Modelling the effects of livestock on nutrient flows in mixed crop–livestock systems

P.J. Thorne

Natural Resources Institute (NRI), Central Avenue, Chatham Maritime, Kent ME4 4TB, UK

Abstract

Some of the effects of the passage of biomass through livestock on the dynamics of whole-system nutrient cycles are relatively clearly defined. However, processes in the livestock component may have other far-reaching effects that are less readily accounted for. For example, changes in diet composition can affect the partitioning of excreted nitrogen between manure and urine. Such changes can interact with animal and compost management practices to affect the dynamics of processes occurring in soil organic matter. A model based on digestive processes in ruminants is described which has been developed to assist in resolving these effects and interactions. Initial simulations with the basic Animal Production/Manure (APM) model have been conducted, both alone and in conjunction with the SCUAF (Soil Changes Under Agroforestry) model. These have been based on a system in which livestock are fed crop residues but may also graze or receive concentrate supplementation to highlight a number of issues, in particular that: animals may, depending on access to grazing and concentrate supplements, act as importers of nutrients into more intensively cropped land; and optimum production from the animal component may not necessarily be associated with maximum losses of nutrients from this land, even when the use of concentrate supplements is limited. Apart from improving our understanding of whole-cycle nutrient dynamics, the approach used in developing the APM model might also allow a unified approach to questions of whole-system productivity in mixed crop–livestock systems. Future efforts will concentrate on defining the parameters of the processes on which APM is based and the validation of the model against field data.

Modélisation de l'influence des animaux d'élevage sur les flux d'éléments nutritifs dans les systèmes mixtes agriculture–élevage

P.J. Thorne

Natural Resources Institute (NRI), Central Avenue, Chatham Maritime, Kent ME4 4TB (R.-U.

Résumé

Certains des effets du transit de la biomasse par le système digestif des animaux sur la dynamique générale des cycles des éléments minéraux sont relativement bien définis. Toutefois, les processus survenant au niveau des animaux mêmes peuvent avoir des conséquences extrêmement importantes mais moins faciles à prendre en compte. Par exemple, les changements de la composition des régimes alimentaires peuvent modifier les proportions d'azote excrété dans le fumier et l'urine. L'interaction de tels changements avec les modes de gestion des animaux mêmes et du compost peut influencer les processus survenant dans la matière organique du sol. Cet article décrit un modèle basé sur les processus digestifs des ruminants et élaboré pour expliquer ces effets et ces interactions. Les premières simulations ont été effectuées soit avec le modèle Production animale/fumure (APM), soit avec celui-ci et le modèle Changements pédologiques en agroforesterie (SCUAF). Ces simulations sont basées sur un système dans lequel les animaux reçoivent des résidus de cultures mais peuvent aussi pâturer ou recevoir une complémentation de concentrés. L'objectif consistait à démontrer que les animaux peuvent, selon l'accès au pâturage et aux concentrés, importer des éléments nutritifs dans les terres soumises à une exploitation intensive et qu'une production animale optimale ne doit pas être nécessairement associée à des pertes accrues d'éléments nutritifs de la terre, même en condition

d'utilisation limitée de concentrés. Non seulement cette approche permet de mieux cerner la dynamique générale des cycles d'éléments nutritifs, mais également elle pourrait déboucher sur une approche globale du problème de la productivité totale des systèmes mixtes agriculture–élevage. Des travaux futurs viseront à améliorer la définition des paramètres intervenant dans les processus de l'APM ainsi qu'à valider le modèle à partir de données de terrain.

Introduction

Models are a useful component in the analytical framework, which includes observation and experimentation, that can be applied to the evaluation of a wide variety of systems. Used in this way, modelling approaches have proved themselves powerful tools for integrating data from a wide variety of sources for the formulation of hypotheses and the testing of assumptions about key processes within a number of systems.

The objectives of models are unlikely to encompass the perfect simulation of observational data. To assume that this might be achievable in most complex biological systems is naive. Furthermore, such a feat would merely reflect the fact that knowledge of the system under study was at a perfect stage and that further analysis would be unnecessary. It is arguable, therefore, that failures of predictive models are in many ways their most interesting features as they can help to focus researchers' attention on those processes about which information is inadequate or inaccurate.

Models have been widely employed to explore the complexities of soil nutrient dynamics and the interactions between the factors which affect these (Parton et al, 1987; Thornley and Verberne, 1989) and, in many cases, have furnished the benefits outlined above. It is surprising, therefore, that a similar approach has not been taken to evaluate fluxes through the livestock component of nutrient cycles. The range of digestive and physiological processes which determine the partitioning and ultimate fate of nutrients as they pass through livestock operate at a similar level of complexity to soil processes. The interactions of these processes with the range of management strategies relating to feed and movement further complicate the elaboration of the subtle effects of livestock on nutrient fluxes within the system as a whole. The development of livestock models that can be interfaced with soil models could also have benefits for the modelling of whole-system dynamics and productivity with nutrient transfers being used to unify soil, crop and livestock components.

Many of the effects of livestock on nutrient cycle dynamics are likely to be susceptible to evaluation using a process-based modelling approach as they are readily quantifiable. The efficiency of extraction of nutrients from feed by animals within a herd, the turnover of ingested nutrients within the animals, both in the short and longer terms and the partitioning of excreted nutrients between urine and faeces have all been assessed in formulating nutrient requirements for domestic livestock (ARC, 1980; IDWP, 1992). It is these processes that can affect the quantity and chemical composition of organic returns to cropland and, consequently, the dynamics of subsequent fluxes in the soil (Tian et al, 1992). There are, however, a number of other factors involved, e.g. the effects of tannin on nitrogen fluxes (Sivapalan, 1982; Rittner and Reed, 1992) that require further quantification. The integration of a modelling approach at an early stage could facilitate the identification of priorities for research in these areas.

This paper, while not able to address these issues in great detail, sets out to demonstrate the potential of a modelling approach to contribute to the analysis of nutrient flows within crop–livestock systems. The principal objective of the Animal Production/Manure (APM) model developed was to assess the utility of a modelling approach for evaluating the effects on outputs, including nitrogen in excreta, of a range of management decisions that smallholders operating mixed crop–livestock systems must make. These decisions relate to the principal areas in which such farmers are likely to have options — stocking density, use of grazing and the use of feed supplements. The model can be used to examine trade-offs between the different productive outputs of the livestock component of the system. Its outputs can also be used to examine the consequences of interventions within the livestock component for other parts of the farming system by using these as input data for soil models.

Materials and methods

Model construction

The APM model is based on the treatments of nutrient and energy absorption and utilisation developed by ARC (1980) for metabolisable energy (ME) and IDWP (1992) for metabolisable protein (MP). The basic input data set required by APM (Table 1) has been minimised to allow the model to be operated in situations were available data are limited. Therefore, some of the feed parameters required by the model must be derived indirectly. These include the feed metabolisability (q = ME / Gross Energy), the acid detergent insoluble nitrogen (ADIN) content of the feed and three parameters which describe the dynamics of protein degradation in the rumen, a, b and c (Orskov and McDonald, 1979). ADIN and a, b and c are required by the MP system upon which the nitrogen component of the model is based and the values used are averages for each feed type. APM assumes that all animals in the herd are identical in type (for example, growing animals of a fixed mean live weight). 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.

Table 1. *Basic input data required for an APM simulation.*

Parameter	Unit
Feeds	
Quantity	kg available/day (as fed) or hours spent grazing
Type of feed	Grass, grass hay, cereal crop residue, legume crop residue, tree fodder, grain, animal protein supplement, vegetable protein supplement
Dry matter	g/kg
Crude protein	g/kg dry matter
Crude fibre	g/kg dry matter
Ether extract	g/kg dry matter
Metabolisable energy	MJ/kg dry matter
Animal	
Species	*Bos taurus, Bos indicus*, buffalo, sheep, goat
Sex	Male, female, castrate
Class	Growing, mature
Live weight	kg
Number in herd	Integer

The composition of the diet consumed by animals in the herd is a function of the capacity of the type of animal selected to consume the feed that is available (its voluntary dry-matter intake; VDMI) and the herd size. If the total amount of feed available is greater than the total VDMI of the herd, it is assumed that feeds with the highest value for q are consumed preferentially. Thus, animals in a small herd will, at a given level of feed availability, tend to consume feeds of a better quality up to their maximum predicted VDMI (Forbes, 1986) and reject those of poorer quality. This approach allows the model to account, in principle at least, for the selectivity observed in animals offered feed in excess of their capacity to consume it (Osafo et al, 1992). When herd size is larger and the quantity of feed available is less than the total VDMI for the herd, a reduction in dry matter intake below VDMI is calculated that is proportional to herd size. Grazing intake is calculated separately, assuming that each animal in the herd consumes a quantity of grass that is proportional to the hours spent at pasture during each day. Thus, for a grazing herd, the potential intake of feeds presented in the stall is obtained by subtraction of the dry matter consumed at pasture from the VDMI of each animal.

The simulation of animal performance is derived initially from the difference between the ME supplied in the feed consumed and the maintenance ME requirement appropriate for the type of animal in the herd, calculated using equations of ARC (1980). 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 ME in excess or deficit of the maintenance ME required. In the latter case, weight loss is

calculated from the amount of body reserves mobilised to meet a shortfall in ME for maintenance (ARC, 1980).

The animals' ability to achieve the level of performance predicted from ME intake depends on the adequate supply of protein for turnover and production. The protein component of the model, based on the UK MP system, uses the same general approach described by Dewhurst and Thomas (1992) who evaluated the effects of dietary changes on urine production. Dietary MP supply is checked against the MP 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 MP utilisation that the current MP intake will support. If MP supply is inadequate for protein turnover, a weight loss is calculated as specified by IDWP (1992).

The MP system also allows the prediction of the partitioning of nitrogen between faeces and urine (Table 2). In animals that are not grazed, it is assumed that all excreted nitrogen is incorporated into compost together with any feeds that are rejected by a herd that is fed in excess of VDMI. In herds that graze for part of the day, it is assumed that the amounts of faecal and urine N deposited on the pasture or range are proportional to the amount of time spent grazing. The current implementation of the model assumes that there is no diurnal variation in faeces or urine output.

Table 2. *Equations used for predicting nitrogen outputs in faeces and urine.*

Species	Faeces		Urine	
	Indigestible nitrogen (g/day)	Endogenous losses (g/day)	From protein utilisation (g/day)	Endogenous losses (g/day)
Cattle	Acid detergent insoluble nitrogen content of the diet	$0.35 \times (weight)^{0.75}$	$MP \times K_{N1}$	$0.13 \times (weight)^{0.75}$
			$(K_N = 0.85$ for maintenetance and pregnancy, 0.59 for growth, 0.68 for lactation)	
Sheep + goats	As above	As above	As above + K_N = 0.26 for wool	$0.02348 \times weight + 0.54^2$

1. K_N is the efficiency of conversion of absorbed nitrogen for different productive purposes and for maintenance.
2. ARC (1980).

Source: IDWP (1992).

Simulation of published experimental and field observations

APM is a mechanistic model (albeit at a fairly low level of disaggregation) in the sense that the parameters used in its construction are related by the discrete, identifiable processes that are said to govern nitrogen and energy transactions in the animal. The scope of the model's applicability depends, therefore, on how generally these processes apply. The key question here is: do the descriptions of processes derived by ARC (1980) and IDWP (1992) for animals under European conditions apply to animals, of different genotypes, kept under more extensive feeding and management systems in Africa or elsewhere? A reliable answer to this question would require detailed validation and testing of the model using individual animal data for several species under a wide range of feed management systems. Such testing of APM might be envisaged for the future when a number of inadequacies, which will become apparent, relating to the parameterisation and data used in the construction of the model have been addressed.

For the purposes of this paper, a simple comparison between APM predictions and experimental observations is presented to illustrate current limitations on the predictive capacity of the model. The

ut data used for this simulation (Table 3) are derived from a nitrogen balance experiment conducted
th indigenous Malawi goats offered a range of hay-supplement combinations (Reynolds, 1981)
iich was selected at random from a number of suitable, published studies.

ble 3.   *Input data for simulation of published data.*

ed	Feed type	Dry matter (g/kg DM)	Crude protein (g/kg DM)	Crude fibre (g/kg DM)	Ether extract (g/kg DM)	Metabolisable (MJ/kg DM estimated)
iloris gayana hay (1)		895	59	427	8	7.40
iloris gayana hay (2)		920	53	435	10	7.40
iloris gayana hay (3)		900	59	362	9	8.15
iloris gayana hay (4)		932	58	445	8	7.40
oncentrate (1)		927	100	60	90	11.75
oncentrate (2)		908	230	100	65	11.44
oncentrate (3)		913	347	99	69	11.29

imal details: One 30 kg mature castrated goat.

urce: Reynolds (1981).

fects of feeding and management strategies on livestock production and nutrient ws in a mixed crop–livestock system

mulations were conducted with APM to evaluate the effects of herd size, availability of grazing and
pplementary feeds and their interactions on liveweight production and nitrogen outputs for
mposting from a livestock holding associated with a specific system. The system used was a
dgerow intercrop of pigeon pea and maize producing 1020 and 2220 kg/ha per year, respectively,
forage dry matter which, for the purposes of the simulation was assumed to be available as feed (6
; of maize stover and 2.8 kg pigeon pea haulm per day). This level of forage production was based
predictions for the crop generated by an example simulation presented by Young and Muraya (1990)
ing the Soil Changes Under Agroforestry (SCUAF) model. The system was chosen so that
ssibilities for using the APM model in conjunction with this soil nutrient model could also be
plored. The APM model simulations were based on the assumption that all forage was removed
om the cropped land and all compost produced was available subsequently for fertilising the crop.

The effects on liveweight production and sources of nitrogen in the compost, of grazing for four
eight hours per day and a fixed availability of concentrate of 0.5 kg or 1 kg per day in addition to
e forage available from crop residues were also examined. The model was also used to examine the
fects of grazing and supplement availability on net nutrient transfers between the livestock
mponent and the crop land. Basic input data for these APM simulations are shown in Table 4.

able 4.   *Basic input data for APM simulations of liveweight production and nitrogen outputs from a livestock holding associated with one hectare of pigeon pea/maize intercrop.*

eed	Feed type	Dry matter g/kg DM)	Crude protein (g/kg DM)	Crude fibre (g/kg DM)	Ether extract (g/kg DM)	Metabolisable energy (MJ/kg DM
		841	59	385	18	8.6
igeon-pea haulm		900	167	297	25	9.99
iroundnut cake		926	495	53	92	14.46
hloris gayana	Grass	282	89	379	10	10.12

nimal details: Varying number of 100 kg growing male *Bos taurus*.

Interfacing with a soil nutrient model

APM model simulations were also conducted in tandem with simulations of soil changes and their consequences for crop productivity over a six-year period that were generated using the SCUAF model. The SCUAF model was developed for making approximate predictions of the effects of agroforestry systems on soil parameters (erodibility and nutrient status) and to use these predictions to assist in the design and conduct of agroforestry experimentation. It is divided into a plant and a soil compartment. The soil compartment simulates changes in soil stability and fertility over a specified period by considering soil erosion — based on a simplified version of the Universal Soil Loss Equation (FAO, 1979) — and carbon and nitrogen cycling. Changes in plant growth over time in response to changes in the soil compartment are estimated using a number of user-specified feedback factors which describe the extent to which soil factors influence plant growth.

The basic input data used for the SCUAF simulations conducted here were presented by Young and Muraya (1990). These simulations assumed a constant rate of inorganic fertiliser application of 100 kg of 40% N per year. Grains from the pigeon pea/maize intercrop were harvested annually for human consumption and therefore represented losses to the system. Residues from both crops (pigeon-pea haulms and maize stover) were also removed for animal feeding but compost was accounted for, where appropriate, as an input to the SCUAF model. The woody above-ground parts of the pigeon pea remain in the system from year to year as standing biomass and the roots which die and decompose at varying rates return nutrients to the labile pools in the soil.

To run the joint simulations, the crop model was used to produce yearly forage inputs for APM. On the basis of these, APM supplied input data on the quantity and quality of organic matter returns to the soil for SCUAF for the following year. Years were considered to be identical except for the levels of removals, determined by SCUAF, and returns, determined by APM.

Feed and compost-management scenarios for each joint simulation were developed using the APM simulations of the effects of herd size, access to grazing and use of supplementary feeding. It was assumed that, for a given feed-management strategy, the farmer adopted a herd size which maximised the live weight gained by the herd as a whole. Thus, the four basic management scenarios used in defining conditions for the joint simulations were:

1. All crop residues removed for feeding but no return of compost. In this simulation, there would be no feedback effects of livestock management on the crop component (net outflow of N in feeds from crop land = 47.28 kg/year).

2. Removal of crop residues for feeding and all compost returned subsequently for fertilising the crop. No grazing or supplementary feeding of a herd of two animals (net outflow of N in feeds from the crop = 19.56 kg/year).

3. As for simulation 2 but with a herd of four animals grazed for 8 hours per day (net outflow of N in feeds from the crop = 21.84 kg/year).

4. As for simulation 3 but with a herd of ten animals also offered 0.5 kg per head per day of supplementary groundnut cake (net outflow of N in feeds from the crop = −31.08 kg/year).

The results of these simulations were related to a baseline simulation in which all crop residues were returned to the crop directly, after harvest. This represents the pigeon pea–maize intercrop with no associated livestock component.

Results and discussion

Simulation of published experimental and field observations

Faecal and urinary nitrogen production from indigenous Malawi goats consuming diets with a range of nitrogen contents observed experimentally (Reynolds, 1981) and predicted by APM using input data derived from this study are shown in Figure 1. Accurate quantitative prediction of the individual

Figure 1. *Comparison of observed and predicted values for N excretion by indigenous Malawi goats consuming different levels of nitrogen (observed values from Reynolds, 1981).*
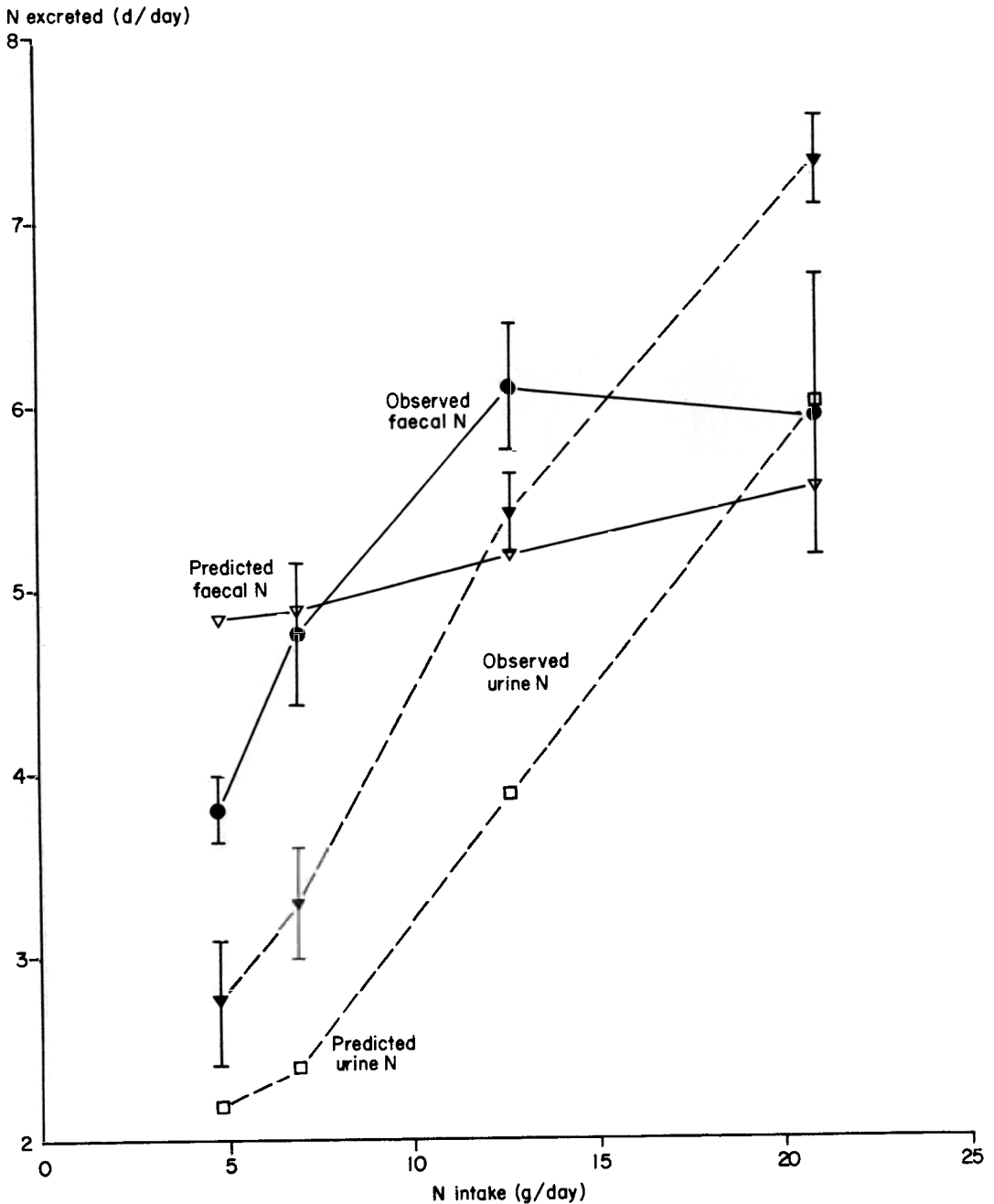
experimental observations was not achieved by the model as, in general, predicted values fall outside the ranges of the errors associated with the observed values. However, the direction and rates of the predicted responses to increasing dietary N were significantly correlated (faecal N, $r^2 = 0.676$; urine N, $r^2 = 0.981$) with those observed *in vivo*.

Similar inaccuracies were also observed in the quantitative prediction of nitrogen balance (Table 5) but again, correlation over the range of treatments was significant ($r = 0.959$). Growth performance

data were not available for the experiment. However, weight changes predicted by the APM model (also shown in Table 5) were, to an extent, consistent with the observed nitrogen balance data. As might be expected animals that were in negative N balance in the experimental study lost weight in the simulations. However, the group with the highest predicted percentage of ingested nitrogen retained was not the group with the fastest growth rate in the experimental study and the levels of N retention predicted might have been expected to be associated with rather higher rates of gain.

Table 5. *Predicted and observed nitrogen balances and predicted growth rates.*

| Treatment | Nitrogen balance | | Predicted weight change (g/day) |
	Observed	Predicted	
Hay	−1.81±0.394	−1.85	−94
Hay + concentrate 1	−1.20±0.357	0.00	−31
Hay + concentrate 2	1.11±0.312	3.98	35
Hay + concentrate 3	7.45±0.378	9.61	17

Source: Reynolds (1981).

The inadequacies of the predictions, for urine N production at least, would appear to be errors of quantification rather than due to the general formulation of the relationships which define the model. This implies that there are inaccuracies in the data used within the simulations. It is suggested that the parameters most likely to be responsible are those which describe protein degradation in the rumen (a, b and c) and ADIN which contributes directly to faecal N levels. Values used in the model are derived means for each different class of feed but, for a, b and c, are likely to be subject to quite large inaccuracies as these parameters are highly variable (Webster, 1993) even when determined for the same samples at different laboratories. The use of ADIN to represent undegradable, undigested nitrogen has been adopted relatively recently, therefore, only limited data are available on which to base model predictions. Thus, increasing the accuracy with which a, b, c and ADIN are quantified is likely to be the most significant barrier to improving the quantitative predictive capacity of the model in future. Direct input of these parameters for feeds used in simulations could be expected to increase accuracy of prediction. However, these data are not widely available for practical situations and insistence on their use would probably compromise the utility of the model.

Effects of feeding and management strategies on livestock production and nutrient flows in a mixed crop–livestock system

Changes in the production of live weight by herds in response to increasing herd size followed similar patterns under all conditions of feed availability simulated with the APM model (Figure 2). Daily liveweight gain (DLWG) by individual animals decreased initially as the quality and quantity of feed available to each one declined. In contrast, total liveweight production increased initially to a peak with increasing herd size. As herd size was increased further, liveweight production declined as the incremental reduction in DLWG in all animals due to the reduction in nutrient intake brought about by the sharing of available feed with an additional animal exceeded the increase in live weight due to that extra animal. Not only the size but also the position and shape of the peak in live-weight production was dependent on feed availability. Increased feed availability due to the provision of supplements or, in particular, grazing shifted the peak to a larger herd size.

Grazing access also tended to broaden the peak as the provision of extra forage, proportional to the number of animals in the herd, allowed the higher quality feeds (pigeon-pea haulm and groundnut cake) to be spread more widely. A similar response to supplementation was observed when a fixed allowance per animal was offered rather than allowing this to vary by the allocation of a flat rate for the herd. The provision of grazing and supplements in this way could potentially allow farmers more

Livestock and sustainable nutrient cycling

Figure 2. *Effects of herd size, supplementation and grazing access and their interactions on growth rates and production of live weight (LW).*
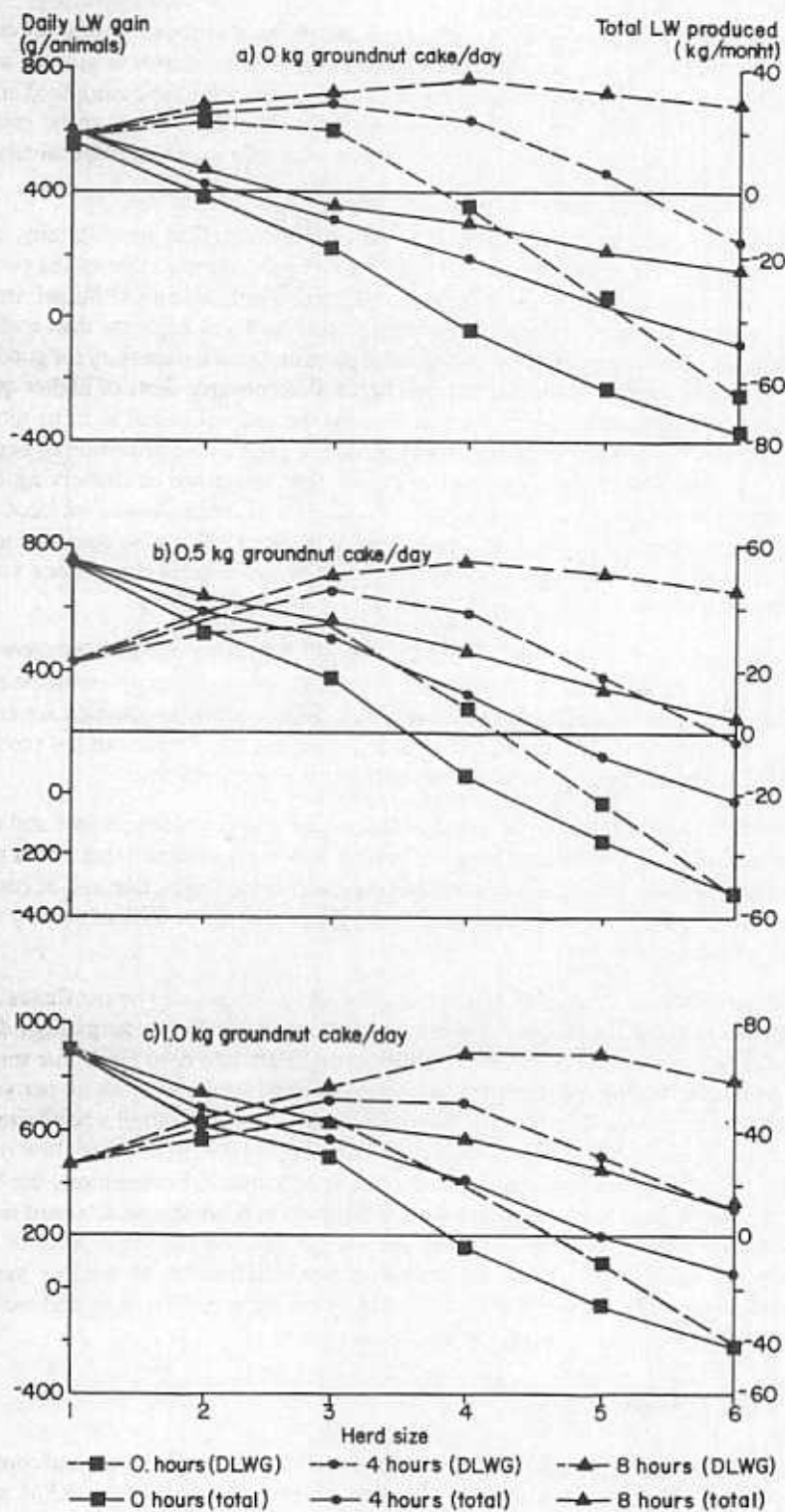
flexibility in planning stocking rates. If total live weight produced is similar over a range of herd sizes, there is scope for optimising other variables such as nutrient fluxes within that range.

The relationships between herd size and the sources and quantities of nitrogen in the compost under the different supplementation regimes are shown in Figure 3 and different levels of grazing access in Figure 4. In general total N in the compost tended towards a minimum with increasing herd size. This minimum was observed when herd size was large enough for all offered feeds to be consumed. Subsequently compost N increased with increasing herd size due to the progressively larger contributions of endogenous urinary and faecal N.

Sources of nitrogen in the compost are likely to have a significant effect on its quality as a soil adjuvant. In small herds which do not consume all the available feed, a proportion of the compost is made up of maize stover and at higher levels of supplementation and grazing a limited amount of pigeon pea haulm. Manure nitrogen is probably of higher value as a soil adjuvant than undegraded plant material (Sandford, 1989) although some undegraded plant material is necessary for good quality compost and efficient urine capture. Animals in small herds also consume diets of higher quality in terms of dietary protein:energy ratio. Under these conditions the ratio of faecal to urine nitrogen is lower. This highlights the importance of management practices, such as the provision of bedding or placement of stalls on land that is to be cropped in future, that are aimed at conserving urine N, particularly when improved feeding practices are introduced. The consequences of ineffective urine capture have been demonstrated in practice by Powell and Williams (1991) who observed increases in DM production of more than 50% in plots treated with manure and urine in comparison with other plots treated with manure alone.

Responses in nitrogen excretion to increasing herd size when grazing access was allowed were similar although total N in the compost was reduced at a particular herd size as a proportion of faeces and urine was excreted on the pasture. If herd sizes optimum for liveweight production are compared for grazing and non-grazing animals, levels of N added to compost are similar but the provision of supplements resulted in higher levels of compost nitrogen at optimum herd size.

The division by the model of nitrogen excreted in faeces and urine between pasture and compost assumes that there is no diurnal variation in output. There is, however, evidence that this is probably not the case in practice as marked diurnal variation in faecal and urine production and N content has been observed experimentally. Betteridge et al (1986) suggested that up to 66% of urinary nitrogen may be excreted during the night.

Figure 5 shows the effects of the size of a herd grazing eight hours per day on net fluxes from the cropland both with and without the provision of 0.5 kg of groundnut cake per animal per day. This simulation illustrates how animals can act as importers of nutrients into crop land. The removal of crop residues for livestock feeding represents a constant flow of 47.28 kg of nitrogen per year from the cropland. In the unsupplemented herd, a net flow of zero does not occur until a herd size of 10 is reached. At this stage, the herd is losing live weight. With supplementation, a net flow of zero is achieved within the range in which live-weight production is maximised. Furthermore, the high rate of supplementation ensures that the peak for live-weight production is broad and, at a herd size of 13, outflows from the plot can be returned in faecal nitrogen alone reducing the importance of efficient husbandry of urine. This latter simulation illustrates how intensification of feeding systems in crop–livestock systems through the use of agro-industrial by-products are likely to lead incidentally to improved sustainability of associated crop production activities.

Interfacing with soil nutrient models

While net fluxes can be evaluated using APM alone, the wider effects of the quantities and composition of compost available in crop–livestock systems need to be evaluated using the APM model in conjunction with the SCUAF model.

Figure 3. *Effects of herd size and supplementation on sources and quantities of nitrogen in compost.*
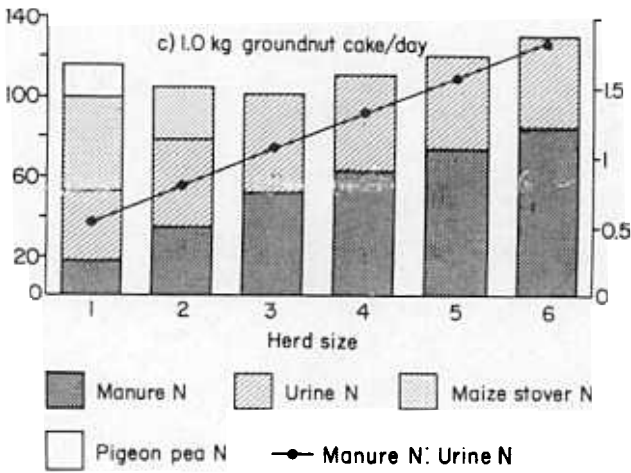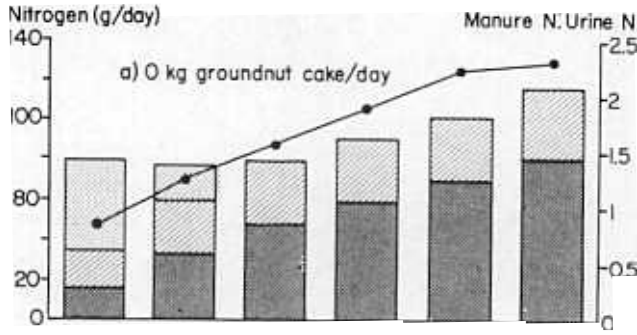
Figure 4. *Effects of herd size and grazing access on sources and quantities of nitrogen in compost.*
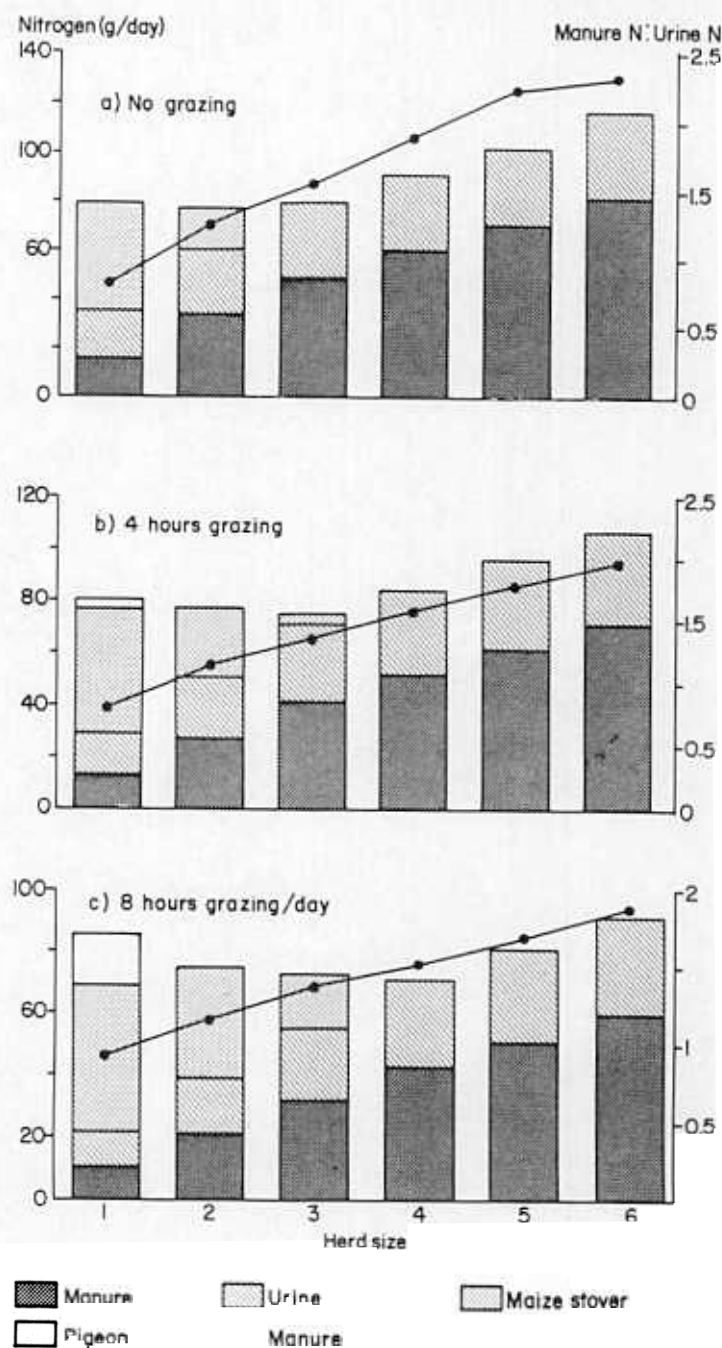
Figure 5. *Effects of size of a grazed herd and supplementation on net nitrogen fluxes from cropland.*
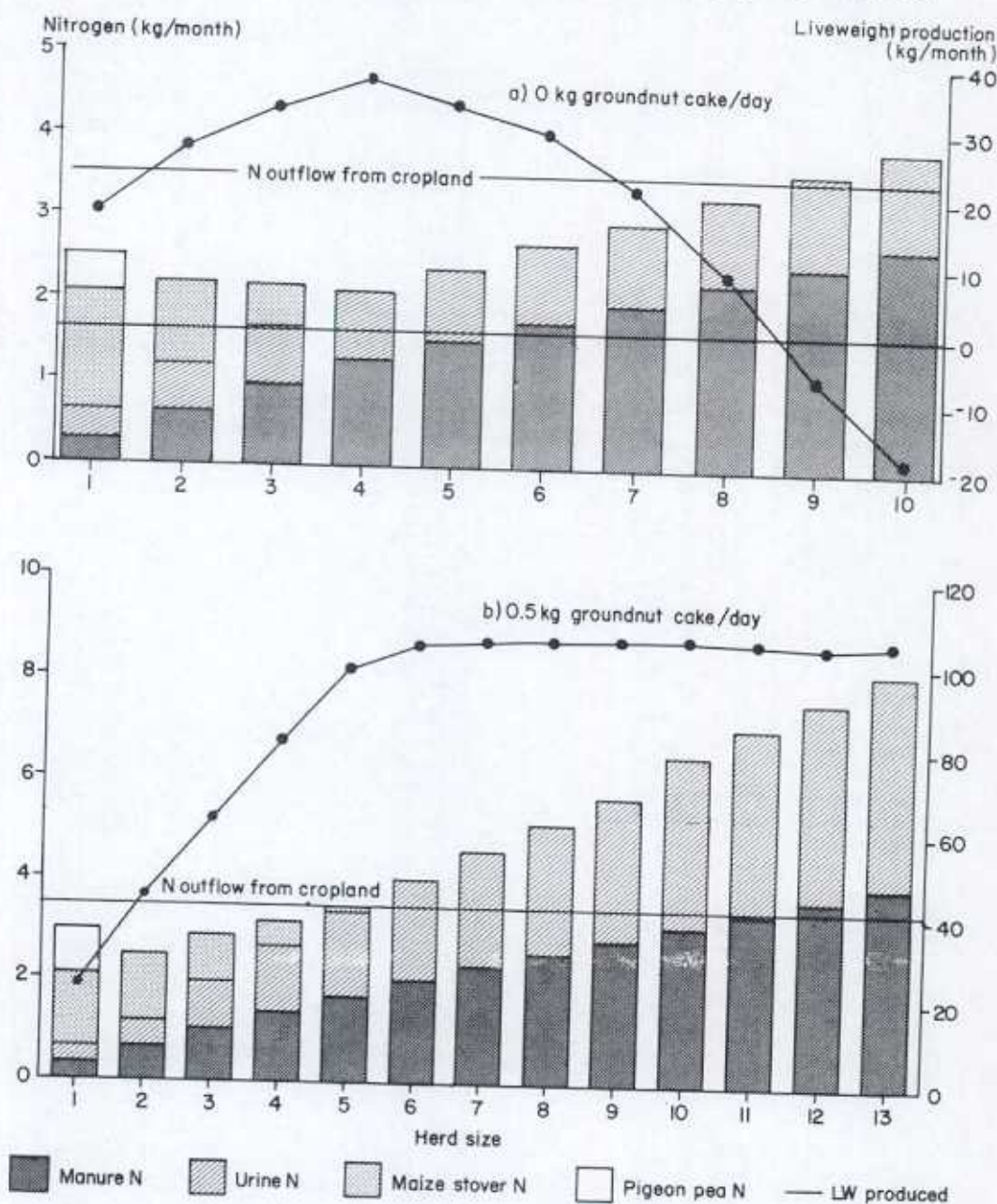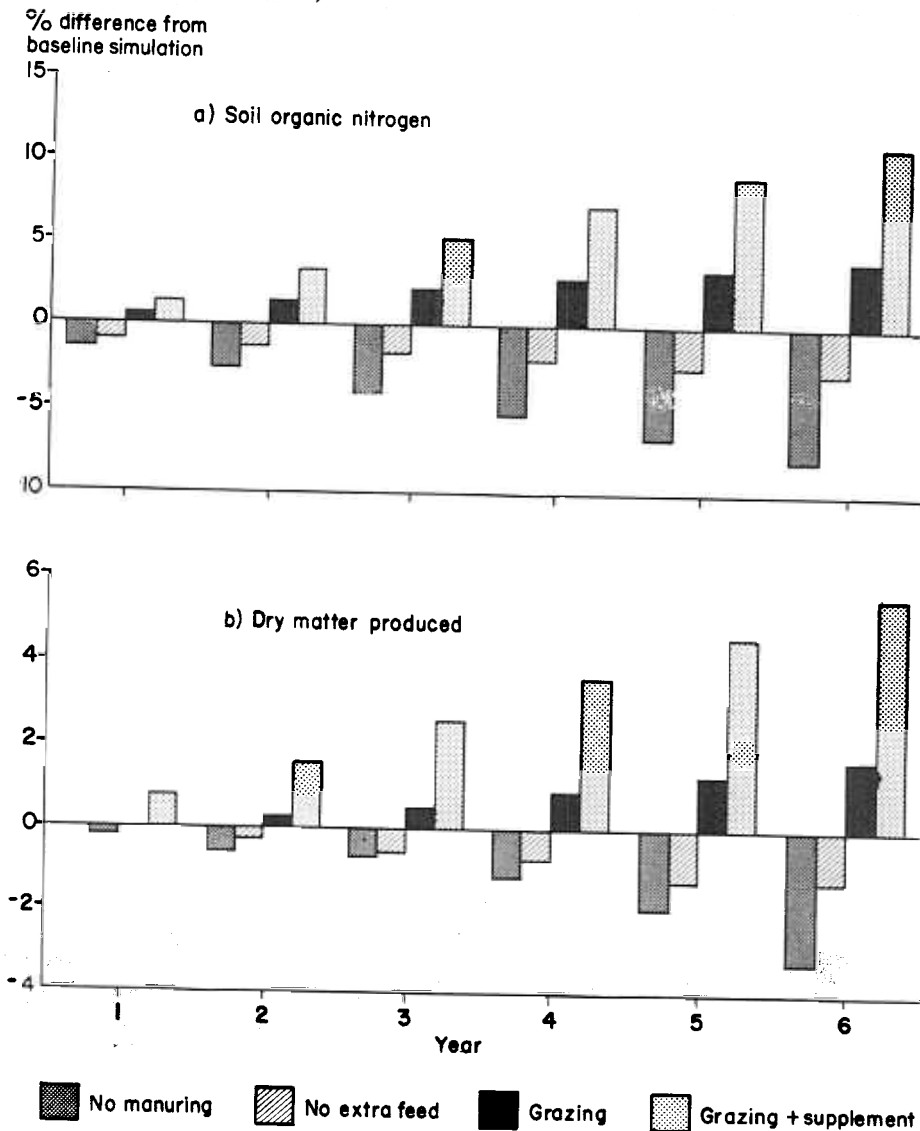

Figure 6 illustrates the consequences of the four scenarios used in the joint simulations on changes in soil organic matter and crop productivity over the six-year period of the simulations. It is not surprising that under scenario 1 the removal of crop residues for feed with no return of compost results in an accelerating decline in soil organic nitrogen and crop productivity. Equally expected is the increase in soil organic nitrogen and productivity observed under scenario 4 where there was a net influx of 31.08 kg/year of compost nitrogen into the plot.

Figure 6. *Effects of feed and compost management scenarios on soil organic nitrogen and crop production (SCUAF simulations).*

% difference from
baseline simulation

a) Soil organic nitrogen

b) Dry matter produced

Year

No manuring   No extra feed   Grazing   Grazing + supplement

Perhaps most interesting are the differences between scenarios 2 (no grazing or supplementation) and 3 (8 hours grazing per day). Although net annual N fluxes were similar (19.56 versus 21.84 kg/year), more than twice the volume of compost dry matter was returned under scenario 3 (2188 versus 1009 kg/year) which supported a herd size of four as opposed to two animals. This is reflected by differences in the ratios of carbon to nitrogen in the organic returns which, under scenario 2, averaged 15.5 and under scenario 3, 34.5. The higher organic-matter returns under scenario 3 are likely to be more beneficial for soil structure and would thereby promote more effective retention of N in the soil.

Conclusions

Modelling studies conducted to date indicate a need for improved parameterisation to account for the effects of livestock on nutrient cycle dynamics under tropical conditions. There are three areas in which this could be particularly improved:

- Integration of the effects of other feed factors such as tannin which affect protein metabolism and soil processes and are found in a range of tropical feeds.

- A treatment of diurnal variation in manure and urine production or, failing this, an ability of the model to test the sensitivity of simulations to variation in these parameters.

- Increase the potential of animal models to interface directly with soil models, a treatment of the degradation of manure and urine, post-voiding.

The current study has also identified problems in assimilating basic data for running simulations of nitrogen transactions in the animal for a wide range of tropical feeds. The use of multivariate statistical analysis to identify groups of feeds with common properties relating to the degradation and digestibility of nitrogen might promote improvements in the ability of the APM model make quantitative predictions.

References

ARC (Agricultural Research Council). 1980. *The nutrient requirements of ruminant livestock.* CAB (Commonwealth Agricultural Bureaux), Farnham Royal, UK. 351 pp.

Betteridge K, Andrews W G K and Sedcole J R. 1986. Intake and excretion of nitrogen, potassium and phosphorus by grazing steers. *Journal of Agricultural Science (Cambridge)* 106:393–404.

Dewhurst R J and Thomas C. 1992. Modelling of nitrogen transactions in the dairy cow and their environmental consequences. *Livestock Production Science* 31:1–16.

FAO (Food and Agriculture Organization of the United Nations). 1979. *A provisional methodology for soil degradation assessment.* FAO, Rome, Italy. 84 pp.

Forbes J M. 1986. *The voluntary food intake of farm animals.* Butterworths, London, UK. 206 pp.

IDWP (Interdepartmental Working Party). 1992. Nutritive requirements of ruminant animals: Protein. AFRC Technical Committee on Responses to Nutrients Report 9. *Nutrition Abstracts and Reviews (Series B)* 62(12):787–835.

Orskov E R and McDonald P. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rates of passage. *Journal of Agricultural Science (Cambridge)* 92:499–503.

Osafo E L K, Owen E, Said A N, Gill M, McAllan A B and Sherrington J. 1992. Feeding sorghum stover to Ethiopian yearling cattle: Effects of amount of stover offered and cottonseed cake supplement on intake and growth. *Animal Production* 54:501. (Abstract)

Parton W J, Schimel D S, Cole C V and Ojima D S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51:1173–1179.

Powell J M and Williams T O. 1991. Etudes de fumure effectuées par le Centre international pour l'élevage en Afrique (CIPEA), Niger. *Echanges Plus* 6:7–9.

Reynolds L. 1981. Nitrogen metabolism in indigenous Malawi goats. *Journal of Agricultural Science (Cambridge)* 96:347–351.

Rittner U and Reed J D. 1992. Phenolics and *in vitro* degradability of protein and fibre in West African browses. *Journal of the Science of Food and Agriculture* 58:21–28.

Sandford S G. 1989. Crop residue/livestock relationships. In: ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), *Soil, crop and water management systems for rainfed agriculture in the Sudano-Sahelian zone.* Proceedings of an international workshop held at the ICRISAT Sahelian Center, Niamey, Niger, 11–16 January 1987. ICRISAT, Patancheru, India. pp. 169–182.

Sivapalan K. 1982. Humification of polyphenol-rich plant residues. *Soil Biology and Biochemistry* 14:309–310.

Thornley J H M and Verberne E L J. 1989. A model of nitrogen flows in grassland. *Plant Cell and Environment* 12:863–886.

Tian G, Kang B T and Brussard L. 1992. Biological effects of plant residues with contrasting che compositions under humid tropical conditions – decomposition and nutrient release. *Soil Biolog Biochemistry* 24:1051–1060.

Webster A J F. 1993. The metabolizable protein system for ruminants. In: Haresign W and Garnsworth (eds), *Recent advances in animal nutrition – 1992.* Butterworths, London, UK. pp. 93–110.

Young A and Muraya P. 1990. *SCUAF, soil changes under agroforestry.* ICRAF (International Cent Research in Agroforestry), Nairobi, Kenya. 124 pp.