REPORT

CONSULTANTS' MEETING

on

# THE IDENTIFICATION OF RESEARCH NEEDS FOR QUANTIFICATION OF NUTRIENT DYNAMICS IN INTEGRATED CROP/LIVESTOCK SYSTEMS WITH A FOCUS ON CONSERVATION AND SUSTAINABILITY ISSUES IN DEVELOPING COUNTRIES

By

Harinder Makkar and Graeme Blair

APRIL 11-14,2000

VIENNA INTERNATIONAL CENTRE

Vienna, Austria

A joint initiative of the Animal Production and

Health, and Soil and Water Management & Crop Nutrition Sections

Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

International Atomic Energy Agency

## 1. INTRODUCTION

A Consultants' Meeting on “ The identification of research needs for quantification of nutrient dynamics in integrated crop/livestock systems with a focus on conservation and sustainability issues in developing countries” was held at IAEA, Vienna, April 12-14, 2000

Four consultants, with expertise in nutrient dynamics drawn from National Agricultural Research Organisations and Universities, attended the meeting together with staff members of the Joint FAO/IAEA Divisions. The list of participants is given in Annex 1.

The meeting was formally opened by Dr Martyn Jeggo, Head of the Animal Production and Health Section, who explained the purpose of the meeting and presented the background to the joint proposal. Dr Harinder Makkar, the Scientific Secretary of the meeting, outlined the background to the proposed project and gave the general guidelines for the meeting. The programme of the meeting is included in Annex 2. In closing the meeting Dr. Phil Chalk, Head of the Soil and Water Management and Crop Nutrition Section, expressed his enthusiasm for the proposed joint programme and thanked participants for their contributions.

The consultants presented reviews of the situation regarding studies of nutrient dynamics in crop/pasture/ livestock systems in developing and developed agricultural systems. These were complemented by a paper on the development of $^{15}N$ techniques to study the contribution of N from crop residues and human, animal and industrial waste products developed at the Seibersdorf Laboratory. Summaries of the presentations are given in Annex 3. The consultants were of the opinion that in view of the Joint FAO/IAEA Division’s comparative advantage in operating (both technically and administratively) Coordinated Research Projects (CRPs) the proposal to initiate an FAO/IAEA CRP on quantification of nutrient budget and flows in integrated crop/livestock systems is appropriate. They identified a well focused area for the CRP and also provided recommendations on its the formulation and implementation.

## 2. PROJECT PROPOSAL

A CRP designed to enhance animal and crop production through improved feeding strategies of ruminants and more efficient nutrient cycling in integrated ruminant/cropping systems was developed. It is proposed that this CRP be conducted in two contrasting agro-economic zones of the tropics namely in irrigated rice based systems in South and/or South East Asia and in the semi-confined crop/livestock system in Africa

## 3. GENERAL RECOMMENDATIONS

3.1. A CRP entitled “Integrated Nutrient Management to Improve Productivity and Sustainability of Ruminant/Cropping Systems in Tropical Africa and Asia” utilising isotopes and jointly conducted by Animal Production and Health, and Soil and Water Management and Crop Nutrition Sections should be initiated.

3.2. The CRP should be initiated and conducted according to the project document included in Annex 4. The substantial comparative advantage of the joint FAO/IAEA Programme in conducting integrated research and training programmes was noted by the consultants

3.3. The objective of the CRP is to enhance animal and crop production through improved feeding strategies for ruminants and more efficient nutrient cycling in integrated ruminant /cropping systems

3.4 Expected outputs from the CRP are:

a). Improved knowledge of nutrient cycling in integrated ruminant/cropping systems and strategies to enhance nutrient capture within the system.

b). Established guidelines for the management of livestock excreta, crop residues and low quality forages.

c). Increased capacity of NARS to integrate nuclear techniques into research programmes and to conduct inter-disciplinary research

d). Published and disseminated research results

3.5 Considerations for the selection of contract holders

a) Ideally the contract holders should be involved in, or have access to, similar research to that proposed here so that nuclear techniques could be introduced to ongoing studies to improve the definition of nutrient flows.

b) Linkages between scientists and/or institutions with expertise in soil fertility, agronomy and animal production is essential.

c) Supplementary funding from national/international donors should be available to enable the scale of the study to be sufficient to encompass the whole soil/ plant/ animal continuum.

d) Separate financial support should be given to soil and animal scientists operating at the same research site to enable the necessary integration to be accomplished.

3.6. The sites to be used should be representative of major agro-ecosystems in Africa and South and South East Asia. Because of the nature of the research the experimental programme will need to be conducted on research or demonstration farms to ensure that both the initial and residual effects of enhanced nutrient cycling are evaluated.

3.7. Isotope techniques to be used in the CRP include some of the following:

a) $^{15}N$ and $^{34}S$ for nutrient dynamics studies to follow the pathways of nitrogen and sulfur in the soil/plant/animal continuum and to understand the mechanisms controlling transformations.

b) $^{13}C$ for constructing carbon budgets and to be able to determine changes in soil organic matter forms and contents.

c) $^{32}P$ or $^{33}P$ to estimate the efficiency of P utilisation in legume production

e) A Technical Contract to study the value of using $^{18}O$ as a surrogate for P should be awarded.

3.8). Contracts should be awarded to 10 soils+10 animal scientists working in partnership in linked projects and jointly funded and managed from D1 and D3 sub-programmes. Joint Scientific Secretariat should be appointed from the Soils and Animal Sections.

3.9) A total of 5-6 Agreement holders should be appointed.

3.10) Because of the nature of the research, particularly the use of stable isotopes, which are a feature of this proposal contracts of $10000 should be awarded per holder.

3.11). The first RCM should be held as soon as possible after the award of Research Contracts and Agreements.

3.12). A combined 1 week training programme on soils, animals and data management should be held at Seibersdorf and Vienna University at first RCM.

3.13). The CRP should be linked as far as possible to projects funded by other Donor Agencies and existing research networks.

ANNEX 1

LIST OF CONSULTANTS

1. Prof. Eric Smaling
The Winand Staring Centre for Integrated Land
Soil and Water Research (SC-DLO0
P.O. Box 125
NL-6700 AC
Wageningen
The Netherland
e-mail: Eric.Smaling@BodLan.BenG.WAU.NL

2. Dr. Graeme Blair
Department of Agronomy and Soil Science
University of New England
Armidale NSW
Australia
e-mail: gblair@metz.une.edu.au
gblair@metz.une.edu.au

3. Dr Stewart Ledgard
Land Management group,
AgResearch, Ruakura Agricultural Research Centre
Private Bag 3123
Hamilton
New Zealand
e-mail: ledgards@agresearch.cri.nz

4. Dr. Steve C. Jarvis
Institute of Grassland and Environmental Research
North Wyke Research Station
Okehampton
Devon EX20 2SB
U.K.
e-mail: steve.jarvis@bbsrc.ac.uk

## ANNEX 2

## PROGRAMME

**Wednesday, 12 April 2000** ***(V.I.C., Meeting Room A-2774)***

| | |
|---|---|
| 09.00 - 09.20 | Opening Session<br>Martyn Jeggo, Head, Animal Production and Health Section<br>Joint FAO/IAEA Division |
| 09.20 - 09.45 | Remarks by Scientific Secretary<br>*Harinder Makkar* |
| 09.45 - 10.15 | Coffee break |
| **Sesssion I** | **Chairperson: S. C. Jarvis** |
| 10.15 - 11.15 | Measuring nutrient stocks and flows: hard and soft approaches<br>*Eric Smaling* |
| 11.15 - 12.15 | The role of isotopes in studying nutrient and organic matter dynamics in livestock/cropping systems, with emphasis on carbon and nitrogen<br>*Stewart F. Ledgard* |
| 12.15 - 12.30 | General discussion |
| 12.30 - 14.00 | Lunch break |
| **Session II** | **Chairperson: Eric Smaling** |
| 14.00 - 15.00 | Identification of Research Needs for Quantification of Nutrient Dynamics in Integrated Crop/Livestock Systems in South East Asia and Latin America with a focus on Conservation and Sustainability Issues<br>*Graeme Blair* |
| 15.00 - 15.30 | Coffee break |
| 15.30 - 16.30 | Opportunities to enhance and interpret nutrient fluxes and imbalances in animal production systems by use of stable isotopes<br>*S.C. Jarvis* |
| 16.30 - 17.00 | General discussion |
| 17.00 - 17.30 | Efficient Resource Management in Vietnam<br>(a 28-min Video by BBC Scotland)<br>Venue: Meeting Room A-2210 |
| 18.30 | Reception at the Chinese Restaurant ‘Shang hau’ |

**Thursday, 13 April 2000** ***(V.I.C., Meeting Room A-2210)***

| | |
|---|---|
| **Session III** | **Chairperson: Stewart F. Ledgard** |
| 08.30 - 09.15 | Indirect techniques for measuring N release from organic residues and manures<br>*Rebecca Hood* |
| 09.15 - 10.30 | General discussion: present state-of-the-art, research needs, identification of the problem to be addressed through CRP |
| 10.30 - 11.00 | Coffee break |
| 11.00 - 12.30 | Identification and documentation of nuclear-based methodologies for use in the CRP and assessment of advantages and disadvantages of these techniques over |

| | |
|---|---|
| | non-nuclear techniques |
| 12.30 - 14.00 | Lunch |
| **Session IV** | **Chairperson: Graeme Blair** |
| 14.00 - 15.30 | Formulation of CRP (Title; Overall objectives; Specific objectives; Justification; Expected outputs; Workplan; Timeframe; Project logframe describing activities, outcomes, performance indicators, means of verification, assumptions and risks; Inputs; Assumptions) |
| 15.30 - 16.00 | Coffee |
| 16.00 - 17.30 | Formulation of CRP .. *continued* |
| **Friday, 14 April 2000** | ***(V.I.C., Meeting Room A-2210)*** |
| **Session IV** | **Chairperson: Graeme Blair** |
| 8.30 - 10.30 | Formulation of CRP .. *continued* |
| 10.30 - 11.00 | Coffee |
| 11.00 - 12.30 | Formulation of CRP .. *continued* |
| 12.30 - 14.00 | Lunch |
| 14.00 - 15.30 | Conclusions and Recommendations |
| 16.00 | **Closing session**<br>**Dr Phil Chalk,** Head, Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Division |

## ANNEX 3

## SUMMARIES OF PAPERS PRESENTED

### OPPORTUNITIES TO ENHANCE AND INTERPRET NUTRIENT FLUXES AND IMBALANCES IN ANIMAL PRODUCTION SYSTEMS BY USE OF STABLE ISOTOPES.

S.C. Jarvis

Institute of Grassland and Environmental Research, North Wyke Research Station, Okehampton Devon, EX20 2DG

The flows and transfers of nutrients within agricultural systems are complex and the presence of livestock increases the complexity. Few, if any, systems are in equilibrium with respect to nutrients inputs and outputs and all are “leaky” to some extent or other: the presence of animals inevitably increases the opportunity for inefficiency. Whilst there is still much need to enhance nutrient use in many parts of the world in order to promote crop/food production particularly in resource-poor environments, there has been considerable recent research which re-examine nutrient behaviour because of pollution effects. Understanding nutrients fluxes and budgets/balances of inputs and outputs within a system and its component parts, provides the means to assess (i) current status, (ii) extent of losses and (iii) potential options for change to reduce losses, increase nutrient use efficiency and sustain or enhance production at minimum cost. Increasingly, nutrient accounting is being used at field, farm and national scales to aid decision making and planning. To do this effectively, requires that the sources and transfers of nutrients to, from and within the system be known. The paper discusses the way in which systems and farm gate balances can be used to promote efficiency of nutrient use in relation to required production levels and to optimise (i) investment in purchased nutrients, (ii) opportunities to capitalise on internal recycling and (iii) other farming activities which influence nutrient balance, surplus and loss. A major challenge for the future will be to balance the on- and off-farm needs of supplying and utilising nutrients in order to maintain long-term sustainability of farming systems, food production and rural resources.

The paper concentrates on aspects of N in livestock systems as this provides one of the main opportunities to increase effectiveness of nutrient use in agriculture throughout the world with the aim of demonstrating some of the key areas in which there is a need for improved understanding. Methods are being developed for understanding and controlling balances and qof the processes involved. Increasingly, stable isotopes are being used to help develop this understanding. Examples are given of the way that enriched sources, and particularly natural abundance levels of N are being used to determine the way that controls over the flows of N at various physical scales within particular ecosystems are operating.

By way of example, three case studies are taken to illustrate opportunities to employ stable isotopes of N to better understand fluxes, provide improved model description and predictive capability and ultimately to improve the management and outputs from the farm The first is an intensively managed 76 ha temperate dairy system, in SW of England; the second is 2 farming systems in the highlands of E. Kenya where traditional soil fertility practices cannot be maintained with an increasing population and land scarcity, and the final case study is that of a balanced, productive and environmentally sound integrated farming system in which modest amounts of external inputs are used to supplement recycled nutrients within a semi-intensive, agriculture-aquaculture management in Asia. The particular general areas within livestock systems which require further definition to enable improved N utilisation and which can be probed by $\delta^{15}N$ studies include: impact of dietary quality on N utilisation and partitioning into excreta, the dynamics of N turnover from excreta, plant residues and soil organic matter and effects of changes in local husbandry/management practices, spatial and temporal effects of excretal return (either at grazing or after storage/application), interactions between N, other nutrients and water availability, N sources and rates of transformation and transfers into loss pathways and construction of soil and systems nutrient balances and the identification and determination of acquistion rates of N by plants from soil, fertilizer, manure or atmosphere.

## NUTRIENT DISEQUILIBRIA IN AGRO-ECOSYSTEMS:CONCEPTS AND CASE STUDIES

Eric Smaling

Wageningen University and Research Centre, Laboratory for Soil Science and Geology, P.O. Box 37, 6700 AA Wageningen, The Netherlands

Amongst the problems that African agriculture faces, soil fertility decline is mentioned as a major pressure. The declining state (lower soil fertility) has led to different responses by researchers, landusers and policy makers. All responses directly or indirectly boil down to some form of 'Integrated Nutrient Management' (INM), which is defined as the 'judicious' manipulation of nutrient stocks and flows. As INM is complex and multi-faceted, it is difficult to derive simple indicators for policy makers from it. The concept of stocks (state) and flows (pressure), however, links well with economic sciences.

A continental study revealed that Africa is losing nutrients at a rather alarming rate, i.e., 22 kg N, 2.5 kg P and 15 kg K per ha per year (Stoorvogel and Smaling, 1990). These values represent the sum of the outputs minus the sum of the inputs mentioned below.

| | | | |
|---|---|---|---|
| IN 1 | mineral fertilizer | OUT 1 | nutrients in harvested parts, milk, meat,etc. |
| IN 2 | organic fertilizer | OUT 2 | nutrients in removed crop residues |
| IN 3 | atmospheric deposition | OUT 3 | leaching |
| IN 4 | biological N fixation | OUT 4 | gaseous losses |
| IN 5 | sedimentation | OUT 5 | runoff and erosion |

This study however, commissioned by FAO, had to deal with a lot of higher-scale problems, i.e., using FAO's production yearbooks, using the 1:5,000,000 FAO Soil Map of the World, generalisation, simplification, and the use of proxies (transfer functions).

It triggered many studies at lower spatial scales (field, farm, village, watershed), in which inputs and outputs are accompanied by internal flows within the system. In other words, INM can be geared towards

- adding nutrients to the system
- saving nutrient from being lost from the system
- recycling so as to maximize nutrient use efficiency

Measurement of nutrient flows is complex: a simple fertilizer trial implies adding nutrients, and harvesting part of the extra nutrients, but what happens to the nutrients that were not taken up by the crop? More spatially complex is the ring management system in West Africa where animals spend the night and early morning around the village, fertilizing this area, while they eat and deplete the bushlands during daytime.

IFPRI has, for its Vision 2020 study, grouped the tropical world into five 'agricultural landscapes', i.e.,

- Irrigated lands
- High quality rainfed lands
- Densely populated marginal lands
- Extensive agriculture in marginal lands

- (Peri)urban agriculture

The complexity of measuring the nutrient balance for these 'landscapes' will be highlighted.

Measurement problems seem to be scientific issues, but they do come back at the policy level. In The Netherlands, a mineral book keeping system is in place (MINAS), which works with farmgate balances. However, a surface balance approach would give other figures and would encompass different incentives for the land user. More accurate compartment approaches are liked by the researcher but generally regarded as too cumbersome to build policies on.

It is very difficult to scale up point research to higher spatial and temporal scales. Examples are given of agricultural landscapes in Madagascar and Nigeria that may help in deciding where to focus research efforts.

It is crucial that scientific development on INM is closely related to policy and landuse, as all these fields are changing simultaneously. Policies are increasingly developed at decentral levels, opening up avenues for INM approaches that were not applied before. Also, landusers become more vocal, and want to be involved in research for development (e.g., participatory technology development). INM therefore should be a joint effort between researchers, policy makers and land users. Research has a key role to play in development of sound methodologies for measurement, modelling and monitoring.

## IDENTIFICATION OF RESEARCH NEEDS FOR QUANTIFICATION OF NUTRIENT DYNAMICS IN INTEGRATED CROP/LIVESTOCK SYSTEMS IN SOUTH EAST ASIA AND LATIN AMERICA EITH A FOCUS ON CONSERVATION AND SUSTAINABILITY ISSUES

Graeme Blair

Agronomy and Soil Science, University of New England, Armidale, NSW 2351, Australia

Between 1979/81 and 1999 livestock numbers increased throughout S.E. Asia and Tropical America despite the increasing human population density in these regions

Indonesia, Myanmar and Thailand dominate the large ruminant population in S.E. Asia. . The large ruminant population in these countries is dwarfed by that in China. In tropical America Brazil, Colombia and Venezuela have the largest large ruminant populations . In S.E. Asia, between 1979/81 and 1999, cattle numbers increased by 91% but buffalo numbers decreased by 3%. The cattle population in Tropical America has increased by 19%.

The largest small ruminant population in S. E. Asia occurs in Indonesia and, in Tropical America, in Brazil and Mexico. There has been a very significant (90%) increase in small ruminants in S.E. Asia.

The major needs of the largely cut and carry systems used in much of S E Asia and Africa is to provide a year-round supply of high quality forages to supplement low quality crop residues and forages cut from roadsides and wastelands. Because of the reluctance of farmers to fertilise forages in these systems it is an imperative that the flow of nutrients from the soil to the plant and then to the animal be as efficient as possible. In the past legumes, particularly tree and shrub legumes, have been the preferred supplementary forage supply but as systems become more intensive increased attention needs to be paid to N fertilised grasses and direct supplementation of animals with N, P, and other nutrients.

The research to be undertaken needs to trace the flow and balance of nutrients (particularly N,P,K,S,Zn and C) through the plant production cycle, particularly the recycling of nutrients when associated with carbon in crop residues and specialist supplementary fodder crops. Studies are also needed on the efficiency of animal feeding and nutrient utilisation, especially in the re-utilisation of manure, urine and bedding material in subsequent crop production.

Additional research is required at providing minimal nutrients to specialist forage crops and to directly supplementing animals to enhance their performance and to provide manure and urine of better quality for application to following food crops.

In systems where biogas is generated studies are needed on the losses and transformations of nutrients that take place in the biogas generator and the fate of nutrients when the various liquid and solid residues from the generator are re-used in agriculture.

In order to study the primary and interaction effects of nutrients in the plant/animal/soil system, it will be necessary to produce multi-labelled plant material.

Because of the widespread occurrence of P deficiency it is recommended that labelled legume forages be produced with a range of P application rates (from farmer practice to high rates). Plant production data should be collected to assess the direct benefits of P fertilisation on biomass production and quality. The forage should be fed to penned sheep or goats (or other appropriate livestock) at a range of supplementary levels to assess animal production gains. Partitioning of $^{15}N$ and $^{34}S$ in the animals can be estimated. Manure, urine, and bedding samples need to be analysed to determine inorganic and organic nutrient concentrations. These "waste" products need to be managed using both local farmer practice and best practice prior to their application to the food crop. These materials should then be applied to soil and the contribution of N, S, and C to crop production and soil organic matter and fertility determined

It is recognised that the research outlined above is complex and expensive but I feel that continuing research on single nutrients, and studying only part of the system will add little to our understanding of the nutrient cycles in plant/animal/soil systems.

## THE ROLE OF ISOTOPES IN STUDYING NUTRIENT AND ORGANIC MATTER DYNAMICS IN LIVESTOCK/CROPPING SYSTEMS, WITH EMPHASIS ON CARBON AND NITROGEN

Stewart F. Ledgard

AgResearch Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand

Integration of livestock and cropping systems can increase the efficiency of use and recycling of nutrients and other resources. In developing countries, a key goal in mixed animal/cropping systems is maximising production of animals and crops, possibly including grain for human consumption, while minimising the need for inputs of resources such as fertilisers, irrigation water and energy. Low organic N levels in soil in some developing countries, such as in Africa, mean that achievement and maintenance of high yielding crops requires appropriate inputs of organic and/or fertiliser N sources. Improvement in organic matter and N levels in cropping soils are generally achieved via crop rotations or inter-cropping with grain legumes or green manures, or by importing external sources of organic material. Recycling of crop residues is also important for retaining organic matter and nutrients in cropped soils.

Increases in the efficiency of these farming systems require a detailed knowledge of the limiting factors or resources for maximising productivity. Isotopes can play a valuable role in identifying, understanding and testing new methodologies associated with soil, water and nutrient resources. Isotopes (particularly $^{15}N$) have been widely used in field studies for determining fertiliser use efficiency, $N_2$ fixation, and more recently for studying the fate of nutrients from organic materials and crop residues. The major benefit in using isotopes in studies of nutrient use efficiency is that it enables the fate of the nutrient to be traced throughout the soil/plant system even where there are large reserves of the nutrient in soil pools. Most research with isotopes has been restricted to above-ground plant components but some recent studies have targeted plant roots. Foliar $^{15}N$ labelling has been used to better quantify root N yields and to determine the uptake of $^{15}N$-labelled root N by subsequent crops. Similarly, $^{13}CO_2$ pulse labelling studies have provided valuable information on the root carbon pools and turnover rates for different plant systems.

In livestock research, isotopes have been used to determine the relative conversion of dietary nutrients into animal produce, animal tissues, dung and urine. However, this is more commonly determined using non-isotopic studies with stall fed animals and nutrient analysis of the various components. Isotopic studies of this kind are most valuable for detailed research tracing nutrient conversion into specific animal components or metabolites. Several studies have used $^{15}N$-enriched plant material fed to animals to generate $^{15}N$-labelled excreta for research on the fate of excreta N.

Quality of the feed source for livestock can have a marked effect on the relative conversion of feed N into animal produce, dung or urine. While this has been well researched in intensive livestock systems in developed countries, there is much less information on the fate of feed N consumed by animals in developing countries where poor quality feed sources may be used. In the latter, more than half of the consumed N can be excreted in dung and this represents an important potential source of N and other nutrients for recycling onto crops.

The system of animal management influences the recovery of nutrients in manure. In developing countries, such as in Africa, animals may be penned continuously and the manure is collected, stored and applied onto cropping areas. The storage method and treatment of manure (e.g. straw may be mixed with it) will influence the temporal availability of nutrients after application to soil. Detailed research is required to better understand the variability in N supply from manures in relation to feed quality and to develop practical recommendation systems for their optimum use in cropping systems. The stable isotopes $^{15}N$ and $^{13}C$ can play a valuable role in such research programmes.

Research requirements in developing counties should be based on local knowledge and identification of specific key limitations to productivity and sustainability in those countries. Ideally, it should also be an integral part of existing research programmes so that other skills (e.g. agronomists, microbiologists) can be utilised. However, some generalisations can be made in relation to some of the key factors controlling nutrient flows and efficiency in livestock/cropping systems.

In developing countries where resource inputs (e.g. fertiliser) can be expensive, it is important to achieve efficient re-use and cycling of nutrients within the livestock/cropping system. An allied component to this is the importance of maintaining acceptable levels of soil organic matter to ensure longer-term sustainability. Thus, it is suggested that a general priority for research in livestock/cropping systems in developing countries is nutrient supply from manures, organic matter sources and/or crop residues. Research could target management strategies to manipulate the nutrient supply to achieve some synchrony with crop demand. The research approach should involve determining nutrient transformations and efficiency using non-isotopic and isotopic techniques, in conjunction with preliminary evaluation of strategies using computer models.

**ANNEX 4**

PROJECT DOCUMENT

## 1. Title of the CRP:

Integrated Nutrient Management to Improve Productivity and Sustainability of Ruminant/Cropping Systems in Tropical Regions of Africa and Asia

## 2. Justification

One of the greatest challenges faced by mankind is to satisfy the nutritional needs of the rapidly expanding global population while at the same time preserving biodiversity and land, water and air resources. Livestock are an important part of the agricultural landscape in terms of outputs of food, fuel and fibre. Livestock produce diverse food products, provide security, complement crop production systems, and generate cash incomes for rural and urban populations, provide fuel and transport, and produce goods that can have multiplier effects and create a need for services. Furthermore, livestock diversify production and income, provide year-round employment and spread risk. There is a rapidly growing demand for livestock products world-wide, as human population pressure and incomes increase and as dietary habits change. Changes in land use and human population are now leading to intensification and expansion in many types of livestock production systems.

Re-utilisation of nutrients on-farm has been a normal practice for centuries. However, the relevance of research in the fields of nutrient stocks, flows, and management has increased due to massive population growth, industrialisation, decrease in availability of arable land, development of high-input livestock systems, increased use of mineral fertilisers, high demand for livestock products as a result of growing world economies, and globalisation of trade.

In developing countries people currently consume an average of 21 kg/capita of meat and fish and 40 kg/capita of milk equivalents as against of 100 kg/capita of meat and fish and 178 kg/capita of milk equivalents in developed countries. By 2020, people living in developing countries are projected to consume an average 38 % more meat and 62 % more milk per capita than in early 1990s (Delgado *et al*., 1999). The increased livestock population required to meet this demand may worsen environmental problems. This calls for development and introduction of systems, which are economically, socially and ecologically sustainable. In mixed farming systems, in particular integrated crop/livestock systems, livestock play a central role in creating more sustainable farming systems. The ruminants in particular are of particular importance in this context in that they can be raised on crop residues, agro-industrial by-products and low quality roughages, which do not compete with human food (Fadel 1999). In addition, integrated crop/livestock systems at present provide 90% of the milk, 77% of the ruminant meat, 47% of pork and poultry meat, and 31 % of the eggs.

Animal protein intake in developing countries has increased sharply over the past decades, and this trend is expected to continue.

The increasing demand for animal products is outstripping population growth. In many parts of the tropics both ruminant and human populations are increasing rapidly._Remenyi and McWilliam (1986) predicted that the demand for forage in S.E. Asia and the S. Pacific would double between 1985 and 2000 if there was no change in the typical feed regime and projected trends in ruminant numbers. This doubling in demand was expected to occur despite a projected decline of 33% in meat self-sufficiency. Increasing food production in the regions means an increasing production of crop residues and agro-industrial by-products and, depending on management, this could be used to not only to sustain the increased animal numbers but also to increase efficiency of animal productivity.

In their assessment of the situation in S.E. Asia Remenyi and McWilliam (1986) pointed out that production of forages was not a traditional activity for the majority of smallholders and farmers in the region. Both land and labour constraints were seen as limitations to expansion of forage production. In the intervening years these problems have been exacerbated by increasing human population.

As a result of these changes new pressures on the environment are developing or could emerge, and should, therefore, be of concern. It is increasingly clear that livestock-environment linkages should be seen in the context of human, economic and political aspects as well as natural resource utilisation. These challenges demand a flexible and dynamic approach in the development and formulation of policies for the livestock sector. The scale and nature of the interaction between livestock production and the environment has been the subject of much speculation and debate. A technical basis for making balanced policy decisions and for formulating intervention plans is generally lacking. A paucity of precise information about ecosystems and their interactions with livestock enterprises can lead to erroneous decisions, particularly at the policy level, and to wrong interventions.

In the last few years a number of organisations, namely FAO, the World Bank, USAID, ILRI, Netherlands Ministry of Foreign Affairs, EU, DANIDA of Denmark, BMZ of Germany, DFID, U.K. etc. undertook a major ‘multi-donor study on livestock-environment interactions’. The catalyst was the United Nations Conference on Environment and Development (UNCED) Meeting in Rio in 1991, which placed environmentally-sustainable agriculture high on the international agenda. The ‘multi-donor study’ included an International Conference on Livestock and the Environment which issued a document containing state-of-the-art reviews. The following were identified as critical issues:

Overgrazing and degradation

Deforestation

Wildlife and livestock interactions

Upsetting the balance between crops and livestock

Soil and water pollution

Emission of greenhouse gases

The interactions between livestock and the environment are many and complex. Deforestation, soil erosion, reduced soil fertility, loss of biodiversity, water contamination, waste disposal and greenhouse and obnoxious gas emissions are some of the recognised environmental problems. Measures that tackle only the superficial effects of environmental damage will never be as effective as policies and interventions which attack the underlying causes.

Meanwhile, many livestock systems are severely under pressure. Free-range systems in Africa are increasingly pushed into marginal areas or have to share feed resources with game animals. The pastoralists of the recent past (Peulh, Masai) have recently turned to semi-sedentary forms of agropastoralism. At the same time, farmers in semi-arid Africa with mixed crop-livestock systems, which depend on communal lands for their grazing needs, see these lands declining in size and productivity. Animals are highly important to very many resource-poor farmers. They provide meat, milk and draft power to subsistence farmers, are living bank accounts, and fulfil an array of social and gender-sensitive functions (e.g. provision of dowry).

The future of ruminant systems in the developing world is clearly in mixed crop-livestock systems, with a reasonable level of overall system productivity. For this to be achieved, a good understanding is needed of the existing fertility of the entire agro-ecosystem, of which the ruminant forms part, as well as the major nutrient flows that determine production (useful or marketable output), productivity (useful output per unit input) and sustainability (total outputs do not exceed total inputs). Hence, the challenge is to direct nutrient flows towards ‘marketable output’ as much as possible, to achieve the highest possible output per unit input (fertiliser, nitrogen fixed,, labour), and to reduce leaching, erosion, gaseous losses and removal of residues from the system. Integration of system components can be used to increase nutrient use efficiency, improve household economics, and reduce the need for imported resources such as mineral fertilisers.

The role of ruminants in the larger agro-ecosystems of which they form part has been under-rated. Piece-meal research efforts on either soil fertility, forage quality, feed supplements, or increased nutrient use efficiency within the animal have not provided the necessary broader ‘systems’ picture that allows animal production to stand out as a vital component to recycle nutrients for increased production. Clearly, there are still knowledge gaps on how best to describe and mobilise the ruminant subsystem as part of these larger systems. Then follow the key questions. What is the best method to improve the productive potential of the system? What nutrient flows should be focused on?

The environment associated with livestock is under pressure. Free range pastoralists are finding it difficult to survive in increasingly harsh environments. At the same time, industrial livestock farmers may be responsible for environmental pollution and have to respond to tough legislation. The huge demand for animal products forces research efforts into the development of mixed crop-livestock systems that are productive (high outputs), clean (few non-useful outputs), efficient (high outputs per unit input) and sustainable (outputs do not exceed inputs). The challenge is to analyse the processes that determine the value of these indicators in different systems, and to design better management systems that are within reach of those who have to implement them. Use of stable isotopes is extremely useful in quantifying and tracing nutrient pathways, and in targeting further research on nutrient flows where there are opportunities for improvement.

Poor animal production resulting from protein deficiency, and poor management of excreta from ruminant animals contributes to poor nutrient cycling in many agricultural systems. As cropping intensities increase in response to increasing population pressures greater amounts of crop residues are potentially available to ruminants but the time and labour available to manage these residues for animal production becomes increasingly limited. Improving the feed conversion efficiency through strategic supplementation with farm grown protein sources offers scope to enhance animal production, lower environmental polluting gases such as methane and carbon dioxide, and to improve the efficiency of nutrient cycling in the food crop sector.

A technical basis and sound quantitative data for formulating guidelines and intervention plans are lacking. A complete knowledge of farming systems and their nutrient inputs/outputs, flows and potential for loss will assist the farmer in his decision to efficiently utilise nutrients and optimise production.

The proposed CRP will be conducted in collaboration with National Agricultural Research Systems (NARS) and International Organisations where appropriate. The research activities will be conducted in Africa and in South and/or South East Asia.

The research will focus on three main lines of investigation:

a) Improving the quantity and quality of leguminous protein supplements, preferably from trees and/or shrubs, for use in crop residue-based feeding systems in which low quality forages are an important part of the animal diet.

b) Manipulation of the flow of nutrients through the animal/plant/soil system, via animal excreta ,and strategic inputs of fertilisers.

c) Monitoring the effects of modified nutrient flows on animal and crop production and system nutrient budgets.

In addition, cost/ benefit analyses will be undertaken to facilitate uptake of the research findings by farmers and the CRP will enhance the in-country capacity to conduct integrated nutrient studies by facilitating linkages between soil scientists, agronomists, animal production specialists, modellers and economists.

The Agency's involvement is justified in that:

a) Isotopes (stable and radioactive) are essential to obtain a quantitative estimate of nutrient flows in these target systems and to evaluate the impact of interventions.

b) The objectives of the proposed project are in line with the strategic objectives of the FAO's Department of Agriculture, the joint FAO/IAEA Programme and its constituent sub-programmes D1 and D3

c) The research approaches envisaged are highly relevant to many Member States of FAO and IAEA.

d) The proposed CRP will entail the formation of a network of international and national research institutes working in tropical areas. The Agency has a strong track record in the conduct of co-ordinated research projects that have successfully brought together scientists from different disciplines in both developing and developed countries. The findings from this CRP could be disseminated through Technical Cooperation projects as has been done with previous CRP's.

e) The Seibersdorf Laboratory of IAEA has strong in-house capacity to support the CRP through training, quality assurance, analytical services, and strategic research capability..

References

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S. and Courbois, C. 1999. Livestock to 2020: The next food revolution. International Food Policy Research Institute, Washington, D.C., U.S.A, 72 pp.

Fadel (1999). Quantitative analyses of selected plant by-product feedstuffs, a global perspective. Animal Feeding Science and Technology 79,, 255-268

Remenyi, J.V. and J.R. McWilliam (1986). Ruminant production trends in Southeast Asia and the South Pacific. Pages 1-6 *in* G.J. Blair, D.A. Ivory and T.R. Evans eds. Forages in Southeast Asian and the South Pacific Agriculture. ACIAR Proceedings 12, Australian Centre for International Agricultural Research, Canberra, Australia.

### 3. Overall Objective

To improve nutrient management in integrated ruminant/cropping systems and enhance animal and crop production, through improved feeding strategies.

## 4. Specific Research Objectives

4.1.To characterise the target systems.

4.2. To increase the productivity of animals through the introduction of legume leaf protein to supplement low quality crop residues and forage.

4.3. To improve the management of excreta to increase re-cycling and reduce losses of nutrients resulting in higher crop production.

4.4. To monitor the residual effects of excreta on soil physical properties and fertility

4.5, To monitor the performance of ruminants and construct nutrient budgets in systems adjacent to the experimental sites to allow comparisons with experimental data.

4.6. To use appropriate models to aid prediction and scaling of the research findings.

4.7. To build in-country capacity to conduct integrated nutrient studies with the aid of nuclear techniques.

## 5. Expected Outputs

5.1. Improved knowledge of nutrient cycling in integrated ruminant/cropping systems and strategies to enhance nutrient capture within the system.

5.2. Established guidelines for the management of livestock excreta, crop residues and low quality forages.

5.3. Increased capacity of NARS to integrate nuclear techniques into research programmes and to conduct inter-disciplinary research

5.4. Published and disseminated research results

These outputs, together with the goal and purpose statements, are presented in a logical framework matrix below.

## 6. Outcomes and Impacts

6.1 Knowledge-based nutrient management strategies implemented by farmers

6.2 Increased productivity achieved through improvements in ruminant nutrition and reduction in nutrient losses from the crop/ livestock system.

6.3 Conservation of soils and biodiversity through improved nutrient management resulting from the use of strategic inputs and re-routing of nutrient flows within the system.

6.4 Reduced emission of greenhouse gases and ammonia and losses and of nitrogen and phosphorus to waters.

6.5 Linkage of scientists in developing countries into groups better able to tackle environmental and production issues resulting from increasing human and animal populations.

## 7. Workplan

7.1 Selection of sites.

Criteria for selecting the systems in which the studies are undertaken should include

a) Systems which occupy large area of the continent

b) Population dependence on the system and resources available to farmers

c)The fragility of the agro-ecosystem

d) Relative importance of the livestock sector

The specific criteria to be considered in each target region includes:

Africa : The farming system targeted should be characterised as agropastoralists with strong inter-relationships between semi-arid cropping and free range (common lands). Farmers in these systems have market access restricted to the local area and hence have limited cash transfer opportunities.

South and South East Asia: The focus of the research should be in rice based agro-ecosystems, with an abundant supply low quality crop residues. Farmers in these systems have access to both local and global markets.

7.2 Experimental outline.

a) Characterise the physical resources and social structure of the crop livestock systems in operation in the target areas.

b) Establish a standardised data management system to allow analysis and transfer of data within and between locations

c) Grow the most suitable tree or shrub legume with and without P fertiliser application

i) In a large area without tracers to use as the main source of supplement

ii) In a small labelled area to produce feed to be fed to animals to determine nutrient partitioning in excreta and to produce labelled manure and urine

d) Supplements to be fed with crop residues at minimal and optimal levels to measure animal production responses to leaf supplementation, and this to be compared with direct supplementation of the animal with urea and P and to the application of legume directly to the crop

e) Collect labelled urine and manure during labelled feeding periods and store under farmer practice or optimal conditions.

f) Apply the excreta to a food crop and measure yield and quality response and trace fate of nutrients (with and without additional N), and

g) Measure direct and residual effects on soil fertility and physical properties.

7.3 Considerations for the selection of contract holders

a) Ideally the contract holders should be involved in similar research to that proposed here so that nuclear techniques could be introduced to the studies to improve the definition of nutrient flows.

b) Linkages between scientists and/or institutions with expertise in soil fertility, agronomy and animal production is essential.

c) Supplementary funding from national/international donors should be available to enable the scale of the study to be sufficient to encompass the whole soil/ plant/ animal continuum.

d) Separate financial support should be given to soil and animal scientists operating at the same research site to enable the necessary integration to be accomplished.

### 7.4 Isotope techniques and required support

Isotope techniques to be used in the CRP include some, or all of the following:

a) $^{15}N$ and $^{34}S$ for nutrient dynamics studies to follow the pathways of nitrogen and sulfur in the soil/plant/animal continuum.

b) $^{13}C$ for constructing carbon budgets and to be able to determine short-term changes in soil organic matter concentrations.

c) $^{32}P$ or $^{33}P$ to estimate the efficiency of P utilisation in legume leaf production

d) A Technical Contract to study of the value in using $^{18}O$ as a surrogate for P should be awarded.

**8. Project logframe**

| Narrative summary | Verifiable indicators | Means of verification | Important assumptions |
|---|---|---|---|
| **Goal (overall objective):**<br>To enhance animal and crop production through improved feeding strategies of ruminants and more efficient nutrient cycling in integrated ruminant /cropping systems | Farmers adopt better feeding and excreta management strategies | Increased animal and crop production<br>Improved nutrient budgets | Human and physical infrastructure available and institutional commitment |
| **Purpose (specific objectives)**<br>1.To characterise the target systems. | Physical and social survey conducted | Report | Staff available with the necessary skills |
| 2.To improve the productivity of animals through the introduction of legume leaf protein to supplement low quality crop residues and forage. | Animal production increases via improved feed efficiency | Feed intake, animal liveweight data | No disease outbreak or effective control measures available or catastrophic climatic events |
| 3. To improve the management of excreta to increase the re-cycling of nutrients which is reflected in improved crop production. | Crop production increases and improved nutrient use<br>Reduced nutrient losses from the system | Crop yield and quality data.<br>Nutrient balance data | As above |
| 3. To monitor the residual effects of excreta on soil fertility and physical properties | Enhanced nutrient supply and retention capacity.<br>Better conditions for root growth and soil better water relations | Soil physical and chemical analysis data | Analytical capability available and QA implemented |

| **Narrative summary** | **Verifiable indicators** | **Means of verification** | **Important assumptions** |
|---|---|---|---|
| 4. To investigate the role of the animal in optimising the transfer of nutrients to the crop | Relative economic returns from animal and crop outputs<br><br>Changed nutrient flows | Economic analysis<br><br>Nutrient budgets | No influence of catastrophic events |
| 5. To monitor the residual effects of excreta on soil physical properties and fertility | Reduced need for fertiliser, soils easier to cultivate and soil water properties improved | Data entered in database and report prepared | Analytical capability available and QA implemented |
| 6. To monitor the performance of ruminants and construct nutrient budgets in systems adjacent to the experimental sites to allow comparisons with experimental data. | Similarity of production and research systems verified | Data entered in database and report prepared | No influence of catastrophic events |
| 7. To use appropriate models to aid prediction and scaling of the research findings. | Contrasting models selected | Model available to extension personnel | Links with research services well established |
| 4.7. To build in-country capacity to conduct integrated nutrient studies with the aid of nuclear techniques. | Preparation of training manual on soils, animal and data management | Training course completed | Competent and enthusiastic staff available |
| **Outputs:**<br><br>I. Improved knowledge of nutrient cycling in integrated ruminant/cropping systems and strategies to enhance nutrient capture within the system. | Data on nutrient pool sizes and flows | Progress reports from participants | Analytical capability |

| Narrative summary | Verifiable indicators | Means of verification | Important assumptions |
|---|---|---|---|
| 2. Established guidelines for the management of livestock excreta, crop residues and low quality forages. | Definition and comparison of management options | Publication of guidelines document | Good quality data available |
| 3. Increased capacity of NARS to integrate nuclear techniques into research programmes and to conduct inter-disciplinary research. | NARS personnel skills enhanced | Increases in quality publications<br>Participation in integrated research projects | Staff commitment |
| 4. Published and disseminated research results | Technical and scientific research papers, conference /workshop presentations | Publications available | Staff time allocated to this task |
| **Activities:**<br>1. Form a research network | a) 10 RC from Animals and 10 RC from Soils in partnership<br>b) 5 AH | 20 RC and 5 AH awarded. | |
| 2. Organise 1st RCM to agree on work plans | Hold 1st RCM (2001) | 1st RCM Report | Suitable proposals submitted. |
| 3. 2nd RCM to evaluate progress in implementation and revise protocols. | Hold 2nd RCM (2002) | 2nd RCM Report | Field experiments conducted and samples analysed. |
| 4. 3rd RCM to evaluate management practices | Hold 3rd RCM (2004) | 3rd RCM Report | Evaluate progress of improved management practices and refine where necessary. |
| 5. Final RCM to present all results | 5. Hold Final RCM<br>(2006) | 5. Final report | Timely submission of final reports |