlands).

Within these areas there also exists the poorest of the poor people, poverty and hunger in Asia. Rainfed areas are sizeable in Asia and account for 66% of the total arable land area of 192 million hectares. It also accounts for 84% of Asia in the total priority arid/semi-arid, sub-humid and humid zones and 63% of the total rural population (TAC, 1992; CGIAR/TAC, 2000). For these reasons, it has been suggested that improved ruminant production should serve as the entry point for the development of the rainfed areas for increasing animal protein production and food security (Devendra, 2000; 2010a). This primary objective needs to be matched by ensuring the supply of adequate dietary nutrients to significantly increase animal performance and productivity on a year round basis.

The choice of production systems and the approaches for the efficient use of the feed resources are therefore together implicated, since both these factors will determine enhanced *per animal* performance. Low productivity is often associated with poor immune system response, resulting in the poor health status and condition of animals, so that improved protein nutrition alone can dramatically influence productivity gains (Leng, 2005). Currently, the efficiency of use of the feed resource within- and between-countries are very variable and range from underutilisation, incomplete utilisation, full utilisation to inappropriate utilisation, with concurrent effects on the national outputs of animal products. The reasons for this are associated with three groups of interrelated factors: *biological*, *methodological* and *institutional*.

This paper discusses the main issues involving these three groups of factors in the context of our understanding of how the available feeds are being managed, the extent, efficiency and their intensive use. Particular reference is made to relate these issues to several case studies and projects, trends in research and development (R and D), the lessons learnt, potential improvements, and strategies for productivity enhancement. It focuses on feed security and emphasises the fundamental issue that significantly improved and intensive use of the feed resources is essential to enable ruminants to play a more dominant role in the supply of meat and milk products for human requirements in the future. More particularly, based on current trends, the paper alludes to the strategies and necessary elements of institutional support that need to be more vigorously pursued for expanding intensification and integrated development to increase productivity from animals. The availability and use of the feed resources and constraints within crop-animal systems in Asia has been previously reviewed (Devendra and Sevilla, 2002).

## THE DAUNTING SCENARIO

The daunting scenario is that animals and their

management will be expected to significantly increase and expand their multifunctional role and productivity in the future. While this is good news for the owners and producers of animals, it also presents major challenges associated with production pathways. These include several awesome facts *inter alia* as follows:

- Agriculture is waning and its share to the gross domestic product (GDP) is declining in many countries, and in East Asia, the Pacific and South Asia, this has dropped from 3.0% in the 1980's to a mere 0.1 in 2000-2003 ( ESCAP, 2008)
- Significant rising incomes in most countries in Asia are driving a concurrent surge in the demand for foods of animal origin, which in the face of inadequate supplies is associated with rising prices for the products
- Urbanisation is on the increase, and in China, India and Vietnam for example, the average annual growth between 1990-2004 was 2.5-3.6% (World Bank, 2009)
- The first Millennium Development Goal to halve hunger and poverty by 2015 is on course to fail. A World Bank study indicates that 100 million additional poor people will be pushed back into poverty
- Poverty will be exacerbated by exploding food crises and rising cost of production inputs. The effects of globalisation will exert increased pressure on small farm systems and the livelihoods of poor livestock keepers due to competitiveness and transaction costs particularly in Asia
- The current trend in land acquisitions by foreign concerns, companies and individuals is of concern, as these impacts on food and feed, development of industrial systems, increased feed requirements and imports, displacement of small farmers, and loss of biodiversity that is maintained under small farm practices
- Inadequate productivity will exacerbate food and nutritional insecurity
- Global climate changes will affect biodiversity and animal performance. IFAD (2009) has reported that climate change is expected to put 49 million additional people at risk of hunger by 2020, and 132 million by 2050.
- A 2.5°C increase in global temperature above pre-industrialised levels will see major losses, with about 20-30% of the plant and animal species (IPCC, 2007).
- Climate change will also affect plant growth, the quantity and quality of crop residues produced, and therefore animal performance.
- The projected annual *per capita* consumption of meat and milk up to 2050 are 44 kg and 78 kg and 94 kg

and 216 kg respectively in the developing and developed countries respectively (Rosegrant et al., 2009).

- Shortfalls in dietary animal protein supplies are far more serious than supplies of energy from cereals. Strategies for productivity growth from animals are therefore urgent (Devendra, 2010b)
- Global resource depletion includes reduced arable land, irrigation water, mineral fertilisers (N, P, K and S) and financial credits.

## BIOLOGICAL FACTORS

The biological factors inherent in feed security include a number of key elements which are as follows:

### Total quantitative availability of feed resources

It is important to keep in perspective the categories and types of feeds available. This is fundamental to provide understanding of their efficient and potential use. Four categories of feeds are identifiable:

- i) Pastures and forages - these include native and improved grasses, herbaceous legumes and multi-purpose trees
- ii) Crop residues - these include such examples as cereal straws and maize stover
- iii) Agro-industrial by-products (AIBP) - good examples are cereal bran, coconut cake, palm kernel cake, soya bean meal, molasses, distillers dried grains and solubles (DDGS); DDGS will be available in the short term of expectations of about 40 million tonnes production until ethanol production from food crops is forced to decline by political pressure that ensure food security.
- iv) Non-conventional feed resources (NCFR)-this category includes diverse feeds and by definition refer to those feeds that are not traditionally used in animal feeding; examples are oil palm leaves palm press fibre, cassava foliage, spent brewer's grains, sugar cane bagasse, rubber seed meal and aquatic plants (Devendra, 1992).

The fibrous crop residues (FCRs), which have in common high biomass, low crude protein and high crude fibre content, of approximately 3-4% and 35-48% respectively. Egan (1989) subdivided crop residues into three categories:

- i) Those with low cell wall, crude fibre and lignin contents, and low *in vitro* digestibility (30-40%) and intake. These are not improved by chemical treatment
- ii) Contains low cell wall contents, medium digestibility (40-50%), and capable of some improvement with chemical treatment, and
- iii) Those with high cell wall contents, not highly lignified, high digestibility (50-60%) and intake.

These FCRs form the base in feeding systems for ruminants, and include all cereal straws, sugar cane tops, bagasse, cocoa pod husks, pineapple waste and coffee seed pulp. Most cereal straws and stovers have lower nutritive values than the haulms from grain legumes or vines from root crops. Complementary to FCRs are those crop residues that have higher protein content, and can therefore be used judiciously to improve the overall diet. This category includes a variety of oilseed cakes and meals, such as coconut cake, palm kernel cake, cottonseed cake, root crop foliages like sweet potato vines and cassava foliage are often used as dietary supplements. Sweet potato vines and peanut haulms for example are widely used to feed pigs in China and the Mekong countries. Quantitative estimates of the availability of feed resources and their use in Asia has been reviewed (Devendra and Sevilla, 2002).

Associated with above, it is particularly imperative to view feed resources from a farming systems perspective and also consider the following interrelated issues:

- Knowledge of the totality and quantitative availability of feeds (forages, crop residues, AIBP and NCFR)
- Understanding their physical characteristics, nutrient composition and digestibility
- Potential inclusion and efficiency of use in production systems
- Noting that the cost of feeding as percentage of total production costs, which account for about 50-60% in ruminants (meat and dairy), and 65-80% in non-ruminants (meat and eggs) in intensive production systems, and
- Self-reliance in the use of feeds.

A brief discussion on some of these aspects is important:

#### **Country situations on the availability of feeds**

Very few countries in Asia have undertaken a quantitative or even qualitative assessment of the availability of feeds. The primary reason for this is probably one of inadequate methodology and understanding of approaches for the assessment. In approximate terms, the quantitative data can be determined from three primary approaches:

- i) Knowledge of the area under crops with feed production potential such as cereals and tree crops like coconuts and oil palm using extraction rates that have been derived experimentally and from the field, for example for NCFR (Devendra, 1992)
- ii) Applying forage dry matter yields for wayside grazing and total road mileage, cereal bunds, undergrowth in tree crops and forest margins, and land area under introduced grasses and legumes
- iii) Similarly also, for the more extensive grazing areas in rainfed environments, including the rangelands.

Using these approaches, it should be possible to quantify approximately the total availability of feeds from the main sources of production. These estimates have been attempted for Peninsular Malaysia (Devendra, 1982), the Philippines (Sevilla, 1994), and specifically for oil palm areas in South East Asia (Devendra, 2009). Feed balance sheets have also been attempted to assess availability and requirements for India and Pakistan, where chronic deficits are common such as in India (Mudgal and Pradhan, 1988; Raghavan, Krishna and Reddy, 1995; Ramachandra et al., 2007) and Nepal (Shrestha and Pradhan, 1995).

Two general conclusions emerge from these various reports:

*Humid areas* - For the humid tropics in most parts of South East Asia such as Malaysia and the Philippines and the Mekong countries, there is underutilisation of plentiful and various types of feeds. This implies considerable opportunities for increased carrying capacities, expanding animal numbers, conservation of surpluses, and commercial production of feeds,

*Semi-arid and arid regions* - By comparison, in the more difficult semi-arid and arid regions of South Asia, there are consistent feed deficits, under-nutrition and reduced productivity from animals. In a recent assessment of the situation in India for example, Ramachandra et al. (2007) assessed the feed resource situation in six AEZs using secondary data and gross assumptions and concluded that in terms of dry matter availability, there was a 10-11% inadequacy to meet the requirements. In these circumstances, a combination of ways of using all available feeds to the extent possible, and exploring increased forage production and conservation are important strategies. The latter is exacerbated by increasing pressure on land use by rapidly rising human and animal populations.

The paucity of information on quantitative aspects of feed availability emphasises the importance and opportunities for more vigorous research on the subject. Issues relevant for this are more detailed and accurate information on land use systems for individual crops, extent of crop cultivation, data on extraction rates for different types and varieties of individual crops, and estimated availability on feeds. Geographical information systems (GIS), satellite surveillance and imagery, and other appropriate techniques will also have a potential role here. An overriding need is that of appropriate methodology to understand feed resources.

Individual countries need therefore to be encouraged to be more pro-active to apply innovative methodologies for understanding of the feed resource base and ways of assessing their characteristics, approximate total availability, and potential value. Additionally, they also need to be made more aware of other factors that may influence these

elements in the future, such as the access to irrigation water and the increasing cost of fertilisers. This is a major concern with many irrigated crops where ground water levels are falling, water is increasingly costly to pump, and the looming concerns of climate change with snow melting and river flows out of synchrony with the cropping needs.

### **Chemical composition and nutritive value**

Most if not all the countries in the Asian region have good documentation on the chemical composition and nutritive value of feeds in published or unpublished form. Even if they did not have it, much of the data for the more common feeds such as grasses and crop residues are accessible from the neighbouring countries and other sources. There is therefore no need for further work and wasteful of funds on this matter.

The only exception to this is for new feeds which have not been characterised, chemical composition data is inadequate or unknown, and those with anti-nutritional properties. The latter include bio-active compounds such as alkaloids, phenolics and tannins. Plants containing above 5% tannins usually tend to have anti-nutritional properties.

Attention is drawn to the recent creation and availability recently of a website and database on tables of nutritive value for farm animals in tropical and Mediterranean regions. The database is a joint INRA/CIRAD/AFZ project supported by FAO and has data sheets on characterisation, composition and nutritive values, uses, and feeding recommendations for the main livestock species. It will be the largest repository and database on nutritive values, access and use of which will have a significant impact on improved animal performance and productivity.

### **Palatability and intake**

Palatability, physical characteristics and deficiencies of critical essential minerals and crude protein influence feed intake, and are important parameters that are associated with total feed availability and feed quality. It is important therefore to also assess the extent of the dietary value to animals of forages and feeds alike. In turn, the extent of this biomass availability and potential use will determine an approximation of carrying capacity, animal productivity and potential improvements.

### **Definition of successful and failed projects**

In order to provide good understanding of the success or failure of individual projects, their analyses and the discussions, it is necessary to define these elements to keep the issues in perspective. We provide the following definitions:

- **Successful** - projects that are able to meet the objectives, contribute especially to food security and increased income, and show evidence of acceptance,

adoption and replication by farmers. Additionally, the projects also demonstrate potential to contribute to self-reliance, stable farm households, and sustainable development. Successful projects also recognise systems perspectives, are usually associated with effective participatory research-extension-farmer linkage, and are often associated with the significant contribution of women to animal production. These issues also have to be sustainable or be able to be modified as resource availability and costs escalate in the future.

- **Failure** - projects that are associated with poor understanding and unsuccessful realisation of the objectives, inadequate technical know-how, are weak, do not have participatory application, have increased costs, do not fit into a time frame, and do not mesh with the farm calendar. The beneficial aspects in socio-economic terms are unrealised and not appreciated. Consequently, the projects do not produce tangible impacts, are seldom considered for wider scaling up, testing and adoption on farm. The poor results impede the incorporation of the technology to enhance wider development of sustainable production systems.

## **ANALYSES OF CASE STUDIES ON FEED RESOURCE USE**

Using the above criteria, it is now appropriate to provide more insights on the results of feed resource use, it is useful to analyse the objectives of a variety of projects and the results from them. In analysing these, it is stressed that the list of projects chosen is by no means exhaustive, knowing that there are numerous other projects both successful and failed, detailed project data for which are not easily accessible. The intention here is to highlight the key elements in the experiences from a variety of projects. For reasons of brevity therefore, a comprehensive range of different types of projects have been chosen in which feed resource use and productivity were central objectives.

Table 1 summarises the findings in 12 projects, including a network project in several countries in Asia. The table indicates the type of project, system or technology applied the objectives and the results. Particular attention is drawn to the last two columns with the headings of lessons learnt, opportunities and challenges; these have implications for the future. The projects reflect a range of findings and issues relevant to project design, objectives, key participants, delivery systems and other features that are conducive to ensuring success. The main results of many of these case studies have been reviewed (Devendra, 2010a), but for illustrative purposes, the key results, impacts and lessons learnt from three different types of projects from out of the twelve are given below.

**Table 1.** Analysis of various case studies on feed resource use, lessons learnt and challenges in Asia

No	Type of project/system and/ technology application	Objectives	Location	Successful (S) or failure (F) and key performance indicators	Reference	Lessons learnt	Opportunities and challenges
1	Three-strata forage system	<ul style="list-style-type: none"> <li>· Increase income</li> <li>· Improve livelihoods</li> <li>· Self-reliance</li> </ul>	Bali, Indonesia	<b>S</b> <ul style="list-style-type: none"> <li>· Increased annual performance</li> <li>· Increased FS*</li> <li>· Increased income</li> <li>· Self-reliance</li> <li>· Institutionalisation of the concept</li> </ul>	Nitis et al. (1990)	<ul style="list-style-type: none"> <li>· Rigorous participatory efforts</li> <li>· Close monitoring</li> <li>· Commitment</li> </ul>	<ul style="list-style-type: none"> <li>· Scaling up</li> <li>· Potential application particularly in semi-arid AEZs in Asia and Africa</li> </ul>
2	Food-feed system	<ul style="list-style-type: none"> <li>· Increase forage supply</li> <li>· Improve soil fertility</li> <li>· Diversification</li> <li>· Sustainability</li> </ul>	Pangasinan, Philippines	<b>S</b> <ul style="list-style-type: none"> <li>· Increased forage supply</li> <li>· Increased FS</li> <li>· Increased income</li> <li>· Stable cropping systems</li> <li>· Increased live weight gain</li> </ul>	Carangal and Sevilla (1993)	<ul style="list-style-type: none"> <li>· Adaptation R&amp;D</li> <li>· Choice of forage legume</li> <li>· Value-addition to rice crop</li> </ul>	<ul style="list-style-type: none"> <li>· Wider adaptation in S.E.Asia</li> <li>· Use of alternate forages in cropping systems e.g. Cassava and <i>Gliricidia</i></li> </ul>
3	Integrated oil palm-ruminant system	<ul style="list-style-type: none"> <li>· Improve animal performance</li> <li>· Increase income</li> <li>· Promote integrated NRM**</li> </ul>	Malaysia	<b>S</b> <ul style="list-style-type: none"> <li>· Increased fresh fruit bunches</li> <li>· Value-addition to oil palm</li> <li>· Increased total factor productivity (crop and animal)</li> <li>· Reduced cost of oil palm production</li> </ul>	Devendra (2009)	<ul style="list-style-type: none"> <li>· Strong feasibility</li> <li>· Integrated production system</li> <li>· Demonstrable sustainability</li> </ul>	<ul style="list-style-type: none"> <li>· Stratification</li> <li>· Increased breeding of animal numbers</li> <li>· Animals for growth and fattening <i>in situ</i></li> <li>· C sequestration</li> </ul>
4	CCotton seed supplementation	<ul style="list-style-type: none"> <li>· Increase beef production</li> <li>· Use of treated straw</li> </ul>	Hunan, China	<b>S</b> <ul style="list-style-type: none"> <li>· Increase income</li> <li>· Increased beef and milk production</li> <li>· Cattle growth rates was 75 % of the rate from feeding grains</li> <li>· Reduced marketing time</li> </ul>	Dolberg and Finlayson (1995)	<ul style="list-style-type: none"> <li>· Innovative use of local feeds</li> <li>· Reduced dependence on purchased concentrates</li> <li>· Strong government support</li> </ul>	<ul style="list-style-type: none"> <li>· Wider adoption</li> <li>· Reduced imports of concentrates</li> </ul>
5	NH <sub>4</sub> treated rice straw utilisation	<ul style="list-style-type: none"> <li>· Increase intake</li> <li>· Increase use of rice straw for ruminants</li> </ul>	Many locations in Asia	<b>F</b> <ul style="list-style-type: none"> <li>· Variable results</li> <li>· Limited evidence of cost-effectiveness</li> </ul>	Devendra (1997)	<ul style="list-style-type: none"> <li>· Weak on-farm methods</li> <li>· Lack of uniform methodologies e.g. urea level</li> <li>· Overemphasis on on-station research</li> </ul>	<ul style="list-style-type: none"> <li>· Scaling up on-farm</li> <li>· Strategic supplementation with treated straw</li> <li>· Increased use of leguminous forage supplements</li> <li>· Economic benefits</li> </ul>
6	Rice – fish – ducks system	<ul style="list-style-type: none"> <li>· Increase income</li> <li>· Promote integrated NRM</li> <li>· Promote sustainability</li> </ul>	Sukamandi, Indonesia	<b>S</b> <ul style="list-style-type: none"> <li>· Increase income</li> <li>· Increased FS</li> </ul>	Suriapermana et al. (1988)	<ul style="list-style-type: none"> <li>· Feasibility in small farm</li> <li>· Positive rice-fish-ducks-integration</li> <li>· Understanding the interactions</li> </ul>	<ul style="list-style-type: none"> <li>· Wider adoption</li> <li>· Scaling up</li> <li>· Demonstrate sustainability</li> </ul>
7	Rice-fish-pigs-ducks system	<ul style="list-style-type: none"> <li>· Promote integrated NRM</li> <li>· Increase income</li> <li>· Achieve sustainability</li> </ul>	Hanoi, Vietnam	<b>S</b> <ul style="list-style-type: none"> <li>· Increased FS</li> <li>· Increased productivity</li> <li>· Increased income</li> </ul>	Nguyen Thien et al. (1996)	<ul style="list-style-type: none"> <li>· Understanding the natural resources</li> <li>· Value of crop-animal-soil interaction</li> <li>· Value of ponds</li> </ul>	<ul style="list-style-type: none"> <li>· Wider adoption</li> <li>· Sealing up</li> <li>· Policy support</li> </ul>
8	Rice-fish-azolla-duck system	<ul style="list-style-type: none"> <li>· Promote integrated NRM</li> <li>· Assess effects and benefits of the interactions</li> </ul>	Munoz, Philippines	<b>S</b> <ul style="list-style-type: none"> <li>· Increased rice yields</li> <li>· Increase fish and duck yields</li> <li>· Increased FS</li> </ul>	Cagauan et al. (1996)	<ul style="list-style-type: none"> <li>· Importance of interactions</li> <li>· Value of sub-systems</li> </ul>	<ul style="list-style-type: none"> <li>· Wider adoption</li> <li>· Scaling up</li> </ul>
9	Multinutrient urea-molasses block licks (MNUMBL) in dairy production system	<ul style="list-style-type: none"> <li>· Increase milk yield</li> <li>· Improve livestock of farmers</li> <li>· Promote self-reliance</li> </ul>	Anand, India	<b>S</b> <ul style="list-style-type: none"> <li>· Increased socio-economic benefits</li> <li>· Increased food and nutritional security</li> <li>· Strong cooperative development</li> <li>· Self-reliance</li> </ul>	Preston and Leng (1984)	<ul style="list-style-type: none"> <li>· Power of empowerment</li> <li>· Effective technology application</li> <li>· Strong participatory efforts with farmers</li> </ul>	<ul style="list-style-type: none"> <li>· Training</li> <li>· Strong institutions support</li> <li>· Policy support</li> <li>· Cooperative development</li> </ul>

**Table 1.** Analysis of various case studies on feed resource use, lessons learnt and challenges in Asia (Continued)

No	Type of project/system and/ technology application	Objectives	Location	Successful (S) or failure (F) and key performance indicators	Reference	Lessons learnt	Opportunities and challenges
10	Forage option for crop-animal system	· Increase forage supplies · Provide forage options	19 sites throughout S.E.Asia	<b>S</b> · Access to option · Feed for animals · Control of soil erosion	Sturr et al. (2001)	· Importance of providing forage options · Participatory approaches · Supporting local production of forage	· Priority for forage development · Scaling up · Training
11	Sloping agricultural land technology (SALT)	· Sustainable alley farming · Increase income	Mindanao, Philippines	<b>S</b> · Increased FS · Increased income · Integrated NRM	Laquihon, Suico and Laquihon (1997)	· Importance of forage options · Value of crop – animal – soil interaction	· Potential application for uplands · Sustainable crop – animal system
12	Asian farming system research network (AFSRN)	· Promote crop – animal system research · Develop system methodologies · Promote understanding of systems perspectives · Strengthen R&D capacity in national programs	72 sites and 9 countries in Asia	<b>S</b> Sustainable agriculture · Increased FS · Increase income · Increase crop yields · Improved understanding of systems perspectives · Strengthened R&D capacity · FSR activities expanded to 14 countries	Carangal and Sevilla (1993)	· Strong network coordination · Institutional support · Sustained funding	· Accelerate information flow · Expand network collaboration · Institutionalisation in national programs · Promote inter-regional information dissemination and cooperation e.g. Asia, Africa and Latin America.

\* FS = Food security. \*\* NRM = Natural resource management.

### Three-strata forage system (Indonesia)

An outstanding example of a strategy that provides a technical basis for development, and is appropriate to systems combining animal production with annual and perennial cropping, is the three-strata forage system (TSFS) in Bali, Indonesia. It has been developed over nine and half years to match the drier low rainfall environment (600-900 mm annual rainfall and 4-8 months dry season). The concept and technology development integrates cash cropping and ruminant production (mainly cattle and goats) in a sustainable crop-animal system, and enhances efficient use of the natural resources especially for small farms. The system and its replicability were developed over nine and a half years of R and D and also have potential application for semi-arid areas in Sub-Saharan Africa (Devendra, 2010).

The TSFS is an integrated way of planting and harvesting forages so that a source of feed is available 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 stratas. The first stratum 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 feeds for the late dry season. The grasses, legumes and trees used were as follows:

#### Strata 1

Grasses: Buffel (*Cenchrus ciliaris*) and Green Panic (*Panicum maximum*)

Legumes: Stylo (*Stylosanthes gracilis*), Centrosema (*Centrosema pubescens*) and Caribbean stylo (*Stylosanthes hamata*)

#### Strata 2

Shrubs: Gliricidia (*Gliricidia sepium*), Leucaena (*Leucaena leucocephala*)

#### Strata 3

Fodder trees: Ficus (*Ficus poacellie*), Hibiscus (*Hibiscus tilleacius*), Lannea (*Lannea corromandilica*).

The major highlights of the systems (Nitis et al., 1990) are:

- Increased forage production enabled higher stocking rates (3.2 animal units/ha) and total live weight gains of 375 kg/ha/year in the TSFS compared to 2.1 animal units and 122 kg/ha/year in the non-TSFS.
- Cattle in the TSFS gained 90% more live weight and reached market-weight 13% faster. Also farmers benefited by a 31% increase in farm income
- The introduction of forage legumes into the TSFS reduced soil erosion by 57% in TSFS compared to the non-TSFS, together with increased soil fertility

- The presence of 200 shrubs and 112 trees logged twice a year produced 1.5 tons/year of firewood, which met 64% of the farmers' annual firewood requirements. This integrated production of food, feed and energy merits major development attention
- The integration of goats in addition to cattle into the system, further increased the farmers' income, and
- Institutionalisation of the concept and the technology.

#### Increased beef production based on ammoniated straw and cotton seed cake

Cereal straws in particular and also crop residues form the main base in feeding systems throughout Asia. These can support moderate-high levels of production in ruminants provided there is efficient means of treating the straw to enhance digestibility and also appropriate supplementation to correct any deficiencies of dietary nutrients. With the provision of additional by-pass proteins, levels of production and efficiency of use of biomass for growth and milk production are greatly improved (Leng, 1991; 2004). The improvement in utilisation of straw by ruminants by adhering to these simple principles is now well demonstrated. In northern wheat belt of China cattle growth rates on straw, with enhanced digestibility approached 0.9 kg per day or 75% of the rate that could be achieved with similar animals fed grain based feed lot diets (Cungen et al., 1999). At these growth rates the numbers of animals that can be fattened on the same quantity of untreated straw increases 10-13 folds (Table 2). The impact of the results is reflected in many Chinese farmers are recording similar growth rates. Similar good responses have also been noted with milk production.

In India milk production, largely from cows fed straw has escalated by the application of good nutritional principles among other applications (Banarjee, 1994). In Vietnam's Mekong Delta the wet season rice straw crop is now being both preserved and treated by adding urea to the wet harvested straw, that at harvest time has higher

nutritional value than the dry season straw and with suitable supplements large increases in animal production are being promoted. As the wet season straw was normally discarded the potential to increase productivity is very high (Le Thi Thuy Hang et al., 2003).

#### AFSRN project

The Asian Farming Systems Research Network (AFSRN) project with its objectives of promoting crop-animal systems research, development of systems methodologies, understanding of systems perspectives, and strengthening of R and D capacity in national programs was established in the 1970s to do research mainly on rice. It started as a cropping systems network. In 1993 the animal component was added to the network to give emphasis to crop-animal systems and also address the totality of farming systems. Some 72 R and D sites in nine countries participated in the network.

Over a period of some 16 years it was very effective in promoting the importance of system perspectives and systems research and methodologies relevant to farming systems research. Increased research capacity was apparent in 14 countries in Asia resulting in institutionalisation of crop-animal systems research. Research Institutes were formed in the Philippines and Thailand, and farming systems offices in Bangladesh, Indonesia, Nepal and Pakistan. In India for example, a Cropping Systems Directorate was established involving 16 Universities (Carangal and Sevilla, 1993).

Considering the results of the range of projects in Table 1, a number of observations merit highlighting:

- With one exception, all the projects except one were successful in meeting the objectives, especially in food security and increased income
- The increased income in all cases was due to higher crop yields, improved animal performance positive crop-animal-soil interactions and impacts

**Table 2.** The potential of balanced supplementation to increase meat production from young cattle fed low quality crop residues treated to increase digestibility<sup>1</sup>

	Cottonseed supplement fed (kg/d)					
	0	0.25	0.5	1.5	2.0	2.5
Live weight gain (g/d)	63	370	529	781	829	892
Straw consumed to produce 100 kg live weight (tonnes)	6	1.1	0.92	0.56	0.48	0.46
Cottonseed cake consumed (tonnes) to produce 100 kg live weight	0	0.1	0.1	0.14	0.22	0.24
Number of animals that can achieve an extra 100 kg of live weight on 6 tonnes of straw	1	5+	6+	10+	12+	13+
Protein meal requirements (tonnes) to allow 100 g live weight gain per group of animals fattened	0	0.5	0.6	1.4	2.6	3.1
Conversion of protein meal to live weight (g live weight gain/g feed concentrate)	-	1.2:1	0.93:1	0.48:1	0.26:1	0.31:1

<sup>1</sup> The calculations are based on the data from research in Hebei, China (Dolberg and Finlayson, 1995).



- The key lessons learnt were the importance of strong participatory efforts with farmers, close monitoring, innovative use of local feeds, importance of technology options for farmers e.g. forages
- The power of training and empowerment not only of farmers, but also of the researchers was significant. Strong institutional support was essential
- Where integrated natural resource management (NRM) is involved, the combined total factor productivity from the sub-sectors was significant
- Wider adoption and scaling up were clearly wanting in all projects, and pathways to enhance this do not appear to have been considered in project formulation
- Except in one project, promoting cooperative development was not considered
- Systems methodologies were not always clear, especially in those projects that emphasised productivity -enhancing technology application
- Several of the projects (No. 1, 4, 5, 7, 8, 10 and 12) owe their success to donor funding, close linkages with researchers and farmers, and close monitoring. In

addition to the projects' success, there was also strengthened R and D capacity in national programs

- The importance of networks and networking in strengthening R and D capacity, NRM, institutionalisation of the concept, understanding of systems perspectives, and improved agriculture was abundantly clear in the AFSRN project.

### COMPONENT TECHNOLOGY APPLICATIONS

Component technology refers usually to single interventions or applications that envisage a predictable benefit often without necessarily considering the total production system and value chain. These are mainly response-oriented, driven by the need for quick results, are easily researchable and managed. They do not require much capital investments. By their very nature and convenience, the bulk of the research tends to be of a fundamental nature and is essentially conducted in experimental stations and university laboratories. Throughout the Asian region, component technology applications concerning the use of

**Table 3.** Examples of component technology applications concerning the use of a range of feeds, the purpose and results in Asia

No.	Component technology	Animal species	Location	Purpose and predictable results
1	Supplementation with forage e.g. <i>L.leucocephala</i> ), cassava leaves	Ruminants	Numerous (e.g. Indonesia, Philippines and Thailand)	· Increase dietary protein · Increase intake · Improve meat and milk production
2	Supplementation with duck weeds ( <i>Lemna spp.</i> )	Pigs	Vietnam	· Increase live weight growth
3	Treatment of cereal straws	Ruminants	Numerous (e.g. India, Sri Lanka and Thailand)	· Increase intake · Promote higher animal performance
4	Urea –molasses block licks (UMBL)	Ruminants	Numerous countries (e.g. India, Pakistan and Thailand)	· Increase intake · Increase dietary nutrient supply · Increase animal performance
5	Oil palm by-products	Ruminant and non-ruminants	Malaysia	· Increase supply with palm kernel cake · Feed lots · Increase productivity
6	Maize and sorghum stovers	Large ruminants	China, India and Pakistan	· Roughage supply · Increased draught supply
7	Sugarcane by-products	Ruminants	India, Pakistan and Philippines	· Increase intake · Increase performance
8	Sugar palm juice	Pigs	Cambodia	· Increase growth rate
9	<i>Azolla (Azolla microphylla)</i>	Fish and non-ruminants	China, India, Japan, Philippines and Vietnam	· Increased productivity · Sustainability
10	Sweet potato roots and vines ( <i>Ipomoea batatas</i> )	Roots and vines –pigs Vines – to ruminants	China, Vietnam, Philippines and Indonesia	· Increased intake · Increased live weight growth
11	Poultry litter	Beef cattle	Philippines and India	· Substitution of purchased dietary proteins · Lower cost of production
12	Spent tea leaves	Cattle	India and Sri Lanka	· Use up to 20% dietary level

feed resources have been widespread in programs that appear to be inadequately rationalised. Many of the component technology projects are often unknowingly duplicated with similar results. More importantly, the research programmes are generally not linked to delivery systems where useful information and technologies that are developed can be subject to more adaptive R and D on farm with the participation of farmers.

Table 3 gives examples of component technologies involving a wide variety of feed resources that have been used in many countries. The results are a mix of successes and failures in which the final details are not always documented. Failures have been associated with lack of understanding and application of the technical know-how, inadequate participatory activities, disinterest, weak delivery systems, increased costs and time. More importantly, the beneficial aspects were seldom considered in terms of wider scaling up and testing on farm in order to promote and incorporate the technology into the development of sustainable production systems.

### METHODOLOGICAL FACTORS

A major limitation concerning feeding systems methodologies and feed resource use is the failure to view these aspects from a farming systems perspective. On the contrary, strong disciplinary emphasis continues in R and D, which often does not link with the real constraints to increase productivity and impacts at the farm level. This in turn affects the following considerations:

- Full knowledge of the availability and potential efficiency of use in production systems that can give predictable levels of performance
- Identification of the objectives of production clearly in terms of potential use, production and profitability
- Recognising that the cost of feeding in individual animal production systems as percentage of total production costs is relatively high and rising, in both ruminants (meat and milk), and in non-ruminants (meat and eggs) in intensive production systems
- Ensuring that the resulting benefits in the efficient use of the available feed resources are consistent with environmental sustainability and development, and
- Self-reliance in the use of available feed resources.

Farming systems research (FSR) is central to efficient NRM in that it provides a well defined approach and methodology that is based on careful problem identification and their resolution. The key features of FSR are that it seeks to provide a good understanding of the farming systems and practices; is needs-based; has systematic methodology; is multidisciplinary; involves the participation of farmers, researchers, community, extension agents, and development agents; and is on-farm. Systems

perspectives ensure that there is a well organised and sequential R and D process that looks at issues in holistic terms. Systems perspectives and systems approaches directly link researchers, extension agents, farmers and is holistic and impact-oriented. It also enhances the research - extension- farmer linkages of great assistance to farmers.

### Research-extension-farmer linkages

Associated with FSR and systems perspectives are research -extension- farmer linkages which are synonymous with technology transfer. It is the traditional model that is used for the technology delivery pathway. Public sector extension services and their efficiency vary between-countries and program focus. Presently the subject constitutes a dilemma. The dilemma stems from concerns about its scope and effectiveness, the technical capacity and commitment, skills of the extension agent, understanding of the various constraints to development, and the methods that are used for diffusion in producing the desired change. These issues are especially relevant at the present time when agriculture is waning and there is a need for more innovative strategies to deal with the changing environment, NRM and food insecurity issues. Additionally, multidisciplinary R and D personnel and extension agents need to remember that there will be increasing pressures on farming in the future which will require more foresight and innovation to cope with emerging issues such as the future cost of energy.

To improve the situation, it has recently been suggested that there is a need to transform agricultural education and develop appropriate formal curricular that combines strong disciplinary orientation, systems perspectives and systems methodologies. These include specialisation at the university level that reflects strong training in agricultural systems, resource management and its implications for the future and the environment (Devendra, 2011). Non -formal education and training also needs to be intensified at different levels, including the training of trainers as agents of change.

### INSTITUTIONAL FACTORS

#### The impact of empowerment and self-reliance

At the heart of all education and training is empowerment. Empowerment enables people to have control and use of their own resources, set their own agendas, and work towards achieving their aspirations. In order to achieve these, they should have access to information and services, and a developed capacity to determine their own future. In the long term, this development also enhances self-reliance, that is, ability to be resourceful to the extent possible with minimum dependence on more expensive external inputs. The education of women has powerful beneficial effects on

agricultural development to include *inter alia* decision making, food and nutritional security, health, productivity, alleviation of poverty and the stability of farm households.

The intent to manage and use their own resources, and articulation of this objective is a direct result of empowerment and self-reliance. In this context, it is instructive to summarise a case study on the uniquely success story of “Operation Flood” in India. This is as follows:

- The producers of large supplies of buffalo milk from the rural areas of the Kaira district to Bombay (now Mumbai) were disturbed by the unfavourable price and market conditions to which they were exposed to.
- In January 1946 they met and resolved to establish Milk Producers’ Societies in each village of the Kaira district in order to collect milk from their members. The Kaira Milk cooperatives consists of a two- tier system with the District Milk Producers Cooperative at the central level, and more than 850 village Milk Producers Cooperative Societies at the village level
- The formation of these provided a position of strength to argue for a guaranteed and appropriate price of milk higher prices of milk in the strong Bombay market. In addition it marginalised the middlemen who exploited the marketing system
- Each Cooperative Society maintains a Milk Collection Centre with trained staff. Milk is received morning and evening, tested for quality, and payment is made for the milk delivered at the previous collection
- The creation of a Women’s Dairy Cooperative Leadership Programme has significantly empowered women in livestock keeping activities, and enabled them to gain more control over the sale of milk and disposal of the income with resultant increased household stability
- Today, the Kaira District Cooperative Milk Producers Union is a Confederation supplying milk to the dairy plant owned by the producers, and for the various products: butter, cheese, ghee, milk powder, baby foods and chocolate. AMUL the trade name under which the products are marketed is well known

throughout India .AMUL is the acronym for Anand Milk Union Limited, as well as “beyond price” in the local language.

- A comparison of incomes from buffalo milk and cow milk in villages with and without cooperatives indicated that the respective figures were 51% and 62% in the former (Sivastra, 1970).
- The AMUL complex continues to demonstrate the benefits of integrated education, research, extension and training activities, and the importance of cooperatives. The production and wide use of multivitamin molasses urea block licks (MNUMBL) for the dairy animals and the recent construction of plants to protect dietary proteins is a measure of effective training, rapid adoption of innovative feeding technology and self-reliance.
- The Cooperative Dairy Development in Anand has brought about profound social and economic impacts. The whole fabric of rural life has been enhanced along with increased milk supplies and nutritional well-being and health, higher income, household stability, village cohesiveness, increased security, employment opportunities.,and pride in dairy development.

The Anand model of India’s “Operation Flood” integrates many important elements. It involves some 13 million farming families and processing about 90 million kg of milk per year, making farmers shareholders of the whole chain of marketing and processing of milk, with resultant improvements to their livelihoods.

### STRATEGIES FOR ENHANCING PRODUCTIVITY FROM ANIMALS

The foregoing analyses and discussions clearly emphasises the need for affirmative action that can contribute collectively to feed security and improved efficiency in the use of the available feed resources. The strategies identified below are particularly important to ensure this efficiency.

#### Priorities for feed resource use

Along with improved understanding of types,

**Table 4.** Priorities for the use of non-forage feed resources in Asia (Devendra, 1997)

Type of feed	Nutrient potential	Species (product/service)
Good quality (e.g. oilseed cakes and meals, cassava leaves) >35% CP	High-protein, high energy supplement, minerals	Pigs, chickens, ducks, ruminants (milk, meat)
Medium-quality (e.g. coconut cake, palm kernel cake, sweet potato vines) 15-35% CP	Medium-protein	Pigs, chicken, ruminants (milk, meat)
Low-quality (e.g. cereal straws and stovers, palm press fibre) <15% CP. Most cereal straws 6-8% CP	Low-protein, very fibrous	Ruminants (meat, draught), camels, equines

availability and nutritional value of feeds, it is equally important to have priorities for their use. The priorities for use are determined by potential value to individual animal species, quantities available, and production location. Priorities for feed resource availability and use also enables home mixing of feeds and concentrate diets for higher yielding animals like dairy buffaloes and cows.

With specific reference to non-forage resources, Table 4 provides three categories of feeds with examples:

- i) *Good quality* - high nutrient content and used strategically mainly for non-ruminant production and milk production in dairy buffaloes, cows and goats
- ii) *Medium quality* - also useful for production in non-ruminants and ruminants
- iii) *Low quality* - mainly FCRs which provide energy for maintenance and for draught in adult ruminants, camels and equines.

Leng (1990; 2009a) have emphasised the following priorities in ruminant nutrition to optimise production from the available feed resources:

- Optimise forage digestibility
- Ensure that feed particle size optimises intake
- Balance the nutrition of rumen microbes to ensure maximum growth with:
  - > Macro and micro minerals
  - > A source of ammonia
  - > Sulphur and phosphorus
- Ensure adequate mineral nutrition
- Feed additional "escape proteins" in catalytic amounts.

With some abundant tropical foliage allowing the animal to select can have enormous benefits through increased feed intake of the most nutritious parts e.g. sugar cane tops. Early work in Mauritius showed that allowing animals to select and using cottonseed meal as the supplement had huge benefits on milk yield.

### Promoting intensive use of crop residues

Increasing productivity from ruminants in the future implies a need for more intensive utilisation of crop residues. The rationale for this is not only the very need to do it, but also the fact that the prevailing production systems are unlikely to change in the foreseeable future (Mahadevan and Devendra, 1986; Devendra, 1989), notwithstanding increasing intensification. 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 especially various leguminous forages as supplements. The potential of these is unexplored and their use as supplements can be intensified (Leng and Devendra, 1995).

Straws have a number of uses, and current feeding practices to ruminants are without appreciation of

production responses that could be achieved with treatment and supplementation. Straws can support moderate-high levels of production in ruminants provided efficient means of treating the straw to enhance digestibility and any deficiencies of nutrients in a diet are corrected. If additional by-pass protein is then provided, levels of production and efficiency of use of biomass for growth and milk production are greatly improved (Leng, 2004). Cereal straws need targeting to implement the known advances on their treatment to improve nutritive value, as well as nutritional strategies via supplementation to increase straw use by ruminants. The scientific basis of feeding supplements to ruminants fed on poor quality forages has been discussed in a number of papers (see Preston and Leng, 1987; Leng, 1991; 2004), and the efficient use of such feeds is a major way to increase animal protein for human consumption in the future. There is no reason why these technologies cannot be put to intensive use and adopted more widely in Asia.

The world produces just fewer than two billion tonnes of cereal grains which is accompanied by about the same yield as the grains (Plate 1). Leng (2009a) has calculated that with the vast majority of some 1,800 million large ruminant equivalents, which are largely low producing, these can be upgraded to moderate to high levels of production with modern technology. The two billion tonnes of straw could be converted into animal products with a feed conversion efficiency of about 10:1 to produce 200 million tonnes of live animal annually which could support four billion people at 25 kg/year. With effective technology application, ruminant production systems could therefore be the major development pathway for the production of animal proteins in the future.

Ruminant production from poor quality roughages like cereal straws has a downside concerning methane



**Plate 1.** Straws can support moderate-high levels of production in ruminants with efficient means of treatment and supplementation. Photo shows rice straw conservation for feeding ruminants in Cambodia (C. Devendra).

production. There are two aspects to this:

- Firstly, slow growth, low milk yield and poor reproductive performance result in poor feed conversion and a large methane output relative to product output (see Leng, 1991). The benefits of high growth rates as a means of reducing methane production per unit of meat production have been confirmed from direct measures of methane output. Provided growth rates (in cattle) are between 0.7 and 1 kg/d, methane production will be minimised and these upper levels of growth are being achieved with cattle fed crop residues (see for example Dolberg and Finlayson, 1995).
- More recently on the other hand, 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).
- Additionally also 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 50% reduction

in methane production by sheep fed nitrate with sulphate 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 replacing urea in a sugar cane /concentrate based diet (Hulshof et al., 2010). This is a major step forward in ruminant nutrition and production.

### Intensification of integrated ruminant-oil palm systems and use of oil palm by-products

Among the ruminant production systems, integrated ruminants systems or silvopastoral systems are very underestimated and merit more development attention. The system enables *inter alia* stratification of production such as in national breeding programmes, producing numbers to support production systems, and *in situ* use of crop residues and by-product feeds from the parent crop (Plate 2). The oil palm is a particularly important “golden crop in Asia”. 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, followed by much smaller areas being found in Thailand, Philippines, India and Papua New Guinea.

A review of available data involving cattle in integrated systems indicates the following beneficial economic impacts: increased productivity from animals and offtakes, increased yield of fresh fruit bunches (FFB) by about 30% with measures of between 0.49-3.52 mt/ha/yr, increased income, savings in weeding costs by about 47-60%, equivalent to 21-62 RM/ha/yr, and an internal rate of return of about 19%. These advantages and economic impacts clearly encourage large scale development of the systems for which a combination of supportive policies, more aggressive technology application on -farm, and overcoming complacency are issues that need to be addressed to promote wider adoption of the systems (Devendra, 2009).

The large land area under oil palm offers major opportunities to integrate with ruminants and increase total factor productivity. Such systems enable good linkages between production and post-production systems, and environmental sustainability, including carbon sequestration. 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 and Vietnam.



**Plate 2.** The oil palm environment enables stratification and provides many benefits to integration with ruminants. The photo shows chopped oil palm fronds being fed to cattle in feedlot in Sabah, Malaysia (C. Devendra).

### Priority for urgent, wider technology application, adoption and scaling up

A combination of inadequate, weak/and or inappropriate

technology application, coupled to the use of weak on-farm methodologies, and lack of wider scaling up have been major impediments to poor animal performance and productivity. Often the potential capacity of the animal for growth and meat or milk production is therefore never realised, resulting in the contribution of ruminants to lag well behind and unable to meet current and projected quality dietary protein human requirements.

There is an urgent need for priority attention to accelerate technology application. The need for such application far outweighs investments in questionable research proposals that are irrelevant. Over the last four to five decades, advances in feed resource use and animal nutrition have identified several valuable technologies in Asia (Tables 1 and 2), and which have been reviewed (Devendra, 1996; 2010a). Some of these such as strategic supplementation with various leguminous forages, which is very common in many parts of South East Asia or UMBL, have been notably significant with attendant reduced cost of production. However, other technologies like food-feed systems, intensive use of ammonia-treated cereal straws, integrated production systems have been slow to scale up and be adopted more widely. To reiterate, participatory methods are crucial for success, including village cooperatives.

### **Reinforcing research-extension-farmer linkages in project formulation**

Associated with technology application is the need to reinforce research-extension-farmer linkages. Throughout Asia, there is diversity in the meaning of the term extension, as well as systems and structures that deal with it. Currently, extension is viewed in numerous ways, from approaches to help farmers to increase production, to marketing arrangements. This has in turn led to scientists to consider research mainly in terms of technological merits and the publication of results, and leave the diffusion of the results and practicalities to others. That view is no longer realistic and acceptable, for several reasons such as inadequate services, inadequate technical know how, lack of understanding of systems perspectives and participatory methods, and capacity to rapidly respond to farm problems. In recent years extension orientation is being further detracted to include innovative structural, funding and managerial arrangements (Rivera and Sulaiman, 2009).

These aspects together are of grave concern to the productivity of small farms and livelihood of small farmers. Research-extension-farmer linkages together with participatory efforts with rural communities help to address problems on the farm, their resolution, and more importantly the adoption of improved technologies. Farmers have in the past not accepted change because it was

uneconomic, but are today confronted in addition to vastly changing circumstances such as resource depletion, competitiveness and globalisation. There needs to be commitment to this work with these processes and make investments in efforts to promote wide diffusion and adoption of suitable technologies. In this context, it has recently been suggested that the transformation of agricultural education and appropriate formal curricular is relevant that combines strong disciplinary orientation, systems perspectives and systems methodologies to enhance the future of animal agriculture (Devendra, 2011).

Village cooperatives are an important conduit for the wider adoption of technologies as was seen in 'Operation Flood' and in surveys on milk producing districts in India (Tripathi et al., 1995). Another example of strong training that promotes learning by doing involving the use of local resources is the MEKARN livestock-based sustainable farming systems in the lower Mekong basin. The participating institutions are Laos, Vietnam, Cambodia and Thailand involving research, training, exchange and dissemination of information.

### **Rigorous application of systems methodologies**

On account of the complex nature of crop- animal systems in Asia, interactions with the environment and now climate change, an understanding of FSR methodologies is essential. The systems approach involves sequentially the following: site selection, site description and characterisation (diagnosis), planning of on-farm research, on - farm testing and validation of alternatives, diffusion of results and impact assessment.

The systems approach needs to be backed by a few other important requirements:

- Recognition of the importance of interdisciplinary participatory approaches
- Formulation of research programmes that have community-based participation to set a common agenda and create ownership. This should involve the continuum of both production and post-production systems
- Programmes that are needs-led and have institutional and structural commitment
- Establishment of effective participatory planning, inter-institutional coordination and collaboration, research management, dissemination of information, and resolution of feedback issues
- Long term commitment to achieving impacts, and
- Education and training in agricultural systems and systems methodologies at various levels
- Recognition of the longer term needs of agriculture in a resource depleting world in the future.

The vigorous agenda for strategic and sustainable

animal production in the future will require an increased commitment to interdisciplinary research and farming systems perspectives that can focus on whole-farm situations and priority AEZs. The evolving scenarios will simultaneously need to address several major issues such as resource depletion, nutrient flows, waste disposal, overgrazing, all year round feeding systems, and zoonosis and policy issues.

### Development of all year round feeding systems

The strategy to ensure the efficient use of the available feeds to match the requirements of the animal resources to the extent possible should have the final objective of developing sustainable all year round feeding systems. This implies good understanding of the biophysical environment and prevailing situations, year round sources of feed supplies, feed deficit times and possible adverse weather conditions such as droughts and floods.

In order to ensure adequate feed supplies to meet current and expanding needs, it is equally important to explore and address additional sources of feed supply (Plate 3), and to ensure maximum efficiency of its use such that less is used to produce the final product -meat.

There are several possibilities for this and include the following:

- Intercropping with cereal crops e.g. rice- *Sesbania rostrata*
- Food –feed cropping systems e.g. cassava-cowpea, rice-mungbean-sirat-ro-rice
- Alley cropping
- Relay cropping
- Forage production on rice bunds e.g. *Sesbania rostrata*, and
- Three- strata forage system
- Harvesting aquatic plants (e.g duckweed) from waste water



**Plate 3.** Cassava leaves are widely used as a source of supplementary dietary proteins. The photo shows cassava cultivation in Thailand (C. Devendra).

- Identifying wasteful processes in the system and finding ways to process previously wasted feeds (e.g. the wet rice straw harvest)

Producing increased feed supplies provides good opportunities to conserve feeds, especially when these are surplus to requirements. More importantly it helps overcome seasonal shortages in feed supplies and helps to expand production systems. Conservation measures need to ensure that there is little or no wastage in the stored feeds. Additionally, surplus feeds also enable farmers to occasionally sell the feeds for profit.

### Development of adaptation and mitigation options to cope with the effects of climate change on feed resources

High temperature and humidity and subsequent reduced feed intake significantly influence productivity, and in the tropics, this may be between half and one-third of the potential of modern cow breeds (Parsons et al., 2001). Cow fertility may also be affected as also fitness and reduced longevity (King et al., 2006).

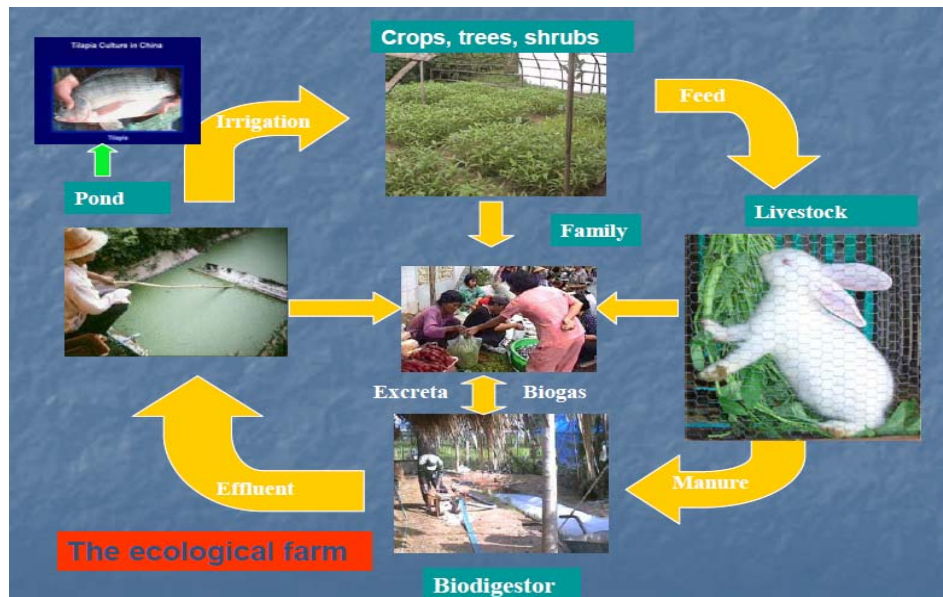
A major direct effect of climate change with respect to higher temperatures concerns the feed resources. The effect involves both quantities available and also quality. Hopkins and Del Prado, 2007) have reported several impacts that are induced on feed crops and grazing systems as follows

- Changes in herbage growth brought about by changes in atmospheric CO<sub>2</sub> concentrations and temperature
- Changes in the composition of pastures, such as the ratio of grasses to legumes
- Changes in herbage quality, with changing concentrations of water-soluble carbohydrates and N at given dry matter (DM) yield
- Greater incidences of droughts, which may offset any DM yield increases, and
- Greater intensity of rainfall, which may increase leaching of nutrients in certain years
- Changes in the timing of the rainy season are of great importance, as is the availability of water for irrigation.

These impacts make a significant overall net effect on the feed resource base on which tropical animals in the tropics are largely dependent on. It concerns not only the totality of cereal straws and other fibrous crop residues that ruminants largely subsist on, but also non -conventional feeds (Devendra and Sevilla, 2002), which for small farms will mean huge losses in productivity and livelihoods. It will be important therefore to develop adaptation and mitigation options to cope with the anticipated effects of climate change, including feed conservation.

### Striving for sustainability of integrated farming systems

Asian farming systems need vigorous, effective and continuing R and D on the efficiency of use of NRM in the



**Plate 4.** Future animal protein production will come from integrated small to medium -sized farms that are close to markets. The figure illustrates the different components involved and their linkages (R. A. Leng, 2009b; adapted from T. R. Preston, 2009).

search for sustainability of integrated systems. We are of the firm belief that in striving for these, the availability and use of the feed resources should spearhead this objective in pathways that are consistent with quantum jumps in productivity. Against the background of the advances that have already been made in Asia, the opportunities to achieve improvements are quite feasible and include improved understanding of *inter alia* the following:

- The benefits and implications of crop-animal-fish-soils- water interactions
- Scaling up and large scale development of annual crops-animals and fish integrated systems, and
- Stratification and development of production options in tree crops-ruminant integrated systems.

Concerning the latter, agroforestry systems have been singled out by the ADB (2009) as an important pathway for C sequestration in South East Asia. The potential to sequester carbon is reported to be 0.70-3.04 tCO<sub>2</sub>/ha per year, reduce CH<sub>4</sub> emission by 0.02 tCO<sub>2</sub>-eq/ha per year, and reduce N<sub>2</sub>O emission by 0.02-2.30 tCO<sub>2</sub>-eq/ha per year. Additionally, the use of improved grasses and legumes. The concept is an important strategy that enhances soil fertility through the inclusion of a legume crop, and possibly also C sequestration. The systems also provide good opportunities for integrated production of food, feed and energy merits major development attention

## CONCLUSION

Feed security and the efficient use of the feed resources are fundamental to maximize productivity from animals. In

this context, the priority development of ruminants (buffaloes, cattle, goats and sheep) in key agro-ecological zones (AEZs) is an important strategy for the future. The justification for this priority focus rests directly with the potential multifunctional contribution in general, especially their capacity for meat and milk production, and hence the development of the relatively weak ruminant sector in most countries in Asia. The efficient and more intensive use of the available biomass from the forage resources, crop residues in addition to AIBP and other NCFR to the extent possible will be the primary drivers of performance and productivity enhancement. Key development strategies include concerted application of productivity-enhancing technology adoption from the large pool of information already available, and an urgent expansion of scaling up of technologies in the context of farming systems. It is also suggested that the future for animal protein production will be for integrated systems from small to medium -sized farms that are close to both rural and urban markets (Leng, 2009b; Devendra, 2010b). Plate 4 illustrates the components involved and their linkages.

## REFERENCES

- ADB 2009. The economics of climate change in South East Asia: a regional review. Asian Development Bank, Manila, Philippines, 225 pp.
- Banarjee, A. 1994 .Dairying systems in India. Wrl. Anim. Rev. 79:34-41.
- Cagauan, A. G., C. Van Hove, E. A. Orden, N. M. Ramilo and R. D. Brankaert. 1996. Preliminary results of a case study on integrated rice-fish-azolla-ducks system in the Philippines. In



- Proc. Symp. on Integrated Systems of Anim (Ed. H. Hayakawa, M. Sasaki and K. Kimura). Prod. in the Asian Region, Chiba, Japan, pp. 35-62.
- Carangal, V. R. and C. C. Sevilla. 1993. Crop-animal systems research in Asia. Proc. V11<sup>th</sup> Wrld. Conf. Anim. Prod. Edmonton, Canada. pp. 367-386.
- CGIAR/TAC (Consultative Group on International Agricultural Research/Technical Advisory Committee). 2000. CGIAR priorities for marginal lands, CGIAR, Washington, USA. (Mimeograph).
- Cungen L. S. Z., G. Tingshuang and S. Waldron. 1999. The "Straw for Ruminants" project in China. Agricultural and Natural Resource Economics Discussion Paper 4/99. School of Natural and Rural Systems Management, University of Queensland. St. Lucia, Australia (Mimeograph).
- Devendra, C. 1982. Malaysian animal production in perspective. Proc. VI<sup>th</sup> Ann. Conf. Malaysian Society of Animal Production, pp. 201-219.
- Devendra, C. 1989. Ruminant production systems in the developing countries: resource utilization. In: Feeding Strategies for Improved Productivity of Ruminant Livestock in Developing Countries, IAEA, Vienna, Austria, pp. 5-30.
- Devendra, C. 1992. Non- conventional feed resources in Asia and the Pacific (4th Edn) RAPA/APHCA Publication. No.4, FAO Regional Office, Bangkok, Thailand, p. 170.
- Devendra, C. 1996. Overview of integrated, animals-crops-fish production systems: Achievements and future potential. In: (Ed. H. Hayakawa, M. Sasaki and K. Kimura) Proc. Symp. on Integrated Systems of Anim. Prod. in the Asian Region, Chiba, Japan. pp. 9-22.
- Devendra, C. 1997. Crop residues for feeding animals in Asia: technology assessment and adoption. In Crop Residues in Sustainable Crop Livestock Farming Systems (Ed. C. Renard). Commonwealth Agricultural Bureau, Wallingford, UK. pp. 24-28.
- Devendra, C. 2004. Meeting the increased demand for animal products in Asia: opportunities and challenges for research. In Responding to the livestock revolution. Br. Soc. Anim. Sci. Publ. 33:209-228.
- Devendra, C. 2005. Improvement of crop-animal systems in rainfed agriculture in South East Asia. In Proc. Int. Conf. Livestock-Crop Systems to Meet the Challenges of Globalisation (Ed. P. Rawlinson, C. Wachirapakorn, P. Pakdee and M. Wanapat), Khon Kaen, Thailand, 1:220-231.
- Devendra, C. 2007a. Goats: biology, production and development in Asia. Academy of Sciences Malaysia, Kuala Lumpur, Malaysia, p. 246.
- Devendra, C. 2007b. Perspectives on animal production systems in Asia. Livest. Sci. 106:7-20.
- Devendra, C. 2007c. Integrated tree-crops ruminant systems: expanding the research and development frontiers in the oil palm. In: Proc. Workshop on integrated tree crops- ruminant systems (ITCRS)/Assessment of status and opportunities in Malaysia (Ed. C. Devendra, S. Shanmugavelu and H. K. Wong). Kuala Lumpur, Academy of Science Malaysia. pp. 5-23.
- Devendra, C. 2009. Intensification of integrated oil palm - ruminant systems: enhancing productivity and sustainability in South East Asia. Outlk. Agric. 38:71-81.
- Devendra, C. 2010a. Small farms in Asia. Revitalising agricultural production, food security and rural prosperity. Academy of Sciences Malaysia, Kuala Lumpur, Malaysia, p. 175.
- Devendra C. 2010b. Food production from animals in Asia: priority for expanding the development frontiers. *Academy of Sciences Malaysia Science Journal* 4:173-184.
- Devendra, C. 2011. Agricultural education and technological change for sustaining productivity enhancement and prosperity in Asia. In: Agricultural Education and Training in Africa (Ed. F. Swanapoel and A. Strobel). University of the Free State, Bloemfontein, South Africa (In press).
- Devendra, C. and D. Thomas. 2001. Crop-animal interactions in mixed farming systems in Asia. *Agric. Syst.* 71:27-40.
- Devendra, C., C. Sevilla and D. Pezo. 2001. Food-feed systems in Asia. *Asian- Aust. J. Anim. Sci.* 14:733-745.
- Devendra, C., D. Thomas, M. A. Jabbar and H. Kudo. 1997. Improvement of livestock production in crop-animal systems in the rainfed agro-ecological zones of South East Asia., Nairobi, Kenya, p. 107.
- Devendra, C., J. F. Morton and B. Rischkovsky. 2005. Livestock systems In: Livestock and Wealth Creation (Ed. E. Owen, A. Kitanyi, M. C. N. Jayasuria and T. Smith). Nottingham University Press, United Kingdom, pp. 29-52.
- Devendra, C., D. Thomas, M. A. Jabbar and E. Zerbini. 2000. Improvement of livestock production in crop-animal systems in agro-ecological zones of South Asia. International Livestock Research Institute, Nairobi, Kenya, p. 108.
- Egan, A. 1989. Living with, and overcoming limits to, feeding value of high-fibre roughages. In; Draught animals in rural development (Ed. D. Hoffman, J. Nari and R. J. Petram). ACIAR Proc. No 27, Australian Centre for International Agricultural Research, Canberra, Australia, pp. 176-180.
- ESCAP, 2008. Economic and social survey of Asia and the Pacific 2008. Sustaining growth and sharing prosperity, Bangkok, Thailand, p. 190.
- Hulshof, R. B. A., A. Berndt, J. J. A. A. Demarchi, W. J. J. Gerrits and H. B. Perdok. 2010. Dietary nitrate supplementation reduces methane emission in beef cattle fed sugarcane-based diets. In Greenhouse gases and Anim. Agric. Conf., Banff, Canada (Mimeograph).
- IFAD, 2009. New thinking to solve old problems. <http://www.ipsnews.net/africa/nota.asp?idnews=45905>. (Accessed on 26<sup>th</sup> March. 2009).
- IMF. 2008. World economic outlook 2008. Research Department, International Monetary Fund, Washington, DC, USA.
- IPPC, 2007. Climate change 2007: Contribution of working groups 1, 11 and 111 to the Fourth assessment Report, of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom and New York, Cambridge University Press
- Hopkins, A. and A. Del Prado. 2007. Implications of climate change for grassland in Europe: impacts, mitigation, adaptation and mitigation. A review. *Forage Sci.* 62:118-126.
- King, J. M., D. J. Parsons, D. T. Turnpenny, J. A. Nyangaga, P. Bakari and C. M. Wathes. 2006. Modelling energy requirements friesians in Kenya smallholdings shows how heat stress and energy stress constrain milk yield and cow replacement rate. *Anim. Sci.* 82:705-716.
- Laquihon, G. A., G. Suico and W. A. Laquihon. 1997. Integration of salt management of crop livestock in slopeland areas: the

- case of "super" SALT (sloping agricultural land technology). Proc. Int. Workshop on Sustainable Crop Livestock Integration in Sloping Lands of Asia. Davao, Philippines; Mimeograph, p. 21.
- Leng, R. A. 1990. Factors effecting the utilisation of poor quality forages by ruminants particularly under tropical conditions. *Nutr. Res. Rev.* 3:277-294.
- Leng, R. A. 1991. Improving ruminant production and reducing methane emissions from ruminants by strategic supplementation. A report prepared for the Environmental Protection Agency of the USA. EPA/400/1-91/004.
- Leng, R. A. 2002. Future directions of animal production in a fossil fuel hungry world. *Livest. Res. Rural Dev.* 14, No.5, <http://www.cipav.org.co/lrrd/lrrd/14/5leng145.htm>
- Leng, R. A. 2004. Requirements for protein meals for ruminant meat production. In: Protein Sources for the Animal Feed Industry. Expert Consultation and Workshop, Bangkok, FAO, Rome, Italy, pp. 225-254.
- Leng, R. A. 2005. Metabolisable protein requirements of ruminants fed roughage based diets. In: (Ed. P. Rawlinson, C. Wachirapakorn, P. Pakdee and M. Wanapat) Proc. Int. Conf. on Livestock-Crop Systems to Meet the Challenges of Globalisation, Khon Kaen, Thailand, Vol. 1:330-347.
- Leng, R. A. 2008. The potential of feeding nitrate to reduce enteric methane production in ruminants. A Report to The Department of Climate Change. Commonwealth Government of Australia. Canberra, ACT, Australia. <http://www.penambulbooks.com>
- Leng, R. A. 2009a. Decline in available world resources-implications for livestock production systems. Proc. Int. Symp. on Sustainable Improvement of Anim. Prod. and Hlth., International Atomic Energy Commission, Vienna, Austria (In press).
- Leng, R. A. 2009b. Animal protein production in a resource depleted world subject to environmental decline and global climate change, Japan Science Council, Tokyo, Japan. (Mimeograph)
- Leng, R. A. and C. Devendra. 1995. Priorities and direction for more effective use of the feed resources by livestock in Asia. Proc. Consultation for the South-East region. In: Global agenda for livestock research, (Ed. C. Devendra and P. Gardiner), International Livestock Research Institute, Nairobi, Kenya, pp. 25-44.
- Le Thi Thuy Hang, Ngo Van Man and H. Wiktorsson. 2003. Effects of urea and lime treatment of fresh rice straw on storage stability, and hygienic and nutritional quality. [http://www.mekarn.org/msc2003-05/theses05/thuyh\\_p1.pdf](http://www.mekarn.org/msc2003-05/theses05/thuyh_p1.pdf)
- Mahadevan, P. and C. Devendra. 1986. Present and projected ruminant production systems. South East Asia and the South Pacific, In: Forages in South East Asia and the Pacific. ACIAR Proc. No. 12:1-6.
- Mudgal, V. D. and K. Pradhan. 1988. Animal feed resources and current patterns of utilisation in India. In: Proc. non-conventional feed resources and fibrous crop residues in India (Ed. C. Devendra). International Development Research Centre, Ottawa, Canada, pp. 139-146.
- Nellemann, C., M. MacDevette, T. Manders, B. Eickhout, B. Svihus, A. G. Prins and B. P. Kaltenborn. 2009. The environmental food crisis - The environment's role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, [www.grida.no](http://www.grida.no)
- Ngoc Huyen Le Thi, H. Q. Do, T. R. Preston and R. A. Leng. 2010. Nitrate as fermentable nitrogen supplement to reduce rumen methane production. *Livest. Res. Rural Dev.* 22, Article No.146. <http://www.lrrd.org/lrrd22/8/huye22146.htm>
- Nguyen Ngoc Anh, Khuc Thi Hue, Duong Nguyen Khang and T. R. Preston. 2010. Effect of calcium nitrate as NPN source on growth performance and methane emissions of goats fed sugar cane supplemented with cassava foliage. Proc. MEKARN Conf. on Livestock production, climate change and resource depletion. [http://www.mekarn.org/workshops/pakse/abstracts/anh\\_grrc.htm](http://www.mekarn.org/workshops/pakse/abstracts/anh_grrc.htm)
- Nguyen, T., C. Q. Nguyen, X. T. Duong and M. Sasaki. 1996. Rice-fish-pig production system in Vietnam. In: (Ed. H. Hayakawa, M. Sasaki and K. Kimura). Proc. Symp. Integrated Systems of Anim. Prod. in the Asian Region, Chiba, Japan, pp. 9-22.
- Nitis, I. M., K. Lana, W. Sukanten, M. Suarna and S. Putra 1990. The concept and development of the three- strata forage system. In Shrubs and tree fodders for farm animals (Ed. C. Devendra). International Development Research Centre, IDRC-276e, Ottawa, Canada, pp. 92-102.
- Nolan, J. V., R. S. Hegarty, J. Hegarty, J. R. Godwin and R. Woodgate. 2010. Use of supplementary nitrate to mitigate methane production and provide rumen degradable N for ruminants. *J. Anim. Sci.* 50 (In press).
- Parsons, D. J., A. C. Armstrong, J. R. Turnpenny, A. Matthews, K. Cooper and J. A. Clark. 2001. Integrated models of livestock systems for climate change studies. *Grazing systems. Glob. Change Biol.* 7:93-112.
- Preston, T. R. 2009. Environmentally sustainable production of food, feed and fuel from natural resources in the tropics. *Trop. Anim. Health Prod.* 41:873-888.
- Preston, T. R. and R. A. Leng 1984. Supplementation of diets based on fibrous residues and by-products. In: Straw and other fibrous by-products as feed (Ed. F. Sundstol and E. Owen). Elsevier, Amsterdam, The Netherlands, pp. 373-413.
- Preston, T. R. and R. A. Leng. 1987. Matching Livestock Systems to Available Resources in the Tropics and Sub -Tropics. Penambul Books, Armidale, Australia, p. 425.
- Raghavan, G. V., N. Krishna and M. R. Reddy. 1995. Priorities for feed resources use in the semi-arid Tropics. In Global agenda for livestock research. Proc. of the Consultation for South Asia region (Ed. C. Devendra and P. Gardiner). Patancheru, India, International Livestock Research Institute, Nairobi, Kenya, pp. 37-52. Ramachandra, K. S., V. K. Taneja, K. T. Sampath, S. Anandan and U. B. Angadi. 2007. Livestock feed resources in different agro ecological zones of India: availability, requirement and their management. National Institute of Animal Nutrition and Physiology, Bangalore, India, pp. 100.
- Sevilla, C. C. 1994. Prospects for sustsinable cattle production in the Philippines. University of the Philippines in Los Banos, Philippines (Mimeograph, 10 pp).
- Shrestha, H. R. and D. R. Pradhan. 1995. Research priorities for animal agriculture by agro-ecological zones in Nepal. In: Global agenda for livestock research (Ed. C. Devendra and P. Gardiner). Proc. of the Consultation for South Asia region.

- Patancheru, India, International Livestock Research Institute, Nairobi, Kenya, pp. 85-102.
- Rivera, W. M. and V. R. Sulaiman. 2009. Extension: object of reform, engine for innovation. *Outlk. Agric.* 38:267-274.
- Rosegrant, M. W., M. Fernandez, A. Sinha, J. Alder, H. Ahammad, C. de Fraiture, B. Eickhout, J. Fonseca, J. Huang, O. Koyama and A. M. Omizzene. 2009. Looking into the future of agriculture and AKST (Agricultural knowledge science and technology). In *Agriculture at a crossroad* (Ed. B. D. McIntyre, H. R. Herren, J. Wakhungu and R. D. Watson). Island Press, Washington DC, USA.
- Sriwastra, R. K. 1970. Importance of animal production in rural economy. *Indian Dairyman* 25:223-243.
- Sturr, W. W., P. M. Horne, F. A. Gabunada and P. C. Kerridge. 2001. Forage options for smallholder crop-animal systems in Southeast Asia: working with farmers to find solutions. *Agric. Syst.* 71:75-98.
- Suriapernama, S., T. Syamsiah, A. M. Fagi and Atunadja. 1988. Optimase daya dukung lahan dengan ristem minapadi-itek pada lahan dengan ristem minapadi-itek pda saevah beririgasi. *Simp. Tananam Pangan* 11, Bogor, Indonesia, pp. 21-23.
- TAC (Technical Advisory Committee). 1992. Review of CGIAR of Priorities and Strategies. Part 1, TAC Secretariat, FAO, Rome, Italy; p. 250.
- Tripathi, H., O. N. Kunzru and G. S. Bishat. 1995. Knowledge level of farm women about dairy farm technologies. *Indian J. Dairy Sci.* 48:346-352.
- Trinh Phuc Hao, Ho Quang Do, T. R. Preston and R. A. Leng 2009. Nitrate as a fermentable nitrogen supplement for goats fed forage based diets low in true protein. *Livestock Res. for Rural Dev.*, 21, Article No.10. <http://www.lrrd.org/lrrd21/1/trin21010.htm>
- van Zijderveld, S. M., W. J. J. Gerrits, J. A. Apajalahti, J. R. Newbold, J. Dijkstra, R. A. Leng and H. B. Perdok. 2010a. Nitrate and sulfate: effective alternative hydrogen sinks for mitigation of ruminal methane production in sheep. *J. Dairy Sci.* 93:5856-5866.
- van Zijderveld, S. M., J. Dijkstra, W. J. J. Gerrits, J. R. Newbold and H. B. Perdok. 2010b. Dietary nitrate persistently reduces enteric methane production in lactating dairy cows In greenhouse gases and animal agriculture conference October 3-8, 2010 Banff, Canada (Quoted by Hulshof et al 2010).
- World Bank, 2009. The state of food security in the world, Washington, DC, USA. p. 56.