R6283: Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems

A Final Technical Report on a Research Project Funded by the Department for International Development's Livestock Production Research Programme

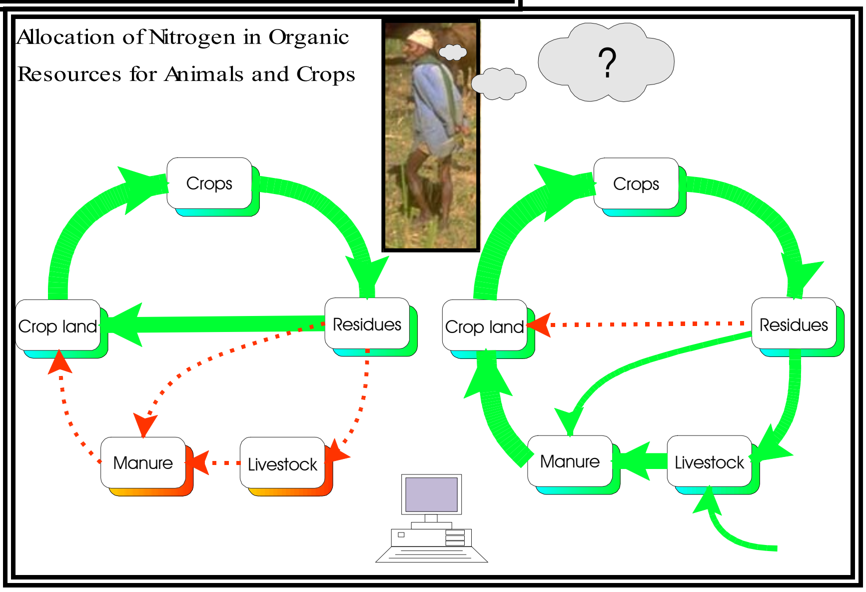

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Table of Contents

List of Tables

List of Figures

Executive Summary

Minimising nutrient losses through promoting effective recycling of nitrogen (and other nutrients) is a key issue in maintaining the sustainability of many smallholder, mixed farming systems. However, it is only recently that the dynamic role that may be played by livestock in mediating N transfers has come to be recognised. This includes the potentially high sensitivity of the N dynamics of the farming system as a whole to changes in livestock feeding management. The varying quality (e.g. N, lignin and polyphenol content) of livestock diets influences feed digestibility, partitioning of nutrients amongst different ruminant tissues and partitioning of excreted nutrients between faeces and urine. The consequences of variation in these partitions for the value of excreta in providing nutrients to the soil and hence supporting crop production, have been poorly understood and under-researched.

This LPP project (R6283: ' Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems') has used both experimental and simulation modelling techniques to examine the implications of changes in N dynamics in animals for the subsequent behaviour of N in soils to which their excreta has been added and for plant growth on those soils. A significant, novel feature of the approach taken in R6283 has been to integrate animal metabolism experiments with soil and plant growth studies conducted under controlled conditions by using characterised manure from the animal experiments. An on-farm study was then established to verify the implications of the results of the experimental studies under field conditions. Despite a number of difficulties during the establishment phase, delivery of project outputs has now been completed to schedule.

Animal metabolism studies indicated the high degree of variation that may be induced in manure quality by dietary manipulation. Changes in both level and form of N supplementation radically altered the total amounts of N excreted and its partitioning between faeces and urine. The results of the studies indicated that the presence of dietary polyphenols might also affect the extent to which faecal N was bound to neutral detergent fibre with considerable implications for the dynamics of N release on the incorporation of manure into the soil.

The dynamics of N mineralisation (measured in leaching tubes) was affected considerably by the provenance of the manure (i.e. the diet that had produced it). Manures produced from diets supplemented with *Calliandra calothyrsus* and *Macrotyloma axillare* had similar N

mineralisation patterns, with net cumulative N release occurring at around week 16 following incorporation. However, N mineralisation from these manures was much faster than mineralisation from manure derived from diets supplemented with poultry manure. Nonetheless, there was evidence that N was immobilised for at least 12 weeks following applications of all manure types suggesting that application at planting (a common local practice) may not always be most effective in promoting crop growth.

The potential significance of these observations was confirmed by seedling growth studies conducted in pots in which the highest dry matter assimilation was observed after 12 weeks in treatments where no manure had been added. Reductions in DM yields associated with the addition of manure produced from the different treatment diets ranged from 6% to 27% in comparison with the un-manured control - a finding that was consistent with the pattern of immobilisation of soil N observed in the leaching tube experiment. Such a lag period between application of manure to the soil and a net release of N has considerable significance for planning organic matter applications in practice. Furthermore, these results would suggest that dietary factors might need to be taken into account in doing this. Early manure applications before planting could provide better synchrony of crop N demand with N release from added manure. Alternatively, the beneficial effects of manure application may only be realised in the growth of a later season's crop.

An on-farm study conducted in the Tea, Coffee and Semi-arid agro-ecological zones to the east of Nairobi, and again using characterised manure, examined whether these experimental findings are borne out in the farmer's field. Initial findings (from one season's crop) were somewhat ambiguous. Lower rates of crop dry matter assimilation in manured and littered plots were consistent with the observations of N immobilisation under controlled conditions. However, the differences amongst litter and manure types observed in the mineralisation and pot growth experiments were not repeated under field conditions. These observations might longer-term studies for confirmation as data were not available on mineralisation beyond 24 weeks (i.e. beyond the first crop). However, it is also likely that appropriate manure and litter handling techniques for conservation of N may be a priority area for research if the potential benefits for soil fertility of the interactions of organic resources with animals are to be realised.

Modelling activities carried out by the project in parallel with the experimental studies described above led to the development of the ANORAC (Allocation of Nitrogen in Organic Resources for Animals and Crops) model. Among other things, ANORAC allows the consequences of different strategies of organic matter use (e.g as litters / green manures or as feeds) to be evaluated. A copy of the model and its documentation is included with this report.

Recommendations

On the basis of the project's main findings, the following are suggested as key areas for future research:

- Collaborative on-farm studies aimed at the development of integrated management strategies. For example, where poor growth during establishment has been identified as a problem on-farm, an examination of the consequences of interventions in livestock management, manure management and composting and agronomic practices *and their interactions* might be used to identify an appropriate range of solutions;
- evaluation of strategies for optimising the balance between diet quality and manure management strategies for maximum transfer of nutrients in manure at application;
- the inclusion of a manure - compost module in the ANORAC model that would allow it to be used more effectively as a decision support tool. This might be undertaken concurrently with the activities outlined above.

Background

Identification of Demand

The importance of nitrogen (N) cycling in the mixed farming systems of sub-saharan Africa and elsewhere has received only patchy attention from researchers and development planners. A notable gap in the knowledge base relates to the pivotal role played by livestock in regulating nutrient flows. The dynamic nature of the nutrient-based interactions between livestock and crops has generally been ignored in experimentation and crop modelling although, on the farm, livestock are a tightly integrated part of the system. The consequences of this for the smallholder farmer is a lack of reliable support in planning the structural and strategic modifications to their farm management practices that changing environmental, demographic and market conditions increasingly demand.

Researchable Constraints

Marked changes in seasonal feed availability and nutritive value occur which are reflected in both the quantity and quality of manure produced. For example, the partition of excreted N between faeces and urine can fluctuate widely with changes in diet composition which affect the degradability of protein in the rumen and post-ruminal release and uptake of nitrogen. The presence of tannins in feeds has also been negatively correlated with protein degradability and, in some cases, overall digestibility. However, research is needed to clarify the consequences of this diet-induced variation in manure quality on the wider dynamics of the soil-crop-animal system.

Different species and classes of livestock produce excreta of varying nutrient compositions. Many of the management practices employed by farmers may deliberately or incidentally influence the quantities and relative proportions of nutrients that are ultimately returned to the soil. As a result, changes in animal movements, carrying capacity in a grazing situation, collection, storage and distribution of excreta from stalled animals, and as stated above, in the use of feed resources can all induce effects in soil N status and thereby in crop growth. The extent and significance of these “knock-on” effects of livestock management and their interactions with soil and crop management strategies is a further area in which, given the paucity of information in the literature, further research will be required.

Assessing the consequences of interventions in one system component for processes in another would require experiments of an infeasible complexity. For example, it would be difficult to conceive a routinely applicable experimental approach that could test for the main effects of and interactions associated with changes in dietary N supplementation on the progress of N mineralisation in the soil when manure produced was incorporated into the soil. This would certainly not be practicable for testing farmers problems at different locations. In order to address this difficulty in a way that might provide a tool that would provide the support that farmers lack in accounting for these complexities, the project took the approach of linking a series of experimental studies which examined the effects of animal management on the processes underlying N transactions in the animal, N release from manure and / or litter incorporated in the soil and the resultant growth of crops. These studies were also used to provide validation data for a mechanistic model which linked the animal and soil system components to allow the effects of different organic resource management strategies on the N status of soils to be predicted under a wider range of conditions and thereby to provide relevant information to support farmers' decision making on organic matter management strategies.

Review of Literature

Production of Manure and Urine

The quantity and quality (concentration and balance of nutrients) of manure and urine available for soil amendment depends on the number and species of animals, the amount and type of feed consumed, the interaction between feed quality and animal digestive factors and on the management of animals between confined, tethered and free ranging conditions.

Marked changes in seasonal feed availability and nutritive value may occur in the tropics, both in grazing and stall-feeding systems. Accordingly, manure production may also be expected to vary (Lambourne *et al*, 1983; Thorne *et al*, 1998). In Mali, Dicko-Toure (1980) measured intake and faecal production by cattle of approximately 250kg liveweight.and found that the average dry matter intake in each month varied from 4.6 to 6.4 kg day^{-1} whilst faecal dry matter production ranged from 2.1 to 3.1 kg day^{-1}. Production was found to be lowest during the dry season when feed was in relatively short supply. Seasonal changes in the nutrient composition of the diet will also affect the quality of the excreta (Powell, 1986).

Observed N concentrations were much lower in the early dry season when crop residues predominated or in the early wet season when diet quality was highest.

The partition of N between faeces and urine can also fluctuate widely with changes in diet composition. In a number of studies conducted in Cameroun and Nigeria (Ifut, 1989; Ogundola, 1989; Njwe and Godwe, 1989; Olubajo *et al*, 1989), the proportion of total N excreted and appearing in the urine varied from 4% in goats consuming cassava peel to 72% in those fed Napier grass (*Pennisetum purpureum*). One factor likely to affect the retention of nitrogen and, thereby, its partition between faeces and urine is the degradability of dietary protein in the rumen. In tropical feeds, this may be affected by the presence of polyphenolics, especially tannins. This diverse group of compounds, known to precipitate protein (Hagerman *et al*, 1992) is present in a wide range of tropical browse species (Onwuka, 1992; Rittner and Reed, 1992). These species are widely distributed and are important components of ruminant diets (Le Houerou, 1980) often providing a proteinaceous supplement to diets that would otherwise be deficient in N. Tannins have been shown to be negatively correlated with both protein degradability (Rittner and Reed, 1992) and protein digestibility (Hagerman *et al*, 1992; Hanley *et al*, 1992). Such effects would be expected not only to increase the amount of N excreted but also to decrease the relative proportion excreted in the urine while increasing that excreted in the faeces as digestion is shifted from the rumen to the intestinal tract.

Different species and classes of livestock produce excreta with varying nutrient concentrations. Young animals that are growing rapidly or dairy cows generally produce manure with a lower nutrient content than fattening animals due to their greater efficiency in extracting nutrients from feeds. The nutrient contents of manure produced by different species in sub-Saharan Africa (McWalter and Wimble, 1976; Kwakye, 1980; Pichot *et al*, 1981) are generally lower than those from the temperate zone (Hanson, 1990). This is to be expected as the feed consumed, the climate and management conditions are very different in the tropics.

The efficiency of conversion of dietary N into animal protein can be very poor in some livestock systems. In a discussion of N cycling in the savannah zone of Nigeria, Singh and Balasubramaniam (1980) stated that less than 10% of N in grass, legumes and crop residues was retained in the body. However, this must be considered a sweeping generalisation as N utilisation and retention is affected by the nature of the diet and the level of intake. In trials with sheep in Tanzania, Sarwatt *et al* (1990) showed that, as dietary N supply increased from 3.1g day^{-1} to 11.3g day^{-1}, as a result of increasing amounts of the legume supplement *Crotalaria ochroleuca* in the diet, apparent N retention increased from -6.5% in the unsupplemented control to 36% in a diet in which 300 g day^{-1} of the supplement was fed. In another study by Ogundola (1989), N retention as high as 53% of intake were observed in calves consuming concentrate diets.

Utilisation of Manure and Urine

By controlling animal movements, adjusting carrying capacity in a grazing situation or storing and distributing excreta from animals kept in confinement, a farmer may influence the proportions of nutrients returned to the soil in a given location.

McIntire *et al* (1988) discussed the effects of the farming system on the utilisation of manure in a review of crop-livestock interactions in Africa. In areas of low cropping intensity, manure is often obtained through paddocking contracts, with cattle being kept on farmers fields in rotation. In such cases, herders have little or no land of their own and, therefore, do not require large amounts of manure for themselves. However, when the intensity of cropping increases so does the demand for manure. As more herders become settled and require manure for their own use, then supplies decrease. When this happens, farmers may need to raise their own animals in order to obtain manure and urine. McCown *et al* (1979) and Von Kauffman and Blench (1989) presented data from West Africa which indicated that the exchange of manure for crop residues was widespread. Powell and Bayer (1985) followed herds of Bunaji cattle on the Abet plains of central Nigeria and found that arrangements were made in which a farmer gave first access to grain-harvested fields in return for manure and urine deposition. It was only after this initial grazing that fields were allowed to revert to the status of a communal resource. The same authors also cited work from Zaria, also in Nigeria, where pastoralists assisted in the harvesting of grain in order to be allowed access to the crop residues.

In systems where animals are grazed or continuously confined to cropland, it is obvious that the length of time spent on a particular area of land will influence the quantity of manure and urine deposited. Differences in animal management in trials in Burkina Faso by Quilfen and Milleville (1983) resulted in appreciable differences in the quantity of manure found on plots;

the range being from 1.2t to 4.5t dry matter ha^{-1}. Animal management can also affect the distribution of excreta. Powell and Mohamed-Saleem (1987), following herds during the crop residue grazing period, observed that voiding by cattle took place consistently in the vicinity of water holes after the morning grazing. This would result in uneven distribution of nutrients and a decrease in the expected amount of material deposited on crop land.

The distribution of nutrients in grazed paddocks will be influenced by such factors as paddock size, stocking rate and grazing system. The high concentrations of nutrients in patches of manure and urine may result in their inefficient use. Where average return of N from grazing was 160 kg ha^{-1} $year^{-1}$, Whitehead (1990) estimated that areas of urine patches received the equivalent of 530 kg ha^{-1} $year^{-1}$. t'Mannetje and Jarvis (1990) have noted that, in urine and manure patches, the palatability of fouled herbage is reduced with animals refusing to graze these areas. Eventually bare patches develop allowing weeds to ingress. Omaliko (1981) also observed rejection of herbage in the Nigerian savannas. Similar effects can be expected in the grazing of crop residues, where material is trampled to the ground, fouled and then rejected by the animal.

Powell (1986), in his calculations of the amount of faeces voided during grazing, assumed that 50% of the total was excreted during a 14h period from morning to evening. However, it is possible that diurnal variation occurs in both the quantity and quality of manure produced. Betteridge *et al* (1986) observed diurnal variation in urinary concentrations of N, phosphorous (P) and potassium (K); concentrations being lower during the day and higher in a 6h period ending at 08:00h. There were also diurnal variations that would have a significant effect on the quantity of nutrients returned to the land. It appears that there are few data and that estimates of manure production are usually based on 24 h total collections.

Nitrogen Losses from Manure and Urine during Storage, Application and in the Field

The quality of excreta is best when it can be applied fresh, but application to crops is seasonal and, therefore, manure from animals in confinement is normally stored. Management of this manure influences directly the loss of N before application. The extent of these losses may vary from 10% with air-dried manure to 80% for manure stored in an open lagoon (Gilbertson *et al*, 1981). Storage as slurry results in minimal volatilisation through the presence of a large liquid volume and the formation of a surface crust (Whitehead, 1990).

Storage in this way can limit losses to between 5 and 15% of the total N compared with estimates as high as 52% in uncovered slurry (Jarvis and Pain, 1990) but incurs a high cost. Gilbertson et al (1981) found that N loss was minimal when manure was stored with an initial total solids content of 20 - 30% or more. Kwakye (1980), working in Ghana, studied the effects of storage method and found that up to 59% of the N and 28% of phosphates were lost after 3 months storage. Losses of N were lowest in manure stored in a pit covered with layers of dried grass and soil (14%), whilst the highest losses occurred in manure spread loosely on a bed of grass.

Application methods can vary amongst farms with considerable consequences for the fate of N in manure but often the failure to incorporate applied manure results in losses. In Burkina Faso and Niger, there is no incorporation even by hand. In Zimbabwe, where animal traction is common, oxen are used only occasionally to incorporate the manure. Therefore, it has been suggested that many field trials in which incorporation has been practised routinely may exaggerate crop responses to manure application. (McIntire *et al*, 1988). Jarvis and Pain (1990) cite work under temperate conditions in which some 40 - 50% of the total N loss from slurries occurred within 6h of application, 70% within 24h and more than 90% over a five day period. Hanson (1990), reporting the results of trials with pig manure, showed that cultivation after application reduced substantially N losses by volatilisation. Without cultivation, losses in liquid and solid manure varied from 10 to 20% and 15 to 30% respectively. With cultivation, losses of less than 5% were observed for both forms of manure.

The nutrients present in faeces are mainly in an organic form and are, therefore, only available for crop growth when mineralised in the soil. However, N from urine is readily available. Horses produce a manure that ferments rapidly and does not persist. Cow manure is more liquid and decomposes slowly. Feeding straw produces manure that ferments slowly whilst supplementation with oilseed cakes and legumes produces manure that is more rapidly fermentable. Feeds that contain high levels of tannins may lead to the production of manure in which the availability of N is low. The transportation required when animals are confined away from cropping land may present major problems. N and other minerals voided in the urine will be largely lost unless these are carefully trapped. Powell and Williams (1991) conducted trials in Niger in which faeces and urine were collected separately and applied to experimental plots. Total dry matter yields (crop and weeds) in plots receiving both faeces and urine were found to be 52% greater than those in plots which had been treated with faeces alone.

Although some cycling of nutrients will take place directly from residues of both mixed pastures and crops in the field, the urine of grazing animals is thought to be a major pathway for N transfer from legumes to grasses in mixed swards. However, there can be no doubt that grazing animals are also responsible for large N losses from pasture. In trials in Australia, N losses from urine ranged from 64 - 80% depending on soil type, temperature and rainfall (Anonymous, 1969). Singh and Balasubramaniam (1980), in the savanna zone of Nigeria, reported that of faecal and urinary N deposited on pastures, more than 50% was lost through volatilisation. There are few data on volatilisation from manure. However, Ryden et al (1987) showed that ammonia losses from manure occurred at a slower rate than those from urine, reflecting the fact that the N present occurs mainly in bacterial cells or as undigested dietary N. The N in urine is present mainly as urea which, in moist soils, is easily hydrolysed to ammonium carbonate from which ammonia is volatilised into the atmosphere.

Clearly, whilst animal management strategies may be used to optimise the delivery of nitrogen to the manure / compost pathway, without effective management of losses, the impact of such interventions may be compromised.

Modelling Nitrogen Dynamics in Mixed Farming Systems

The complexity of the relationships described above suggests an important role for modelling in evaluating the role of livestock in nutrient cycles and, ultimately, for planning optimum management strategies for practical situations.

Current soil nutrient models have focused mainly on the effects of direct litter deposition or incorporation of crop residues into the soil and its effect on soil fertility (e.g. SCUAF, Young and Muraya, 1990 and CENTURY, Parton *et al.*, 1987). Where the existence of the feed-manure is acknowledged, the characterisation of plant and manure quality has generally been inadequate (Thornley and Johnson, 1990) and unable to encompass the wide variety and quality of fodder available in the tropics. Even where some characterisation of manure quality has been attempted (e.g. McCown et al, 1996), this has not been approached mechanistically and is therefore insensitive to the key processes in the animal component of the system that have been described above.

Plant quality factors which affect animal intake and performance are often also related to litter decomposition and nitrogen mineralization processes in the soil. Some of these factors like C:N ratio and lignin/N ratio are already incorporated into existing models (CENTURY) and the relationships between the degradation of plant material in the rumen and the mineralisation of organic N in soils has been investigated within the Wye College-Merida, Mexico DfID funded link (Armendiz, 1997) - indicating a number of interesting parallels. Recent research has demonstrated that for many tree based systems the presence of polyphenols may severely reduce the contribution of pruning material to increased soil fertility (Handayanto *et al.*, 1994; Fox *et al.*, 1990; Palm and Sanchez, 1991). As in the case of animal nutrition the activity of polyphenols (its protein binding capacity) appears to be more important than total polyphenol content under non-leaching conditions (Handayanto *et al*., 1994).

The potential of a simulation modelling approach to integrate these diverse processes in soils and animals and to analyse the consequences of livestock related management decisions on nitrogen flows in crop-livestock systems has been illustrated by Thorne (1995). This model was used to predict the partitioning of excreted nitrogen between faeces and urine and the availability of nitrogen for soil incorporation from crop residues and manure / compost under different fodder / grazing management regimes. It did not, however, attempt to predict the partitioning of N into labile and recalcitrant pools and was not suitable, generally, for integration with a mechanistic soil model.

Project Purpose

The project was designed to contribute to output 1.4 of the Livestock Production Programme's Forest-Agriculture Interface Production System. Its purpose may therefore be stated as:

The role of livestock in forest-agriculture (and hillside) systems assessed and improved strategies for increased contribution of livestock to sustainable farm production developed and promoted.

Research Activities

Implementing the Project

Demand for a project to address the issues covered by R6283 was first identified during discussions with members of staff at the Pakhribas Agricultural Centre (PAC) in Nepal. The project's field work was originally designed to be located in Nepal with one Ph.D. student funded by PAC and a second, funded by the project, responsible for its day-to-day conduct. The development of the simulation model would take place in the UK but with regular interaction and exchange of ideas with those implementing the field experimentation.

Within 12 months of the project's inception, it became apparent that structural changes within the NARs in Nepal which lead to an effective moratorium on establishing new initiatives at PAC during this period would prevent the project from delivering its outputs within the specified deadline. Reluctantly, it was decided that the field studies should be located elsewhere.

Strong institutional links have existed over a number of years between NRI and the International Livestock Research Institute (ILRI) which, in its turn, has established an excellent working relationship with the NARs in Kenya and, in particular, the Kenya Agricultural research Institute (KARI). Furthermore, ILRI had already sought to establish collaborative links with Wye College in legume N cycling research. It was apparent that the activities envisaged under R6283 would fit well with the established priorities of both KARI and ILRI. Therefore, with the agreement of all parties, the field work was relocated to Kenya in May, 1996. Subsequently, ILRI and KARI have been extremely supportive of the project and staff members from both institutions have played a fully integrated role in its activities.

The difficulties experienced in establishing the project's experimental programme in Nepal delayed it, effectively, for 12 months. Furthermore, the work programme, originally designed for 2 Ph.D. students, had to be shared between 1 student and the two project leaders from NRI and Wye College. It is, therefore, with some relief that we reach the stage of preparing this final technical report describing its outputs!

The Experimental Programme

Experiment 1: The Effects Of Feed Nitrogen And Polyphenol Levels On The Fate Of Ingested Nitrogen In Steers

This experiment was conducted at the Kenya Agricultural Research Institutes National Agricultural Research Centre at Muguga, 20 km north of Nairobi, Kenya (S 1 13 53.0 E 36 38 1.1) between March and July 1997.

Seven Friesian-Ayrshire steers (mean bodyweight 246 kg ±26) from the Muguga farm were selected, inspected by a vet and treated for endo- and ectoparasites. The steers were fed a daily basal diet of barley straw (25g dry matter (DM) kg^{-1} bodyweight (W)) alone or supplemented with 0.15 or 0.3 of the DM offered as *Calliandra calothyrsus*, *Macrotyloma axillare* or poultry manure giving a total of seven dietary treatments (Table 1). The experiment used an incomplete carry over design based around five, 20 day periods. This allowed each of the seven steers to be used to test five of the seven diet treatments. During the course of the experiment, animals were weighed weekly and the DM offer of basal diet and supplements was recalculated according to this new weight.

Table 1: *Descriptions of the Treatments Used in Experiment 1.*

Treatment No.	Treatment description
BS	Barley straw basal diet offered at 25 g DM kg BW^{-1}
CC15	Barley straw supplemented with 15% *Calliandra calothyrsus*
CC30	Barley straw supplemented with 30% *Calliandra calothyrsus*
MA15	Barley straw supplemented with 15% *Macrotyloma axillare*
MA30	Barley straw supplemented with 30% *Macrotyloma axillare*
PM15	Barley straw supplemented with 15% poultry manure
PM30	Barley straw supplemented with 30% poultry manure

Animals were adapted to diet for 14 days at the start of the experiment and each time the diet was changed During this adaptation period, they were kept in large individual pens (8m by 4m). The adaptation period was followed by a six day collection period in metabolism crates. The crates were situated on the first floor of a purpose built unit, with facilities for the separate collection of faeces and urine on the ground floor.

The fresh supplements were cut each morning, chopped to a length of approximately 100 mm and offered within one hour of cutting. Poultry manure was prepared before the start of the trial by screening wood shaving-based poultry manure through a 5mm mesh. All supplements were offered at 08.00 h after removal of the previous day's refusals from the feed containers and crate floor. The un-chopped barley straw basal diet was split, half being offered after complete consumption of the supplement in the morning and the remainder at 16.00 h. Water and a mineral lick were available *ad libitum.* Feed offers and refusals were weighed daily throughout the whole experiment, duplicate sub-samples (500 g) of the basal diet and supplements were taken daily, dried for 48 h at 60°C in a forced draft oven. During the six day collection period in the metabolism crates feed offers and refusals were weighed daily. Duplicate sub-samples (500 g) were taken, dried for 48 h at 60°C in a forced draft oven and bulked over the six day collection period.

Urine was collected directly into acid (2M H_2SO_4), weighed twice daily and a sub-sample (50 ml) frozen; bulking over six days was carried out prior to analysis. During the six day collection period in the metabolism crates total faecal output was weighed daily. Duplicate sub-samples (500 g) were taken, dried for 48 h at 60°C in a forced draft oven and bulked over the six day collection period. Total daily faecal production was used to calculate the digestibility of dry matter (DMD).

All feed, refusals and faecal samples were analysed for the following components: nitrogen (Kjeldahl digestion followed by steam distillation; Tecator); ADF and NDF (Ankom Technology Corporation, Fairport, USA.); NDF-N (Ankom incubation followed by nitrogen determination) and total ash (by heating for 4 h at 500°C). Feed samples were also analysed for total extractable polyphenols (Folin-Ciocalteau) and protein binding capacity (Dawra, 1988). Urine N was determine by Kjeldahl digestion followed by steam distillation using the Tecator system.

Data on intake, digestibility and chemical composition of feed offered, refusals and excreta were analysed by ANOVA using the SAS General Linear Models procedure (SAS Institute, 1988).

Experiment 2: Rumen Degradability Of Dry Matter And Nitrogen Measured By the *In Situ* Technique

This experiment was also carried out at the KARI Muguga, experimental farm.

Four Friesian-Ayrshire steers (mean bodyweight 259 kg ±20) from the farm were selected, inspected by a vet and treated endo- and ectoparasites. Rumen cannulae (internal diameter 150mm) were fitted four weeks before the start of the experiment.

The experiment was designed as a 4 x 4 latin square. Steers were fed a basal diet of barley straw either alone (BS) or supplemented with *Calliandra calothyrsus* (CC), *Macrotyloma axillare* (MA) or poultry manure (PM) to provide a daily intake of 384 g crude protein. All feed offered was consumed for the supplemented diets throughout the trial. The steer on the straw only diet was offered barley straw *ad libitum* (30g dry matter (DM) kg^{-1} bodyweight). Daily feed samples were taken for DM and nitrogen content and the steers were weighed weekly. The DM offer of the basal diets and supplements was recalculated weekly according to account for changes in N content and bodyweight.

The animals were adapted for 14 days at the start of the experiment and after each change of diet during which time they were kept in large individual pens (8m x 4m). The adaptation period was followed by a six day experimental period during which the *in sacco* incubations were carried out. The steers were kept in the same individual pens during this experimental period.

The fresh supplements (*C. calothyrsus* and *M. axillare*) were cut each morning, chopped to a length of approximately 100 mm and offered within one hour of cutting. Poultry manure was prepared before the start of the trial by screening wood shaving based poultry manure through a 5mm mesh. All supplements were offered at 08.00 h. The unchopped barley straw basal diet was divided into two with half being offered after complete consumption of the supplement in the morning and the remainder at 16.00 h. Water and mineral lick were available *ad libitum.* Feed offers and refusals (barley straw diet only) were weighed daily throughout the whole experiment, duplicate sub-samples (500 g) of the feed and supplements were taken daily and dried for 48 h at 60°C in a forced draft oven.

All feed and refusals were analysed for the following components: nitrogen (Kjeldahl digestion followed by steam distillation; Tecator); ADF and NDF (Ankom Technology Corporation, Fairport, USA); NDF-N (Ankom incubation followed by nitrogen determination); ADL (Ankom Technology Corporation, Fairport, USA); total ash (by heating for 4 h at 500°C); Total extractable polyphenols (Folin-Ciocalteau) and Protein Binding Capacity (Dawra, 1988)

For incubation in the nylon bags, barley straw (whole stem), *Calliandra calothyrsus* (leaflets and petioles <5 mm diameter), *Macrotyloma axillare* (whole plant) and poultry manure (screened to 5mm) were dried for 48 h at 60°C in a forced draft oven and ground to pass a 3 mm sieve. Approximately 3 g of sample (0 to 48 h) and 5 g of sample (72 and 96 h) were placed into pre-weighed rumen *in situ* filter bags [Ankom Technology Corporation, Fairport, USA; pore size 50 µm (± 15 µm)]. The bags were placed in the rumen at 8.00 h before the morning feed. Bags containing barley straw, *Calliandra calothyrsus* and *Macrotyloma axillare* were removed after 6, 12, 24, 48, 72 and 96 h. The poultry manure samples the bags were removed after 2, 4, 8, 12, 24 and 48h. Duplicate bags were used at each removal time from each steer. Following removal from the rumen, the bags were placed into a bucket of cold water and washed several times until clean water was left after washing. After washing the bags were dried for 48 h at 60°C in a forced draft oven. The initial soluble loss was determined by placing four nylon bags representing each treatment into cold water, soaking for 30 min, agitating by hand for 10 min and washed several times until clean water was left after washing. The bags and their contents were dried for 48 h at 60°C in a forced draft oven.

Table 2: *Descriptions of the Treatments Used in Experiment 3.*

Treatment No.	Treatment description
SO	Control (soil only)
CCL	*Calliandra calothyrsus* litter
MML	*Macrotyloma axillare* litter
BSL	Barley straw litter
PM	Screened poultry manure
BSF	Faeces generated by a barley straw diet
CC15F	Faeces generated by a barley straw diet supplemented with 15% *Calliandra calothyrsus*
CC30F	Faeces generated by a barley straw diet supplemented with 30% *Calliandra calothyrsus*
MM15F	Faeces generated by a barley straw diet supplemented with 15% *Macrotyloma axillare*

MM30F	Faeces generated by a barley straw diet supplemented with 30% *Macrotyloma axillare*
PM15F	Faeces generated by a barley straw diet supplemented with 15% poultry manure
PM30F	Faeces generated by a barley straw diet supplemented with 30% poultry manure

After oven drying duplicate samples were bulked and DM and N contents of the time course samples were determined. These data were fitted to the model of Orskov and MacDonald (1979). The insoluble fermentable DM was calculated using the equation of Dhanoa, (1988.

Data describing OM and N digestibility, chemical composition of feed offered and refused were analysed by using the SAS General Linear Models procedure (SAS Institute Inc., 1988). Correlation coefficients were calculated between chemical composition of the feeds, the fractional rate constant and degradability at the various times.

Experiment 3: Investigation Of Decomposition And N Mineralization Of Different Quality Manures In A Leaching Tube Incubation

This experiment used the manure that had been generated and characterised during experiment 1 to examine the general hypothesis that these would display different N-release patterns when incorporated, subsequently into the soil. The experiment was carried out in a controlled environment at Wye College. 12 experimental treatments were tested (Table 2).

Soil (0-20 cm) was collected from KARI-Muguga Research Station, Kenya, air-dried and ground to pass a 2 mm sieve. A 50g sample of this soil was mixed with acid-washed sand (1:2 w/w) and plant litter and faecal samples added to give equal additions of nitrogen (150 μg N per tube), no faecal sample was added to the control tubes. Each mixture was shaken by hand in a plastic container and poured into individual tubes. Another layer of sand was put on top of the soil-sand mixture to avoid soil disturbance on addition of the leaching solution. 80ml of distilled water was added to each tube to bring the soil-sand mixture to water holding capacity (WHC), after one hour suction was applied to bring the mixture to approximately 80% of WHC. After each leaching the tube was left overnight to drain and the same suction applied to each tube to bring the water content to 80% of WHC thus ensuring adequate aeration of the mixture and avoidance of denitrification problems.

The 12 treatments were each replicated in five leaching tubes which were randomised in racks and placed in a growth room at 25°C. Leachings (150 ml) were conducted after 1, 2, 4, 6, 8, 12, 16, 20 and 24 weeks. The volume of collected leachate was measured and mineral N content (NO_3-N and NH_4-N) measured on an autoanalyser. Cumulative net N mineralization or immobilization was calculated by difference between the cumulative net N in the control and amended soils.

Data for N mineralization/immobilization were analysed using the General Linear Model procedure, with treatment and replicate as the main factors. The rate constant for N release (kN) was calculated by fitting the % N remaining to a single exponential decay model. Correlations between N mineralization/immobilization and the derived rate constant and the initial chemical composition of the incubated samples were conducted.

Experiment 4: Investigation Of Decomposition And N Mineralization Of Different Quality Manures On Short Term Maize growth

This experiment used the manure that had been generated and characterised during experiment 1 to examine the general hypothesis that these would display different N-release patterns when incorporated, subsequently into the soil and that these differing release patterns would affect N availability in the soil and hence short term maize growth. The experiment was carried out in two glasshouses at KARI-Muguga Research Station between August 1997 and March 1998. 13 experimental treatments were tested (Table 3).

Table 3: *Descriptions of the Treatments Used in Experiment* 4.

Treatment No.	Treatment description
SO	Control (soil only)
FERT	Fertiliser control
CCL	*Calliandra calothyrsus* litter
MML	*Macrotyloma axillare* litter
BSL	Barley straw litter
PM	Screened poultry manure
BSF	Faeces generated by a barley straw diet
CC15F	Faeces generated by a barley straw diet supplemented with 15% *Calliandra calothyrsus*
CC30F	Faeces generated by a barley straw diet supplemented with 30% *Calliandra calothyrsus*
MM15F	Faeces generated by a barley straw diet supplemented with 15% *Macrotyloma axillare*
MM30F	Faeces generated by a barley straw diet supplemented with 30%

	Macrotyloma axillare
PM15F	Faeces generated by a barley straw diet supplemented with 15% poultry manure
PM30F	Faeces generated by a barley straw diet supplemented with 30% poultry manure

Soil (0-20 cm) was collected from KARI-Muguga Research Station, Kenya, air-dried and ground to pass a 5 mm sieve. To air-dried soil (4 kg) plant litter and faecal samples were added to give equal additions of nitrogen (25 kg N ha^{-1}), no faecal sample was added to the control. Each mixture was thoroughly shaken and poured into individual pots (20 cm diameter). Distilled water was added to each pot to bring the soil mixture to 80% of water holding capacity (WHC).

The 12 treatments were each replicated in five pots, these were randomised between the two glasshouses. Four maize seeds were planted and thinned to two, one week after germination. Each week the daily water required to maintain 80% of WHC was calculated and this amount added for the remainder of the week. After 10 weeks the shoots were harvested and roots separated from the soil. The dry weight and Nitrogen content of the shoots and roots were determined.

After the first harvest the pots were again planted with maize seeds and the same protocol repeated for a further 10 weeks to investigate the residue effect of the treatments.

Data for dry matter and Nitrogen content of the shoots and roots were analysed using the General Linear Model procedure with block (glasshouse), treatment and replicate as the main factors.

Table 4: *Descriptions of the Treatments Used in Experiment 5.*

Treatment No.	Treatment description
SO	Control (soil only)
F20	Fertiliser at 20 kg N ha^{-1}
F40	Fertiliser at 40 kg N ha^{-1}
F60	Fertiliser at 60 kg N ha^{-1}
CCL	*Calliandra calothyrsus* litter
MML	*Macrotyloma axillare* litter
BSL	Barley straw litter
PM	Screened poultry manure
BSF	Faeces generated by a barley straw diet
CC15F	Faeces generated by a barley straw diet supplemented with 15%

	Calliandra calothyrsus
MM15F	Faeces generated by a barley straw diet supplemented with 15% *Macrotyloma axillare*
PM15F	Faeces generated by a barley straw diet supplemented with 15% poultry manure

Experiment 5: On-Farm Trial In Three Agro-Ecological Zone's To Compare Fresh Litter As A Soil Amendment And Different Quality Manures To Maize Grain And Stover Yields.

This experiment used the manure from the 15% supplementation rate that had been generated and characterised during experiment 1, to examine the general hypothesis that these would display different N-release patterns when incorporated into the soil and that these differing release patterns would affect N availability in the soil and hence maize stover and grain yields. The experiment was carried out in three AEZ's (Coffee, Tea and semi-arid) in Central Province of Kenya during the short rains of the 1997 season. 12 experimental treatments were tested (Table 4).

Three farms were selected for each AEZ, each farm had one replicate of each treatment. Plot size was 6 m x 4 m, holes were dug at a spacing of 75 cm x 30 cm. Plant litter and faecal samples were added to each hole to give equal additions of nitrogen (25 kg N ha^{-1}), no faecal sample was added to the control. Three seeds were planted per hole, the plants were later thinned to one plant per hole. All plots were kept weeded.

Data for dry matter yield and nitrogen content of stover and grain were analysed using the General Linear Model procedure with treatment and replicate as the main factors.

Experiment 6: Effect Of Bean-Maize Intercropping, Phosphorus And Manure Additions On N_2 Fixation Of *Phaseolus Vulgaris* In The Central Highlands Of Kenya

This experiment was intended to provide a preliminary view of the importance of the interactive effects of manure and P additions in an situation where and N fixing crop is used in intercrop (bean - maize) typical of the Kenya Highlands. It was carried out in experimental plots established at the KARI Muguga experimental station.

Table 5: *Descriptions of the Treatments Used in Experiment 6.*

Treatment	Treatment description
Sole -P	Sole cropped *Phaseolus vulgaris* with no P supplemention
Sole +P	Sole cropped *Phaseolus vulgaris* with 60 kg ha^{-1} P_2O_5
Inter -P	*Phaseolus vulgaris* intercropped with *Zea mays*; no P supplemention
Inter +P	*Phaseolus vulgaris* intercropped with *Zea mays*; 60 kg ha^{-1} P_2O_5
Inter +Manure	*Phaseolus vulgaris* intercropped with *Zea mays*; 12t fresh manure ha^{-1}

Sole bean crops and intercropped bean-maize crops were planted in the 1996 long rain season. Bean planting density was 15 x 40 cm and was applied to both the sole and intercrop systems. Maize in the intercrop was planted at 30 x 75 cm. Phosphorous was applied at the recommended rate of 60 kg P_2O_5/ha while the manure with a 25% moisture content was applied at a rate of 12 t Freshweight / ha. A total of five experimental treatments were tested (Table 5)

Simulation Modelling: Allocation of Nitrogen in Organic Resources for Animals and Crops (ANORAC)

ANORAC is a simulation model for evaluating the trade-offs associated with the allocation of organic resources in mixed farming systems for use as fodder or for soil amendment. It is based on revised versions of two existing models:

- APM (Thorne, 1995). This model describes the effects of different animal feeding and management strategies on outputs of N in manure and urine.
- CENTURY (soil-submodel; Parton *et al*, 1987). CENTURY predicts the release patterns of N from organic litter incorporated into soils.

The two models have been substantially revised during the development of ANORAC and then linked using a specially designed manure application module.

ANORAC uses an assessment of the quality of single or mixed organic resources to predict the value of these resources for improving the supply of nitrogen from the soil and for optimising N mineralisation patterns in soils. A key issue that can be addressed using the model is the evaluation of the relative benefits of allocating organic resources directly to the litter pathway or in using animals to recycle N through manure and urine. Thus ANORAC may be used to examine strategies for improving the efficiency of nitrogen utilisation in mixed farming systems.

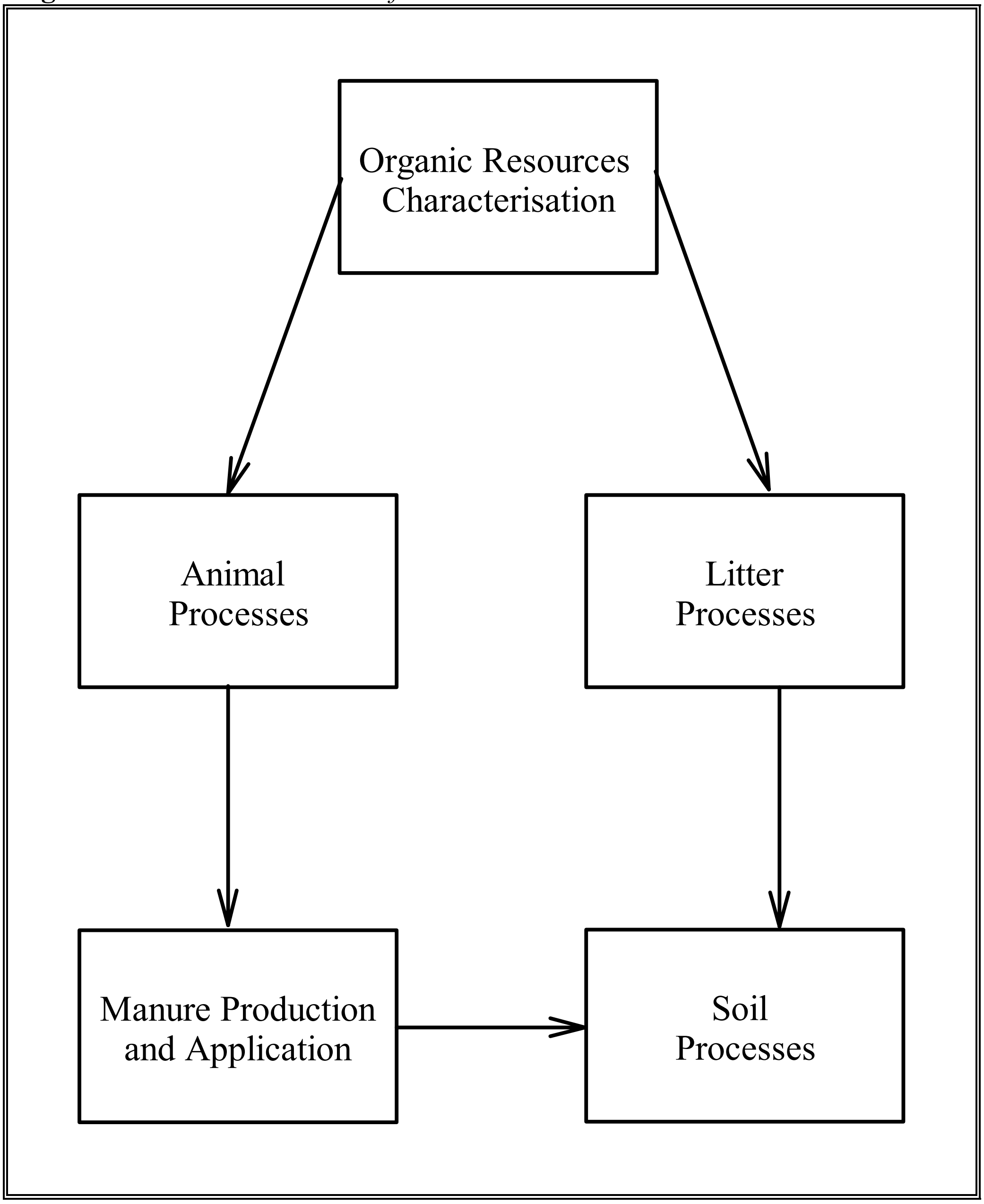
In its current incarnation, ANORAC is intended as a strategic tool for researchers, planners and extensionists. It is designed to assist its users to devise and pre-test integrated strategies for optimal organic resource use on mixed farms.

The Core Structure of ANORAC

The model has five main components (Figure 1):

- an organic resource characterisation module;
- an animal module;
- a manure production and application module;
- a litter management module;
- a soil organic matter module.

Figure 1: *The Core structure of the ANORAC mode*l.



Minimum Input Dataset

Organic Matter Resource Quality

These variables are used to define the quality of he available organic resources as both feeds or for soil amendment. ANORAC simplifies the description of organic resources by allowing only two different materials to be described.

- Protein (g/kg, equal 6.25 x %N)
- Metabolisable Energy (ME, MJ/kg DM)
- Acid detergent insoluble nitrogen (ADIN, g N/kg)
- Lignin content (g/kg)
- In sacco degradation constants
    - a - water soluble N (as a proportion of total N in the range 0-1)
    - b - potentially degradable N (as a proportion of total N in the range 0-1)
    - c - degradation rate constant (per hour)

Animal component

The following variables are used to describe the livestock holding associated with the system, the amounts of feeds used and the composition of the diet.

- Number of animals
- Mean bodyweight (kg / animal)
- Mean dry matter intake (kg / animal)
- Level of inclusion of Resource 1 (basal diet) and Resource 2 (supplement) in the diet (g/kg)

Organic matter handling for soil amendment

- Litter addition day
- Excreta addition day
- Urine recovery (0-100%, proportion of urine which is not lost during storage and subsequently applied to the soil at the excreta addition day).

Litter (soil amendment) composition

- Proportion of basal and supplement resources added to the field (g/kg)
- Amount of litter added to soil (kg DM/ha)

Soil parameters

- Initial total topsoil (0-0.2m) %C and %N
- Proportion of clay and silt content (0-1)
- Soil temperature (^oC)

Facultative soil input parameters

- Soil bulk density (g/dm3, default 1.3)
- Initial active and slow soil C pools (kg C/ha/0.2 m)
- C:N ratio of active soil organic matter pool

System Requirements

ANORAC requires an IBM PC or compatible system and STELLA 5 Research ® systems modelling software[1]. It is not necessary to own a copy of STELLA 5 Research ® as the ANORAC installation includes the runtime version of this software.

STELLA 5 Research ® requires:

- a PC Windows operating system (3.1 or 95)
- an 80486 processor (running in 386 enhanced mode if the installation is under windows 3.x)
- 8 MB RAM

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1 - the STELLA 5 Research ® software can be obtained from:

HPS (High Performance Systems, Inc.), Hanover, NH 03755, New Hampshire, USA. FAX: 603-643-9502. E-mail: support@hps-inc.com

or in the United Kingdom from:

Cognitus Ltd, 1 Park View, Harrogate, N. Yorks HG1 5LY. FAX 01423 567916. E-mail: info@congnitus.co.uk

A full installation of the ANORAC model (including STELLA 5 Runtime) requires approximately 8 MB of free hard disc space.

ANORAC has been tested on several PC systems running 16 and 32 bit Windows™ operating systems. However, its compatibility with a particular hardware setup cannot be guaranteed.

The Animal Component of ANORAC

The animal component of ANORAC is based on the treatments of nutrient and energy absorbtion and utilisation outlined by Harkins *et al* (1974) for energy supplies and by AFRC (1992) for protein. The basic input data set required has been minimised to allow the model to be operated in situations were available data are limited.

ANORAC assumes that all animals in the herd are identical in type (for example, growing animals of a fixed mean liveweight). This approach simplifies simulations for a range of herd sizes and is considered justifiable as the model is designed principally to examine the effects of livestock, as a system component, on nutrient fluxes.

The simulation of animal performance is derived initially from the difference between the energy supplied in the feed consumed and the maintenance requirement appropriate for the type of animal in the herd. A mean, daily rate of production (milk or liveweight change) and total production (or liveweight loss) during one month is calculated from the amount of energy in excess or deficit of the maintenance energy required. In the latter case, weight loss is calculated from the amount of body reserves mobilised to meet a shortfall in ME for maintenance.

The animals' ability to achieve the level of performance predicted from energy intake depends on the adequate supply of protein for turnover and production. Dietary protein supply is checked against the protein required to support the level of production by the energy component. If the former is found to be inadequate, a correction is made to the predicted production level on the basis of the rate of protein utilisation that the current protein intake will support. If protein supply is inadequate for protein turnover, a weight loss is estimated. The model's simulation of nitrogen transactions at various points in the ruminant digestive tract is used to predict the partitioning of ingested N for productive purposes (in the animal) to urine and to two faecal pools (labile and recalcitrant).

The Soil Component of ANORAC

Both the plant litter and soil components of ANORAC are based on the soil-submodel of CENTURY as described by Parton *et al*. (1987). The litter-soil organic matter model component incorporates multiple organic matter compartments each decomposing at different rates that vary as a function of monthly soil temperature. The model includes both nitrogen and carbon flows. Plant residues are divided into structural pools that have 1-5 year turnover times and metabolic pools that have 0.1-1 year turnover times prior to transfer into soil organic matter (SOM) pools. The lignin : N ratio of plant residues controls partitioning into structural and metabolic material. The decay rate of structural material is a function of its lignin content.

The soil submodel is composed of three organic matter fractions. These are:

- an active fraction of soil C and N consisting of live microbes and microbial products along with SOM with a short turnover time (1-5 year);
- a pool of C and N (slow SOM) that is physically protected and/or in chemical forms with more biological resitance to decomposition, with an itermidiate turnover time (20-40 years); and
- a fraction that is chemically recalcitrant (passive SOM) with the longest turnover time (200-1500 years).

While most new incoming materials enter the SOM model via the active soil pool the lignin fraction feeds directly into the slow SOM pool. Additionally, stabilisation of SOM is a function of soil texture with sandy soils being less efficient than fine-textured soils.

The nitrogen model is structured in the same way as the carbon-flows (SOM). It is assumed that most N is bonded to C. The C : N ratios of structural (150), active (8), slow (11) and passive (11) fractions remain fixed, although there is an option to change the C : N ratio of the active (or soil microbial) pool. The N content of the metabolic pool is allowed to vary as a function of the N content of the incoming plant material, with the plant N not needed to create structural material passing to the metabolic-N pool. N flows were assumed to be stoichimetrically related to C flows and were equal to the product of the C flow rate and the fixed N : C ratio of the state variables receiving the C. Either mineralization or immobilization of N may result from C flow, depending on the initial C : N ratio of material, the C : N ratio of pools receiving the C, and the fraction of the C flow lost as CO_2 respiration (30-80% of the total C flow). Both soil organic matter (soil C) and plant available soil mineral N pools are major outputs of ANORAC. Assessing changes of these main variables allow the user a rapid evaluation of the potential impact of given managerial treatments on the sustainability of and nutrient supplies within the modified system.

The current version of ANORAC does not give estimates of leaching or gaseous losses from the soil mineral N pool nor does it have a defined plant growth model. It is anticipated that these components might be easily added using appropriate modifications of existing plant growth and nitrogen leaching models;

The Manure Component of ANORAC

ANORAC characterises manure in a way that is analagous to its characterisation of plant litter (see above). The same turnover times and C : N ratio concepts have been used. The model assumes that ADF passes the digestive system unaltered and is the major contributor to a structural manure pool together with undigested microbial by-products.

Losses from the urine pool in the manure component can be set allowing for differences in N recovery efficiency depending on the storage conditions and handling procedures.

Manure can be stored for a period that may be defined by the user before being applied to the soil. At present the model does not simulate losses during this period that may arise as a result of inefficient manure / compost management and therefore predicts potential N flows under conditions of optimum management. As this is a major issue in many mixed farmer systems, further development of ANORAC to include a manure handling component would improve its utility in decision support.

Outputs

The Experimental Programme

Experiment 1: The Effects Of Feed Nitrogen And Polyphenol Levels On The Fate Of Ingested Nitrogen In Steers

The chemical compositions of the barley straw basal feed and the three supplements are shown in Table 6. The experimental diets were designed to produce a wide range in diet quality, with varying levels in N content and the fibre fractions. The compositions of the raw ingredients confirm that this objective was achieved.

Polyphenol levels were as expected, with *Calliandra calothyrsus* exhibiting the highest levels of TEP and the highest protein binding capacity (PBC). All samples displayed some PBC and the figures for *Macrotyloma axillare* and poultry manure (94 and 66 µg BSA mg^{-1} sample respectively) may be considered low values. The value of PBC for *Calliandra calothyrsus* (248 µg BSA mg^{-1} sample) is consistent with other data reported in the literature (Handayanto, 1997). The range of quality found amongst the basal diet and the three supplements justifies their inclusion in this experiment to investigate the effects of diet quality on nutrient partitioning between urine and faeces.

Supplementation and level of supplementation increased ($P<0.05$) total organic matter (OM) intake for all diets except PM15 compared to the BS diet (Table 7). The PM15 diet did not show an increase in OM intake as some substitution of the basal diet was observed with this level of supplementation. Otherwise, effects of supplementation were found to be additive for total OM intake for all supplements and all levels of inclusion. No significant effects ($P>0.05$) of supplement type or level of inclusion on OM digestibility were observed.

Calliandra calothyrsus at both levels of supplementation resulted a significant ($P<0.05$) reduction in the digestibility of ADF and ADL compared with the straw only diet. *Macrotyloma axillare* was the only supplement to increase ($P<0.05$) the digestibility of any of the fibre parameters (NDF-N).

Table 6: *The Chemical compositions of the feeds used in experiment 1.*

	Dry matter (g kg^{-1})	Ash (g kg^{-1} DM)	Nitrogen (g kg^{-1} DM)	ADF (g kg^{-1} OM)	ADF-N (g kg^{-1} ADF)	NDF (g kg^{-1} OM)	NDF-N (g kg^{-1} NDF)	ADL (g kg^{-1} OM)	TEP (g kg^{-1} DM)	PBC (µg BSA mg^{-1} sample)
Barley straw	846	67	4.0	485	0.79	711	1.43	59.1	2.7	66
Calliandra calothyrsus	272	70	42.5	294	7.04	327	11.6	137.4	67.9	248
Macrotyloma axillare	185	81	24.8	363	4.25	456	7.67	93.0	9.1	169
Poultry manure	856	305	26.3	221	2.76	324	3.81	59.0	2.8	94
SE_d (n=5)	14	8	3.7	15.5	1.24	17	1.64	12.1	7.4	23

DM = dry matter; ADF = acid detergent fibre; OM = organic matter; ADF-N = nitrogen in acid detergent fibre; NDF = neutral detergent fibre; NDF-N = nitrogen in neutral detergent fibre; ADL = acid detergent lignin; TEP = total extractable polyphenols; PBC = protein binding capacity.

SE_d = standard error of the difference.

Table 7: *Effects of dietary treatment on feed intake and digestibility in steers (experiment 1).*

	Total intake (g OM kg^{-1} W d^{-1})	Apparent Digestibility (g kg^{-1})					
		Organic matter	Acid detergent fibre (ADF)	Nitrogen in ADF	Acid detergent lignin	Neutral detergent fibre (NDF)	Nitrogen in NDF
BS	13.7	500	540	-250	180	590	100
CC15	17.5	490	480	-200	80	560	230
CC30	20.4	520	470	-430	20	560	180
MA15	18.1	560	560	-60	190	610	370
MA30	19.5	530	540	230	250	590	510
PM15	15.2	470	510	-170	140	570	190
PM30	18.1	460	500	-140	110	560	210
SE_d (n=5)	0.7	2	2	20	4	2	8

OM = organic matter; W = liveweight; d = day.

SE_d = standard error of the difference.

Diet quality appeared to exert a more pronounced effect on faecal than urine production (Table 8). All supplemented treatments, with the exception of MA15, produced more faeces ($P<0.05$) than the straw only diet. Only MA30 and the two poultry manure treatments produced significantly more urine than the straw diet.

Table 8: *Effects of dietary treatment on the production of excreta (experiment 1).*

	Faecal production (g OM kg^{-1} W d^{-1})	Urine production (g urine kg^{-1} W d^{-1})
BS	7.1	12.6
CC15	9.0	14.0
CC30	9.9	14.4
MA15	8.1	16.2
MA30	9.7	19.4
PM15	8.0	12.9
PM30	9.1	18.0
SE_d (n=5)	0.4	2.0

OM = organic matter; W = liveweight; d = day;

SE_d = standard error of the difference.

Higher N intakes were observed with all supplements at both levels in comparison with the BS diet These reflected both the increased dietary N concentrations and the increased OM intakes associated with supplementation of the basal diet (Table 9). Supplementation with CC and MA had little effect on the proportion of ingested N excreted in the urine whilst supplementation with PM resulted in a marked increase. This observation was explained at least in part by a large shift in the faecal N : urine N partition resulting from NPN supplementation.

With increasing level (from 150 to 300 g / kg) of *Calliandra calothyrsus* supplementation, the ratio of faecal-N to urinary-N doubled, but decreased with *Macrotyloma axillare* and was unaffected by poultry manure supplementation. These results are broadly consistent with the large shift in N excretion from urine to faeces that has been reported with increasing dietary polyphenol contents by some authors (e.g. Powell *et al*., 1994). Perez-Maldonado and Norton (1996) found that feeding *Calliandra calothyrsus* (75 g kg^{-1} total condensed tannins) to sheep and goats had no effect on urinary-N excretion (2.28 v 2.64 g N d^{-1}) but did increase faecal-N excretion (3.38 v 4.98 g N d^{-1}) when compared to a control diet of pangola grass (*Digitaria decumbens*).

Table 9: *Effects of dietary treatment on the partitioning of ingested nitrogen between faeces and urine in steers (Experiment 1).*

	N intake (mg kg^{-1} W d^{-1})	Urinary N (mg kg^{-1} W d^{-1})	Faecal N (mg kg^{-1} W d^{-1})	Urinary N as a % of N intake	Faecal N as a % of N intake	Faecal N : Urinary N	N retained (% of intake)
BS	63	0.5	76	0.8	121	152 : 1	-21.4
CC15	210	1.3	142	0.6	68	109 : 1	31.8
CC30	324	0.8	190	0.2	59	238 : 1	41.2
MA15	152	0.4	106	0.3	70	265 : 1	30.0
MA30	223	0.6	125	0.3	56	208 : 1	43.7
PM15	158	17.5	113	18.3	71	6 : 1	17.4
PM30	246	23.2	154	15.5	62	7 : 1	28.0
SE_d (n=5)	35	0.4 [1] 2.7 [2]	9				7.0

N = nitrogen; W = liveweight; d = day;

SE_d = standard error of the difference ([1] - for barley straw and poultry manure; [2] - for *C. calothyrsus* and *M. axillare)*

The reasons for such inconsistency is not immediately apparent and may be worthy of consideration given their potential importance for flows of N through the system.

Faeces produced from diets supplemented with *Calliandra calothyrsus* had significantly (P>0.05) higher concentration of ADF-N, ADL and NDF-N than those of the *Macrotyloma axillare* diets (Table 10). Significant increases in faecal NDF-N and the proportion of excreted N bound to NDF were found with increasing level of *Calliandra calothyrsus* supplementation.

Table 10: *Effects of dietary treatment on N-binding to manure fibre fractions (experiment 1).*

	ADF ($g\ kg^{-1}$ OM)	ADF-N ($g\ kg^{-1}$ ADF)	NDF ($g\ kg^{-1}$ OM)	NDF-N ($g\ kg^{-1}$ NDF)	ADL ($g\ kg^{-1}$ OM)	% of faecal-N bound to NDF
BS	421	2.34	546	2.29	92	14
CC15	446	4.12	536	4.63	129	18
CC30	470	6.26	558	6.38	156	21
MA15	433	2.88	541	3.20	110	15
MA30	439	2.56	551	3.28	111	15
PM15	378	2.29	487	2.64	90	11
PM30	367	2.47	473	2.86	93	11
SE_d (n=5)	8	0.35	4.6	0.27	5	

OM = organic matter; ADF = acid detergent fibre; ADF-N = nitrogen in acid detergent fibre; NDF = neutral detergent fibre; NDF-N = nitrogen in neutral detergent fibre; ADL = acid detergent lignin;

SE_d = standard error of the difference.

Increasing OM and N intake can be achieved when a low quality basal diet is supplemented with *Calliandra calothyrsus* , *Macrotyloma axillare* and poultry manure. Many other authors have shown increases in DM intake and improved digestibility with legume supplementation of low quality crop residue diets, e.g. sorghum stover and lablab (Abu, 1992), maize stover and Leucaena (Banda, 1985), t'ef straw and cowpea/lablab (Abule, 1995).

The excretion of urinary-N was very small (less than 0.01 of excreted N) and not significantly different (P>0.05) for barley straw, *Calliandra calothyrsus* and *Macrotyloma axillare* diets suggesting that polyphenols in the diet had no effect on the partition of N between urine and faeces. Feeding poultry manure resulted in a rapid fermentation in the rumen, with excess ammonia being excreted as urea in the urine, thus producing a large loss of nitrogen to the animal. It is possible that feeding the legume supplements produced a slower fermentation in the rumen and therefore resulting in little excess ammonia production. More efficient recycling of urea absorbed into the blood via the rumen and saliva may also have led to lower levels of urinary excretion of urea.

Steers fed *Calliandra calothyrsus* had the highest proportion of NDF-N in their faeces. Indigestible feed nitrogen in the faeces can be measured by the NDF-N content as this fraction is insoluble in neutral detergent solution (Mason, 1969). This increase in faecal NDF-N is consistent with results from other authors who found higher total faecal nitrogen contents, which could be explained by higher faecal NDF-N levels, where tanniferous feeds were fed (Rittner, 1987; Tanner, 1988). Higher NDF-N values for these faeces could be attributed to the presence of indigestible tannin-protein complexes (Reed, 1986). Formation of these complexes may explain the increased content of NDF-N in faeces derived from *Calliandra calothyrsus* supplemented diets.

The reduction of lignin digestibility observed with *Calliandra* supplementation could be due to an increase in lignin content between feed offered and faeces excreted. This result is similar to observations of Norton and Ahn (1997) who found that from 55 to 250% more lignin was found in the faeces than was consumed and Osburn *et al.* (1971) found increases in lignin of between 25 and 140% when feeding Sainfoin (*Onobrychis viciifolia*). This reduction in ADL, as well as the reduction in ADF digestibility, can be explained not only as reduced digestibility *per se* but maybe as an artefact of the methodology used to measure these fibre fractions. Gains in acid detergent fibre and lignin may be due to tannin-carbohydrate complexes rather than tannin-protein complexes (Norton, 1997). Also lignin and tannin complexes with macromolecules are insoluble and can analyse as lignin (Van Soest, 1987).

Feeding of *Calliandra calothyrsus* resulted in faeces with an increased N content. If faeces are conserved on-farm and utilized as the primary fertilizer source, a higher faecal-N content will be expected to increase N additions to the soil. The increased amount of N bound to the NDF fraction may affect the release of some of this extra faecal-N when the manure is added to the soil. Bound N in association with polyphenols has been shown to be more slowly released, thereby restricting the supply of N for immediate use by the crop (Handayanto, 1997).

However, this slower release could produce better synchrony of N supply to crop demand throughout the growing season and also contribute to N recapitalisation in soil.

Experiment 2: Rumen Degradability Of Dry Matter And Nitrogen Measured By the *In Situ* Technique

Chemical compositions of the feeds are shown in Table 11. These are comparable with those observed in experiment 1 for the same feeds. *Calliandra calothyrsus*, whilst exhibiting the highest concentration of N, also had the largest proportion of that N in bound form and displayed the highest total phenol content and protein binding capacity.

Samples of the test feeds (barley straw, *C. calothyrsus*, *M. axillare* and poultry manure) incubated in rumens of steers fed different diets varied widely in their speed and extent of DM degradation (Figure 2). No significant differences ($P>0.05$) were found between the extent of DM degradation of the various samples incubated and the diet of the steer for any of the incubation times. When the average 96 hour DM degradation of each sample was taken across the different diets, the order of degradability was poultry waste (54.6%) compared to 55.4%, 70.3% and 76.8% for barley straw, *C. calothyrsus* and *M. axillare* respectively.

The water soluble DM (W; as measured by the Time 0 washing loss) varied significantly ($P<0.05$) between samples. It was very low for barley straw (3%) compared to 15%, 34% and 39% for poultry manure, *C. calothyrsus* and *M. axillare* respectively (Table 12). Insoluble fermentable DM (B; fermentable DM corrected for the washing loss) also varied amongst samples, with barley straw having a significantly higher ($P<0.05$) insoluble fermentable content than *Calliandra calothyrsus* and *Macrotyloma axillare* but not ($P>0.05$) than poultry manure. The degradation rate (c) was significantly higher ($P<0.05$) for *Macrotyloma axillare* compared to the other samples, averaging 0.095 in the different diets.

Table 11: *The chemical compositions of the feeds used in Experiment 2.*

	Nitrogen (g kg^{-1} DM)	ADF (g kg^{-1} OM)	ADF-N (g kg^{-1} ADF)	NDF (g kg^{-1} OM)	NDF-N (g kg^{-1} NDF)	ADL (g kg^{-1} OM)	TEP (g kg^{-1} DM)	PBC (µg BSA mg^{-1} sample)
Barley straw	3.5	502	0.50	738	1.27	60.9	2.0	66
Calliandra calothyrsus	38.7	318	7.80	371	15.75	173.0	61.3	269
Macrotyloma axillare	25.8	356	5.35	459	10.20	106.4	10.4	169
Poultry manure	21.2	213	2.05	326	3.22	56.4	2.9	94

DM = dry matter; ADF = acid detergent fibre; OM = organic matter; ADF-N = nitrogen in acid detergent fibre; NDF = neutral detergent fibre; NDF-N = nitrogen in neutral detergent fibre; ADL = acid detergent lignin; TEP = total extractable polyphenols; PBC = protein binding capacity.

Figure 2: *DM degradability of feeds incubated in steers fed different diets (*0*, Barley straw only;* □*, Straw + Calliandra calothyrsus;* Δ*, Straw + Macrotyloma axillare;* ∇*, Straw + poultry manure; bars represent* SE_d*).*

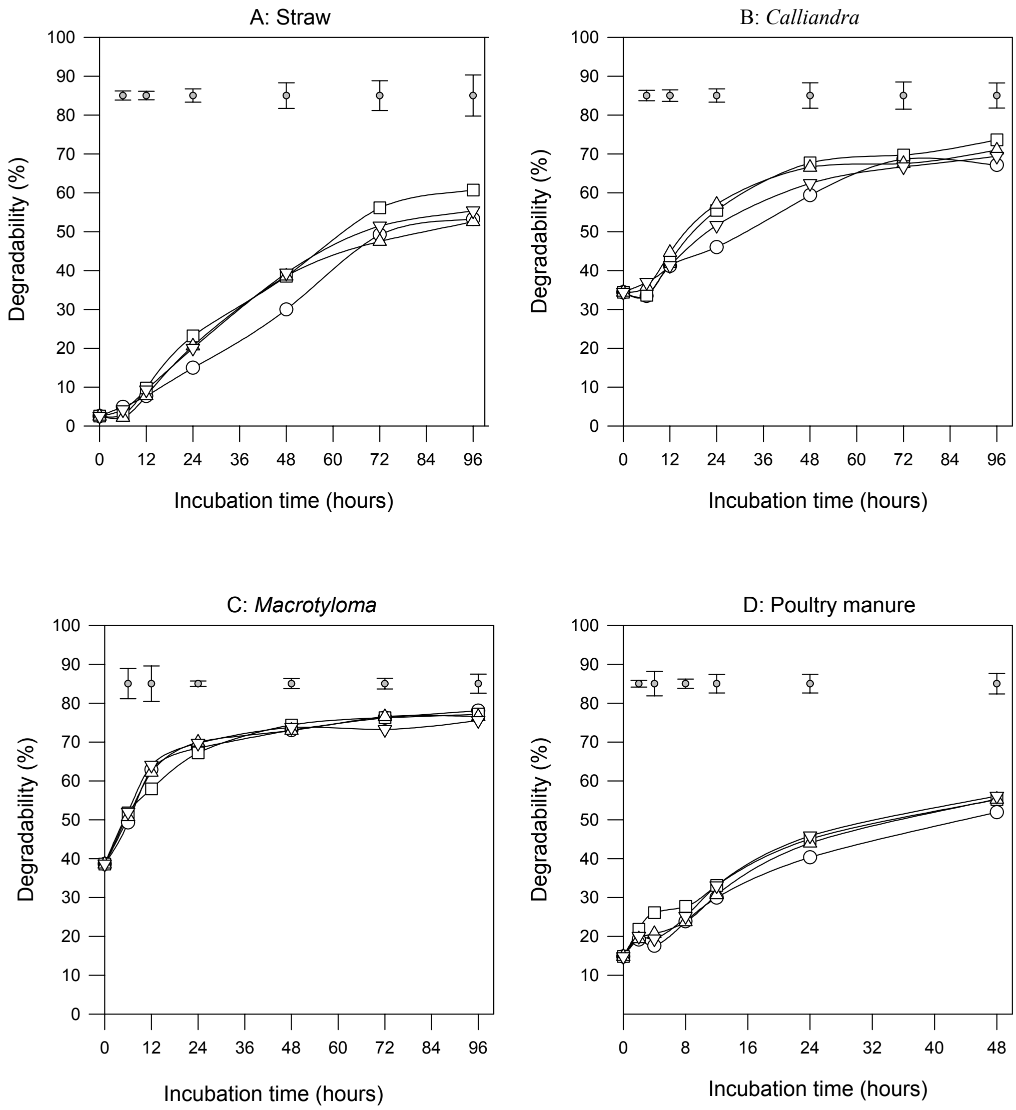


Table 12: *Estimated and derived parameters of in situ DM degradability.*

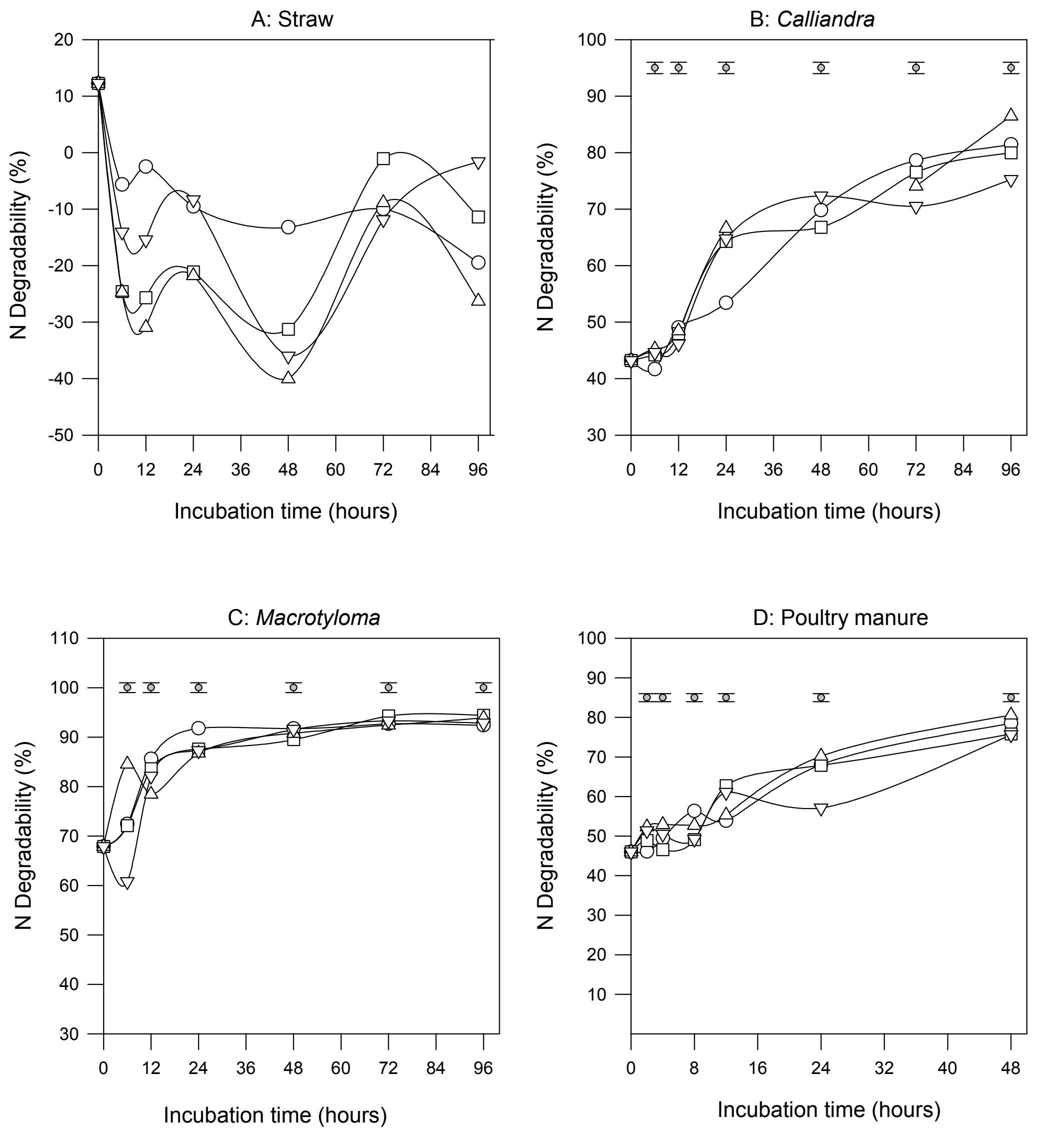
Diet	Sample	W (%)	B (%)	c (h^{-1})
Straw only	PM	14.8	57.3	0.035
Straw + MA	PM	14.8	51.3	0.037
Straw + CC	PM	14.8	53.6	0.035
Straw + PM	PM	14.8	52.1	0.039
Straw only	CC	34.4	47.7	0.029
Straw + MA	CC	34.4	40.6	0.051
Straw + CC	CC	34.4	36.5	0.052
Straw + PM	CC	34.4	37.9	0.032
Straw only	MA	38.6	36.6	0.113
Straw + MA	MA	38.6	38.5	0.061
Straw + CC	MA	38.6	37.2	0.098
Straw + PM	MA	38.6	47.1	0.088
Straw only	Straw	2.5	50.5	0.035
Straw + MA	Straw	2.5	60.1	0.022
Straw + CC	Straw	2.5	62.7	0.024
Straw + PM	Straw	2.5	68.0	0.019
SE_d		1.7 (9 df)	6.1 (32 df)	0.018 (32 df)

W = Water soluble N; B = potentially degradable N; c = ruminal degradation rate of N; CC = *Calliandra calothyrsus*; MA = *Macrotyloma axillare*; PM = poultry manure

Degradation curves for feed N are shown in Figure 3. Experimental variability was considerably more pronounced than for the dry matter data. This probably reflected, in part at least, an inherent variability in the ruminal release of N from the feed samples and was particularly pronounced in the case of barley straw.

This variability in individual observations compromises the interpretation of these data on N release patterns. However, it is clear from the different gross patterns observed that the effects of dietary treatment on N partitioning observed in experiment 1 may, in part at least, have been associated with differences in the behaviour of the test feeds in the rumen.

Figure 3: ***N** degradability of feeds incubated in steers fed different diets (*0*, Barley straw only;* □*, Straw + Calliandra calothyrsus;* Δ*, Straw + Macrotyloma axillare;* ∇*, Straw + poultry manure; bars represent* SE_d*)*



Experiment 3: Investigation Of Decomposition And N Mineralization Of Different Quality Manures In A Leaching Tube Incubation

Chemical analyses of the litter and manure samples used in the experiment are presented in Table 13. Of the plant material, levels of total N and soluble N (nitrate + ammonia) were highest in *Calliandra calothyrsus*. *Macrotyloma axillare* had the highest soluble C content. The legumes, *Calliandra calothyrsus* and *Macrotyloma axillare* had the highest levels of fibre-bound N (ADF-N and NDF-N) and lignin (ADL) when compared with the straw and poultry manure.

Levels of soluble N and C in faeces were much lower than those of the plant litters. Manure from the animals fed *Calliandra calothyrsus* contained significantly ($P<0.05$) higher amounts of bound fibre (ADF-N and NDF-N) and lignin (ADL) than the other manures.

The effects of treatment on times to net N mineralisation for are summarised in Table 14.

Table 14: *Effects of treatment on the time until the occurrence net N mineralization in leaching tubes (experiment 3).*

Sample	Time (weeks) to net N mineralization
Plant litter samples	
CCL	1
MML	24
BSL	-
PW	-
Faecal samples	
BSF	-
CC15F	17
CC30F	16
MA15F	18
MA30F	16
PW15F	-
PW30F	-

Table 13: *The chemical compositions of litter and manure samples used in experiment 3.*

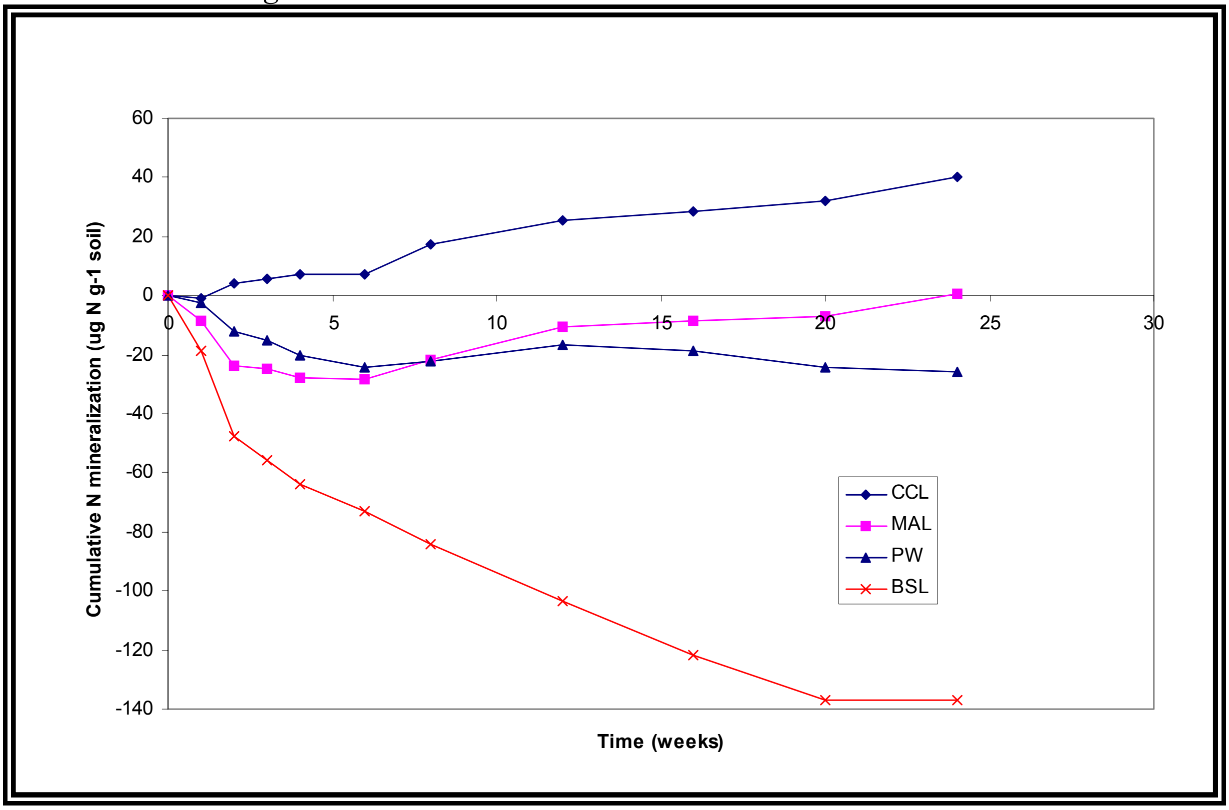
	Nitrogen (%)	Nitrate-N (µg g-1)	Ammonia-N (µg g-1)	Total organic-N (µg g-1)	Total soluble-C (mg g-1)	ADF (g kg-1 OM)	ADF-N (g N kg-1 NDF)	ADL (g kg-1 OM)	NDF (g kg-1 OM)	NDF-N (g N kg-1 NDF)	TEP (g kg-1 DM)	PBC (µg BSA mg-1 sample)
BSL	0.4	34	46	760	20.2	485	0.79	59	711	1.43	2.7	66
CCL	4.1	989	185	5769	63.8	294	7.04	137	327	11.6	67.9	248
MAL	2.4	497	135	4496	86.6	363	4.25	93	456	7.67	9.1	165
PML	2.2	244	252	4258	19.7	221	2.76	59	324	3.81	2.8	94
BSF	0.9	5.7	26	1028	21	421	2.34	92	546	2.29		
CC15F	1.4	5.8	27.7	985	14.2	446	4.12	129	536	4.63		
CC30F	1.7	7.7	25.3	882	14.7	470	6.26	156	558	6.38		
MA15F	1.1	6.5	21	1026	17.6	433	2.88	110	541	3.2		
MA30F	1.2	6.5	25.3	1045	15.2	439	2.56	111	551	3.28		
PM15F	1.2	5.7	20.8	1197	15.4	378	2.29	90	487	2.64		
PM30F	1.3	7	28.7	1403	14.6	367	2.47	93	473	2.86		
SE_d						8	0.35	5	4.6	0.27		

OM = organic matter; ADF = acid detergent fibre; ADF-N = nitrogen in acid detergent fibre; ADL = acid detergent lignin; NDF = neutral detergent fibre; NDF-N = nitrogen in neutral detergent fibre; TEP = total extractable polyphenols; PBC = protein binding capacity

SE_d = standard error of the difference

Calliandra calothyrsus litter resulted in net mineralisation of N from the first leaching at week 1 (Figure 4). *Macrotyloma axillare* reached net mineralization by week 24. However, there was net immobilisation of N throughout the experiment with barley straw and, to a lesser extent, poultry waste.

Figure 4: *Cumulative N mineralisation from samples of Calliandra calothyrsus (CCL), Macrotyloma axillare (MAL) and barley straw (BSL) litters and poultry waste (PW) incubated in leaching tubes at 25°C.*

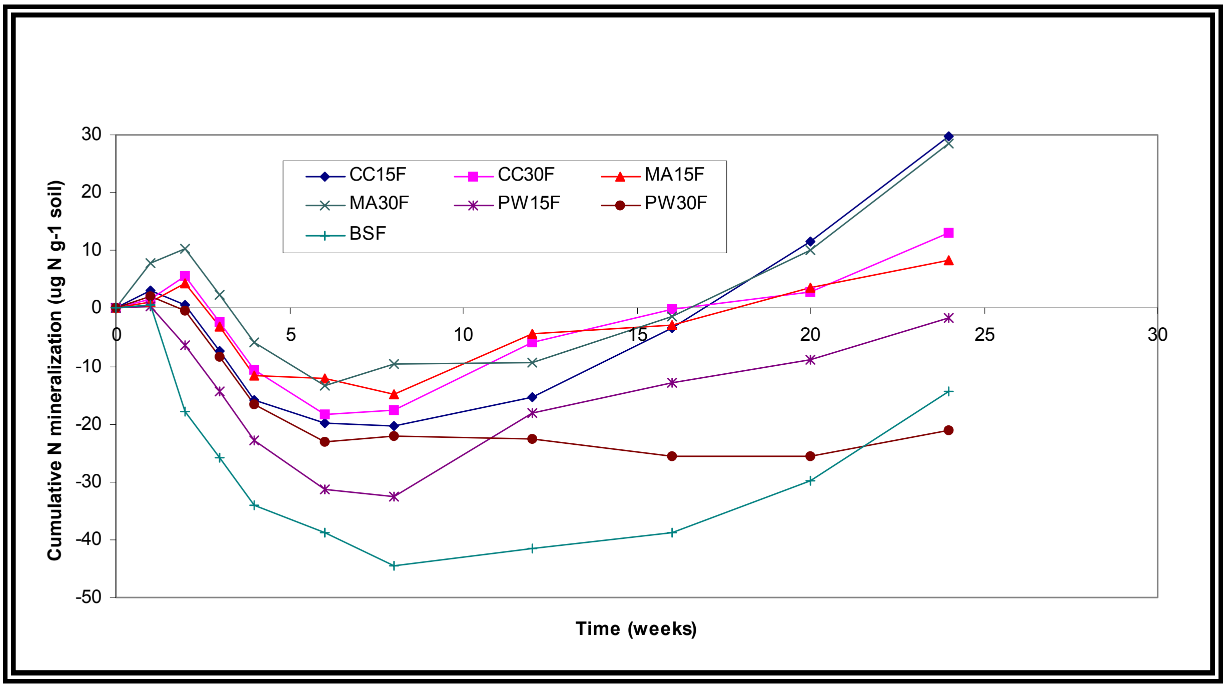


Mineralisation of N from the faecal samples illustrated the pronounced effects of the passage of organic material through the animals digestive tract (Figure 5). All faecal samples exhibited net N mineralization at the Week 1 leaching, although only the 30% *Macrotyloma axillare* still showed net N mineralization at the Week 3 leaching. All faecal samples immobilized N from Week 4 although the time to net mineralization varied considerably with treatment.

Taken together, the results presented in Figures 4 and 5 suggest a number of potential, practical implications for N-supplies for crops. The beneficial effects on N-dynamics of passing of fibrous feeds such as barley straw through an animal are clear. Both the extent and duration of the immobilisation period were greatly reduced in soils augmented with barley straw manure when compared with soils augmented with raw barley straw.

On the other hand, the rapid release or relatively limited immobilisation of N associated with the incorporation of litters such as *C. calothyrsus* are incorporated into soils might suggest that farmers might prefer these materials as soil adjuvants to the manures that would result from feeding them. However, these materials would be available in relatively small quantities on small mixed farms. The results presented here show that their use as supplements to the crop residues that are usually available in much larger quantities on such farms has clear benefits. These may accrue, not only in terms of the production responses that are well documented, but also in the improvements in manure quality (i.e. shorter and less severe N immobilisation) observed in the supplemented diets.

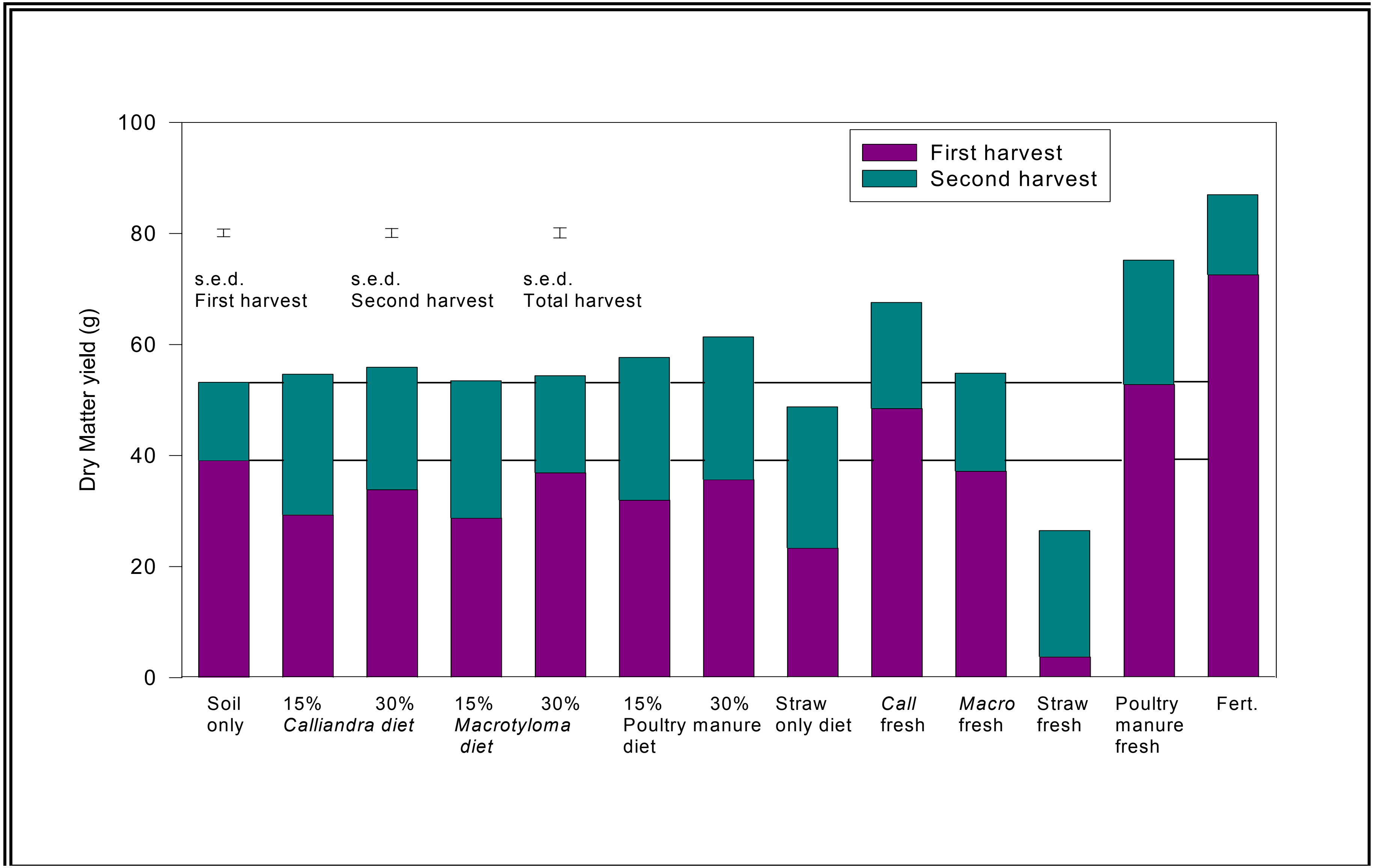
Figure 5: *Cumulative N mineralisation from faecal samples produced from diets supplemented with Calliandra calothyrsus (CC15F and CC30F), Macrotyloma axillare (MA15F and MA30F) and poultry waste (PW15F and PW30F) or from a barley straw (BSF) only diet incubated in leaching tubes at 25°C.*



Experiment 4: Investigation Of Decomposition And N Mineralization Of Different Quality Manures On Short Term Maize growth

At the first harvest (10 weeks) the plants grown in the soil only control produced significantly ($P<0.05$) more dry matter (DM) than the experimental treatments in which faeces or fresh litter had been incorporated into the soil (Figure 6).

Figure 6: *Effects of treatment on maize shoot dry matter yields (experiment 4; first harvest: weeks 1 - 10, second harvest: weeks 10 - 20).*



Significant higher DM yields, in comparison with the control were only observed in the fresh *C. calothyrsus*, fresh poultry manure and fertilizer treatments. These observations were consistent with the mineralisation patterns observed in experiment 3. Faeces produced from animals supplemented at the 15% level resulted in significantly lower ($P<0.05$) DM yields than faeces from those supplemented at the 30% supplemented level.

Between the first and the second harvests (at 20 weeks), all treatments stimulated the production of significantly ($P<0.05$) more DM than the soil only control. During this period, the effects of supplementation on the ability of manures to promote plant growth appeared to be reversed with the faeces from diets supplemented at the 15% level producing significantly more ($P<0.05$) DM than faeces from the diets incorporating 30% supplement.

When the total DM yields over both harvests are considered together, these shorter term effects appear to cancel each other out to some extent. Apart from the fertilised treatment, only, fresh additions of *C. calothyrsus* and poultry manure resulted in significantly ($P<0.05$) higher DM yields than the control. Incorporation of fresh straw significantly ($P<0.05$) reduced DM yields reflecting the extended period of severe net N immobilisation observed with this treatment in experiment 3. No other significant ($P>0.05$) treatment effects were observed.

In general, the results of this study are consistent with the N release patterns observed in the mineralization experiment (experiment 3). *C. calothyrsus* litter promoted net N mineralization from week 1 in the leaching tubes (see Figure 4) and had significantly ($P<0.05$) higher DM yields than the soil only control for both 10 week harvests (Figure 6). All the incorporated faeces immobilized N in the leaching tubes used in experiment 3 (see Figure 5) and, in this experiment, maize DM yields from soils into which these faeces had been incorporated were significantly ($P<0.05$) lower than from the soil only control.

The main inconsistency between the two studies lies in the growth promoting effects of poultry manure addition which appeared to immobilise N in the leaching tubes. It is suggested that this effect may have been due to competition between the plant roots and the microbial biomass for the mineralized N. It is also possible that, in leaching tubes, poultry manure addition may have led to losses of N through de-nitrification resulting in innacurate estimation of immobilized N.

The study clearly establishes that the feeding strategies practised by farmers may affect crop growth responses to manure additions. The fact that the relative magnitude of these effects at different stages of the crop's growth may also be influenced by the provenance of the manure, highlights the integrated planning of manure production and utilisation might become important in systems that attempt to improve the management of N flows through the feed - animal - soil pathway.

Experiment 5: On-Farm Trial In Three Agro-Ecological Zones (AEZs) To Compare Fresh Litter As A Soil Amendment And Different Quality Manures To Maize Grain And Stover Yields.

These on-farm studies were harvested between the end of March and early April 1998. In the Tea AEZ, only one farm could be harvested as the crops had suffered losses due to animals and theft. Therefore, no results are reported here for the tea zone.

Results for stover and grain DM yields on farms in the Maize - Sunflower (semi-arid) AEZ are presented in Figure 7. Few significant treatment effects ($P>0.05$) were observed in stover and grain DM yields. The addition of fresh straw and fresh *M. axillare* to the plots resulted in significant reductions ($P>0.05$) in grain DM yield. In general, however, the consequences of manure addition appeared to be no different in terms of crop productivity than the addition of the fresh materials from which these had been derived..

Figure 8 presents the crop production results for the the Coffee - Maize AEZ. Again few significant effects ($P>0.05$) of treatement on stover and grain DM yields were observed. Only the addition of fresh poultry manure appeared to result in significant enhancements of stover DM yield. Similarly the differences between plots treated with manure or litter could not be distinguished.

The results of this on-farm study reflect those of the pot experiment to the extent that, over a 5-6 month period, no differences in the plant growth resulting from additions of fresh plant material or faeces derived from supplemented diets feeding these plant materials were observed. Data from experiment 3 show that immobilization may occurs for as long as 24 weeks; beyond the first seasons growth of maize. This would suggest that anticipated benefits from these organic matter additions might not be expected in the first season but would appear as mineralization continues during a second season.

However, the gross differences in N mineralisation resulting from and growth responses to the addition of the different litters and manures do not appear to have been expressed under field conditions. This may have been due, in part, to the higher residual variability that would necessarily have been encountered on the farm. However, it seems likely that the storage of the material added to the field plots may have reduced the variability amongst them.

Storage losses would tend to reduce variation in manure quality for two reasons connected with the fact that storage changes are likely to be associated with an increase in the proportion of more recalcitrant forms of N. Firstly, there is likely to be less inherent variation in recalcitrant N as these are generally not affected by exposure to the digestive processes that are associated with passage through an animal. Secondly, the release of N in the soil from these bound forms is, by definition, much slower so effects on crop growth are likely to be much less pronounced. Thus, storage is likely to exert an equalising effect on manures of different original qualities. Therefore, the identification of storage and composting techniques that maintain the improvements in quality of manures that might be induced by targeted feeding would appear to be a valid topic for future research.

Figure 7: *Effects of treatment on grain and stover yields on farms in the maize - sunflower agroecological zone.*

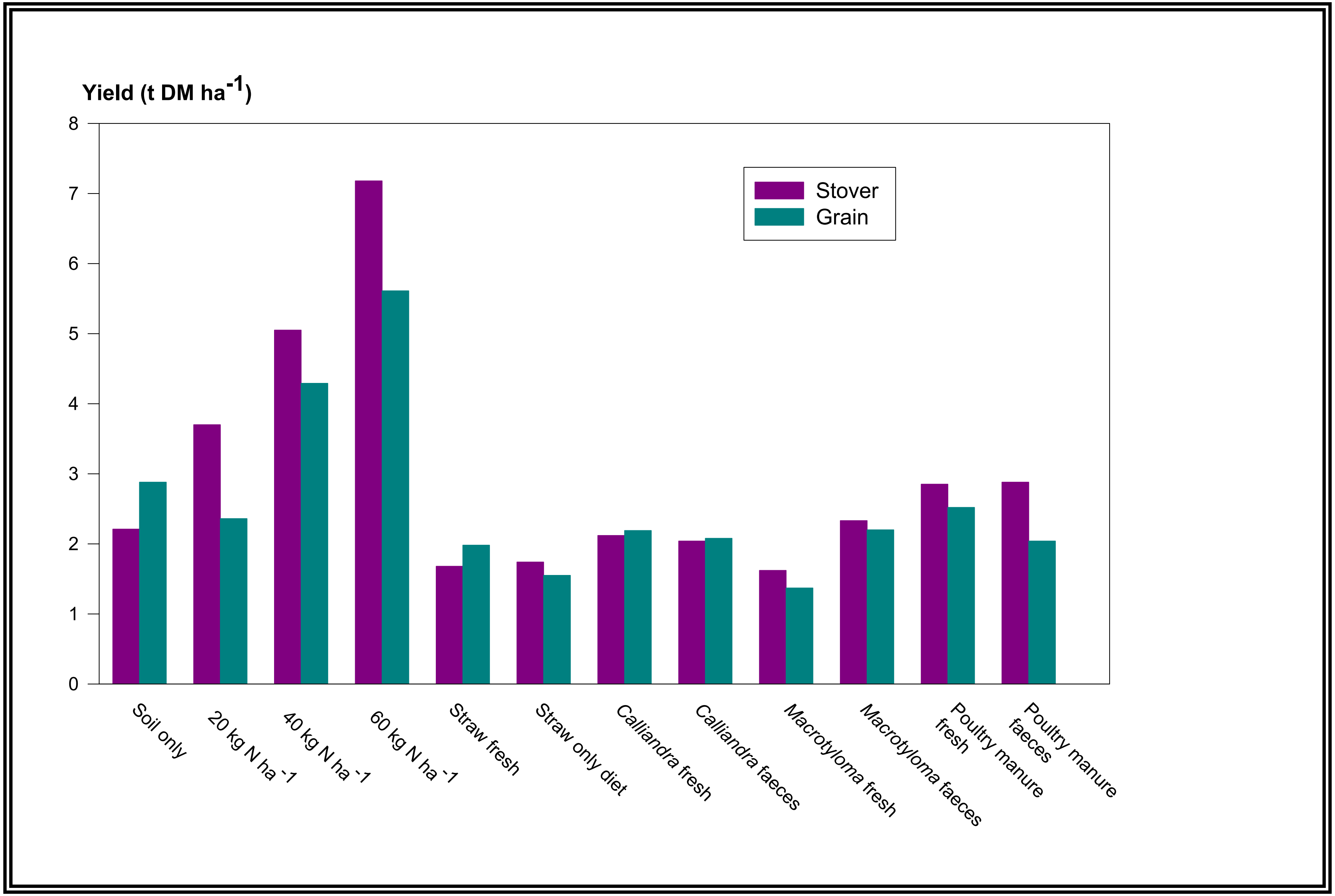
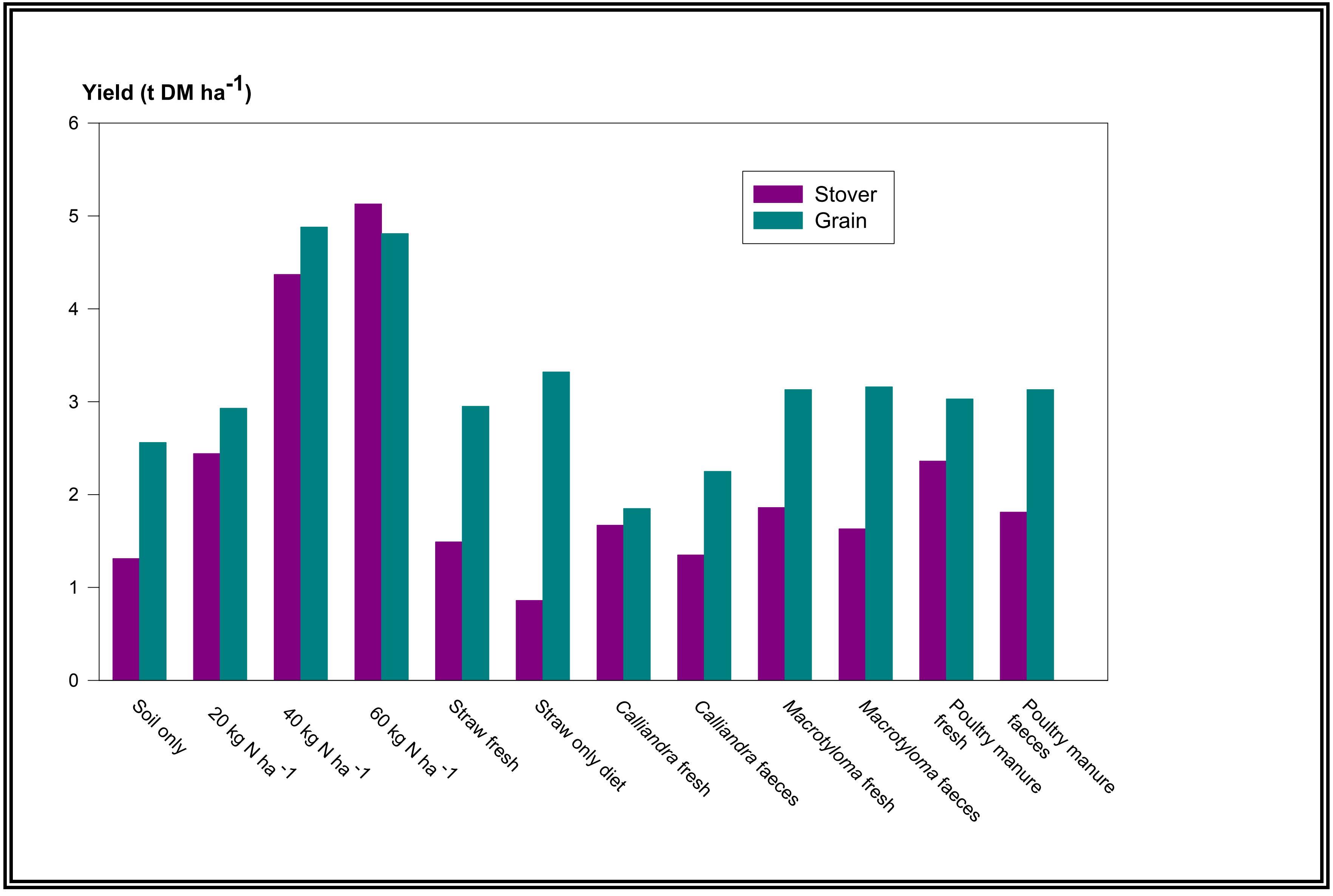


Figure 8: *Effects of treatment on grain and stover yields on farms in the coffee - maize agroecological zone.*



Experiment 6: Effect Of Bean-Maize Intercropping, Phosphorus And Manure Additions On N_2 Fixation Of *Phaseolus Vulgaris* In The Central Highlands Of Kenya

Due to low rainfall during 1996 (650 mm) crop yields were low (Table 15). Intercropping lowered the bean grain yields by 10-23%. This decrease was more pronounced in the treatment without phosphorus addition. Bean plants were well nodulated. N_2 fixation was evaluated using the natural ^{15}N abundance method. Preliminary investigations had suggested that the soil was sufficiently naturally enriched in ^{15}N ($\delta^{15}N$ of 7 ‰). Enrichments in bean grains (-0.2 to 1.3 ‰) were substantially lower than in the non-fixing maize grain (4.3-4.8 ‰) reference plant and allowed thus the calculation of the proportion of N derived from N_2 fixation. Intercropping beans with maize increased the proportion of N_2 fixed in beans on average from 55% to 69%. This increase in the N_2 fixation ability compensated for the lower bean yield in the intercropping systems and therefore the amounts of N_2 fixed were slightly higher in intercropped versus the sole bean system. Intercropping thus provides a strategy for a better N resource use were the maize crop competes efficiently for available soil mineral N and the legume replenishes part of the extracted N by inputs via N_2 fixation. However, the amounts of N_2 fixed appear not to be enough to replenish whole systems N exports in grain crops and thus additional N_2 inputs are needed. In mixed farming systems such additional N_2 inputs could be derived from the inclusion of pasture legumes in the napier grass plots. Subsequent recycling of manure to the crop system could prove of valuable benefit for the long-term nutrient and soil organic matter balance.

Table 15: *Bean yield and amount of N_2 fixed in bean grains, Muguga, Kenya 1996 long rains*.

Treatment	Bean yield (kg/ha)	% N derived from N_2 fixation (%)	Amount of fixed N_2 in grain (kg N/ha)
Sole -P	398	59	7.9
Sole +P	489	51	8.5
Inter -P	316	73	8.5
Inter +P	398	64	9.0
Inter + manure	252	64	6.1

Additions of P increased the standing biomass and grain yields in both monocropping and intercropping systems suggesting that the soil (humic Nitosol) was P deficient for bean production. However, there was no effect of P on the proportion of N_2 fixed and hence the increase in the amount of N_2 fixation due to P addition was small. Under normal, more favourable environmental conditions the effect of P on bean production and N_2 fixation may have been much larger as the increased demand for P would have exacerbated the differences between the two treatments.

Manure application had a negative effect on bean yield. This confirms our other observations with fresh manure in both pot experiments and on farmers fields. It appears that short-term nutrient immobilizations induced by the high C:N ratio of the manure was responsible for this effect. Subsequent observations in 1998 suggested however a positive effect on bean performance in the same field with repeated applications of manure. Thus the benefit from adding fresh manure may not be obtained in the first cropping season but may lead to long term maintenance of soil organic matter and nutrient replenishment and hence sustained improved yields where manure is repeatedly added. These observations suggest that more attention needs to be given to manure management and its long-term impacts on soil fertility and crop yields.

Simulation Modelling: Allocation of Nitrogen in Organic Resources for Animals and Crops (ANORAC)

A copy of the ANORAC model and a manual describing its use is attached to this report.
This section briefly describes and example of a simulation using ANORAC.

Example Simulations using ANORAC

Contribution of Outputs

The Wider Implications of this Research

The research carried out under the project has established a number of important principles:

- Livestock feed management decisions *do* have the potential to infuence N flows in soils into which manures of different provenances are incorporated;
- the effects of these decisions may even be expressed in plant growth, although inherent variability and a number of other factors may combine to mask these effects;
- many of the interventions associated with the "improvement" of feeding strategies may result in positive influences on system-wide N flows. Technologies (particularly in manure management and composting) are required to capitalise upon these (i.e to counter the effects of masking factors);
- livestock are clearly an integral and dynamic part of the mixed farming system. The tendency to treat manure as a readily characterised and relatively static organic resource that has seen in much soil fertility research is probably misguided.

It is suggested that these issues are not always adequately considered when component livestock research (with a focus on livestock in mixed farming systems) or soil and agronomic studies on N flows and utilisation in systems that also include livestock are undertaken. For this reason, the adequate dissemination of the project's findings, in a readily digestible form, amongst component researchers in the NARS and elsewhere needs to be prioritised.

In anticipation of some of these findings, the rationale behind the project accepted that suitable tools or approaches are probably not available for evaluating the complex, dynamic situation *vis a vis* N flows that they imply. The ANORAC model represents an initial attempt to deliver such a tool. Notwithstanding a number of limitations, ANORAC appears to be able to evaluate, reasonably effectively, the trade-offs relating to N management that arise when decisions on the use of organic matter must be made. The model has been developed using software that offers a user-friendly interface and therefore should be widely accessible to the intended end-users of the project's outputs.

Dissemination of Outputs

Cadisch, G., de Oliveira, O. C., Cantarutti, R., Carvalho, E., and Urquiaga,S. (1997). The role of legume quality on soil carbon dynamics in savanna ecosystems. In *Carbon and Nutrient Dynamics in Natural and Agricultural Tropcial Ecosystems* (L. Bergstrom and H. Kirchman, eds.), pp. 47-70. CAB International, Wallingford.

Kimani, S.K., Gathua, K.W., Mugane, P.G. and Cadisch, G. (1997) Effects of phosphorous and manure application on bean yield in the central Kenya Highlands. Paper presented at the First All Africa Crop Science Congress. 13 - 17 January, 1997 at the University of Pretoria, Hartfield, South Africa.

Delve, R.J. (1998) *The Effects of Livestock Feeding Management on Soil Fertility*. Wye College, University of London. Unpublished Ph.D. Thesis (in preparation)

Delve, R.J., Tanner, J.C., Kimani, S.K., Giller, K.E., Cadisch, G. and Thorne, P.J. (1998) The effects of feed nitrogen and polyphenol levels on the fate of ingested nitrogen in steers and their implications for nitrogen cycling in mixed farming systems. In: Food, Lands and Livelihoods. Setting Agendas for Animal Science. 27 - 30 January, KARI Conference Centre, Nairobi, Kenya. p87.

Thorne, P.J. and Cadisch, G. (1998) *ANORAC. Allocation of Nitrogen in Organic Resources for Animals and Crops*. Chatham, United Kingdom, Natural Resources Institute. ??pp.

Distribution of ANORAC

The ANORAC model is freely distributable software. It may be obtained from:

Dr Peter Thorne
Natural Resources Management Department
Natural Resources Institute
Central Avenue
Chatham Maritime
Kent ME4 4TB
UNITED KINGDOM

Dr G. Cadisch
Department of
Wye College
University of London
Wye
Ashford
Kent
UNITED KINGDOM

Enquiries regarding the ANORAC model may be made by e-mail to anorac@nri.org.

A website describing the ANORAC model and allowing it to be downloaded over the internet will shortly be available at http://www.nri.org/anorac

Requirements for Further Research

Short Term

The project has established on-farm sites in three agro-economic zones of the Kenya Highlands. The results of studies of the effects of different litter and manure applications to maize crops on farms were somewhat inconclusive as it was only possible, given the time constraints that arose as a result of difficulties in establishing the project, to run this study for one season. It is suggested that this study should be funded to continue over a 12 month period so that the carry-over effects of the different organic matter additions may be evaluated in more detail. A proposal for the allocation of the sum of £14 000 to this short continuation project is attached at appendix 1.

Longer-term

Key areas for future research that have been identified by the activities of this project include:

- Collaborative on-farm studies aimed at the development of integrated management strategies. For example, where poor growth during establishment has been identified as a problem on-farm, an examination of the consequences of interventions in livestock management, manure management and composting and agronomic practices *and their interactions* might be used to identify an appropriate range of solutions;
- evaluation of strategies for optimising the balance between diet quality and manure management strategies for maximum transfer of nutrients in manure at application;
- the inclusion of a manure - compost module in the ANORAC model that would allow it to be used more effectively as a decision support tool. This might be undertaken concurrently with the activities outlined above.

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Annexe 1: Proposal for Continuation Funding - R6283, ' Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems'.

Background

Minimising nutrient losses through promoting effective recycling of nitrogen (and other nutrients) is a key issue in maintaining the sustainability of many smallholder, mixed farming systems. However, it is only recently that the often pivotal role played by livestock in mediating N transfers has come to be recognised. This includes the potentially high sensitivity of the N dynamics of the farming system as a whole to changes in livestock feeding management. The varying quality (e.g. N, lignin and polyphenol content) of livestock diets influences feed digestibility, partitioning of nutrients amongst different ruminant tissues and partitioning of excreted nutrients between faeces and urine. However, the consequences of variation in these partitions for the value of excreta in providing nutrients to the soil and hence supporting crop production, are poorly understood.

LPP project R6283 (' Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems') has used both experimental and simulation modelling techniques to examine the implications of changes in N dynamics in animals for the subsequent behaviour of N in soils to which their excreta has been added and for plant growth on those soils.

Key Findings

A significant, novel feature of the approach taken in R6283 has been to integrate animal metabolism experiments with soil and plant growth studies conducted under controlled conditions by using characterised manure from the animal experiments. An on-farm study was then established to verify the implications of the results of the experimental studies under field conditions.

Animal metabolism studies indicated the high degree of variation that may be induced in manure quality by dietary manipulation. Changes in both level and form of N supplementation radically altered the total amounts of N excreted and its partitioning between faeces and urine. The results of the studies indicated that the presence of dietary polyphenols might also affect the extent to which faecal N was bound to neutral detergent fibre with considerable implications for the dynamics of N release on the incorporation of manure into the soil.

The dynamics of N mineralisation (measured in leaching tubes) was affected considerably by the provenance of the manure (i.e. the diet that had produced it). Manures produced from diets supplemented with *Calliandra calothyrsus* and *Macrotyloma axillare* had similar N mineralisation patterns, with net cumulative N release occurring by week 16 following incorporation. However, N mineralisation from these manures was much faster than mineralisation from manure derived from diets supplemented with poultry manure. Nonetheless, there was evidence that N was immobilised for at least 12 weeks following applications of all manure types suggesting that application at planting (a common local practice) may not always be most effective in promoting crop growth.

The potential significance of these observations was confirmed by seedling growth studies conducted in pots in which the highest dry matter assimilation was observed after 12 weeks in treatments where no manure had been added. Reductions in DM yields associated with the addition of manure produced from the different treatment diets ranged from 6% to 27% in comparison with the un-manured control - a finding that was consistent with the pattern of immobilisation of soil N observed in the leaching tube experiment. Such a lag period between application of manure to the soil and a net release of N has considerable significance for planning organic matter applications in practice. Furthermore, these results would suggest that dietary factors might need to be taken into account in doing this. Early manure applications before planting could provide better synchrony of crop N demand with N release from added manure. Alternatively, the beneficial effects of manure application may only be realised in the growth of a later season’s crop.

An on-farm study conducted in the Tea, Coffee and Semi-arid agro-ecological zones to the east of Nairobi, and again using characterised manure, has started to examine whether these experimental findings are borne out in the farmer’s field. Initial findings (from one season’s crop) are that the immobilisation observed in the leaching tubes and indicated by the lag in growth responses observed in the pot experiment may well be occurring in the field as few differences have been observed between treatments thus far. It is suggested that, in view of the results of the mineralisation and pot growth experiments, the single-season on-farm trial as originally planned is likely to prove inadequate for a proper assessment of the impact of the different quality manures on crop production.

Justification for Continuation Funding

In order to verify this assumption, it is proposed that the on-farm trial should be extended to cover three more growing seasons. The first of these will be used to test whether effects of the manure application made in September 1997 can be observed on crop growth now that net mineralisation should be occurring in the fields. Seasons 3 and 4 will be used to test for both immediate and residual effects of a further, larger application made in advance of the September 1998 growing seasons.

Specifically the extended programme of on-farm studies will allow the following hypotheses to be tested more fully:

1. Repeated applications of faeces lead to a build-up of soil organic matter with an enriched N content. Over several seasons mineralisation will release more N in synchrony with crop demand.

2. Differences in manure quality will lead to different release patterns with time

Budget for Proposal to Continue On-Farm Studies (R6283)

Item	Cost (Kenyan Shillings)
Experimental expenditure	
Production of different quality faeces	30,000
- two people for two months for two seasons	
Planting and plot maintenance - farmer costs	36,000
- land preparation 1000/- per farm per season	
- seed 500/- per farm per season	
- weeding 500/- per farm per season	
Field team from KARI-Muguga	280,000
- trial set-up, Day 90 assessments, harvesting, two visits	
Transport	150,000
Laboratory analysis	50,000
Program supervision	
Postdoctoral inputs	400,000
- four months (Sept/Oct 98 and March/April 99)	
NRI and Wye College input	100,000
- two days each	
Travel	140,000
- two LGW - NBO return flights (Sept. 98, March 99)	
Accommodation for postdoc' at ILRI	120,000
- four months at USD450 per month	
Contingency	100,000
Total	1,406,000
	(= GBP 14,000)