Enhancement of Smallholder Dairy Production under Tropical Conditions through Supplementation to Optimise Roughage Intake, Digestibility and Microbial Protein Synthesis

Ph.D. Thesis

by

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Summary

This thesis addresses the nutritional related constraints facing the smallholder diary sector in Tanzania in general and Morogoro in particular. Smallholder dairy production practices and feeds were assessed though a structured survey carried out between January and March 1999 (**Paper I**). Monthly collection of forages used by farmers was done over a one-year period. The forage samples were analysed for chemical composition and in vitro organic matter digestibility to determine the annual variations in the nutritional quality. It was found that smallholder producers were playing a key role in the provision of dairy products that are in high demand in urban areas like Morogoro, in Tanzania. One of the limiting factors to enhanced productivity was the fall in milk yield (more than 40%) during the dry season. Forage analyses revealed that there was a fall in nitrogen and Metabolizable energy contents and organic matter digestibility with advancing dry season.

The impact of low nitrogen in the basal feeds on animal performance was further investigated in an on station experiment set to determine the effects of nitrogen supplementation on feed intake, digestibility and rumen fermentation in animals fed poor quality forage (**Paper II**). In a 5x5 Latin square design, five ruminally fistulated heifers were assigned to either low quality hay only or supplemented with either low or high level of true protein (soyabean cake) or non-protein nitrogen (urea) (**Paper II**). At each level of supplementation, both urea and soyabean cake were iso-nitrogenous. Both soyabean cake and urea supplementation of poor quality forages led to significant improvement in the dry matter (DM), organic matter (OM) and plant fibre digestibility and microbial protein synthesis. Soyabean cake showed marginally higher (not significant) responses in most parameters at all levels compared to urea except for digestible NDF digestibility where the high level of urea supplementation showed a higher (not significant) value compared to soyabean cake. The superiority of soyabean cake may have been due to the extra DM, energy, pre-formed amino acids, minerals and extra amino acids arising from by-pass protein invariably associated with this supplement. Calculated price of supplemental protein from soyabean cake was about 3.3 Tsh compared to 0.1 Tshs per gram CP urea (see Table 1). Therefore, as far as fermentation of plant fibre was concerned, urea was equally good and a better option given the high prices of true protein sources like soyabean cake.

One other interesting observation during the survey (**Paper I**) was the attempts by farmers to offer supplements to their cows especially the lactating ones. Surprisingly, most of the supplements used were energy rich (maize bran, molasses and cassava flour)

while protein rich supplements were rarely used. A second on station experiment was set to investigate the effects of the commonly used supplements and a feed additive called "Magadi" on the intake and utilisation of poor quality roughage (**Paper III**). The experimental set up was a 5x5 Latin square design involving 5 ruminally fistulated heifers, 5 treatments and 5 periods of 28 days each. The treatments were poor quality hay plus maize bran (2.7kg DM) (control), or the control plus starch (0.9 kg DM cassava flour), sugars (1.3kg DM molasses) or "Magadi" (0.3kg). The fifth treatment was the poor quality hay supplemented with concentrate mixture (2.8kg DM) containing energy (68% maize bran) and protein (31% sunflower cake) and 1% mineral commercial mineral powder instead of the maize bran used in the control.

Inclusion of "Magadi" or molasses or cassava flour in animals receiving equal amounts of maize bran produced variable results. Sugars increased OM intake and digestibility with little change in NDF digestibility compared to the control. Starch increased DM and OM intake and digestibility but reduced NDF digestibility due to high passage rate of NDF. "Magadi" did not improve DM intake but NDF digestibility and microbial protein synthesis were higher compared to supplementation with maize bran alone. There was also a higher in situ degradation of hay DM from dacron bags soaked in "Magadi" for 24 hours prior incubation in the rumen of standard cows compared to those soaked in tap water. This suggested that better response might be obtained through treatment of poor quality hay with "Magadi" than direct feeding. The supplement that contained a mixture of maize bran and sunflower cake fed to about 35% of total DM intake improved intake and digestibility of poor quality roughage compared to supplementing with plain maize bran as is the common practice with smallholder farmers in Morogoro.

It was interesting to investigate whether the energy-protein concentrate mixture could be used by smallholder farmers in Morogoro as dry season supplement in order to arrest or reduce the fall in productivity during this season when the basal feeds are deficient in nitrogen and to some degree, energy. The major ingredients for making such a mixture (maize bran and sunflower cake) are easily available and reasonably cheap in Morogoro. Farmers were trained on how to compound such supplement on their own at farm level. The effect of feeding the concentrate mixture or maize bran alone as commonly done by most farmers was assessed through an on farm trial involving a total of 18 farms and 47 milking cows (**Paper IV**) in urban and peri-urban areas of Morogoro.

The concentrate mixture significantly (P<0.001) increased milk yields compared to feeding maize bran alone, as is the common practice by smallholder farmers.

In conclusion, there is great opportunity of increasing productivity in the smallholder dairy sector through judicial use of locally and cheaply available supplements and feed additives like "Magadi". Nitrogen supplementation was found to be more crucial than energy in improving the utilisation of poor quality forages. More feeding trials are required to determine appropriate levels and combinations of locally available supplements for optimal utilisation of the poor quality forages that are the basal diet for dairy cows in Tanzania and also to investigate further the best use of additives like "Magadi".

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Dedication

First and foremost to my Heavenly Father whom I adore and trust, and who gives me the strength to endure and prevail against many odds (Phillipians 4:13).

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Declaration

I declare that the work this PhD thesis is my original work submitted to the Royal Veterinary and Agricultural University (RVAU), Copenhagen, Denmark.

Signature......FRMlay..................................

Date........14\5\2001...

List of papers included in this thesis

I. Smallholder Livestock Production in Urban and Peri-Urban Areas of Morogoro, Tanzania. Results from a survey carried out between February 1999 to February 2000.

II. The effect of source and level of nitrogen supplementation on intake, rumen fermentation and plant fibre kinetics in animals fed poor quality hay.

III. The effect of maize bran alone or in combination with either sunflower cake, cassava flour, molasses or "Magadi" on intake and rumen function NDF kinetics.

IV. Comparison of maize bran or maize bran sunflower meal mix on the performance of smallholder dairy cows in urban and peri-urban area in Morogoro, Tanzania.

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1.0 INTRODUCTION

1.1 Importance of the livestock sector in Tanzania

Tanzania is located in the equatorial zone of East Africa at Latitude 1° S and 12° S and longitudes 30° E and 39° E. Total area is 945,000 Km^2. The population was estimated to be 25 million people, 85% of which live in the rural areas by the 1988 census. The population annual growth was estimated to be 3.3% (Tanzania Agriculture, 1994). The research work was carried out in and around Morogoro town. The town is the regional headquarter of Morogoro region (see Map in Figure 1) and is about 200 km from the capital Dar-es-Salaam and an area of 260 km^2 (Planning Commission Report, 1997).

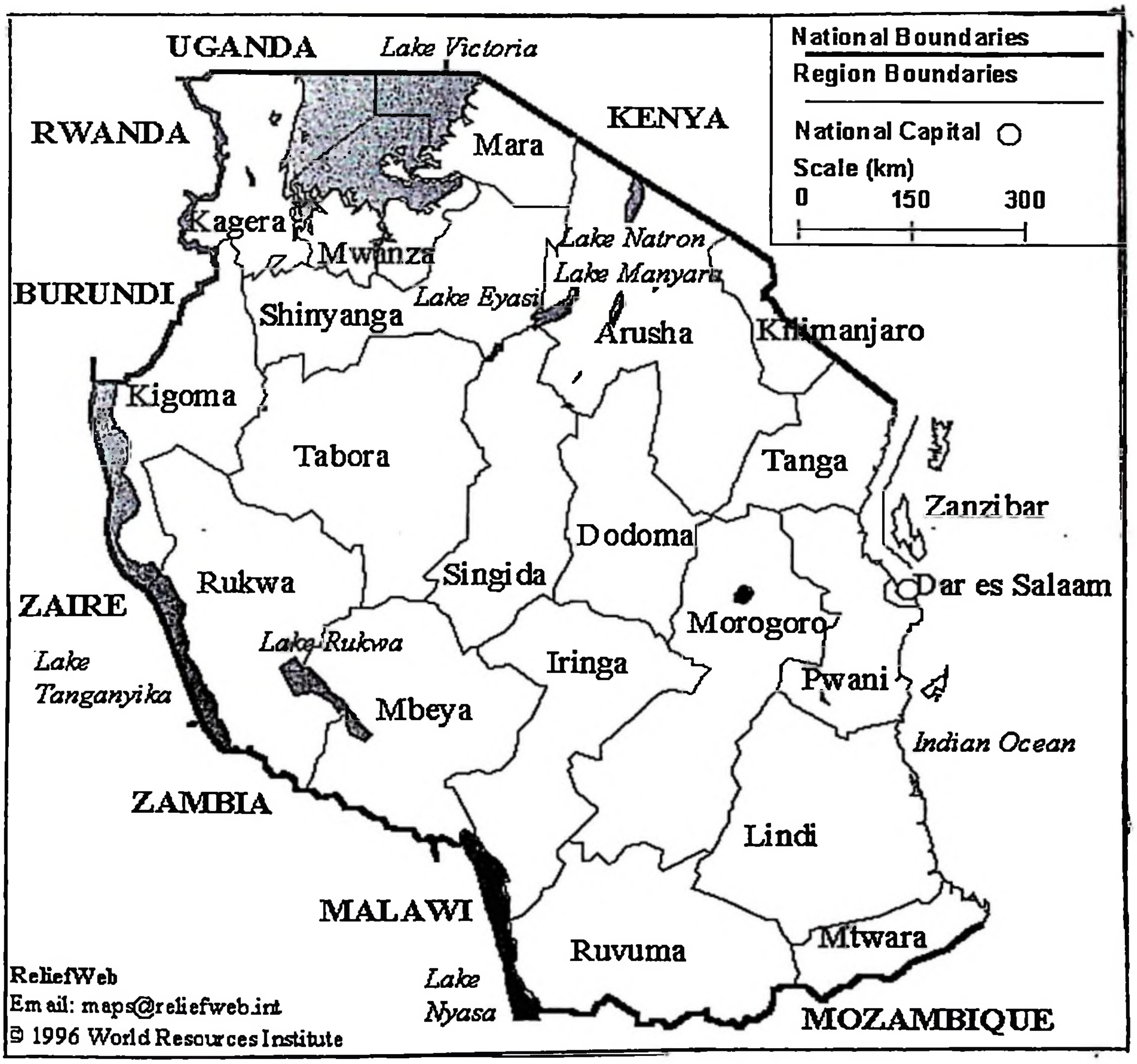

Figure 1 Map of Tanzania showing national and regional boundaries.

Like in many other developing countries, livestock is a major component in agriculture in Tanzania. Livestock contributes 30% of the agricultural gross domestic product (GDP) and 18% of national GDP. Livestock produce food, act as living bank reserve, provide draught power, manure, and fuel (dried manure or biogas. Livestock are closely linked to the social and cultural lives of many people (Wilson, 1995). As shown in Figure 2 cattle is the most important livestock with a national herd of 15.6 million, followed by goats (10million), sheep (3.5 million), poultry (27 million) and pig (0.4 million) according to livestock census of 1994/95 (Magere, 1998).

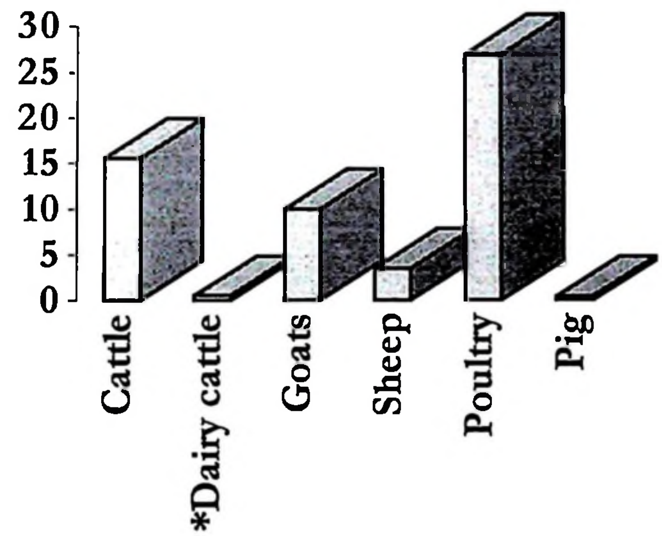

Figure 2. The population of the major types of livestock kept in Tanzania according to the livestock census held in 1995. * Crossbreeds and exotic dairy cattle based on census carried out in 1984. (Sources: Magere, 1998, and Tanzania Agriculture, 1994)

1.1.1 *The challenge of meeting the rising demand for animal protein*

Tanzania has one of the highest urban population growth rates in the world (Figure 3). From a mere 2.5% of total population living in urban areas in 1948, it reached 13.8% in 1980, 18.5% in 1988 and was projected to be 33% in the year 2000 (Kulaba, 1984).

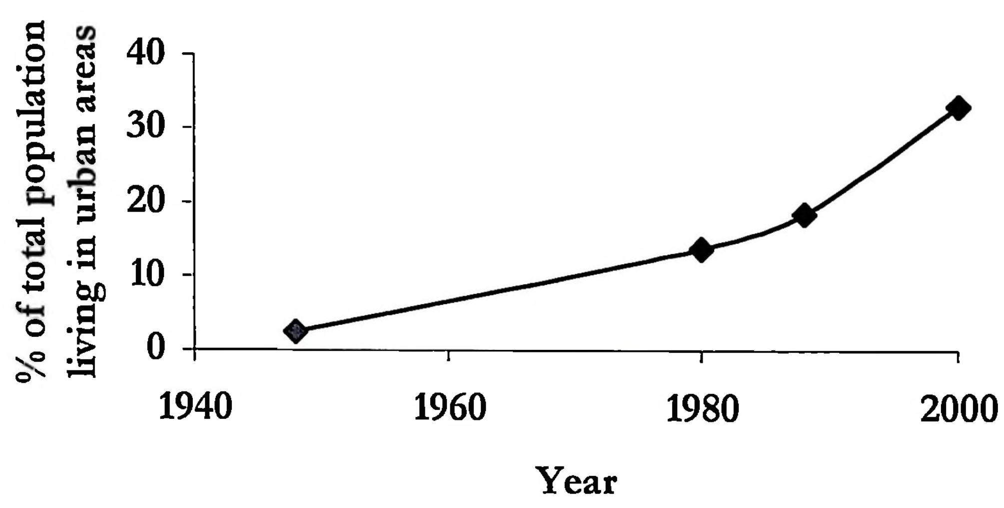

Figure 3. The urban human population growth trends in Tanzania from 1948 to 2000.

The big rise in people living in the urban areas poses a big challenge on resources that are necessary to sustain them (Swai et al., 1992, Wilson, 1993). Topmost is the availability of adequate food and more so, animal protein. In response to the failure of the traditional and the government run dairy farms to meet the demand for dairy products in urban areas, urban and peri-urban dairy keeping became inevitable.

1.2 Dairy production systems in Tanzania

1.2.1 Traditional pastoral and agro-pastoral systems

This is commonly practised by nomadic and agro-pastoral tribes the biggest being the Maasai who move from place to place with large herds of cattle in the Maasai steppe areas in Tanzania in search of pasture and water. The main aim of keeping cattle in this system is however a wealth symbol for status, paying dowry, as living bank and also for meat from culled old cows and bulls. Milk production per cow is very low mainly due to the low genetic potential as well as poor management practices. As such almost all produced milk is consumed at household level with very little surplus going to the market. From time to time, blood harvested from the jugular vein of live animals is also used as a source of protein. For the tribes that are also engaged in agriculture, oxen power is an important factor of keeping cattle. The main breeds of cattle kept are the Tanzanian short horn Zebu, Ankole and Boran cattle.

Tanzania short horn zebu cattle belong to the large classification of the Small East African Shorthorn Zebu. They are small bodied, with pronounced hump, short hairs and deeply pigmented. Though they were kept by a variety of tribes in Tanzania such as Sukuma, Nyamwezi, Chagga, Hehe, Warangi, the nomadic peoples especially the Maasai now own the majority that the Zebu cattle in Tanzania.

The Ankole cattle (also called Ankole longhorn) are common in North-Western parts of the country (Bukoba, Kigoma and Musoma). They are characterised with small hump and medium to large lyre-shaped horns. They were originally kept by pastoral tribes called Bahima and Watusi in Uganda, but have now spread to North-Western Tanzania, Rwanda, Burundi and some parts of Congo (Pyne and Wilson, 1999).

Boran cattle are now increasingly being used for crossing with exotic breeds due to their relatively large body size and milk production compared to the Tanzania short horn zebu cattle. They are thought to originate in Ethiopia and spread into Somalia and Kenya.

1.2.2 Intensive smallholder dairy farming

Intensive smallholder dairy farming comprises zero-grazing (cut-and carry), semi-zero-grazing (stall feeding combined with limited grazing or tethering in open spaces or in the fields after harvesting the crops). This is commonly practised in the highly humid highlands, humid lowlands and in urban and peri-urban areas, though it is now extending even into the semi-arid areas of Tanzania. Few animals (1-8 cows per household) are kept due to small landholding and also the high labour demand with increased number of animals. Feeds are carried from the fields on head, by bicycle or rarely using carts and motor vehicle (Mlay et al., 2000) to the homesteads where animals are kept.

Urban and peri-urban smallholder dairy farming has been on the increase in many developing countries (Swindell and Rimmer, 1988; Maxwell and Zziwa, 1993; Memon and Lee-Smith, 1993; Shapiro et al., 1995). In Tanzania, several factors emerged and combined together to cause economic hardship and the most hit people were the urban dwelling wage earners. This was reflected in the Governments inability to pay living wages to its employees who in turn engaged in sideline projects as a means of surviving the economic hardship (Ndalichako, 1998). Though it lacks the legality, urban agriculture in Tanzania is on the increase (Mlozi et al., 1992).

The main breeds of cattle kept are improved grade dairy types, mainly crosses between exotic breeds (Friesian and Ayrshire) with either Boran or Zebu cattle.

The acquisition of improved cattle by smallholders was slow due to limited supply and relatively high prices. The few who could afford were able to obtain surplus heifers from state owned heifer multiplication units and dairy farms while others bought F1 bull calves for later use for breeding with local cattle. Currently, there are more opportunities for more and more smallholders to obtain improved heifers through assistance from dairy development projects in form of soft loans to buy the animals or Heifer-in- Trust (HIT) schemes (Lekule et al., 1998; Rutamu and Uden, 1999). Under HIT interested farmers are given the basic training on feeding, housing and management of improved cattle and those that satisfy the conditions set by sponsoring organisation are given an in-calf heifer. After calving, the first female calf is passed reared for passing to another farmer while the previous one gain full ownership on the cow and calf bulls that may have been born before the female calve. This was made possible by the change in policy both at National and International levels that livestock development is part and parcel of rural development and an essential tool to combat poverty at the grassroots level (Kuiper, 1992).

Some very few smallholder dairy farmers keep the Mpwapwa breed dairy cattle, a new breed developed at Mpwapwa research station in Dodoma region. The characteristic composition of the Mpwapwa breed were estimated to be 60% from Asian (Sahwal), 30% from African (Zebu and Borana) and 10% from European (Friesian) cattle (Syrstad, 1990). However, there are still very few Mpwapwa-type cattle in the country estimated to be 3000-4000 in 1988 (Katyega, 1988).

1.2.3 Medium and large-scale commercial dairy farms

Large scale dairy production with herd size ranging from 100 and above is practised in farms run by private companies, missionary organisations and some very few state farms. The initial Government agricultural policy soon after independence was for large-scale commercial production with direct state involvement (Tanzania Agriculture, 1994). Concerted efforts were made in the early seventies to eighties to import exotic pregnant heifers, calves and bulls from Europe (mainly Britain and the Netherlands). The animals were reared in dairy farms and ranches run by Government parastatals (Coulson, 1982). Some farms, then referred to as heifer multiplication units specialised in breeding programmes between the local Zebu and Boran with exotic breeds to produce F1 heifers as an effort to improve the genetical potential of the local cattle. The F1 heifers with good management are able to produce at nearly the same level with exotic cattle under the tropical conditions and also are able to survive better in the tropics (Syrstad, 1986).

Most of the then newly introduced exotic animals could not cope with the tropical conditions of heat stress, high incidence of diseases, and poor management the results of which were high mortality and low productivity. However, some animals were able to acclimatise and are doing fairy well especially in places where the management is good (Kifaro, 1995).

By the early eighties it was apparent that most of the dairy state farms were operating at a loss due to several problems. Diseases, poor nutrition, poor management, bad location (some are in remote areas not easily accessible all year round), were among the main reasons behind the failure of these farms. Only a handful of the ventures are still government run, the rest were closed or sold to private individuals and companies (Tanzania Agriculture, 1994). However, the Governments drive to increase the number of crossbreed heifers had some positive ripple effects, as many smallholder dairy farmers were able to purchase improved stock from the Government owned dairy farms.

1.3 Animal feed resources in Tanzania

1.3.1 Natural pasture

Grazing land in Tanzania covers about 51% of the total land area (Kidunda et al., 1990) with a wide variety of grass and few legume species and trees (FAO, 1960). The natural grasslands are dominated by rapidly maturing grasses. As they mature, lignin content increases while protein and minerals contents, and organic matter digestibility falls. The most common grass species are *Chloris guyana* (Rhodes grass), *Cenchrus ciliaris* (Blue buffalo grass), *Brachiaria brizantha* (Signal, palisade or brea grass), *Cynodon spp* (African couch or star grass), *Andropogon gayanus* (Gamba grass), *Panicum maximum* (Tanganyika grass) *Pennisetum purpureum* (Napier grass), *Setaria sphacelata* (golden millet or Rhodesia grass), *Hyperrhenia rufa* (thatching grass)and *Borthriochloa inscupta* (pinhole grass). Most of theses grsses species formed the basal feed for smallholder dairy cows in Morogoro (**Paper I**).

The most common legume species are *Desmodium spp*, *Macroptilium atropurpureum* (Siratro or purple bean), *Neotonia weightii* (Glycine), *Clitoria ternatea* (butterfly pea), *Sylosanthes guianensis* (Stylo or Brazilian lucerne), *Centrosema pubescens* (Centro) *and Medicago sativa* (Lucerne). Maintenance of a favourable balance of legumes and grasses is a crucial aspect in ensuring higher voluntary intake, dry matter digestibility and overall animal performance. However, it has been a common observation that most of these legume species fail to compete with the natural grasses and therefore do not strive very well either in nature and in places where attempts were made to oversaw them with the natural pasture (Kusekwa et al., 1990). This was also obvious during the survey (**Paper I**) where the fodder collected by smallholder farmers rarely had legumes. Only *Macroptilium atropurpureum* was identified among many samples that were collected for analysis.

Fodder trees also form an important component among the natural pastures. These trees remain evergreen even during the dry season due to their long and extensive root systems and therefore act as valuable source of green fodder during this part of the year. One example is the *Acacia species* that form an important source of nitrogen for ruminants in the wild as its thorny system makes it difficult to harvest for use as cattle feed by smallholders. Other important fodder trees that smallholder farmers are being encouraged to establish along the borders of their plots as fodder for dry season feeding are *Leucaena leucocephala, Gliricidia sepium, Sesbania sesban and Calliandra calothyrus* which are potential sources of protein for supplementation of the poor quality roughage.

1.3.2 Crop residues

Crop residues form an important source of feed to ruminants in smallholder production systems in Africa (McDowell, 1988). In Tanzania, the use of crop residues and agricultural by-products can vary from place to place depending on the major crops grown in the various areas. For example, in major banana growing areas like Kilimajnaro, Arusha, Kagera and Mbeya, banana leaves and pseudo-stems are basal feed to dairy cattle. Other residues such as stovers from maize, sorghum, millet, beans, rice and wheat straws are used mainly in areas where these crops are cultivated. In areas around large sugar cane plantations, sugar cane green tops and bagasse are also important by-products fed to dairy animals. The extent of use of the crop residues to feed dairy cattle is largely influenced by the distance between the household where animals are usually kept and the field where the crop is cultivated. The implication being that the further the distance, the less the chances of using the crop residues due to transportation problems (Massawe et al., 1998).

1.3.3 Supplements

Farmers have always known the importance of feeding supplements to dairy animals. However the amounts and frequency of feeding supplementary feeds depends on the easiness of acquisition in terms of cash and labour. Preference is given to lactating cows and the supplements are offered during the milking time. The main objective on farmers' view is to calm the animal thereby easing the milking process.

1.3.3.1 Energy rich supplements

One supplement that is widely used all over the country is maize bran probably due to maize meal being a staple food in most homesteads. Annual maize production in Tanzania stood at 2.8 million tonnes in 1998 (FAO/WFP, 1999). Some amounts of maize are also imported to cushion for occasional crop failures in parts of the country due to unfavourable weather conditions. Estimates show that in the milling of grade maize meal, maize bran forms 15% of the amount processed. Thus about 420,000 tonnes of maize bran are produced annually which is mostly used as feed for ruminants, pigs and poultry.

Rice polishing is another source of energy rich concentrate available for feeding ruminants especially in the major rice growing areas like Mbeya, Morogoro, Shinyanga and Mwanza regions (see Map in Figure 1). Rice production in Tanzania in 1998 was slightly over 1 million metric tonnes. Despite its easy availability in Morogoro and almost similar price to maize bran, rice bran was not much used by smallholders in this area. During the survey (**Paper 1**) some farmers were of the opinion that rice bran was inferior to maize bran and sometimes when they used it milk production went down. Given the fact that the chemical composition of the two products are not very much different, it might be interesting for future works to investigate the basis of those allegations.

Cassava (*Manihot esculanta*) is a potential source of energy with tubers containing 80-90% pure starch. Tanzania is among the high cassava producing countries in Africa. Annual production level was 1548129 tonnes in 1998 (FAO/WFP, 1999). Though the bulk of the production is used for human consumption, by-products like cassava feed peals and leaves are fed to animals. Cassava leaves are a good source of nitrogen (can reach as high as 22% of DM depending on time of harvest) to ruminants.With the increase in the degree of intensification in dairy activities, use of energy supplements will certainly increase in future and cassava will certainly assume more importance as a source of energy to ruminants. Shem, M. N. (1999, Personal communication) acknowledged that he was earning more by feeding his surplus maize grain to dairy animals than selling the grain. Cassava is easy to grow and produces more starch per unit of cultivated area compared to cereal crops with much far less inputs in terms of fertilisers (El-Shakawy, 1993). Farmers like Shem stand to realise higher profits if they switch to cassava. But equally important was the need to investigate how feeding cassava will affect the digestibility of the basal forage, which will be covered later.

Cane molasses production in Tanzania has increased tremendously over the years due to the increase in the capacity of the 4 major sugar processing plants namely Tanganyika Planters Company (TPC) in Kilimanjaro, Kagera Sugar Company in Kagera and Mtibwa and Kilombero sugar companies in Morogoro. The annual sugar production in Tanzania stood at 120000 tonnes in 1999/2000 with Mtibwa and Kilombero sugar companies producing 27000 and 53500 tonnes each. Assuming a ratio of 1 tonnes of molasses per 3 tonnes of sugar (Ndosi, E. 2000, Personal communication) the amount of molasses produced in Tanzania is estimated to be about 40000 tonnes annually with 26,833 tonnes produced in Morogoro. Though some molasses is used for alcohol production, the bulk of it is available as animal feed especially for cattle. Some smallholder dairy farmers visited during the survey (**Paper I**) were found to spray molasses on poor quality forage and stovers as intake stimulator, dust reducer and also as energy source to ruminants.

1.3.3.2 Protein supplements

1.3.3.2.1 Legume forage, trees and shrubs

Legume forages and shrubs are important source of nitrogen to animals. However, as pointed out earlier, the survival of legume forages in the natural pastures is highly limited due to severe overgrazing by ruminants and competition with the natural grasses. Recently some attention is being directed to legume tree and shrubs such as *Leucaena leucocephala* and *Gliciridia sepium* that can be vital in rural based smallholder producers with adequate land (Sarwatt and Mtengeti, 1990; Ndemanisho et al., 1998; Temi, 1999).

1.3.3.2.2 Oil processing by-products

There are various oil-processing by-products available for use as sources of supplemental protein to ruminants, but availability is greatly influenced by crop performance as dictated by weather and also transportation problems. As such, prices of the products tend to vary greatly from place to place and are reasonably cheaper at the local areas where they are produced. Oil processing by-products like cottonseed cake, sunflower cake, soyabean meal/cake, coconut, groundnut and sesame cakes are important sources of protein to ruminants. The CP contents and digestibility of various oil processing by-products tend to vary depending on the nature of the original seed, the oil extraction techniques used and the content of hulls mixed in the products (Göhl, 1981).

Cotton is one of Tanzania most important export earner. The major cotton growing areas are Mara, Mwanza, Shinyanga, Kagera, Kigoma and Singida regions (see Map in Figure 1). Located in the major cotton growing areas are plants that extract oil from cotton seeds with concurrent production of cottonseed cake as a by-product. The exact figure of the amount of cottonseed cake production per year is unknown, but with the estimated yield of cotton (lint) of 67000 tonnes per year (1998 figure), the amount of cottonseed cake would also be substantial. The CP content of cottonseed cake range between 20-47% and digestibility (sheep) between 68-83% (Göhl, 1981). Reported value of CP content of cottonseed cake in Tanzania was 25.3% of DM (Ndemanisho et al., 1998). Supplements containing cottonseed cake as a nitrogen source was reported to improve intake and performance of dairy cattle (Nkya et al., 1998) and in goats (Ndemanisho et al., 1998).

There has been tremendous push in growing sunflower crop by smallholder farmers in various areas of Tanzania especially with introduction and well adoption of manual oil rum press (Hayman, 1992). Sunflower strives well in humid to semi-arid areas of Tanzania. The oil extracted manually is used as human food while the protein rich by-product (sunflower cake) is fed to cattle, poultry and pigs. The chemical composition of sunflower cake can vary depending on the extraction method. Reported figures (% of DM) for manual extracted sunflower cake are 5.1, 21.9, 59.1, and 17.0 for ash, crude protein, NDF and fat respectively (Temi, 1999).

Soyabean cultivation is done albeit at a small level in Tanzania especially in the southern highlands and Ruvuma region. Soyabeans are excellent and affordable source of protein and fat for humans. Soyabean cakes, has CP contents range from 26-56% while CP digestibility range from 85-92%.

Coconut cake is also used to some extent in the coastal belt where coconut strives best. CP content of coconut cake range between 19-25% and CP digestibility (sheep) of 91% (Göhl, 1981).

1.3.3.2.3 Protein supplements of animal origin

Animal protein sources like fish, blood and meat meals are good sources of supplemental protein to ruminants. The CP content of meat meal in use in Tanzania was reported to range from 50-80.5% and between 88-95% for blood meal (Göhl, 1981). CP content of fishmeal in Tanzania was reported to be 63% of DM (Mgheni, 2000). Mgheni et al. (1993) showed that fishmeal supplementation of poor quality forage improved the performance of growing goats. However, due to unreliability of supplies and scarcity, these products are rather expensive and are therefore very rarely used by smallholder farmers.

1.3.3.3 Mineral supplements

Commercial mineral supplements are available from dealers in Tanzania who import them from Multinational companies. Most brands contain a combination of macro and micro minerals sold under different trade names such as MACKLIC SUPER and those containing minerals and vitamins as well e.g. MINOVIT SUPER and PHARMVITA (Mgheni, 2000). As with most imported products, prices of mineral supplements are fairly high and ranged between 1500-2000 Tsh per kg depending on the brand at the time when this study was being carried out. As such, only institutions and few smallholder farmers regularly gave their animals mineral supplements.

A locally available feed additive called "Magadi" which is very similar to Magadi soda, a commercial product harvested from lake Magadi in Kenya, is commonly used by smallholder farmers in Tanzania. Chemical analysis of Magadi (**Paper III** Table 3) showed Magadi to be rich in calcium, sodium, potassium, iron as well as copper manganese and zinc. The high digestibility of ash in animals fed "Magadi" (**Paper III**) showed high availability of the minerals in "Magadi" to the animal. Though the mineral composition in "Magadi" may not suffice the requirements of the animals, it is still a good option for smallholder farmers who do not use the commercial mineral supplements. Otherwise, it can also be used together with a lower level of the commercial products thereby reducing the costs considerably.

1.4 Current status of the dairy industry in Tanzania

Dairy Industry development is a matter of high priority in developing countries because it contributes significantly to improved human nutrition and has far reaching effects on social and economic lives of the majority of the people most of whom are poor (FAO, 1985). Despite the huge number of cattle, the dairy industry in Tanzania is still poorly developed (Kapinga, 1989). This is due to several factors. Topmost is the fact that the majority of cattle are the local Zebu type with low genetical potential for milk production kept under pastoral system with the bulk of milk produced used at the household level. Other factors include poor nutrition and management, diseases, poor infrastructure and resource base and marketing. So far, Tanzania is a net importer of milk products (Mdoe and Wiggins, 1997)

There has been a steady rise in the cattle population in Tanzania since the year 1912 to 1995. (Figure 4). It is agreed that current land under livestock in most tropical areas has almost been stretched to the limits of their carrying capacity (Cees de Han, 1991). However, the increase in the number of cattle in Tanzania was possible due to the presence of vast uninhabited savannah plains that allowed free movement of Maasai pastoralists with their herds of cattle. Even in areas that were previously thought unsuitable for cattle due to heavy tsetse infestation are now used due to wide and successful use of chemoprophylaxis drugs like Samorin against trypanosomiasis. However, though the number of animals can be high, they mostly would be in very poor body condition especially during the dry season.

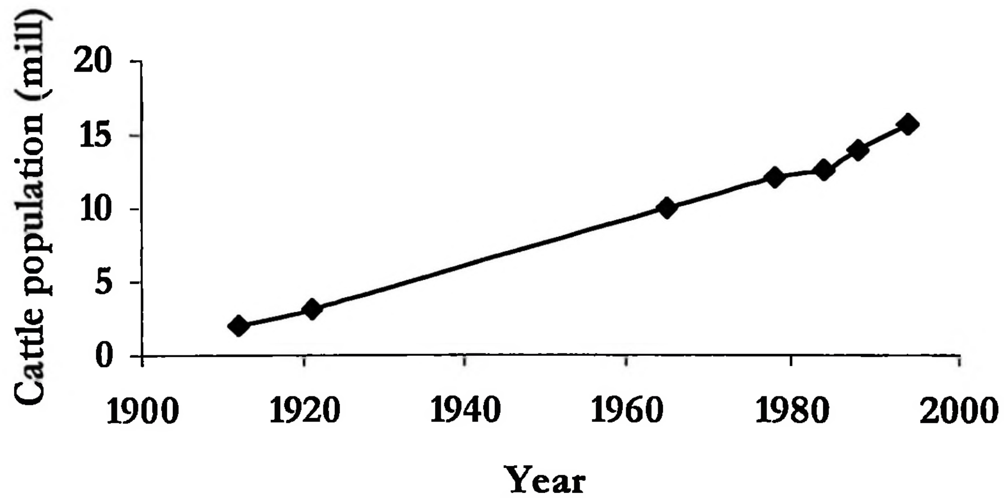

Figure 4. The cattle population growth trend in Tanzania from 1912 to 1988.

Improved dairy cattle (crossbreeds) and exotic dairy cattle are very few in numbers. As shown in the population census carried out in 1988, though they comprised less than 5% of the total cattle population, they were able to produce about 50% of marketed fresh milk. Records show that the average milk yield per lactation in the smallholder sector is higher (2500 L) compared the large commercial farms (1800 L) and pastoral system (140L)(Tanzania Agriculture, 1994) but still low compared to Europe (4100 L) (Figure 5).

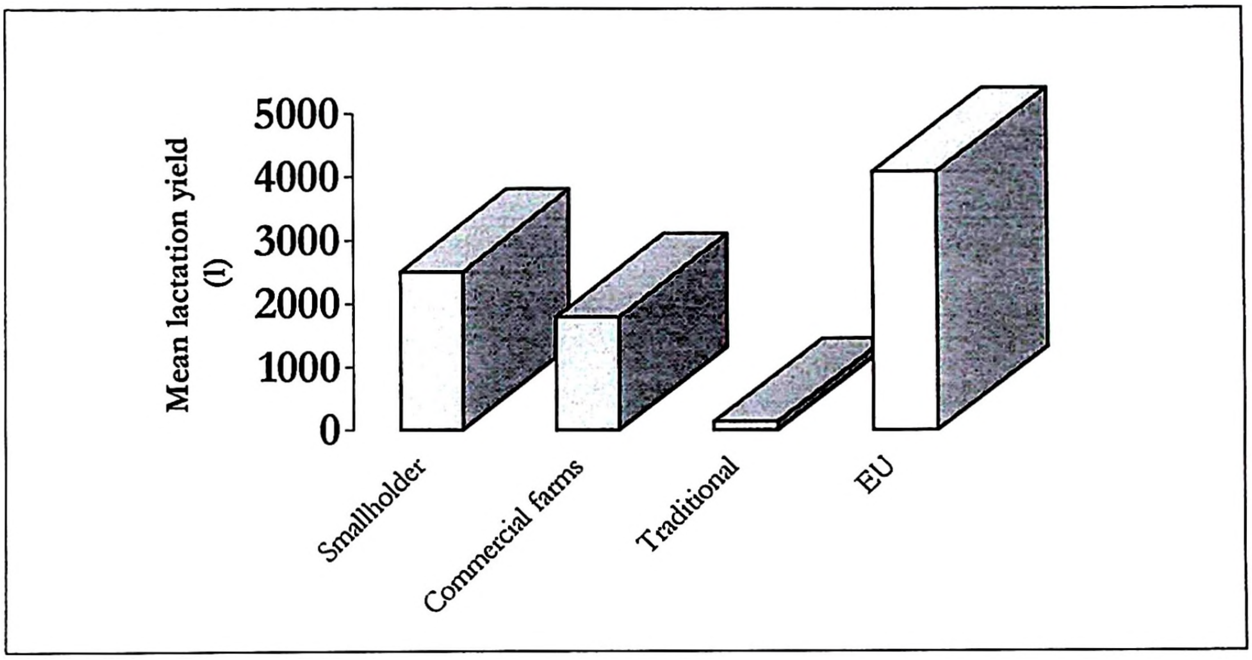

Figure 5. The lactation yield in the smallholder, commercial and traditional dairy sectors in Tanzania in comparison to European countries (1988-1990).

1.4.1 Prospects of smallholder dairy production in Tanzania

Since 1980s the Government of Tanzania is putting a lot of emphasis on smallholder dairy development after the apparent failure of the large scale Government owned farms. There is also widespread agreement that livestock and dairy development is an essential tool to reduce poverty at grassroots levels by improving household incomes, employment and food production. There are several projects under non-governmental organisations (NGOs) or between the Government of Tanzania and Donor countries aimed at enhancing small holder dairy development in various areas of the country. Examples are the Foundation for Sustainable Rural Development (SURUDE) in Morogoro, the Chunya Smallholder Dairy Development Project (CSSDDP) and the Southern Highlands Dairy Development Project (SHDDP) run with assistance from Japan and Swiss governments respectively. Others are the Kagera Livestock Development Programme (KALIDEP) and Tanga Smallholder Dairy Development Programme (TSDDP) in Kagera and Tanga regions run with assistance from the Netherlands. Smallholder dairy farming is fast expanding in all urban areas of Tanzania. Even in the semi-arid areas of Dodoma that experienced severe land degradation in the past years, smallholder dairy cattle combined with crop farming is being encouraged to make the best use of resources and nutrient recycling (Ogle, 1990).

There is also a possibility for private investors to open medium to large dairy farms due to the Governments efforts to liberalise the economy and encouraging private investment in various fields including dairy production. However, the removal of restrictions on import of milk and milk products (Mdoe and Kurwijila, 1998) is also a set back to medium and large scale producers since locally produced dairy products fail to compete with the relatively cheap imported products.

1.4.2 Constraints facing smallholder dairy production in Tanzania

1.4.2.1 Seasonal fluctuation in quality and amounts of basal roughage

Success of the dairy industry in Tanzania will greatly depend on efficient utilisation of the abundant poor quality forages through increased productivity per animal rather than in the increase in number of animals. This view was also echoed by Ørskov (1998) and Websters and Wilson (1966) who were of the opinion that for economic and environmental reasons, ruminants need to be maintained on fibrous feeds as far as possible, to avoid direct competition with monogastrics for scarce food resources. As seen earlier, ruminants are able to convert low quality protein in forages and non-protein nitrogen sources into high quality animal protein needed by man. Unfortunately, the efficiency of this conversion is low. In fact the output: input ratio is more than 50% lower than would be expected (Tamminga et al., 1995). Up to 30% or more energy in the ingested feeds can be lost through heat and methane.

The feeds generally found in Tanzania especially during the dry are fibrous and very high in ligno-cellulose, low in protein (4-5%), and other essential nutrients like minerals and low digestibility (40-45%). This was evident in the feed analyses of forage samples collected from smallholder farmers over a one-year period. Such feeds are therefore unable to meet the maintenance requirements and to support a modest level of production (Preston and Leng, 1984; FAO, 1989; Leng, 1990; Kimambo et al., 1993).

1.4.2.2 Low productivity

Low milk yield as a result of low feed intake is a major problem facing smallholder livestock production systems in most tropical countries (Wandera et al., 1993). Unless the imbalance of nutrients required by the microbes and the host animal are corrected through strategic supplementation, there is a lot of inefficiencies that occur during

fermentation process and also in the utilisation of absorbed nutrients (Morrison, 1948; Blaxter et al., 1956; Van Soest, 1994; Cochran and Galyean, 1994).
Past breeding programs have improved the genetical potential substantially and most animals kept by smallholders are moderate to medium producers (5-10 L/day) (Lekule and Sarwatt, 1998; Mlay et al., 2000). There is a great need of continued education to smallholder farmers especially in nutrition and disease control.

1.4.2.3 Limitation of space

Most smallholder dairy production systems in Tanzania are located in areas where there is extreme land scarcity with the major priority of land use being crop production (in the rural) and constructional projects (housing, industry and means of communication) in the urban areas. Under such circumstances, raising production through increasing the number of animals per household may not be the best option due to limitation of land and labour. It is even difficult to set aside a portion of the farm for pasture establishment. It should be possible for rural based producers to establish swards of forage grasses like *Saiteria spp, Penisetum purpurium* and fodder trees like *Leucaena leucocephala* and *Gliricidia sepium* along borders and contours in their farms. But, this may not be possible for landless dairy producers in cities and towns. As most feeds are likely to be obtained outside the homesteads, transportation of bulky feeds is not always easy (Massawe et al., 1998). Chances are that the use of concentrates may increase thereby leading to competition with monogastric animals.

Though there are some advantages of dairy activities in urban and peri-urban areas, there are also risks of zoonoses and other insect vector transmitted diseases to man due to soiled environments around cattle barns that are very close to human residential houses.

1.4.2.4 Deterioration of natural pastures and feed conservation

Natural pastures supply the bulk of fodder used in most dairy production systems in Tanzania. However, in many places, the natural pastures have been misused and/or mismanaged with overgrazing and uncontrolled bush fires. Part of the problem is the land tenure system in Tanzania where grazing lands belongs to the Government and therefore users do not feel any obligation to use it properly or to do any conservation and pasture development efforts. There has been rapid deterioration in some places like Dodoma and Kondoa to an alarming proportion such that the Government with assistance from donor agencies had to intervene to rehabilitate the land (see Larsson, 1993)

Taking advantage of the excess amounts of fodder during the rainy season through conservation either as hay or silage has not been easy in Tanzania as is the case with most tropical countries due to several reasons. Hay making is difficult because the optimal hay making periods coincides with the peak rainy period thereby making it very difficult to obtain adequate sunshine to dry the materials (Kavana et al., 1999).

Hay making so far has been left to some Government parastatals and missionary institutions who has the facilities for such work. The quality of the hay is however very poor since the work is done after the rainy seasons when the grass is at advanced mature stage. This was very clear from the chemical analysis of the hay used in the on station experiments (Papers II and III). Some surplus hay bales are sometimes available for sale to smallholder farmers and research institutions. A 15 kg hay bale was selling at 600Ths in 1999 when this study was going on. At the same time, a kilo of maize bran, cassava flour and molasses was selling at 50, 300 and 60 Tsh respectively. Calculations of the price per Mega Joule of ME from hay, maize bran, cassava, and molasses were 9, 5, 27 and 7 Tsh respectively. Though rarely do farmers buy hay bales, it might be more advantageous to buy maize bran or molasses rather than buying the hay bales. Market price of a kg of cassava flour was rather high (300 Tsh/kg). This was due to the fact that the flour was meant human consumption and only used in this case, for experimental purposes. However, the price level would be much lower for a farmers who grows the crop in a backyard garden and feed directly chopped cassava tuber pieces to the animals without milling.

Silage making is less weather dependent and could be a better option (Kavana et al., 1999). However, currently most fodder is obtained from natural growing herbage that may not be the best crop for ensiling and sometimes is obtained too far away from the homestead. Therefore, conservation efforts will most likely add extra labour cost in an already labour intensive scenario. However, for farmers who are committed to conserve forages, silage making as opposed to hay will be the best option.

1.4.2.5 Milk marketing and processing

The survey done in Morogoro (Paper I) also showed that marketing of the milk produced would likely be a hindrance in the future. As more and more surplus milk is available from both the increase in the number of producers and also from increased yield per animal with improved husbandry techniques, the disposal of the surplus milk will be difficult. There is a need to set up small scale milk collecting and processing centres preferably under farmers co-operative unions as experience showed that privately owned ones in Morogoro were not doing very well. Similar concerns were voiced by Kurwijila et al. (1992) who were of the opinion that retail prices of processed milk products like butter and cheese were more stable and uniform compared to raw milk. It was strongly felt that small-scale dairy processing plants near the producers would go a long way in enhancing dairy production in Tanzania.

1.4.2.6 Breeding

As seen earlier, many small holder farmers have been assisted to acquire the F1 heifers. However, it appears that no breeding mechanisms are in place to give farmers access to good quality breeding bulls or artificial insemination (AI) services. Therefore, farmers are either forced to leave theirs cows open for a long time or use whatever bull is easily available including the local Zebu cattle bulls. This result to reduction of the genetic potential acquired by the F1 heifers, which need to be maintained or further improved in situations where proper management is possible.

The crossbreeds currently used by smallholder farmers in many places are hard to characterise due to uncontrolled breeding. For example during the survey (**Paper I**), 25 out of 122 farmers visited owned breeding bulls which they also charge other farmers who brought their animals for service. Only 5 of the bulls were considered good breeding bulls based on body conformation and estimated exotic blood level of 60-75% percent. The remaining bulls did not fit to be used as breeding bulls and some had exotic blood level of between 45-50%. Zalla (1982) reported wide spread use of poor quality bulls among smallholder farmers in the northern part of Tanzania. This is an area where Government and other institutions involved in the smallholder dairy development need to pay more attention to.

1.5 Research priorities

A lot of research work has been done with the aim of assisting farmers to increase productivity but so far the impact in terms of adoption by farmers has been minimal. Why? Part of this problem has been the inability to involve the main stakeholders who are the end users of the technology- **Farmers**. Even some of their knowledge seems not to be taken seriously by researchers who most of the time, though in good faith research on what farmers ought to do rather than what farmers are doing and how to improve on what they are doing.

So, a good starting point to revolutionise dairy industry in Tanzania is to work closely with farmers. Once confidence is built through active participation and demonstrations, this will pave the way for improvement on farmers' knowledge and easy acceptance of non-traditional techniques.

On farm research work especially in the poor tropical countries is very challenging indeed due to influence of many factors beyond the control of the researcher and the need to meeting the statistical analysis standards. However, farmers' interest is for higher yield at the minimum cost in terms of investment and labour. If we as researchers can demonstrate that, then farmers will be able to adopt the technology and in the process improve productivity. Technologies that are expensive, labour intensive and risky, no matter how good they might be are likely to be rejected by smallholder farmers.

Major research areas that can bring an immediate impact on ruminant production in the tropical areas are thus listed as follows:

(1) Characterisation of locally available feed resources and maximisation of digestibility of the poor quality fibrous basal feeds through:

- Identification, evaluation (best by in vivo methods) and documentation of seasonal variability both qualitative and quantitative
- Pasture establishment, improvement, and simple techniques for pasture preservation and conservation
- Devising appropriate supplementation strategies (using mostly cheap local resources) in order to address the deficient nutrients and especially nitrogen, minerals and other growth factors that are major causes of reduced microbial growth in the rumen
- Improving the potential digestibility of the poor quality forage through treatment using inexpensive proven effective ingredients that are locally available such as ash, and "Magadi"

2) Improving the protein to energy ratio (P/E) of absorbed nutrients so as to increase productivity through high efficiency of utilisation of the nutrients for growth, lactation and tissue deposition through:

- Optimisation of microbial protein synthesis in the rumen by a combination of methods as shown in (1) above and also provision of adequate water and salts so as to increase the dilution rate and therefore avoiding wasteful re-cycling of microbial protein in the rumen.

- Provision of by-pass protein either from protein sources known to have natural resistance to rumen degradation e.g. animal protein sources like fish meal or plant protein sources containing high amounts of condensed tannins. Alternatively, extent of degradation of protein sources can be reduced through treatments such as formaldehyde and toasting (soyabean cake).

3) Energy supplementation to meet the requirements of specific production without causing reduction in the efficient utilisation of the basal feeds. There is apparent failure of the traditional feed evaluation techniques based on Western standards to characterise the nutritional value of most poor quality forages used in the tropics (Leng, 1990). This makes it necessary to rely more and more on feeding trials designed to show animal responses under different feeding conditions, levels and combination of feeds. In that way the most effective feeding strategy using locally available feed resources for enhanced ruminant productivity can be documented and made available to farmers.

4) Breeding policy that will ensure the improved blood level attained by F1 heifers to is maintained to make the best use of the heterosis. Further improvement should only be done when and where there is mechanisms in place to ensure higher management especially better nutrition to the animals.

1.6 Main objectives of this study

From the above given background information, there are many areas that needed further research in order to alleviate some of the constraints facing smallholder dairy farmers in Tanzania in general and Morogoro in particular. A need was felt to gain an insight in the rapidly growing but still controversial urban and peri-urban dairy farming. Special emphasis was put in the collection of information on people, animals, feeds, production, marketing and overall management of the dairy industry in the urban and peri-urban areas of Morogoro.

The second objective was to investigate the possibilities of addressing to the fall in productivity due to the nitrogen deficiency in pastures during the dry season through strategic nitrogen supplementation.

Thirdly some farmers were found to be using energy rich concentrates and a feed additive called "Magadi" which they claimed stimulates intake and milk yields. It was interesting to investigate how these supplements influenced the intake and utilisation of the poor quality forages.

Finally, though there are cheaply available sources of nitrogen supplements like sunflower cake in Morogoro, farmers seemed unaware of the advantages of mixing the energy and protein supplement for enhanced animal performance. A farm made concentrate was formulated and tested both on station and on farm trial with smallholder farmers. The idea was to establish close working relationship with smallholder farmers in an attempt to convince them to make the best use of the locally available feed supplements.

2.0 GENERAL DISCUSSION

2.1 Analysis of feed

2.1.1 Nutrient composition

Evaluation of feed resources is an essential factor in setting up feeding standards that will match a desired type of production. Such knowledge can be made available in Feedstuff tables that can be used by farmers so as to assist them in efficient feed planning and also to make the best use of the available feed resources. The chemical composition of feed in terms of DM, protein, ether extract, cell walls, soluble carbohydrates component and minerals is a good indicator of the quality of the feed. However, knowledge of the feed chemical composition alone is of little interest unless the intake and digestibility of by the animal (Ørskov and Ryle, 1990) and also the expected animal response (Madsen et al., 1997) is also known.

The protein and fibre content of feeds are the two most important chemical entities that influence greatly the nutritive value of tropical feeds. Proximate analysis (Weende system) (Van der Honing and Alderman, 1988) has long been used as the basis characterisation of feeds in terms of chemical composition in combination with digestibility experiments to estimate nutrient digestibility. One limitation of this system is that crude fibre is considered as a chemically uniform substance, something that is not true. Over the years, various ways of fibre fractionations has been proposed but each appeared to have some shortcomings (Mgheni, 2000). However, those based on Van Soest and Wine (1967) and Goering and Van Soest (1970) have been more acceptable and are now widely used in many feed evaluation systems.

2.1.2 Fractionation of plant fibre

Plant fibre forms the largest proportion of the diets eaten by ruminants in most production systems. Fibre is the structural portion of plants that gives support. It is mainly located in the cell wall (CW). It is made up of mainly β1-4 linked polysaccharides that are only hydrolysed by microbial enzymes (Hans, 1997). Typically fibre is a combination of the following chemical group of compounds: Hemicellulose, cellulose and pectins and lignin. Various assays of fibre come up with different ways of grouping fibre and the main differences are due to the chemicals and processes involved in the analytical procedures. The major classifications based on analytical procedures are Crude fibre (CF), Acid detergent fibre (ADF) and Neutral Detergent Fibre (NDF).

CF is derived according to the Proximate or Weende method where feed sample is boiled for 30 minutes in acid followed by boiling for another 30 minutes in alkali. In the process hemicellulose is dissolved by the acid while the alkali dissolves some of the lignin. Hence CF is not a good measure of cell wall components. In short, the CF method severely underestimates the total plant cell wall of feed (Van Soest, 1994).

ADF is based on the Van Soest and Wine (1967) method where a feed sample is boiled for an hour in a detergent sulphuric acid solution. The acid solution dissolves hemicellulose, leaving only cellulose and lignin.

NDF is determined by boiling a feed sample for one hour in neutral (pH 7) detergent solution which ensures minimal losses of hemicellulose and lignin. Thus NDF is a reliable estimate of the major cell wall components- hemicellulose, cellulose and lignin. However most of the pectic substances are solubilized and this can seriously underestimate cell walls of plants with high proportion of pectic substances (e.g. legumes). There is also a fact that some heat- damaged proteins are retained and thereby cause overestimation of cell wall carbohydrates. That said, NDF so far is the best descriptor of the plant cell wall constituents (Jung and Allen, 1995)

2.1.3 Determination of feed digestibility

Feed digestibility is an important parameter of feed evaluation that indicates the possible extent of nutrient extraction from that feed. Digestibility in the rumen of a given feed is directly proportional to the rate of digestion and inversely proportional to the rates of disappearance of the material through passage (Allen and Mertens, 1988). Therefore, in order to determine the effective degradability in the rumen of feeds, it is important to quantify both the rates of digestion and passage.

Digestibility of feeds can either be measured directly by in vivo or indirectly through the use of markers (Uden et al., 1980). There is some reasonably good laboratory methods of estimating feed digestibility (Omed et al., 1989; Weiss, 1994). The most common ones are the in sacco or dacron bag technique (Mehrez and Ørskov, 1977; Ørskov and MacDonald, 1979; Kristensen et al., 1982), in vitro methods based on Tilley and Terry (1963) or gas production measurement (Blummel and Ørskov, 1993). Others are enzymatic methods (Assoumani et al., 1992; Weiss, 1994; Weisbjerg and Hvelplund, 1998) and the use of near-infrared (NIR) technique (Givens et al., 1991). Empirical equations based on the chemical analysis have been used though the results are inconsistent (Weiss et al., 1992; Van Soest, 1994).

In the determination of the effective degradation of feeds, it is important to quantify the both passage and digestion rates. Passage rate can be determined through the use of markers (Uden et al., 1980; Beachemin et al., 1989; Ramanzin et al., 1991; Huhtanen and Kukkonen 1995.). As it may not be possible to measure the rate of passage under all situations, assumed rate of passage rate based on a number of experiments can be used (Madsen et al., 1995). Detailed coverage of the merits and demerits of the above methods are however beyond the scope of this study.

It must be emphasised that the best evaluator of feeds is the animal itself. Thus, despite the high costs, time and labour involved, the in vivo method so far remain the most reliable in feed evaluation when properly carried out (Valdes and Jones, 1987; Schneider and Flatt, 1975; Michalet-Doreau and Ould-Bah, 1992; Cochran and Galyean, 1994). It also gives the possibilities of studying animal responses due to a given feed or the associative effects of feeds in a ration. Moreover, in vivo method will continue to act as a control or reference for the other methods (Weiss, 1994; Cochran and Galyean, 1994).

2.2 Voluntary feed intake (VFI)

As pointed earlier on, knowledge of the nutritive value of a given feed is not of much use if voluntary intake of that feed is not known (Garnsworthy et al., 1990).

The most important factor influencing production response of an animal is the total quantity of the absorbed nutrients which are in turn determined by intake and digestibility of the ingested feed (Poppi et al., 2000; Romney and Gill, 2000).

2.2.1 Factors that influence voluntary feed intake

Feed, animal and environmental factors influence voluntary feed intake by ruminants. The factors that influence and therefore play a role in the regulation of feed intake in ruminants have been extensively studied (Forbes, 1995; Kennedy et al., 1986; Ketelaars and Tolcamp, 1992; Ingvartsen, 1993; Dulphy and Demarquilly, 1994; Poppi et al., 2000). However, this discussion will limit itself to feed related factors that influence the intake of poor quality roughage that are the basal feed for ruminants in the tropics for a big part of the year. These are the chemical composition of the diet mainly nitrogen and NDF contents and the impact on the extent of digestibility and rates of clearance of NDF. Increased NDF clearance from the rumen reduces rumen fill thereby creating space for more intake (Allen and Mertens, 1988; Madsen et al., 1997).

Poor quality forages fed to animals during the dry season are high in NDF and lignin and low in protein contents. These factors are mainly responsible to reduced digestibility (Van Soest, 1994; Wilson and Kennedy, 1996; Wilson and Hatfield, 1997; Reed et al., 2000). Any intervention designed to improve intake and utilisation of poor quality forages must address to the central issue of how to increase the clearance of NDF in the rumen through digestion and passage. NDF poses special problems as it is slowly degraded and requires more resident time in the rumen that will limit further intake. Yet, the animal needs to eat as much as possible so as to increase the chances of nutrient availability. The ultimate intake level is determined by the interplay between the rate of digestion (kd) and the rate of passage (kp) which determines the obtained digestibility.

Intake and digestibility are both the functions of the key parameters that determine potential digestibility of feed i.e. the rate of digestion (kd) and the rate of passage (kp). The two values are the ultimate determinants of the level of nutrients that can be extracted from a given feed and therefore the final animal productivity obtained from consuming that feed. Voluntary feed intake is well correlated to the rate of feed degradation, as kd influences nutrient release to the microbes as well as to the animal and also passage of particles out of the rumen. At a high rate of digestion, more nutrients are made available to the rumen microbes thereby increasing microbial growth and activities. From results of experiment (**Paper II**) intake of DM and forage were linearly correlated to the rate of digestion of DNDF (Figure 6). It appeared that kd and kp were linearly correlated to intake (Figure 7).

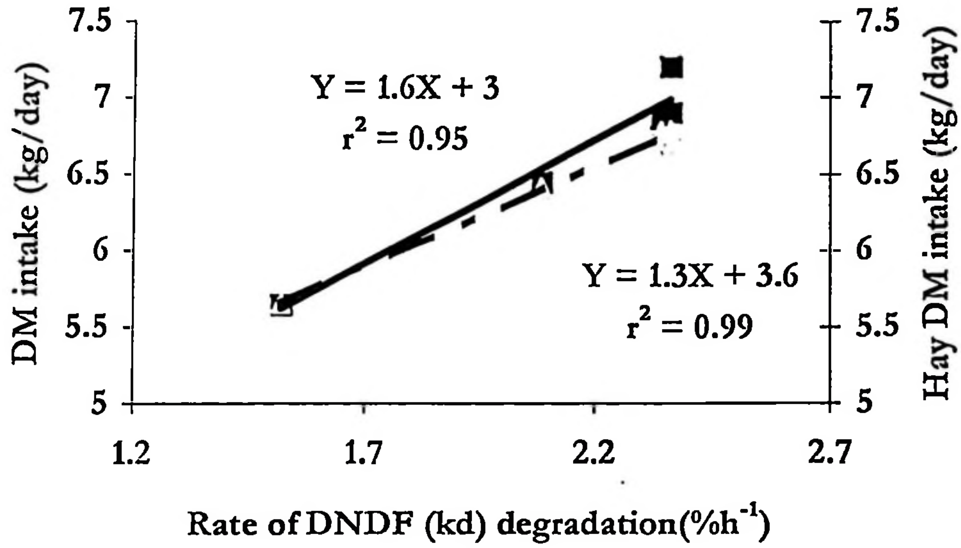

Figure 6 The relationship between DM (■) and hay (▲) intake with the rate digestion rate (kd) of DNDF (paper II)

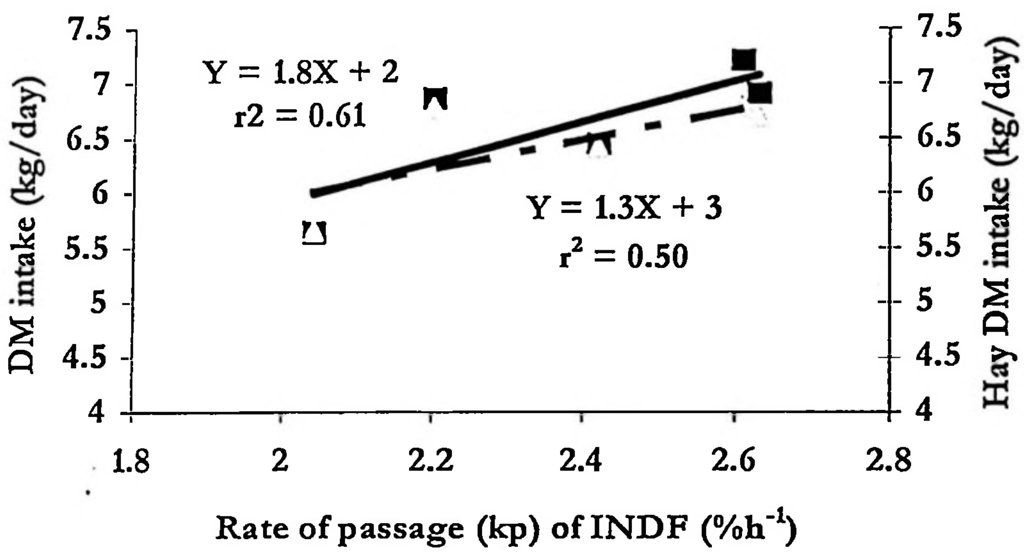

Figure 7 The relationship between DM (■) and hay (▲) intake with the rate passage rate (kp) of INDF (paper II)

The rate of passage (kp) is influenced by particle size, liquid outflow rate and the level of feeding and also physical processing of forages such as chopping and grinding. It is also influenced by environmental factors especially temperature where it increases with fall in ambient temperature (Kennedy et al., 1986).

A question may be asked, in alleviating fill, which one is the most important factor, the rate of digestion or passage? The answer to this question depends on the intra-rumen conditions as determined by the ration composition. If the conditions favour optimal cellulolysis, both the rates of digestion and passage can be equally important. But under conditions that are sub-optimal for cellulolysis, particle breakdown to the minimum size to be legible for passage (<1mm) mainly through chewing during rumination may be the dominant factor in reducing the fill. For example, in rumen environment where nitrogen availability is limiting, improving the rumen degradable protein intake through nitrogen supplementation had a slightly bigger impact on the rate of digestion (kd) than rate of passage (Figure 8). Clearance of digestible NDF (DNDF) is determined by the sum of kd and kp, whereas clearance of indigestible NDF (INDF) is only determined by passage. Thus with feeds containing a high proportion of INDF, particle breakdown during chewing and rumination to size legible for escape from the rumen (≤ 1 mm) are important factors that contribute to clearance of materials in the rumen.

Microbial digestion is known to cause weakening of plant cell wall structure and therefore making them easier to breakdown during chewing and in the process increasing clearance of NDF through passage (Poppi et al., 2000). This was also demonstrated in the results (Figure 9) where kp was linearly related to kd.

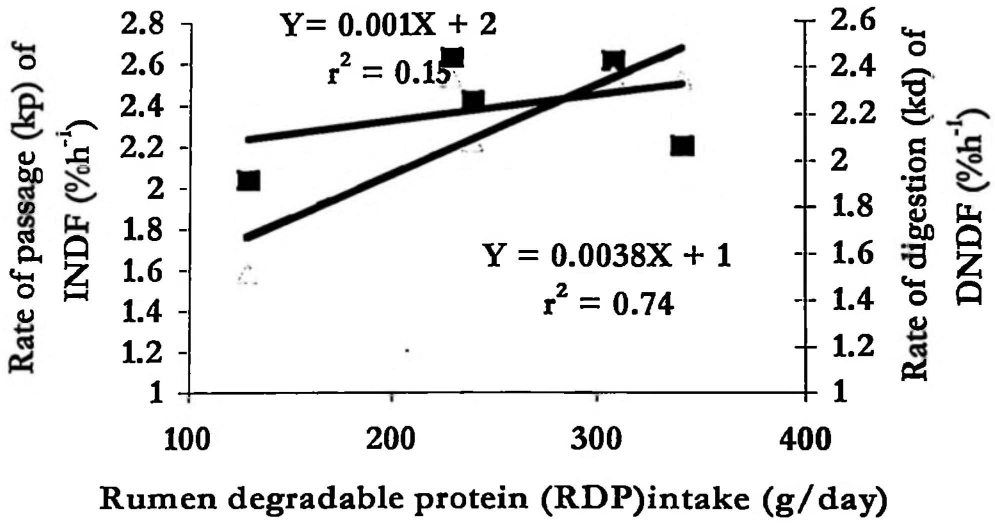

Figure 8 The relationship between rates of passage (kp) (■) and digestion (kd) (▲) of NDF with rumen degradable protein (RDP) intake (paper II)

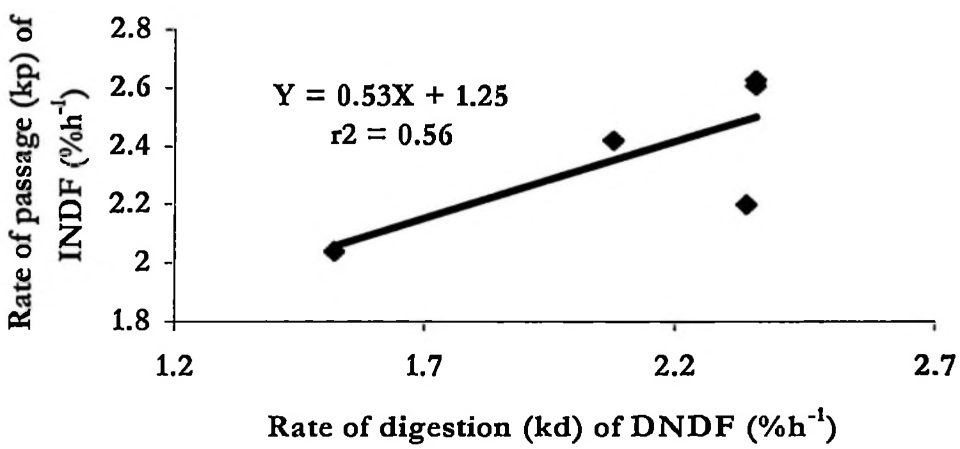

Figure 9 The relationship between the rate of passage (kp) and the rate of digestion (kd) of NDF (paper II).

The rumen fill of NDF observed in this study (**Papers II and III**) remained fairly steady despite some differences in DM intake among the treatments. But, does this condition hold true at all times? Probably not. Understandably, a given ruminant animal have an upper limit on how much forage they can consume per day as dictated by its rumen capacity (Mould et al., 1982). Whether this upper limit is reached depends on the nature of the diet, the physiological status as well as environmental conditions especially with grazing animals. For example high quality forages that have high digestibility may lead the animal to stop further intake before the rumen is full. Conrad et al. (1964) were of the opinion that the physical control is the dominating factor up to a certain breakpoint in digestibility beyond which relationship between intake and digestibility become negative as metabolic control become more and more dominating feature.

Difficulties in acquisition of feed in animals grazing very sparse or thorny swards can make the animal stop eating even if the rumen is not full. Likewise, very dry feeds like straws and stovers that require huge chewing efforts can have similar effects. It has been observed that ruminants eat less of feeds that contain high levels of toxic substances such as alkaloids, condensed tannins and glucosinolates (Reed et al., 2000) as well as poor quality silage or those contaminated with fecal materials (Provenza, 1995)

Under some situations either due to long term adaptation to poor quality diets or physiologic demands e.g. lactation, animals have been noted to tolerate a higher rumen fill of the feeds so as to allow maximal extraction of nutrients through digestion (Ørskov and Ryle, 1990; Poppi et al., 2000). This can be the major reason of the observation by Mould et al. (1982) that Zebu cattle in Bangladesh had large rumen volume relative to their body weight compared to Friesian breeds. In other situation e.g. high concentrate feeding or very unpalatable feeds, animals stop eating before the rumen is full.

2.2.2 Other options for improving utilisation of poor quality forages

2.2.2.1 Feeding practice and physical processing

The more feed which is consumed, the more nutrients will be available to the microbes and the host animal. One way of stimulating intake is to offer large amounts of feeds so as to allow the animals to select the best nutritious parts thereby improving both the quality and quantity of the consumed part.

Chopping and grinding reduce particle size. Therefore, the time used for chewing during rumination is reduced while passage increases thereby allowing increased overall feed intake. Feeding small amounts of green forages with poor quality feeds have been reported to improve intake of the poor quality forage as the green forage acts as a rapid bacteria growth media and a protein source that seeds the rest of the digesta (Leng, 1990)

2.2.2.2 Chemical treatment of poor quality forages

Enhanced rumen microbial cellulolytic activities due nitrogen and moderate energy supplementation may not be utilised to the full depending on the accessibility to the digestible components of the cell walls. This has a big implication to the type of poor quality forage in the tropics where the level of lignin that is indigestible is high. In grasses lignin forms strong ester bonds with the structural carbohydrates and in the process shield some parts digestible cell wall carbohydrates from microbial colonisation and eventual hydrolysis by microbial enzymes.

Chemical treatment of low quality roughages (e. g. straws) is proved to increase both intake and digestibility. According to Chesson (1981) and Hartley (1985), alkali treatment maximise the plant cell wall damage thereby promoting microbial colonisation as well as slowing down lignin accumulation on the cell wall surfaces either by specific lignin degradation or solublilisation. Commonly used chemicals are sodium hydroxide, urea, ammonia and ammonium salts. Urea, ammonia and ammonia salts have an added advantage. Apart from increasing digestibility they also improve the N content hence a higher microbial protein synthesis. However, for a country like Tanzania, these chemicals have to be imported and therefore are fairly expensive. The use of cheaply locally available materials like "Magadi" and ash can cut the cost dramatically.

Urio (1981) found that "Magadi" was a good source of alkali that was effective in treating poor quality roughage so as to improve their intake and digestibility. Kimambo et al. (1998) reported significant increases in in vitro and in sacco digestibility of maize stover treated with alkali derived from saw dust and fire wood ashes compared to untreated maize stover. Treatment with ash from saw dust was found to improve digestibility more than sodium hydroxide treatment. However, acceptability of the treated forages by animals and also the adoption of the technique by smallholder farmers remain to be investigated. With more studies, it may be possible to calculate the amount of ashes from various sources and "Magadi" that would be required to effectively treat a given weight of forage and practical application of either or both techniques under smallholder dairy production system.

Where condition allows a combination of locally available ingredients like "Magadi" or ash can be used in combination with urea so as to increase both digestibility and the nitrogen content of the poor quality forage. Zaman and Owen (1995) have proved additive effect of alkali from naturally occurring calcium compounds (lime) and urea. Lower levels of application are required when both chemicals are used compared to when only one type of chemical is used. For example Sirohi and Rai (1995) showed that using of 3% urea and 4% lime at 50% moisture improved digestibility of rice straw to the same level as using 5% urea.

2.3 Rumen metabolism

2.3.1 Nutrient fermentation

2.3.1.1 Carbohydrates

Mammals lack the enzymes that are capable of hydrolysing ligno-cellulose. Ruminants and other hind gut fermenters are able to utilise the plant structural carbohydrates due to symbiotic association with anaerobic microbes in their digestive tracts (Hungate, 1966; Ørskov, 1992; Krause and Russel, 1996). There are three major classes of microbes in the forestomachs and hindgut of herbivores. These are bacteria, protozoa and fungi (Hungate, 1966).

Ruminant feeds contain variable amount of cell wall contents (cellulose, hemicellulose, pectins and lignin), and cell contents (starch and sugars) as well as proteins and some fat. The proportions of these ingredients in forages vary with ages of the forages. Young forages have high amounts of water-soluble carbohydrates and protein and as the plant matures, the proportion of structural carbohydrates (cell wall) increases.

Soluble carbohydrates and starch are very quickly fermented to volatile fatty acids (acetate, propionate and butyrate), methane carbon dioxide with release of ATP by Saccharolytic bacteria. Depending on the nature and amounts of starch in the feed, some starch may escape rumen fermentation to be digested in the small intestine and absorbed as glucose into blood.

The plant cell wall is a component that is entirely dependent micro-organism in the gastrointestinal tract for their degradation (Aitchison et al., 1986; Van Soest, 1994). The complexity of plant cell walls require a multitude of enzymes specific for each component and involves attachment, enzymatic induction and eventual hydrolyis to simple sugars that are eventually fermented to volatile fatty acids, methane and carbon dioxide. This makes the fermentation of cell walls a slow process and also highly susceptible to changes in the intra-ruminal conditions. The extent of cell wall digestibility depends on the degree of lignification that increases with plant maturity.

2.3.1.2 Nitrogen

Microbes in the rumen degrade part of ingested protein to peptides, amino acids and finally to ammonia. Non-protein nitrogen sources are also hydrolysed to ammonia. Ammonia is the principal molecule utilised for protein synthesis by most microbes though some are known to utilise peptides, amino acids and branched-chain fatty acids as well. The part of protein degraded in the rumen is referred to as rumen degradable protein (RDP). Some of the protein usually passes through the rumen to the small intestine without being degraded and this fraction is referred to as rumen undegraded protein (RUP). A portion of RUP is digested in the small intestine to provide extra amino acids to the animal (Hvelplund and Madsen, 1985; Madsen et al., 1995).

2.3.2 Microbial growth

The carbohydrates provide the carbon skeleton that is linked to nitrogen (ammonia) in protein synthesis. The efficiency of microbial cell growth Y_{ATP} is defined as the amount of cell biomass (g DM) per mole ATP available during fermentation. The amount of ATP produced is determined the amount of VFAs and methane production and will influence the P/E ratio of the absorbed nutrients. The theoretical highest Y_{ATP} is 26 in very highly efficient rumen fermentation. The molar proportion of individual VFAs reflect the metabolic activities of the dominant microbial species in the rumen (France et al., 2000) as influenced by diet through pH. For example at near neutral pH most common with fibrous diets, cellulolytic and methanogenic bacteria predominate and acetic acid and methane are produced in larger amounts (Ørskov and Ryle, 1990). At pH below 6.0 commonly occurring with high concentrate feeding, Saccharolytic bacteria predominate with low acetate, relatively higher propionate and/or butyrate and high lactic acid (Ørskov and Ryle, 1990). Inefficient rumen fermentation, such as frequently occurring with ruminants feeding on poor quality roughage limited in nitrogen (ammonia) are characterised with high acetate, high methane low propionate and low microbial yield such that the Y_{ATP} value can go below 4. Therefore, increasing the efficiency of rumen fermentation of millions of animals kept in the tropics is not only beneficial in terms of higher productivity, but also will have implication on reduced global warming due to reduction in methane emission form the animals.

Total microbial yield is mainly influenced by the growth conditions in the rumen which in turn is determined by the diet (Hungate, 1966). Deficiencies of nutrient(s) like energy and nitrogen (Leng, 1990; Hvelplund and Madsen, 1990), minerals, vitamins and growth factors required by rumen microbes reduce microbial growth efficiency leading to reduced microbial biomass and eventually reduced feed digestibility and intake. Other factors such as the dilution rate (Prigge et al., 1978; Rogers et al., 1982; Hvelplund and Madsen, 1985; Ørskov, 1992) and the protozoa in the rumen (Brodiscou and Jouany, 1995) influence the amounts of microbial protein available to the animal. Increasing dilution rate increase passage of bacterial cells out of the rumen thereby reducing the maintenance energy cost. Protozoa predate on bacteria and since most of them sequestrate in the rumen, large population of protozoa reduces microbial protein eventually available to the animal.

The interaction between carbohydrate and protein (N) metabolism in the rumen is very strong (Nocek and Russel, 1988). Microbial metabolism in the rumen is highly dependent on the rate of hydrolysis of carbohydrates (CHO) to provide energy (ATP) and the carbon skeleton for protein synthesis. Diets that are composed of protein and energy sources that degrade at almost similar rate in the 24-h feeding cycle are most likely to result in high microbial synthesis of protein. Moreover, it is still debatable whether synchronisation of energy and protein release increases microbial yield, but many reports (Strobel and Russel, 1986; Hoover and Stokes, 1991; Broderick and Merchen, 1992; Cotta and Russell, 1996) have shown overall higher efficiency of microbial growth with synchronisation.

2.3.2.1 Quantification of microbial yield

(I) Microbial protein forms a big proportion of amino acids absorbed from the small intestine (Nocek and Russel, 1988; Clark et al., 1992; Stern et al., 1994; Dijkstra et al., 1998). Therefore, it is essential to assess the size of this contribution under different feeding regimes for effective feed formulation.

(II) Estimates of the microbial protein synthetic potential is of great help in seeking the best ways of manipulating fermentative processes in the rumen to maximise the microbial yield (Broudiscou and Jouany, 1995). This is especially crucial in production systems (poor quality forages) where the animals are almost solely dependent on microbial protein for all metabolic needs (maintenance, growth, production and reproduction).

Microbial yield can be expressed as the amount produced in a unit time, usually per day e.g. g N per day or g crude protein per day. Alternatively, it can be expressed in terms of the efficiency of production i.e. g N/energy expended. The denominator can be the amount of organic matter apparently or truly digested, or ME energy utilised or units of ATP, or carbohydrates digested. When expressed in terms of organic matter digested, there is a confounding effect due to microbial cells and debris being part of the organic matter flow to the duodenum and faeces. It is more reasonable to use digested carbohydrates in the calculations because fat and protein contributes very little to the energy supply in the rumen (Madsen et al., 1995).

Estimates of microbial growth and yield can be done by in vitro (Ørskov, 1992) or by vivo methods. Several methods are possible though the degree of accuracy and precision can vary greatly. Where animals with duodenal fistulae are available it is possible to estimate the microbial N entering the duodenum by the difference in the total non-ammonia nitrogen and the rumen undegraded dietary N with corrections for endogenous N (Hvelplund and Maden, 1985; Ørskov, 1992). The other approach is to use markers that are specific to microbial components only such as the diaminopimelic acid (DAP) and aminoethylposphonic acid (AEP), Adenosine Triphosphate (ATP) (Broderick and Merchen, 1992) and Ribonucleic acid (RNA) (Ushida et al., 1985).

External markers have been successfully used to quantify microbial protein synthesis. Commonly used ones are such as Ammonium sulphate or Chloride enriched with the isotope ^{15}N or enrichment using $Na_2{}^{35}S$ or sulphates $Na_2{}^{35}SO4$ or ^{32}P. They work on the principle that labelled molecules will be utilised by microbes during synthesis of amino acids. For detailed coverage of the various techniques and the limitations see the review by Broderick and Merchen (1992).

Of more interest for this study was the method of estimation of microbial protein synthesis based on urinary purine derivatives excretion (Chen et al. 1990; Chen et al., 1995; Chen et al., 1998). Most of the other mentioned techniques require either elaborate equipment and/or surgically prepared animals and are therefore less practicable under field conditions and in developing countries. The method based on purine derivatives excretion has shown to be promising, though total urine collection is necessary due to diurnal variations in the excretion of purine derivatives.

The basis of the method based on urinary purine excretion rest on the fact that most ruminants' diets contain negligible amount of nucleic acids which are mostly degraded in the rumen, therefore almost all the nucleic acids arriving at the small intestine are of microbial origin. The purines are absorbed and converted into uric acid (by mucosa cells) before passage into the liver where the bulk of uric acid is converted into allantoin. In cattle, the major purine derivatives are allantoin and uric acid while xanthine and hypoxanthine occur in trace amounts. It has been established that the daily purine derivative excretion is linearly correlated to the amount of microbial protein absorption from the gut

The equation relating the purine excreted to the microbial protein synthesis was derived using *bos taurus* cattle and does not hold true to other ruminants and even to local breeds of cattle in the tropics (FAO/IAEA, 1997). Work is still going on to establish the validity of the equation or deriving a new one suitable to local tropical breeds (FAO/IAEA, 1997). However the equation is still widely used by workers in the tropical areas. The reasons may be due to easiness of application and for data meant to be used for comparative purposes between treatments, absolute values may not be a necessity as long as the procedure is carried out correctly for all treatments.

At any rate, microbial protein synthesis assay from the excretion of purine derivatives has some limitations especially on the assumptions as narrated above that make the values not to be taken as absolute values (Boever et al., 1998). Big variability exist between MN supply estimated from the urinary excretion of PD derivatives and the potential MN calculated from nutrient intake. Estimates based on PD is a measure of the MN production as affected by other factors like rumen pH, rumen turn-over rate and individual variations (Boever et al., 1998; Jetana et al., 2000). As a result of all these factors, the efficiency of microbial N synthesis had been observed to vary from 10 to 70gN/kg OM truly digested in the rumen.

Low efficiency of microbial protein synthesis with tropical forages used by smallholder dairy farmers in the northern parts of Tanzania due to protein deficiency has also been reported (Shem et al., 1999). In this study, total microbial protein (g/day) and the efficiency of the synthesis (MN/kg dig CHO) were significantly improved by nitrogen supplementation (**Paper II**). However, the microbial protein synthesis was not improved when animals were given concentrate supplements (**Paper III**). Since the levels of concentrate feeding did not cause drastic pH changes, it was not likely that microbial growth was impaired due to low pH. The main reason for the relatively low microbial protein synthesis (**Paper III**) was possibly due to increased partitioning of nutrients for VFAs production. The amounts of VFAs produced are inversely related to the amounts of microbial cell produced (Ørskov and Ryle, 1990).

2.3.3 Quantification of plant fibre kinetics by rumen evacuation technique (RET)

The rumen pool sizes of the various fibre components combined with the outflow from the rumen have been used to describe quantitatively digestion and passage rate and the responses to changes in the fibre source or the intraruminal conditions (Robinson et al., 1987). The method gives values of passage and digestion rates than are more close to dynamic events occurring in vivo compared to those determined by in vitro methods due to problems associated with microbial environment with the in vitro methods (Huhtanen, 1998). With this technique, it is also possible to obtain the rates of passage and digestion of the various fibre fractions i.e. total fibre (NDF) and the digestible NDF and passage rate of the indigestible NDF.

The rumen evacuation technique is based on the simple one compartment model. Such model assumes the rumen as containing a homogeneous collection of particles with steady flux rates. The rate of fibre digestion (kd) is a constant fraction of the amount of potentially digestible fraction and the rate of passage (kp) out from the rumen is a constant fraction of the ruminal pool of fibre.

The equations for determination of digestion kinetics from rumen evacuation technique are given as:

Rate of intake (ki) ($\%h^{-1}$)= 1/24 * Daily intake (kg)/rumen pool size kg

Rate of passage (kp) ($\%h^{-1}$)= 1/24 *Duodenal output (kg)/rumen pool size kg

Rate of digestion is calculated by the difference between the intake rate and passage rate i.e. Rate of digestion (kd) ($\%h^{-1}$) = ki - kp

Mean retention time (MRT) is calculated as the reciprocal of the passage rate

i. e. MRT (h) = 1/kp

These factors are combined to give the equation of digestible plant fibre (DNDF) digestibility as being equal to the ratio of the rate of digestion to the sum of rate of digestion and passage rates i.e. kd/kd+kp.

The assumption, that particles in the rumen are homogenous and have equal chances of escape, on which the simple one compartment model is based, is not true. The fact is that at any one time, the rumen contains a conglomeration of particles of various sizes and ages and all particles do not have an equal chance of escape (Pond et al., 1988; Ellis et al., 1994). A two-compartment age-dependency model was proposed to account for the selective retention of newly ingested particles that need time for processing (size reduction through chewing and digestion) before they are legible for escape out of the rumen.

Estimates obtained through rumen evacuation refers to the total dietary fibre and not to the individual fibre sources in the ration. Therefore, in the study of intrinsic features of a certain fibre source, it is important that other additives or supplements given have very small amount or no fibre at all as to avoiding confounding the results (Stensig and Robinson, 1997, Stensig et al., 1998). In this study (**Papers II and III**), this was not critical as the main aim was not to study the intrinsic properties of a single fibre source but rather the effects of changed intraruminal environment due to supplementation to kinetics of total dietary fibre.

The rumen evacuation technique gives a reasonably true estimate of the true estimate of the rate of passage of the indigestible NDF and the rate of digestion of the digestible NDF. However, rates of passage of NDF and DNDF is underestimated if there is an age dependent passage (Weisbjerg, 2000 Personal communication).

One major limitation of the RET is that the method requires preferably rumen, duodenal and ilieal fistulated animals and is laborious. Hence it is not very suitable for routine digestibility studies. However, it is possible to correct fecal flow to duodenal flow of NDF using the following equations:

(I) Duodenal NDF flow (kg/day) = Fecal NDF flow (kg/day)/0.85 (Robinson et al. 1987).

OR (II) Duodenal NDF flow (kg/day) = Fecal flow (kg per day) + (NDF intake per day *0.065) (Weisbjerg, M. R., Personal communication)

Since duodenal flow of indigestible NDF = Fecal flow of indigestible NDF, the flow of digestible NDF can be determined by difference as shown below

Duodenal DNDF flow (kg/day) =Duodenal flow NDF (kg/day)– Fecal INDF flow (kg/day).

In the determination of the kinetics of total NDF and digestible NDF, it is important to determine the INDF in feeds, rumen, duodenal, ileal and fecal samples by long incubation of samples in the rumen using nylon bags on standard fed animals (Aitchinson et al., 1986; Dado and Allen, 1995). While various workers have used different duration of incubation e.g. Tamminga et al. (1989), 10 days, Stensig (1996), 21 days, Huhtanen and Kokkunen (1995), 14 days, Robinson et al. (1987) and Mgheni (2000), 30 days, it is not yet clear as to what would be the best duration. Low repeatability and lack of reproducibility (Noziere and Michalet-Doreau, 2000) and particle losses from dacron bags are factors that can contribute to some of variations in reported works. Losses of particles from the bags can be limited either by using dacron bags with small pores or by correction of particles losses (Weisbjerg et al., 1990). However, post-ruminal recovery of INDF has so far been very difficult. Recovery rate has ranged between 90 to above 100% due to problems associated either with sampling or the nylon bag technique (Stensig et al., 1998; Stensig, 1996).

2.3.4 Associative effects of dietary ingredients

It is agreed that it is not easy for a single feed ingredient to contain all the required nutrients needed by the animal and its rumen microbial population. Therefore feeds are given in a mixture (ration) aimed to meet the nutrient requirements of animal and the microbes in the rumen. The nutrients concentration in a given diet and the extent they are made available to the animal/microbes through digestion have a big impact on overall feed intake and therefore animal performance (Forbes, 2000). Whereas marginal deficiencies of an essential nutrient can lead to higher intake as an attempt to extract as much nutrient as possible from the amount consumed, severe deficiency just like excessive amounts of the nutrient lead to reduced feed intake. Gross excess of nutrients e.g. ammonia, can be toxic in the rumen and at tissue level thereby causing reduced feed intake and at worse, animal death.

When feeds are given in a ration, there can be either positive or negative associative effects (Ørskov and Ryle, 1990; Huhtanen, 1991). For example the digestibility of feeds in a ration might not be additive due to negative or positive associative effects (Frederiksen, 1973; Mould et al., 1983; Mould, 1988; Thomas, 1990). Positive associative effects are such as the observed increase in digestibility of fibre in poor quality forage when limiting nutrients (e.g. nitrogen, minerals and vitamins) are given as supplements (Maeng et al., 1976; Ndlovu and Buchanan-Smith; 1985, Leng, 1990). Negative associative effects such as the depression in fibre digestibility when high level of rapidly soluble carbohydrates are given (Huhtanen, 1991) can occur. The associative effects are caused by the change in the microbial profile or the intra-ruminal environment to either favour or disfavour the digestibility of the dietary component (Frederiksen, 1973).

2.3.4.1 Effects of nitrogen supplementation

One of the greatest limiting factors for efficient utilisation of low quality forage is the low nitrogen content that limits digestibility and intake (Mawuenyegah et al., 1997; Heldt et al., 1999). Nitrogen supplements increase ammonia availability and therefore enable optimal growth of ruminal microbes and increases feed digestibility and intake (Preston and Leng, 1984; Madsen et al., 1997). Increases in microbial biomass also lead to increased amounts of amino acids available to the animal as long as the re-cycling within the rumen does not limit passage down to the small intestine.

The relationship between VFI and the dietary CP level is very strong. Ellis et al. (2000) in the review of factors influencing VFI in ruminants noted that the CP content of the diet is curvi-linearly related to VFI with very rapid increase in intake with CP range of 40-190 g/kg DM and a gradual increase up and beyond 1000g /kg DM. The implication being that maximum feed intake is hard to achieve under normal feeding conditions due to inefficiencies of N digestion in the rumen.

While the CP content of the diet may be an important parameter, its extent of rumen degradability is equally important. The extent of rumen protein degradability is the ultimate determinant of the N availability to rumen microbes as well as the amount of protein that by-pass rumen degradation and, depending on its extent of intestinal digestibility, can act as an additional source of amino acids to the animal. The advantage of increasing the intake of rumen degradable protein in improving intake and digestibility of poor quality forage were clearly evident (**Paper II** and also in Figure 10). Even the nitrogen balance (retention) was from negative values (control) to positive values at an energy intake around maintenance (see Figure 11).

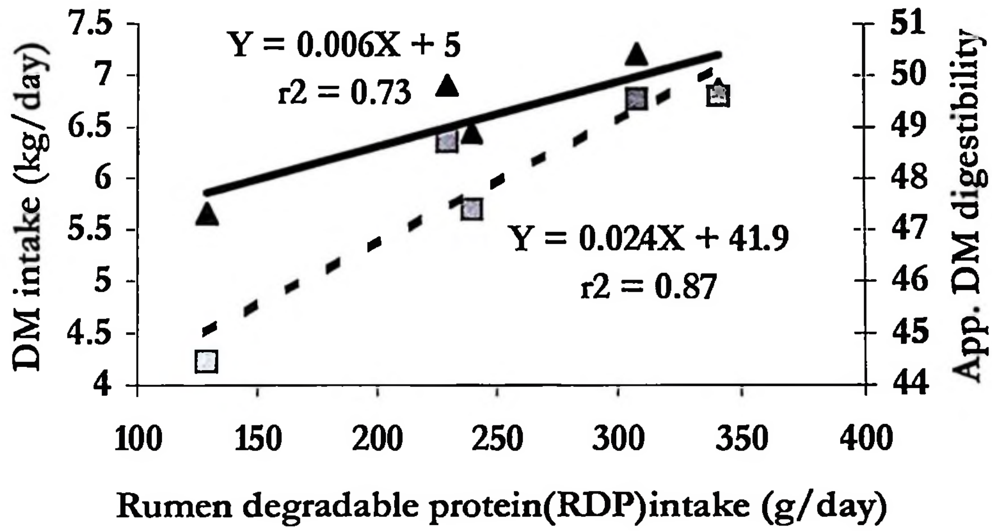

Figure 10 Relationship between dry matter intake (▲) and digestibility (■) with the intake of rumen degradable protein (paper II)

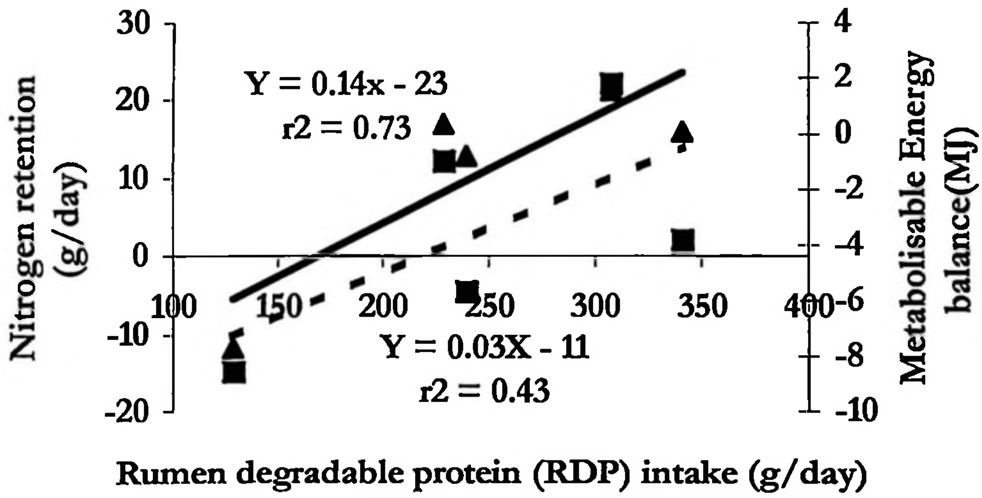

Figure 11 The relationship between nitrogen retention (▲) and energy balance (■) with intake of rumen degradable protein (paper II).

2.3.4.2 Effects of the sources of nitrogen supplementation: Non-protein nitrogen (Urea) Vs True protein (Soyabean cake)

The effects of a given nitrogen source on rumen fermentation and supply of the host animal with amino acids depends on the rate and extent of degradation in the rumen as well the digestibility of rumen undegraded protein in the small intestine (Mgheni et al., 1994). Non-Protein sources of nitrogen like urea are highly soluble and almost 100% hydrolysed to ammonia in the rumen. The extent of rumen degradation of true proteins differ with source (structure), treatment (if any) and the retention time in the rumen. Generally, plant proteins are extensively degraded in the rumen (given adequate retention time) while animal proteins are less degraded due to the presence of disulphide bonds.

Many reports show that true proteins are superior to non-protein nitrogen sources in enhancing intake and digestibility of feeds. The reasons are that probably some of the microbes have specific requirements for peptide, amino acids and branched chain fatty acids that are not available when NPN source is fed (Owens et al., 1984). Yet, other reports (Leng, 1990) indicate that cellulolytic bacteria do not have specific requirement of such nutrients whereas the saccharolytic bacteria do. Therefore any benefit of true protein over non-protein nitrogen is explained in terms of availability of energy, minerals, pre-formed amino acids supporting rumen fermentation and those from bypass protein digestion in the small intestine which stimulate overall body functions and therefore, increase food intake.

The advantages of nitrogen supplementation (irrespective of source and level) to no supplementation on intake and digestibility of DM and OM as well as NDF digestibility were clearly demonstrated in this study (**Paper II**). Urea exhibited linear increases in rumen load of DM and NDF with a slight increase in passage rate, but digestion rate was much more increased such that digestibility was higher than the control and soyabean cake. It appeared that the increased passage rate with soyabean cake lead to a slight fall in the digestion rate of NDF and DNDF though this did not affect the overall high digestibility compared to the control but not to urea. These findings concurred with the other findings that true protein (soyabean cake) was superior to urea in enhancing feed intake and digestibility relative to no supplementation (control). However, in this study there were only marginally higher (not significant) values between soyabean cake compared to urea, except with DNDF digestibility where the reverse was true. This implies that as far as fibre digestibility of the forage used in this study was concerned, availability of adequate ammonia was top priority compared to source of nitrogen.

Reports from the literature show that rumen ammonia levels for optimal utilisation of forage based diets can vary depending on the amount of energy available from the basal diet as well as the experimental conditions. Suggested levels range from 10-20mg N/100ml(Perdok and Leng, 1990) though higher values have been reported (Song and Kennely, 1989; Mehrez et al., 1977; Wallace, 1979). Leng (1990) obtained maximum straw intake in cattle at mean ammonia concentration of 20 mg N/100ml and maximum digestibility of straw from dacron bags at ammonia concentration of 15mg/100mL. Rumen ammonia levels in this study (**Paper II**) ranged between 2-4 and 5-8mg N/100ml ruminal fluid with soyabean cake and urea respectively with the lowest value occurring in the control (non supplemented). In this study (**Paper II**), highest NDF digestibility was obtained at rumen ammonia concentration of 8mg N/100ml during high level of urea supplementation. This however, does not rule out the possibility that higher concentrations would have given higher digestibility though using too high levels of urea can predispose the animals to urea toxicity.

Supplemental protein price of the common protein sources available to smallholder farmers in Tanzania was calculated using maize bran as standard for energy according to the equation:

Energy cost feed (Tsh/ME)-Energy cost standard feed (Tsh/ME) divided by the protein concentration in the feed (g/ME) – protein concentration in the standard feed (g/ME) (Østergaard, 1969) (Table 1).

Table 1. CP and energy contents and estimates of the prices for supplemental protein of the various sources of protein supplements available to smallholder farmers in Tanzania.

Feed	CP (g/kg DM)	ME(MJ /kg DM)	Price/kg DM (Tsh)	Price/ME (Tsh)	CP/ME (g)	Energy cost difference (Tsh)	CP/ME difference (g)	Price of supplemental protein (Tsh/gCP)
[1]Maize bran	109.0	11.8	54.40	4.60	9.2	-	-	-
Soyabean cake	438.0	14.7	1068.38	72.68	29.8	68.07	20.6	3.3
Sunflower cake	236.0	8.0	74.30	9.35	29.7	4.74	20.4	0.2
Cotton seed cake	358.9	8.55	105.82	12.38	42.0	7.77	32.7	0.2
Fishmeal	633.0	11.0	1363.64	123.97	57.3	119.36	48.0	2.5
Urea	2880	-	280.00	-	-	-	-	0.10

[1]Used as standard feed for comparison with the others

The calculated cost of supplemental protein in Tsh per g CP was 3.3 for soyabean cake, 2.5 for fishmeal, 0.2 for both sunflower and cottonseed cake and 0.1 for urea. Given the relatively high cost of soyabean cake, it would be more reasonable to use urea or sunflower cake or even cottonseed cake depending on easiness of availability. As pointed earlier, this study (**Paper II**) has shown that urea supplementation is quite effective in improving intake and digestibility of poor quality forage to meet the maintenance requirements of the animals. It is surprising, however, to see so little effort being put in the wider use of urea by smallholder farmers in Tanzania. The use of urea for treating forages has been done during on station trials (Mgheni et al., 1994) but no record exist on practical application by smallholder farmers. Multi-nutrient blocks containing urea, molasses and minerals have been in use in many developing tropical countries and great achievements in improvement of intake and digestibility of poor quality forage have been reported (Preston and Leng, 1984; Yen et al., 1997).

Wide scale use of urea molasses mineral blocks (UMMB) in Tanzania will certainly increase ruminant productivity. There have been some attempts to introduce the use of such technology in Morogoro (Plaizier et al., 1998) but wide scale adaptability by farmers has not been possible. Why? The top down approach where blocks and mixture were handed to farmers was part of the problem since once the researchers left, then everything stopped. Urea (fertiliser grade), molasses, mineral mixtures and cement are available in Tanzania but it is doubtful if smallholder farmers have time and expertise needed to prepare the blocks in the right way. It might be a good idea for the Government or a private company or individual businesses to produce the blocks en masse and sell to smallholders at a reasonably cheap price as is currently done in India by the National Dairy Development Board of India. But so far nothing have been done in that respect in Tanzania.

Can farmers spray urea on the forage or mix it with molasses and feed directly? This will certainly be a plausible idea since it will reduce the labour involved in case of treatment or making blocks. But the question here is how much to give? Feeding urea directly to about 1% of the DM intake increased intake of DM, OM and NDF and their corresponding digestibility (**Paper II**). With dairy cows consuming an average of 10kg DM per day, mixing about 100g of urea with the amount forage given to the animal per day will be adequate. Values can be adjusted when a farmer has access to extra sources of energy like molasses and cassava. However it appears that there is a lot to be done in convincing the farmers about the safety of urea as long as proper doses are administered.

Scepticism still abound among smallholder farmers from the previous bad experience when some farmers lost animals due to accidental urea toxicity when attendants overfed urea molassed blocks. Experience from other countries has shown that it takes time to build smallholder farmers' confidence in accepting new ideas (Leng, 1994) and therefore things may change in future.

2.3.4.3 Effects of concentrates and "Magadi" supplements

The results from of **Paper II** showed that even with a moderate nitrogen supplementation, the improvement of intake and digestibility of the poor quality roughage was just adequate to meet the maintenance requirements of the animals. It was evident that with the type of poor quality forage used, nitrogen supplementation alone may not be sufficient to support growth and productive functions and maintenance of body weight. This brings us to the issue of concentrate supplementation. Concentrates are largely grouped under those that contain high amounts of rapidly fermentable carbohydrates (mainly sugars and starch) or those that contain high amounts of protein. Under normal conditions, concentrate mixtures containing energy, protein and minerals are compounded to give the best balance of nutrients to the microbes and the ruminant animal. However, it is a common observation that smallholder farmers use the type of concentrate that is easily and cheaply available locally without much consideration to their effects on overall rumen functions. Sometimes, perhaps due to ignorance, the advantages of combining the locally available energy and protein supplements for enhanced ruminant productivity are not fully utilised. This prompted the study of the impact on intake and rumen functions of energy, protein and mineral supplement ("Magadi") used by smallholder farmers in Morogoro (**Paper III**).

One concern of the use of energy rich supplements is the effect on depression of the digestibility of the fibre component due to pH and 'carbohydrate effect'. Low pH is known to cause reduced digestion of plant fibre through altered enzyme secretion and activity and microbial attachment. On the other hand the depression of fibre that could not be reversed by neutralising agents (carbohydrate effect) is thought to be due to substrate preference, with the cellulolytic microbes utilising simple sugars in the fed concentrate instead of breaking down cellullose (Mould et al., 1983).

It was interesting to note that none of the supplements and additive assessed (**Paper III**) had very big impact on ruminal pH (Figure 1 **Paper III**). For most part of the day, average pH was maintained above 6.3, despite moderate levels of VFAs since these are major cause of low rumen pH when present in high amounts. One reason could be the fibrous basal feed necessitated long hours of chewing, a process that stimulates saliva secretion. Saliva is rich in phosphates and carbonates that buffer the rumen contents. The impact of addition of extra sources of rapidly fermentable carbohydrates (molasses and cassava) did as expected increase DM and OM intake mainly due to extra DM and OM from the supplements and therefore apparent DM and OM digestibility was higher than the control. This was thought advantageous since the intake of the poor quality hay was not depressed by intake of the energy rich concentrates.

This study showed that the effect of the supplements/additive on fibre digestibility was not due to changed rumen pH (Mould et al., 1983; Mould, 1988). Rather, it was due to the changes in either rumen pools or the passage rate or rate of digestion or a combination of these factors. Digestibility of NDF was unchanged with molasses due to little change in the passage rate and a slight increase in the rate of digestion. It was possible that the amount of molasses consumed (1.31kg/day/cow) was not adequate to cause adverse effects on the intra-ruminal condition. Khalili and Osuji (1994) reported an upper limit of molasses intake beyond which fibre digestibility in animals fed poor quality forage start to be compromised to be 1.5 kg DM/day/animal

Cassava flour on the other hand caused a slight increase in the rumen load of NDF, increased the rate of passage with little change in the rate of digestion. This led to the observed significantly lower NDF digestibility. The high passage rate of NDF with cassava flour disagreed with the findings of Stensig et al. (1996) and Robinson et al. (1987) where increasing starch amounts in the diet tended to reduce the passage rate of NDF. Probably differences due the sources of starch, purity and amounts offered, and the degree of processing could explain some of the disparities observed.

How much of the supplements can be fed without jeopardising digestibility of the fibre component in the diet? With the single levels given during this study, it is hard to be conclusive. But from the observation of the extent of NDF digestibility and nitrogen retention, some suggestions can be made. Since, the CP content of the hay was very low, the initial step would be to increase N availability through nitrogen supplementation; in this case of maize bran (2.7 kg DM with 10.9% CP) 294g crude protein. When this is done, molasses (78% DM) and cassava tubers (65%DM) can be given up to 15 and 11% of DM intake respectively without seriously affecting fibre digestibility. However, extra N supplementation would probably have been more beneficial. Higher levels of molasses and cassava supplementation must be accompanied by additional protein supplementation using the most cheaply available nitrogen sources like urea, sunflower cake or cottonseed cake. It is strongly recommended to feed cassava as freshly chopped or dried tubers pieces so as to avert the negative effect of fine processing as observed during this study.

The concentrate mixture was found to be superior to other treatments in increasing DM and OM intake mainly due to increased intake of the basal forage. Rumen NDF digestibility was increased due to tremendous increase in the rate of digestion, though the passage rate was also slightly increased due to the increased intake. It was clear that intake increased as a result of fast clearance of materials from the rumen through increased digestion and passage. This was the most ideal situation that was deemed appropriate to improve intake and utilisation of poor quality roughage through improving the nitrogen content in the usually maize bran based supplement commonly used by smallholder farmers. As seen before, sunflower cake and maize bran are ingredients that are easily and cheaply available in Morogoro. As will be discussed later, the potential of a concentrate mixture containing sunflower cake and maize bran in improving milk yields was demonstrated to smallholder farmers with very encouraging results.

Magadi soda is a naturally occurring sodium sesquiscarbonate. A "Magadi" locally used in Tanzania is similar to Magadi soda and has been noted to improve intake and digestibility of forage by buffering acids in the rumen to avert drastic fall in pH that is common with high concentrate feeding. There was no significant improvement in hay DM intake when "Magadi" was fed to the animals. This was contrary to the belief by smallholders that "Magadi" improves intake of basal feeds. Literature findings (Nangole et al., 1983) showed that cattle not used to Magadi soda needed more than 30 days to get accustomed to it before substantial changes in intake were obvious. The 14 days adaptation period was thus too short to observe the full impact of "Magadi" on intake. However rumen pool size of NDF and rate of passage was reduced but the rate of digestion was increased thereby causing an overall higher NDF digestibility. Perhaps, as earlier argued, future uses of "Magadi" should include treatment of forages and therefore allowing time (14 days or more) for the alkali effect to take place before feeding to the animals. Treatment was thought to be more beneficial from the results of significant increases in DM disappearance of hay incubated in dacron bags when the bags were soaked in Magadi suspension compared to those soaked in tap water for 24 hours prior to incubation in the rumen (**Paper III**).

2.4 Post-ruminal digestion

2.4.1 Protein digestion in the intestines

The amino acid requirement of the ruminant animal is met from the digestion of microbial cells and to some extent the rumen by-pass protein entering the small intestine rumen (Madsen, 1985; Hvelplund et al., 1995; Madsen et al., 1995, Broudiscou and Jounay, 1995). In the ruminant production system in most tropical areas, microbial protein supplies almost 100% of the amino acids absorbed from the small intestine as the basal feeds have very little or no by-pass protein. Absorbed amino acids are utilised by the animal as building blocks for protein needed for maintenance and production requirements. With high producing animals, microbial protein alone may not be able to meet the requirement. Therefore increasing the amounts of by-pass protein in the ration will provide more amino acids from the digestion of the by-pass protein in the small intestine.

2.4.2 Hind gut fermentation

Post ruminal (caecum and proximal colon) digestion of plant fibre can occur when potentially digestible fraction of the plant fibre escapes from the rumen before it is fully digested. This especially can happen with very finely ground forages, during higher intake level or when conditions in the rumen are depressive to fibre digestion e.g. low pH due high concentrate feeding or feeding high amounts of fats (Igwuegbu and Sutton, 1982). Though post ruminal digestibility of fibre increases with a fall in total tract digestibility (Tamminga, 1993), there is always a limit to the extent the hind gut plant fibre fermentation can compensate for reduced fibre fermentation in the rumen (Huhtanen and Vanhatalo, 1998). Huhtnen and Kukkonen (1995) noted that despite having the same physico-chemical environment as the rumen, the viable microbial counts are low and the digesta retention time is relatively short in the hind gut compared to the rumen. Increased hindgut fermentation will increase the loss of N in faeces as microbes synthesised in the gut are excreted. This will reduce the N excretion in urine and eventually the re-cycling to the rumen.

2.5 Effects of farm made concentrate mixture using locally and cheaply available source of energy and nitrogen as dry season supplement to improve dairy production

One important but seemingly tough task is to transform knowledge gained from laboratory to solve practical production problems. Firstly, farmers have their ways and reasons of doing certain things that may not be immediately clear to a researcher. Secondly, it is really hard to break old habits unless the benefits of doing so as clearly demonstrated.

Moderate concentrate supplementation can improve utilisation of poor quality forage as long as pH does not fall below 6.2 (Broster et al., 1981; Beever, 1989; Garg and Gupta, 1992). Commercial dairy meals in Tanzania are hardly available. Even where and when available the prices are relatively high due to the costs involved in compounding and transaction (Msangi et al., 1998; Nkya et al., 1998). This is the main reason for smallholder farmers to rely on cheaply and locally available maize bran as a main supplement to lactating dairy cows. There is always an added advantage of mixing energy with nitrogen rich supplements as long as the ingredients used are fairly cheap and locally available. In Morogoro, sunflower cake either from oil processing factory and/or at homesteads where oil is extracted manually can be mixed with maize bran to improve the nitrogen content in the maize bran.

Results from on station experiment (**Paper III**) indicated the superiority of a concentrate mixture containing maize bran, sunflower cake and mineral powder (68, 31 and 1% DM), respectively, compared to maize bran alone on rumen functions. Since all the ingredients used are locally and cheaply available in Morogoro, it was interesting to see whether such findings would improve the performance of smallholder dairy cattle especially in increasing milk yields. Farmers were trained on how to compound the concentrate mixture at farm level. For those without weighing scales, approximate amounts of ingredients to fill buckets and tins commonly used in the homesteads were calculated. Thus, it was easy for farmers to estimate the amounts of ingredients to mix using such simple facilities.

The results (**Paper IV**) showed a significantly higher milk yield in cows fed the concentrate mixture compared to those fed maize bran alone. This clearly demonstrated the importance of increasing the amount of nitrogen available from the basal feeds and maize bran by the use of nitrogen sources like sunflower cake in order to increase milk yields. Depending on availability and price, other sources of nitrogen such as cottonseed cake and urea can also be used. However, a study done by Nkya et al. (1998) using a maize bran-cottonseed cake mixture had an almost similar increase in milk yield as obtained in this work (**Paper IV**) at a relatively higher level of supplementation.

This study (**Paper IV**) showed that the returns of using concentrates were very high. De Wolf, a prominent dairy farmer in Dar-es-Salaam acknowledged that the ratio between selling price of one litre of milk to the cost of one kg of concentrate was still very good and gave an estimate of 50-75% of milk price (De Wolf, 1999). This fact appears to be elusive to most smallholder dairy farmers and to some extent researchers and agricultural extension officers in many parts of Tanzania. There is a need to change the 'song' concentrates are expensive to a new one saying strategic use of concentrates pays to those who are willing to invest more in feeding dairy cows. This will entail using concentrate supplementation in due consideration of the yield potential of the actual cow and the stage of lactation in order to get a high peak lactation and to sustain that. Therefore, supplementation with concentrate should be a continuous process with due respect to the quality and quantity of the basal diet as intermittent supplementation as commonly done by smallholder reduce the overall response to supplementation and thereby the returns. This fact was clearly demonstrated in this study (**Paper IV**) where continuos supplementation with either MB or MBS allowed the cows to sustain the yield from the first week to the 12th week of treatment with residual effect up to three weeks post treatment (Figure 2 Paper IV)

3.0 CONCLUSIONS AND RECOMMENDATIONS

- Smallholder dairy farming in the rural and urban areas of Tanzania provides livelihood to many people and contributes substantially to the overall National Economy
- Poor nutrition as accentuated by the fall in quality and quantity of the basal forage with dry season was identified as the major cause of the observed low milk yields and infertility among smallholder dairy cows.
- Efforts to improve digestibility and thereby intake of the basal forage through strategic supplementation are very necessary. It was found that nitrogen deficiency in the forages was the major critical factor reducing the efficiency of their utilisation thereby leading to low digestibility and low microbial protein synthesis.

- Nitrogen supplementation was deemed necessary to increase the digestibility and therefore efficient utilisation of the poor quality forage commonly fed to cattle in Tanzania. As far as the digestibility of fibre from poor quality forages is concerned, ammonia concentration in the rumen (level of rumen degradable protein) was of more relevance than the source of nitrogen used. The implication being that non-protein sources like urea can be used to optimise the digestibility and intake of poor quality forages. Use of true protein sources can be optional depending on easiness of availability and cheapness and in situations where a certain amount of by-pass protein is necessary to support a high level of production. In this study the highest plant fibre digestibility was obtained with ruminal ammonia nitrogen concentration of 8 mgN/100ml.
- Future efforts should be directed in the preparation of multi-nutrient mixtures that can address to the deficient nutrients in the basal forage in a form that can easily be acceptable to farmers. Production of Urea Molasses Minerals Blocks en masse by the Government or private individuals and companies will be most desirable provided the prices are not too high and farmers are well instructed on their proper use. Locally available mineral sources like "Magadi" can be incorporated in such blocks.
- The use of rapidly fermentable energy sources in animals fed poor quality forages need to be approached with care due to risks of causing low pH thereby causing reduced fibre digestibility. However, the use of such supplements in amounts currently done by smallholder farmers in Morogoro did not appear to have serious consequences on fibre digestibility. It is suggested that more benefits would be realised by concurrently feeding with nitrogen sources when high amounts of energy rich supplements such as molasses and cassava are used. However, for farmers who have no means of obtaining nitrogen supplements, they can still use the energy rich supplements at the current levels.
- The contention by smallholder farmers that "Magadi" improves intake of basal feeds was not substantiated in this study. This was probably due to short adaptation period. However there is a need to investigate further the potential of "Magadi" as a source of alkali that can be used to treat poor quality forage.
- Use of a farm made concentrate mixture containing maize bran and sunflower cake increased milk yield and was economically profitable compared to the common practice of using maize bran alone. Sunflower cake is cheaply and

locally available in homesteads where oil from sunflower seeds is extracted manually using the ram press. Farmers in the urban and peri-urban areas of Morogoro can procure their supplies from the nearby oil-processing factory. Therefore, farmers are encouraged to use the concentrate mixture that they can easily compound at farm level. Alternatively, they can feed the ingredients (e.g. maize bran and sunflower cake or cotton seed cake and mineral powder) separately at the recommended proportions so as to cut down the labour involved in the mixing of the ingredients.

- Much remain to be done on the characterisation of the feeds used by smallholder in Tanzania. Of equally importance are studies on the effects that occur when feeds are given in combination as is usually done under local feeding conditions. This entails doing more in vivo studies on various feed combinations to build a sufficient data-base that can be useful in feed formulation as well as advising farmers on how they best make efficient use of the local feed resources.
- The underlying causes of farmers unwillingness to offer adequate protein and energy supplements to dairy animals in the name of 'high cost' does not make sense at all. Many studies have shown that there are good returns for the extra costs incurred due to supplementation. Therefore, researchers and field extension personnel need to constantly remind farmers of this fact so that there can be a change in attitude.

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Paper I

Smallholder Livestock Production in Urban and Peri-Urban Areas of Morogoro, Tanzania. Results from a survey carried out between February 1999 to February 2000.

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Abstract

Urban smallholder livestock farming in Tanzania has seen a tremendous rise since the late seventies. Several factors acting singly or concurrently led to the trend we are observing today. The major driving forces are social-economic and to some degree political in nature. A survey was carried out to investigate the smallholder dairy production in urban and peri-urban areas of Morogoro, Tanzania between February to March 1999 followed by monthly collection of forage samples to February 2000. Visits were made to 122 farms during which observations, discussions and filling a questionnaire forms were done during interviews with farmers.

The average number of people and cattle per family were 7.4 and 6.0 respectively. Milk yields from lactating cows seemed to be high just after the rainy season (average of 10.5 L/cow/day), but declined rapidly with the onset of the dry season (mean of 6.6 L/day/cow). The main cause of this fall in productivity was the fall in quality and quantity of forage on which the animals depend. Distance to the source of forages ranged between 1-8 km during the wet season (April-June) but was 3-35 km during the dry season.

Smallholder farmers were found to be aware of good animal management practices and except for occasional outbreaks of tick borne diseases, there was no major animal health problem reported. About 93% kept records showing treatments, service and calf birth dates. Only 45% of the visited farms regularly gave supplementary feeds and most of the time they gave maize bran to lactating animals. About 15% of the farms sprayed molasses on straws and standing hay to improve intake by the animals. Nitrogen supplements were rarely used. Only 14% of farmers visited occasionally used either cotton seed cake or sunflower cake. Nearly 90% of the surveyed farms were less than one acre in size since the plots initially planned as high-density residential areas. Now, the same plot has to accommodate animal barns most of which were poorly constructed and very close to residential units thereby increasing risk of disease transmission between herds as well as to man and offensive odours to people. Breeding services were most of the time unreliable and farmers were using any bull they can lay hands on irrespective of the quality of the bull.

It is concluded that smallholder dairy producers in urban and peri-urban areas were playing a vital role in the provision of the much-needed dairy products to urban consumers. It was felt necessary to address to some of the problems faced by this sub-sector such as low productivity due to poor nutrition especially during the dry season, breeding and milk marketing and processing.

Key words: Urban and peri-urban, Morogoro, smallholder, dairy, survey, feeds

INTRODUCTION

Urban agriculture in general and livestock keeping in particular is a common phenomena in Tanzania (Mlozi et al., 1989; Swai et al., 1992; Mlozi et al., 1992) like in most other developing countries (Shapiro et al., 1995; Maxwell and Zziwa, 1993; Memon and Lee-Smith, 1993; Millington, 1985). Though some products are consumed at household level, the bulk are intended for cash sale to generate income to supplement the meagre incomes of salaried workers and small business people (Ndalichako, 1998; Mosha, 1991). Dairy keeping in Morogoro has seen a tremendous rise since 1994 with numbers of cows and annual yields almost doubling by the year 1998 (Table 1)

Despite its great contribution to increased household incomes and supply of highly needed animal proteins to the consumers (Mdoe and Mlagwa, 1997), the sub-sector is faced with several problems. First, its legality is still a controversial. The local government (Urban Authorities) act 1982, Morogoro Municipal Council by- laws of 1999 section 3, states that animals are to be kept in 'specified areas' and not in residential areas. But the so-called "specified" areas are yet to be clearly defined. Second, is the difficulty of ensuring adequate animal feed supply all year round. Thirdly are the risks of zoonoses to producers and consumers (Mosha, 1991), and environmental pollution. Fourthly are the problems associated with marketing of animal products especially milk where there seems to be no clear policy or structure in place to safeguard producers and consumers.

Due to the importance and the 'complexities' of the urban and peri-urban livestock farming, an in-depth study of this sub-sector was carried out in Morogoro. The objectives of this study were: (i) To gather information on the current production practices, limitation and future prospects of urban and peri-urban livestock keeping with special emphasis on dairy farming. (ii) To assess the basal feeds (roughage) and the influence of climate on their nutritive quality. (iii) To determine the types and extent of use of energy and protein supplements by smallholder dairy farmers.

Table 1. Dairy production trends in Morogoro District between 1994-1998

Year	Number of farmers	Number of cows	Annual yield (l)	* Yield /cow (l)	Milk Value (Tsh)
1994-95	2175	1160	1,707, 000	1472	306,334,120
1995-96	2950	1198	1,709,000	1427	397,200,000
1996-97	3000	1800	3,000,000	1667	450,000,000
1997-98	3650	2970	3,650,000	1229	730,000,000

Data obtained from Morogoro District Veterinary office

*Calculated based on the assumption that all cows were milking since the number of dry cows was not recorded

MATERIALS AND METHODS

Study area

The study was carried out in Morogoro urban and peri-urban area at an altitude of 528m above sea level with an average rainfall of 800-1200 mm per annum. Peak rainfall falls in April-May. The mean maximum temperature is 32.4°C (November-February) with lowest temperature (14.8 °C) occurring between June and October. Morogoro town is located 250 km West of Dar-es-Salaam along the Tanzania-Zambia highway. Morogoro urban covers an area of 260 km^2. According to the census carried out in 1988, human population in Morogoro town was estimated to be 117,601 peoples and was projected to reach 201,740 peoples by the year 2000 (Planning Commission Report, 1997).

Survey

A sample survey was carried out using a questionnaire and personal observations on the farming practice on the visited smallholder households. The questions covered the farmer's bio-data, experience in dairy keeping, animal nutrition, animal health and other management aspects. A total of 122 farmers were visited (Table 2). The wards and the number of farmers visited shown in brackets were as follows: Kihonda (16), Mazimbu (18), Mbuyuni (18), Mlimani (21), Forest/Boma (22), Kilakala (14), Bigwa (4), Kichangani (9) (see Table 2). Visits and interviews were also made at the two privately owned milk collection centres in Morogoro. These were Morogoro and Mojata milk collection centres.

Farm visits for discussion with farmers and also personal observation, body weights and body condition scoring began on the 15th February 1999 and completed on the 31st March 1999. Further visits were made to at least 5 farmers randomly selected from each ward each month from April 1999 to February 2000 to collect forage samples for chemical analyses.

Forage and feed samples

Forage samples were collected from each farmer on the first visit. Thereafter random feed samples from selected farmers were collected on monthly basis so as to follow the changes in nutritional value of pastures over one year period. Forages were analysed for dry matter (DM) by drying to constant weight in hot air oven at 60 °C for 48 hrs. Nitrogen (N) contents were analysed by the Kjeldal method (AOAC, 1990) using semi-automated N analyser (Kjeltec system 1002, Tecator AB, Hoganas, Sweden). Crude protein (CP) was calculated as 6.25 X N content.

NDF analysis was done according to the methods described by Van Soest et al. (1991). In vitro organic matter digestibility (IVOMD) was determined by the method based on Tilley and Terry, (1963). The Metabolizable energy of forages were calculated using the regression equation given in AFRC (1993)

$$ME\ (MJ/kg\ DM) = 2.63 + 0.109 * IVOMD$$

Where IVOM = In vitro Organic matter digestibility (%)

Body weights and body condition scores and estimates of exotic blood levels

Body weights of 157 lactating animals were estimated by heart girth measurement. Body condition score were done on a scale of 1-5 by the method of Edmondson et al. (1989) where 1 is severe under-conditioning and 5 being severe over-conditioning. Estimates of the extent of exotic blood level in 393 mature heifers and 25 bulls owned by visited farmers based on farmers memory of the description of bulls use used, or other means of breeding (AI) and personal observations of the body features.

RESULTS

Trends in milk yield production in Morogoro district (1994-1998)

From table one, it appears that the number of farmers as well as cows and milk produced increased substantially from 1994 to 1998. The number of milking cows was not recorded. Lactation yield per cow estimated based on the assumption that all cows were milking showed some big variations. Between 1994-1996 lactation yield was about 1400 L per cow. However, there was a sharp rise in 1996-1997 fiscal year (1667 L) followed by a drop to 1229 L in the following year.

Farmers bio-data

A total number of farmers visited was 122, with the total number of people in the families being 899 with an average of 7.4±2.39 people/household (Mean plus Standard Deviation). Family size, land holdings and cattle numbers and age distribution patterns in the various wards are shown in Table 2.

Table 2. Number and location of farms visited, family and plot sizes. Mean values given as Mean ± standard deviation of the mean

Ward	No. of farms	Family size	Plot size (acre)
Kihonda	16	6.4±2.06	0.8 ±0.27
Mazimbu	18	7.2±2.13	0.9±0.35
Mbuyuni	18	6.9±2.07	2.4±1.22
Mlimani	21	8.2±3.19	0.8±0.33
Forest	22	7.8±2.87	0.9±0.17
Kilakala	14	7.2±2.08	0.8±0.22
Bigwa	4	6.9±2.81	0.6 ±0.17
Kichangani	9	7.0±2.38	0.5±0.14

Mlimani and Forest wards had the highest number of people per family (8) while the rest of the wards had 6-7 people per family. Land holdings were usually very small (<1 acre) in most farms and only in Mbuyuni ward the average land holding per farm was about 2 acres.

About 89% of the interviewed farmers were also employed either by the Government or private companies in various capacities like accountants, teachers, doctors, soldiers and other administrative positions. The remaining 11% solely depended on the income from the dairy farms and most were retired civil servants. Women (wife) were mainly in charge to make follow up of the day to day operations in 50% of the farms, while men (husband) were in charge in 21.3% of the farms. Only 18% of the farms had both the woman (wife) and man (husband) sharing the responsibility of overseeing the day to day activities of the farm. The remaining farms had other family member as the responsible person to look into the day to day running of the farms. About ninety six percent of the surveyed farms depended on hired labourers who collected the feeds, fed and milked the animals and also cleaned the animal barns.

Animals and management practices

The total number of dairy cattle kept were 734 with an average of 6 head of cattle per household (range of 1-36 in all wards visited). Cattle distribution in the various visited farms is shown in Table 3. The type of cattle kept were crosses of Boran and/or local zebu cattle with exotic breeds mainly Friesian, Ayrshire, Simmentol and to a lesser extent Jersey. Mlimani ward had the highest average cattle number per farm (12) followed by Mazimbu and Forest (7), then Kihonda and Mbuyuin (6) while the remaining wards had 4-5 animals per farm.

Table 3. Cattle numbers and distribution in the various wards of Morogoro municipality covered during the survey.

		Cattle population					
		Age distribution			Total number and Average		
Ward	No. of farms	>3yrs	1-2yrs	<1yr	Total	Range/farm	Average/farm
Kihonda	16	54	12	26	92	2-16	5.5±3.53
Mazimbu	18	74	28	28	130	1-36	7.2±7.80
Mbuyuni	18	69	20	25	114	1-16	6.3±4.31
Mlimani	21	78	23	27	128	1-22	11.6±5.88
Forest	22	82	23	38	143	2-12	6.5±2.74
Kilakala	14	39	8	20	67	2-12	4.8±3.01
Bigwa	4	9	3	3	15	2-7	3.8±2.36
Kichangani	9	29	7	9	45	1-12	5.0±3.57

About 157 lactating cows in the surveyed farms were weighed using heart-girth measurement and also scored for body condition (Table 4). Mean weight of cows in the various wards ranged from 319± 15 to 437± 74 kg. The overall mean cow body weight for all farms was 400± 68.6 kg (Mean ± Standard deviation) with a range of 256-550 kg (Table 4). Mean body condition score was lowest in Bigwa (3.3± 0.05) and Forest (3.4± 0.10) while the remaining wards had cows with mean body condition of about 3.5. Their average body condition score for all farms covered during the survey was 3.5 ± 0.12 (Mean ± Standard deviation) with a range of 3.1- 4.0.

Table 4. Body weights and body condition scoring of some cows owned by smallholder farmers in the various wards of Morogoro covered during the survey. Values expressed as Mean±standard deviation of the mean.

			Body weight		Body condition score		
Farm location	No. of farms	Number of cows	Mean	Range	Mean	Range	Time of weighing and scoring
Mbuyuni	18	28	440±60	340-533	3.5±0.10	3.1-3.6	16-23/2/1999
Mlimani	21	38	389±52	288-503	3.5±0.18	3.1-4.0	24-31/2/1999
Forest	22	38	377±71	256-506	3.4±0.10	3.2-3.6	2-10/3/1999
Kilakala	14	11	386±42	344-455	3.5±0.08	3.4-3.6	11-15/4/1999
Bigwa	4	4	319±15	300-332	3.3±0.05	3.3-3.4	16/03/99
Kichangani	9	5	401±93	300-550	3.5±0.05	3.4-3.5	17-18/3/1999
Kihonda	16	19	437±74	350-550	3.5±0.06	3.4-3.6	19-24/3/1999
Mazimbu	18	14	401±62	330-500	3.5±0.07	3.3-3.6	25-31/3/1999

The estimates of levels of exotic blood in a total of 393 mature heifers and cows and 25 breeding bulls in the surveyed farms showed a very big variation (Table 5). However, majorities of the animals were estimated to have exotic (mainly Friesian or Ayrshire) blood level of between 45-50%.

Table 5 Estimated blood levels of mature heifers, cows and bulls owned by smallholder farmers visited during the survey

Number and type of animals	%of number total assessed	Exotic blood level (%) (Friesian or Ayrshire)
Number of Heifers and cows		
45	12	30-40
280	71	45-50
55	14	55-70
13	3	>75
Number of Breeding bulls		
5	20	60-75
20	80	30-50

Of the surveyed farms, 73, 24 and 3% practised completely zero grazing, partial grazing and full time grazing respectively. Table 6 indicates the variety of livestock owned by the respondents that included cattle, chicken, goats, pig and sheep in decreasing order of importance.

Table 6. Number and types of livestock reared by the surveyed households in Morogoro.

Type of livestock	Number of Farmers	Number of livestock	Average/farm
Cattle	122	734	6.0
Local chicken	53	491	9.3
Commercial chicken	14	2737	196
Goats	37	395	10.7
Pig	21	371	17.7
Sheep	5	20	4.0

When asked about their future plans, 32.8% of the visited farmers wanted to maintain their current number of cattle, 24.6% wanted to reduce their number of cattle in favour of fewer but highly yielding ones while 42.6% wanted to increase their current number of cattle. The land/premises where animals were kept varied from individually owned plots (55.7% of the visited farms) to rented premises (44.3% of the visited farms). Nearly 90% of the plots in the surveyed area were less than one acre in size (Table 2).

Basal forage

The major forage species fed to animals were *Cynodon spp, Hyperrhenia rufa, Panicum maximum, Pannisetum purpureum, Urochloa spp and Neotonia wightii.* Table 7 shows chemical composition of some forage species used by small holder farmers during the survey period together with their chemical composition. The CP content of the forages ranged from 16.4 with *Pennisetum purpurium* to 3.8% in *Borthochloa spp.* Crude fibre content ranged from 26 in *Urochloa mosambincesis* to 42.6 % in *Chloris guyana.* The NDF contents were high in almost all the forages ranging between 78.3 (*Chloris guyana*) and 55% (*Microptilium atropuperium*).

Table 7. The chemical composition and in vitro organic matter digestibility (IVOMD) for forage species that form the basal diet of cattle in Morogoro.

Type of grass/legume		Composition, %DM							
Latin name	Common name	CP	Crude fibre	NDF	ADF	Lignin	Ca	P	IVOMD
Grasses									
[1]*Pennisetum purpurium*	Elephant/Napier grass	16.2	31.8	60.3	34.1	3.4	0.33	0.3	53.9
[1]*Tripascum fasciculatum*	Guatemala grass	16.4	33.5	63.9	35.3	3.2	0.1	0.3	51.9
[3]*Chloris guyana*	Rhodes grass	5.5	42.6	78.4	44.3	6.4	0.2	0.1	43.9
[3]Hperrhenia rufa	Thatching grass	4.03	35.9	72.1	43.7	9.7	0.5	0.1	56.6
[3]Borthochloa spp	Pinhole grass	3.8	38.3	69.5	43.0	7.4	0.4	0.1	21.0
[2]*Cynodon dactylon*	Star grass	8.9	33.0	67.5	36.4	6.6	0.4	0.1	36.6
[2]*Urochloa mosambicensis*	Sabi grass	14.9	26.0	73.4	39.8	-	0.3	0.2	49.5
Legume									
[2]*Microptilium atropurperium*	Siratro	13.0	41.7	55.4	43.2	8.7	0.7	0.1	65.3

[1]Harvested at pre-bloom growth stage
[2]Harvested at mature stage (post bloom)
[3]Harvested at advance stage of maturity (standing hay)

The ADF content varied less between the grasses (34.1-44.3%). Lignin content was highest in *Hyperrhenia rufa* (9.7%) and lowest *Pennisetum purpurium* (3.4%). All the forages showed some variations in the content of Calcium (Ca) and Phosphorous (P) ranging from 0.13-0.71% (Ca) and 0.07-0.29% (P). The in vitro organic matter digestibility was also variable. It was highest in *Microptilium atropurperium* (65.3%) and lowest in *Brothrochloa spp* (21%).

The distance travelled in search of fodder varies greatly depending on weather, farm location and the means of transport at hand (see Table 8). Some farmers went as far as 35km in search of fodder during the dry season. Owning a vehicle, especially a pick-up or a truck was found to be an added advantage. About 48% of the families owned a motor vehicle, 54% a bicycle, 3% a motorcycle, and 4% a human drawn cart locally called "mikokoteni". The rest depended on trading on foot in search of feeds or used hired means of transport.

Table 8. Distances to the forage sources during the rainy and dry seasons. Mean values given as Mean ± standard deviation of the mean

		Distance to forage source (km)			
		Rainy period (March-June)		Dry period (July-February)	
Farm location	No. of farms	Mean	Range	Mean	Range
Kihonda	18	3.0±1.06	2-5	10.0±3.69	4-15
Mazimbu	21	3.0±1.15	1-5	8.2±5.21	3-20
Mbuyuni	22	2.1±0.90	1-5	10.2±5.71	3-20
Mlimani	14	1.8±1.08	1-5	13.8±9.34	3-35
Forest	4	2.6±1.76	1-8	12.9±6.76	5-24
Kilakala	9	2.0±1.07	1-4	8.0±4.39	3-20
Bigwa	16	1.3±0.50	1-2	8.5±5.07	4-15
Kichangani	18	2.4±1.24	1-4	12.0±14.71	3-50

Forty five percent of farmers used energy rich supplements (Table 9) mainly maize bran given to cows during milking. Another 40.2% occasionally gave little amount of nitrogen supplements mainly cottonseed cake and sunflower cake while 14.8% rarely gave any supplement. Only 14% of the farmers occasionally gave molasses to animals when feeding maize stovers and/or rice straw.

Veterinary services

About 39% of the farms had easy access to and frequently used veterinary services from the district and/or ward headquarters as well as from Soikone University of Agriculture. It was found that 93% of the surveyed farmers routinely de-wormed their animals and also provided prophylactic treatment against trypanosomosis at three months interval. The most common diseases and disease conditions affecting their animals with the affected farms in bracket were: None in particular (63%), mastitis (11.5%), East Cost Fever (10%), trypanosomosis (3%), worms (3%), abortions (5%), infertility (4%) and foot-rot (2%).

Animal management and production

Animal barns were ranked according to mode of construction, space per animal, roof and general cleanliness as good, satisfactory or poor. Twenty three percent were found to be good, 64.8% satisfactory and 12.2% poor. Only 50.8% had separate calf unit, the remaining kept the calves in the same barn with mature animals.

About fifty three of the surveyed farms practised bucket feeding while the rest allowed the calf to suckle from the dam after milking (Table 9). Twenty-six farmers reported calf mortality in the past three years. Twenty-nine calves out of 384 born in the last three years (1997-1999) in farms practising bucket feeding died. At the same time 7 calves out of 348 born in farms that allowed the calves to suckle from the dam died. No records were available to show the age at which the calves were dying, but most farmers estimated most deaths occurred between 1-4 months of age. The overall reported calf mortality during that period (5%) was surprisingly very low. However, 4% of the mortality occurred in farms that practised bucket feeding while the remaining 1% occurred in farms that allowed calves to suckle from the dam.

Table 9. Calf rearing, supplementation and breeding policy at the various visited farms in Morogoro Municipality

	Farms	% of total farms visited
Calf feeding		
Suckling	58	47.5
Bucket	64	52.5
Weaning age		
3-4 months	82	67.2
5-6 months	35	28.7
>6	5	4.1
Type of supplements		
Bran only	55	45
Bran and others	49	40.2
None	18	14.8
Breeding		
Own bull	25	20.5
Hired bull	85	49.7
AI	7	5.7
AI and bulls	5	4.1

Around ninety three percent of the surveyed farms had record keeping books mainly showing treatment and birth records. Shown in Table 10 are yields reported by farmers in the visited wards during wet and dry season. Mean milk yields varied greatly during the rainy period (9-12 L/day/cow) and also during the dry season (6-9 L/day/cow) in the various farms covered during the survey (Table 10). Highest mean yield per cow/ward during the wet season was reported in Mlimani (12 L/day/cow) while highest yield during the dry season was reported in Bigwa (8.5 L/day/cow). Overall mean daily milk yields per cow per day were 10.5±3.84 and 6.6±3.12 L during the wet and dry season respectively at 3-4 months post calving.

Table 10. Reported milk yields during the wet and dry seasons by cows owned by smallholders interviewed during the survey. Mean values given as Mean ± standard deviation of the mean

		Milk yield per cow (l) 3-4 months post calving			
		Rainy period (March-June)		Dry period (July-February)	
Farm location	No. of farms	Mean	Range	Mean	Range
Kihonda	18	10.9±3.67	5-18	6.0±2.96	2-10
Mazimbu	21	11.4±4.31	5-20	7.2±2.78	2-13
Mbuyuni	22	12.2±3.49	6-20	7.4±2.83	2-12
Mlimani	14	10.4±3.71	4-20	6.4±3.51	2-16
Forest	4	9.5±4.14	3-20	5.9±2.71	2-12
Kilakala	9	10.2±3.51	5-16	7.9±3.62	2-14
Bigwa	16	9.3±5.12	2-14	8.5±5.00	2-14
Kichangani	18	8.8±3.23	5-15	4.7±1.5	2-7

The average amount of milk consumed at home was 2.1±0.91l/day. The disposal of excess milk was either by customers who bought it at farmer's homes or sold outside (farmers') household e.g. local shops, customers' homes, hotels, restaurants and milk collection centres. Despite the presence of milk collection centres (2) in Morogoro (Mojata and Morogoro milk centres) only 11.5% of the farmers recalled selling milk to the privately owned milk centres.

The distribution of mature heifers, cows and bulls in the surveyed area was as shown in Table 11.

Table 11. The distribution of breeding bulls and female animals (heifers of breeding age and cows) the various wards covered during the survey.

Ward	No. of farms	No. of mature heifers and cows	Number of bulls	Ratio of bull to females
Kihonda	18	48	4	1:12
Mazimbu	21	63	6	1:11
Mbuyuni	22	64	4	1:16
Mlimani	14	72	5	1:14
Forest	4	75	4	1:19
Kilakala	9	37	1	1:37
Bigwa	16	9	0	0
Kichangani	18	25	1	1:25
Total	122	393	25	1:15

The overall ratio of bull to females was not bad as it was within the recommended level of 5-8% bulls in a herd in the tropics (Pyne and Wilson, 1999). However, the distribution of bulls was not even. None of the visited farmers in Bigwa had a bull and there were a high number of females to bull in Kichangani and Kilakala. Farmers that owned breeding bulls

(21% of total visited) also charged other farmers whom brought their cows for service. The charges ranged from 0-5,000 Tsh per service. However, most bulls were not of high quality with 80% of them having exotic blood level of between 30-50%. Only 4% of the farms solely depended on artificial insemination (AI) (Table 9) available from Sokoine University of Agriculture at a cost of 3000-5000Tshs per insemination.

Use of manure

It was found that 45% of the farm owners in the surveyed area owned maize farms (1-10 acres), and 70% owned vegetable gardens (0.25-1 acre). Only 2 farmers had problems of manure pile up. Most farmers used the manure as fertiliser in their farms. Two farmers owned biogas plants.

Annual variations in forage quality

The changes dry matter contents (DM) of the forages and rainfall is indicated in Figure 1. DM of the freshly cut forage was low the rainy period (March-July).

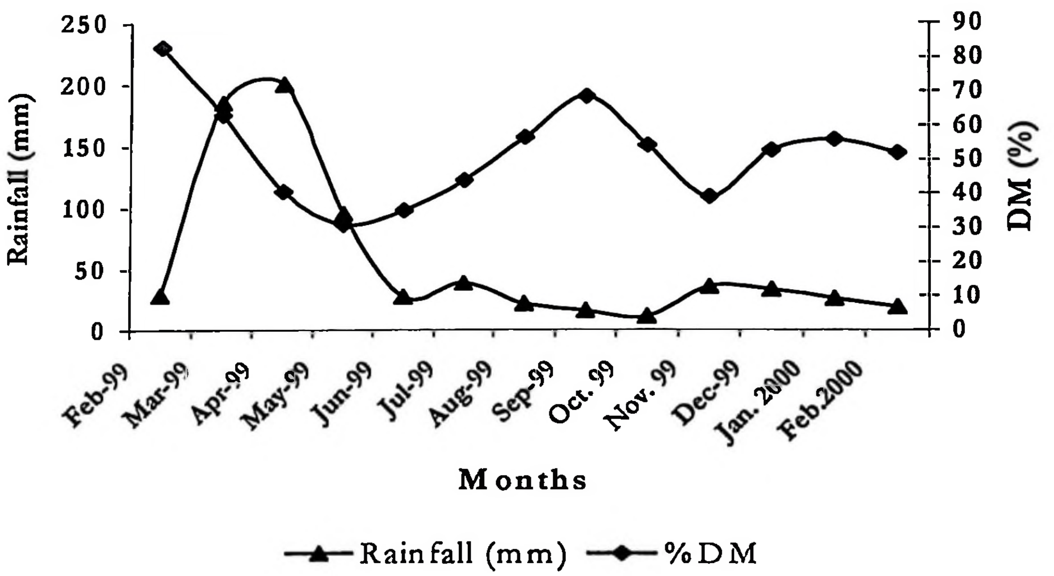

Figure 1. Changes in the DM of forage with rainfall between February 1999 to February 2000.

DM increased with decreasing amount of rainfall period reaching the highest level in September at the peak of dry season. At the onset of short rains in October and November DM of forages dropped to some degree.

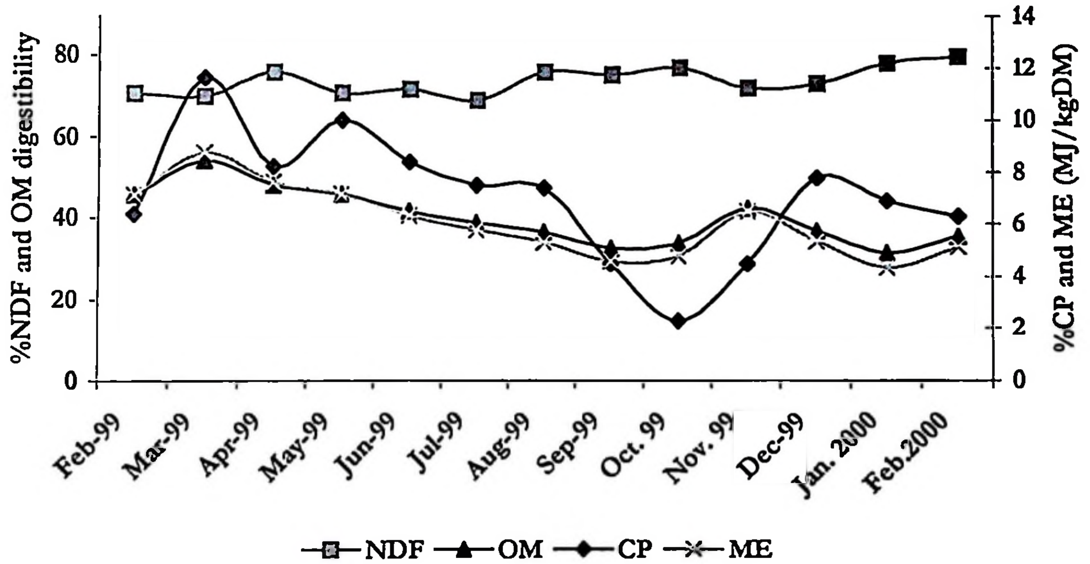

Figure 2. Annual changes in NDF and CP (% of DM), OM digestibility and ME content of forages used by smallholder farmers in Morogoro.

Shown in Figure 2 are the annual variations in the NDF and CP contents of forages as well as the organic matter digestibility and the Metabolisable energy content. Great variations were noted in the NDF content of the forages. The percent NDF values ranged from 80.0 (February 2000) to 69.2% (July 1999). Highest CP content was obtained in March 1999 (11.6) and the lowest CP content occurred in October 1999 (2.3%). There was a slight rise in the CP content of forages collected in November to December due to the sprouting of grasses following the short rains during that period. The in vitro organic matter digestibility was highest in the samples collected in March 1999 (54.2) and lowest for samples collected in January 2000 (31.7%). The energy value for forages varied accordingly with the highest value of 8.8 MJ/kg DM (March1999) and the lowest value of 4.4 MJ/kg DM in January 2000.

DISCUSSION

The survey revealed that urban livestock keeping in Morogoro was on the increase. The indicated by the data obtained from Morogoro district veterinary office (Table 1) clearly showed an increase in the number of farmers and cattle with time. The low mean lactation yield figures, and the flanctuations observed in that period were not out of expectation. The amount milk reaching the market in Morogoro district is influenced from time to time by some limited supplies from Maasai pastoralists who keep the local Zebu cattle under extensive traditional grazing system. The pastoralists on their trek for search of pastures sometimes camp in some areas of Morogoro district and some surplus milk from the Maasai community enters the market. This also explains the apparently lower lactation yield for

Morogoro district (1229 L) compared to the value calculated using data collected among the smallholders in the urban and peri-urban areas of Morogoro district (2377 L) during the survey period.

Dairy keeping is seen by those engaged in it as a means of generating extra income to supplement the salaries of the farm owners most of whom were also Government or private company employees. The initial capital required to buy animals and construction of barns can be substantial. For example, a crossbred heifer of breeding age was selling for between 150,000-200,000Tsh (about 190-250 USD) during the time when the survey was carried out. This was rather expensive when one considers that annual income per person (per capita) in Tanzania was estimated to be 500USD during the time of this study. Thus, employment by the Government or private company offers opportunity for savings from the monthly salaries, easy access to credit facilities and retirement benefits. Other contributing factors to the rise in urban dairy farming included the rise in the number of people per family. This is partly a result of increased child birth rates and survival in towns as well as youth migration from the rural to urban areas in search of 'brighter' future. The presence of reliable veterinary and extension services and the availability of a ready market for the products and sometimes subsidised inputs (Holden and Cappock, 1992) are some of the other driving forces to increased urban livestock keeping.

The fact that women were playing a bigger role in running most dairy enterprises was a strong pointer in the change of attitude in the intra-domestic dynamics in property owning and income generation. Women these days are striving to increase the household incomes through small projects especially livestock keeping (Mdoe, 1993). The finding that 95.9% of the households depended on hired labour, mostly youths, was a good pointer to the contribution of the livestock enterprises in job creation (Mdoe and Mlangwa, 1997). As seen earlier, most farmers had salaried employment outside the homestead and therefore most of the farm work had to be done by hired labourers. However, these labourers were highly underpaid, with most being paid well below the minimum wage stipulated by the Government.

The average milk yield per cow per day per cow during wet (10.5 L) and dry was rather good given the fact that most animals were crossbreeds. However, with better nutrition, the milk yields during the dry season can be increased. Using the overall mean daily yield per cow in this study (8.6 L) it was possible to estimate mean lactation yield in the urban and peri-urban dairy farmers in Morogoro assuming a lactation length of 278 days for crossbred animals with 50% exotic blood (Pyne and Wilson, 1999). Mean lactation yield of the cows owned by visited farms was estimated to be 2377 L that was slightly lower than the average yield (2500 L) in smallholder dairy cows in Tanzania (Tanzania Agriculture, 1994). In a review of various sources of data on dairy production systems in Tanzania, Kishinhi (1999) estimated lactation yield of 2060 L at 335.5 days lactation length in smallholder dairy production system. The difference in the reported figures may be due to the differences in sample sizes, the levels of crossing of the animals, and lactation lengths used to arrive to the figures. The average body condition score (3.5 ± 0.12) in this study was far higher than that of animals used by Plaizier et al. (1998) (2.9 ± 0.12) which belonged to an institution in Morogoro. The observed differences were possibly a reflection of the higher efficiency and keenness by the smallholder farmers.

The average number of cattle per household differed between farms located in the various wards (Table 3). The overall average number of heads of cattle (6) per household was found to be rather high relative to the space and the difficulties of feed acquisition. Surprisingly, a greater number of farmers were interested to increase the number of the animals. The idea of having a large herd of cattle as a wealth status symbol and 'living bank', which is very common in the traditional sector, was probably gaining ground among the 'elite' urban and peri-urban farmers. Farmers that practised partial grazing (PG) and full time grazing (FG) (23.8 and 3.3% respectively) were very few. This may have been a reflection the dwindling grazing land as more and more land was used for building construction. There was also a high possibility that the urban by-laws that restricts roaming about of animals and the heavy penalties imposed on defaulters may have greatly discouraged the two systems.

It appeared that some forage species analysed were of good quality when harvested at an early growth stage. For optimal animal performance, the level of crude protein content in pasture had to be at least above 7%. This can be achieved if the forages are cut young or a good combination of mature grasses and legumes. Unfortunately, legume species were very rarely encountered during sampling, with *Microptilium atropurperium* sampled at a time when its CP content was not very high (13%). The changes in forage quality with time have been widely reported (Kidunda, 1988; Nkya et al., 1998). This was also clearly demonstrated in Figures 1 and 2. During the dry season, CP content in the pastures was low and DM was high due to increasing maturity of the pastures leading to higher cell wall content (NDF) and lignin, low CP and Metabolisable energy contents and an overall poor organic matter digestibility. This underscores the importance of nitrogen supplementation to dairy cows in Morogoro especially during the dry season.

The distance covered in search of forage varied depending on the farm location and also with season (Table 4). Farms located in areas with open grounds that are not yet developed (e.g. Bigwa) had some advantage in terms of acquisition of forage. Even the change in milk yield during the dry season was not as drastic in such areas compared to the other areas. As dry season advances, the quantity of forage falls as well, making it necessary to trek long distances in search of fodder. Farmers that owned means of transport were not very badly affected during dry spells since they could obtain fodder from as far as 35 km from the farms. It was not clear whether the increased cost of fuel could be recovered from sales of products. However, 62% of the farmers in the surveyed area indicated that they were able to break even.

Despite the fact that about 45% of the farm owners cultivated maize crop, the use of maize stovers as animal feed was not very common. This might be due to the fact that most maize plots were located in the outskirts of the town far from where the animals were kept.

The common practice of harvesting maize when the cobs are extremely dry makes it hard to transport the stovers due to bulkiness and shattering of the extremely dry leafy parts that are the most valuable component. Logistics of transportation of maize stovers from where maize is cultivated to the place where dairy animals are kept is also a common problem in other places of Tanzania such as Kilimanjaro and Arusha (Massawe et al., 1998). Therefore, even though some farmers could go as far as 35 km in search of fodder, they opt to carry green natural grasses from river and dam basins which though very mature, are slightly of better quality and more can be carried compared to stovers.

Ironically, farmers were not willing to give more supplements and properly formulated concentrates to the animals due to what they considered as high cost. Nkya et al. (1998) had similar observation in their work with smallholder farmers in Morogoro. Farmers tended to find it hard to invest more cash to feed the animals properly especially in the provision extra sources of nitrogen (protein) so as to generate more profits from higher yields. This is one area where continued education and demonstrations need to be directed to. One way of going round the cost issue may be to assisting farmers to concentrates at farm level using cheaply available local sources of energy such as maize bran and sunflower cake which are easily available in Morogoro or cottonseed cake. The use of leguminous plants like *Leucaena leucophala* (Shem, 1996) is another option though adequate spaces to establish the trees might limit their wide use with farmers in urban areas. There is also a possibility of using urea directly or in form of multi-nutrient blocks (molasses urea mineral blocks) (Plaizier et al., 1998). More efforts are needed to produce such blocks en masse at a reasonably fair price and educating farmers on the proper use of such products so as to avoid toxicity to animals.

Smallholder farmers were found to be keen on routine de-worming, prophylactic treatment against trypanosome and prompt seeking of veterinary services when necessary. However, this study revealed that, most farmers paid little attention on the importance of having a properly constructed separate calf-rearing unit. Thus, calves were easily prone to pneumonia, diarrhoea, worms, kicking and trampling by mature animals. It is surprising that farmers reported rather very low calf mortality (5%) given the conditions under which calves were reared. Perhaps their keenness to ensure the calf suckles the colostrum for three days post calving gave some degree of protection to the calves. Farms that practised bucket feeding were more prone to calf deaths. This could imply that calves were given cold milk in dirty containers or were given too little milk due to big temptation to sell as much milk as possible.

The major causes of infertility among the animals were difficulties in heat detection and the unreliability of bull/or artificial insemination (AI) services. As indicated in Table 11, there was uneven distribution of breeding bulls among the various wards and also most bulls were of poor quality. Even charges of bull and AI services for farmers who did not own bulls seemed rather high. These factors led to many animals being left open for a long time thereby leading to long calving intervals and low productivity. For the farmers that had bulls, problems related to inbreeding were also eminent. Thus, it was obvious that farmers greatly needed assistance to be able to carry out well defined breeding policy with specific objectives of obtaining improved and disease and climate tolerant animals. F1 crosses (50% exotic and 50% local blood) would be the best breed given the relatively higher feed and management requirements with increasing percentage of exotic blood.

Animal housing was an area that appeared not given proper consideration by most visited farmers. It was observed that most animal barns were poorly constructed and very close to residential housing units. This predisposed the people living in the nearby houses to fly nuisance, diseases, bad smells from manure and effluents, and soiled and littered surroundings.

The marketing of dairy products (mainly fresh milk) was an area that lacked cohesion. Farmers complained that proprietors of milk collection centres were exploiting them. Apart from the stringent conditions for acceptance of milk, the price (150 Tsh/l) was far too low compared to the price of 250-300 Tsh per litre when farmers sell milk directly to consumers. No wonder most farmers preferred to sell their milk directly to consumers and only sold to the collection centres when they had no other alternative. This led to below capacity operation of milk collection centres. That said, it must be pointed out that there was a strong need of establishing a milk collecting and processing plant in Morogoro. The now common practice of selling milk directly to consumers is a big health risk to consumers especially if the milk is not properly boiled before consumption.

With all the visited households being engaged in crop (maize) and gardening, the use of manure as a fertiliser was common and thus only two farmers had problems with manure pile-up. Crop residues, weeds and waste vegetables cultivated near the homesteads were also used to feed animals thereby ensuring efficient nutrient re-cycling. Another phenomena that was increasingly becoming popular was the use of cow dung to produce bio-gas thereby cutting significantly household electricity bills (Lekule, 1998. Personal communication). The use of biogas is becoming more and more popular among smallholder farmers in many parts of Tanzania due to the advantages of alleviating the workload on women who had to collect firewood, cultivate the fields and look for the children (Rutamu, 1999). It is also helps in environmental conservation in the drastic reduction of forest destruction for firewood and charcoal.

CONCLUSION

This study has shown that livestock keeping and especially dairy animals were on increase with many people engaged in it. It appeared that smallholder urban and peri-urban livestock producers will continue to play a vital role of meeting the high demand of animal products to urban dwellers for years to come. Therefore efforts need to be directed in solving some of the major problems hindering increased productivity such as provision of nitrogen and energy supplements that will address to the nutritional deficiencies in the poor quality basal forage particularly during the dry season. Participatory education to farmers to keep fewer but properly fed improved animals will lead to not only increased household incomes but also will contribute greatly to the Nation's efforts to be self sufficient in dairy products.

Breeding problems can be addressed by assisting farmers to get access to good quality bull services. Alternatively, improvement of delivery of reliable AI services to farmers will be a great and will cut the costs of keeping bulls in the farms. Encouraging private investors as well as revitalising the services currently available at Sokoine University of Agriculture can do this. The exotic blood level of the crosses needs to be maintained at around 50% with the current level of management and feeding. Further genetical improvements can be done only where high management and better nutrition is possible. For example some full time smallholder farmers and private companies with ability to invest in land, pasture development and supplementary feeds may be able meet the requirements of such improved breeds.

In future, urban planning need to include areas with big plots designated to interested small to medium scale dairy production so as to keep such activity a bit away from the congested human dwelling areas. There is also a need to investigate the impact of increased livestock keeping in towns on the urban dwellers health status especially with diseases that can be directly transmitted from animals to man (zoonoses) and those that are spread by insect flies that multiply in soiled wet environments.

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Paper II

The effect of source and level of nitrogen supplementation on intake, rumen fermentation and plant fibre kinetics in animals fed poor quality hay.

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Abstract

The effect of nitrogen supplementation of poor quality hay on dry matter (DM) intake and digestibility, rumen fermentation and plant fibre kinetics was investigated using 5 ruminally fistulated mature heifers (1/2 Boran x 1/2 Friesian). The experimental set-up was 5x5 Latin square with 5 treatments and five periods of 28 days each. In each period, 14 days were for adaptation to treatments, 7 days in vivo digestibility trial and rumen fluid sampling, and the last week used for three rumen evacuations. The treatments were: Poor quality hay only (HO) which was the control, hay with low urea (32g/day) level (HLU), hay with high urea (64g/day) level (HHU), hay with low soyabean cake (210g DM/day) (HLS), hay with high (420g DM/day) soyabean cake (HHS). At a given level of supplementation, urea and soyabean cake was iso-nitrogenous. Hay was provided ad libitum with 10-15% refusal. Drinking water was provided ad libitum through automatic drinkers coupled to water flow meters.

It was found that nitrogen supplementation led to significant increases in DM and OM intake and digestibility. Nitrogen retention and microbial protein synthesis were also significantly improved with nitrogen supplementation.

Mean daily ruminal fluid ammonia (mg N/100mL) was also influenced by supplementation with urea showing significantly ($P<0.001$) higher values compared to other treatments. Mean daily ruminal fluid pH seemed not to be significantly affected by treatments. Ruminal fluid total volatile fatty acids (mM) increased with N supplementation and was significantly ($P<0.05$) higher in HHS compared to the control

Both urea and soyabean cake significantly improved both the rate ($P=0.05$) and extent of DNDF digestibility ($P=0.01$) compared to the control.

In conclusion, nitrogen supplementation of poor quality hay greatly improved the intake and digestibility of DM, OM, NDF and microbial protein synthesis. Supplementation with soyabean cake was superior to urea in most aspects except for plant fibre digestibility where urea showed numerically (not significant) higher value compared to soyabean cake.

Key words: Low quality hay, intake, digestibility urea, soyabean cake, supplementation, fermentation, microbial protein, NDF kinetics

INTRODUCTION

Poor quality forages are in most cases the sole diets of ruminants in the tropics (Jackson, 1981) especially during the dry season. The low nitrogen content and to a lesser extent energy; minerals and vitamins (Chamberlain, 1989) are the most limiting factors to their intake and digestibility in ruminants. The deficiency of these essential nutrients necessary for efficient microbial growth lead to low rates and extent of digestion in the rumen of forages deficient in nutrients (Minson, 1982). This in turn cause reduced voluntary feed intake (VFI) thereby causing very low animal performance (Leng, 1990; Goodchild and McMeniman, 1994; Wilson and Kennedy, 1996).

One major limiting nutrient with low quality forages is nitrogen that is needed by microbes for growth and digestion of feed constituents (Goodchild and McMeniman, 1994). It has been estimated that in tropical forages the ratio of digestible organic matter to nitrogen falls very drastically as they mature (Butterworth, 1967). Low quality forages usually have less than 80 g CP/kg and a high proportion of cell wall carbohydrates, low proportion of soluble cellular components and organic matter (OM) digestibility of between 40-50% (Leng, 1990).

An adequate nitrogen supply to the rumen microbes is very important for maximal rate of digestion of the carbohydrates supplied with the feed as well as high microbial protein synthesis (Madsen and Hvelplund, 1988). It has been reported that ruminants fed low quality forages when adequately supplemented with the deficient nutrients can attain or even surpass high feed conversion efficiency compared to animals feed high quality forages (Preston and Leng, 1987). Therefore, research efforts in the areas where poor quality forages is a major basal diet to ruminants should put great emphasis on devising appropriate supplementation strategies in order to ensure a balance of the nutrients required by the animal and its microbes for optimal performance (Leng, 1990).

Optimisation of microbial protein synthesis with animals fed low quality forages is of utmost importance, since the animals' amino acid requirements are almost 100% supplied by microbial protein as almost no by-pass protein is available from the basal feeds. Nitrogen supplementation can be achieved either through the use of non-protein nitrogen (NPN) like urea, ammonia and biuret, or from true proteins (Hvelplund and Madsen, 1990; Ørskov, 1992; MacDonald et al., 1995). The effect of nitrogen supplement on rumen functions differs with respect to the source, which in a way also influences the rate and extent of protein degradation in the rumen as well as to the amount offered (Chen et al., 1987). Many reports show that true proteins are superior to NPN in improving intake and digestibility of poor quality forages (Hemsley, 1968; Church and Santos, 1981; Argyle and Baldwin, 1989; Ben-Gedalia and Yosef, 1989). Previously, this superiority was attributed to specific requirement of amino acids and peptides by cellulolytic bacteria or the effect of branched chain fatty acids resulting from deamination of amino acids (Hemsley and Moir, 1963). However, this explanation has not been fully accepted in all instances (Leng, 1990; Maeng et al., 1989; Silva and Ørskov, 1988). There is a feeling that perhaps the amount of protein that by-pass the rumen, provides the animal with extra amino acids that tip the balance in favour of true proteins (Leng, 1990).

Against this background of apparently conflicting findings and the need to investigate further animal responses to diets deficient in nitrogen (Madsen et al., 1997), this experiment was set. The main objective of this study was to observe responses in feed intake, digestibility, rumen function, N-balance and plant fibre kinetics in animals fed poor quality forage supplemented with N from either urea or soyabean cake.

MATERIALS AND METHODS

Animals feeds and feeding

Five-rumen fistulated, mature non-pregnant crossbred heifers (1/2 Boran and 1/2 Friesian) were used in 5 x 5 Latin square. The animals were weighed at the beginning of the experiment (IBW) and at the end of each period (FBW). The experimental period lasted for 28 days including 14 days of preliminary period followed by 7 days VFI, in vivo and in situ digestibility determinations and 7 days used for rumen evacuations. Five (5) treatments were compared (Table 1).

Table 1 Type and amounts of nitrogen supplements given to the animals

	Treatments				
Supplements (g/day)	HO	HLU	HHU	HLS	HHS
Urea	-	32.0	64.0	-	-
Soya	-	-	-	210	420
Sodium sulphate	-	11.2	22.4	-	-
Mineral powder	50	50	50	50	50

HO: hay only; HLU: hay low urea; HHU: hay high urea; HLS: hay low soyabean cake; HHS: hay high soyabean cake

Treatments were hay only (HO) (control), hay with low (32g/day) urea level (HLU), hay with high (64g/day) urea level (HHU), hay with low (210g DM/day) soyabean cake, hay with high (420g DM/day) soyabean cake (HHS). At a given level of supplementation, urea and soyabean cake was iso-nitrogenous. With urea, sodium sulphate was also included so as to give N: S ratio of 10:1 (Silva and Ørskov, 1988).

Poor quality mixed hay cut at an advanced stage of maturity was purchased from Mpwapwa in Dodoma region. The predominant plant species in the hay were *Cynodon dactylon* and *Panicum maximum*.

The hay was chopped to small size using a hand-machete to minimise selection. The animals were fed individually ad libitum. Feeding was adjusted everyday to be 10-15 % in excess of the ad libitum intake using the previous day level of intake. Half of the estimated daily hay and supplements for each animal were given at 7.30 in the morning and the remaining half was given at 4pm in the evening. All feeds and orts were weighed daily, sampled, and prepared for subsequent analyses. The DM determination was carried out everyday in both feeds and orts. Fresh and clean water was provided from the automatic drinkers system equipped with flow meters where record was read at 8.00 each morning. The difference between consecutive meter readings reflected the water intake (l) in a given day by the respective animal.

Urea mixed with sodium sulphate and mineral powder was put directly into the rumen through the cannula

Faeces and urine collection

Faecal materials were collected manually from 7 am in the morning to seven 7am the next day when it was weighed to get the amount of fresh fecal material voided per day for each animal. Then, the fecal material for each animal was thoroughly mixed in large plastic basins and a 5% sample taken. The samples were immediately deep-frozen at –15°C. At the end of the collection period (7 days), samples were de-frozen and pooled for each animal. The pooled samples were then thoroughly mixed and a sub-sample of 500 g taken for each animal. The samples were oven dried at 60 °C spread on wide round aluminium pans (30 cm diameter) to constant weight to determine DM. Samples intended for rumen incubation were then ground through a 2.0 mm sieve and those for other chemical analyses were ground through 1 mm sieve.

Daily urine output was done by the use of special urine funnels held onto the vulva. Each funnel was linked by a pliable tube to big collecting plastic container (50l capacity) where 500ml of 17% sulphuric acid was initially added to maintain the urine pH values below 3. Acidification of the urine was important to avoid microbial destruction of purine derivatives. Values of purine derivatives obtained in the assay were correction for the dilution effect of the acid added. About 2% of daily collection for each cow was sampled and filtered through two layers of surgical gauze to remove large particles. Daily samples were then deep frozen at –20°C and at the end of the collection period, thawed and bulked for each animal. A sub-sample of 50ml per animal was taken and deep-frozen till the time for purine derivative assay.

Ruminal fluid pH, ammonia and Volatile Fatty Acids (VFAs) concentration

A day before the onset of rumen evacuation, 24h rumen fluid samples were taken for determination of diurnal variations in pH and ammonia concentrations.

The sampling times were at 7.30am (before morning feeding), 9 am, 12 noon, 15.00pm, 18.00pm, 21.00pm, 0.00 (Midnight) 3.00 am, 6.00 am and 8 am the next day. At the indicated sampling hours, materials from the ventral rumen sac were scooped by hand and squeezed through four layers of cheesecloth into a clean beaker. About 100ml of the liquid was taken. The pH was immediately taken using a portable pH meter. Then, 30mls of the fluid was decanted into a 50ml sample bottle and acidified to pH 4.0-4.5 by adding 3mls of 5M sulphuric acid to limit loss of ammonia from the sample. Corrections were made for the dilution effect of the 3ml sulphuric acid in the final estimates of ammonia and VFAs. Samples were put in an ice packed cool box and taken to the laboratory. In the laboratory, the samples were centrifuged at 3000 rev/min for 20 min so as to precipitate feed particles and the supernatant was put into 20ml test tubes, then deep frozen at –20 °C till the time for VFAs and ammonia assay.

The concentration of ammonia was estimated by a standard procedure as described by Chaney and Marbach (1962) using alkaline hypochlorite/phenol nitroprusside.

The concentration VFAs in the ruminal fluid were determined by using a gas chromatography (HP 6890 GC) coupled to peak integrator (HPGC Chemostation, Hewlett and Packard, 1990-1998) by the method by Richardson et al. (1989) with some minor modifications.

In situ degradability

The in situ degradability study was carried out simultaneously with intake and in vivo digestibility trials. Incubated feed was the basal hay and soyabean cake used during the trial. The feed samples were incubated on Day 16 and taken out before rumen evacuations started. Feeding regime and water supply were therefore similar to the intake trials. Forage samples were air dried and milled to pass through a 2mm screen. Rumen incubation times (h) were 0, 2, 4, 8, 16, 24, 48, 72, 96, 144 for hay and to a maximum of 72 h for soyabean cake. Approximately 1 g of hay and 5g for soyabean cake were incubated in nylon bags (measuring 7.5 x 10 cm and pore size 36 x 36 μm) in duplicate for each incubation time for DM degradation. All bags were inserted at the same time during morning feeding and taken out as scheduled, rinsed and frozen to arrest microbial activity. After the longest incubation time (144 and 72 hours for hay and soyabean cake respectively) all samples were machine washed in cold water for 20 min. Samples for DM were filtered through N-free filter paper of known weight. The residue was dried in an oven at 100°C for 20 h. Particle loss determination was carried out according to the procedures described by Weisbjerg et al. (1990). In sacco long incubation (21 days) was used to determine the INDF in feeds, rumen contents and faeces. Approximately 2 g of hay, rumen digesta and faecal samples and 10g of soyabean cake were weighed into nylon bags measuring 7.5 x 10 cm and pore size of 36 x 36 mm and incubated in the rumen of heifers for 21 days. The residues were transferred into a beaker and boiled in 100 ml of NDF solution to obtain the INDF residue. The residue was ashed in a furnace at 550 °C to obtain ash free INDF that was used to calculate the DNDF and INDF.

Measure of rumen pool size

Rumen pool size of NDF was measured by rumen evacuation method for 3 days during the last seven days of the experiments in accordance to Aitchinson et al. (1986), Dado and Allen (1995) and Stensig et al. (1998a). Evacuation protocols were such that a minimum time interval of 48 h between two evacuations was allowed to avoid any effect that might occur on subsequent measurements. Rumen evacuations were performed at 7.00 h (morning) on Day 24, at 12 noon (mid-day) on Day 27 and 17.00pm (afternoon) on Day 29. The rumen mat was removed from the rumen manually by hand and the material not removable by hand was removed by scooping with a cup that was small enough to pass through the rumen cannula. The mat fraction was separated from the bailable liquid and both fractions weighed. About 1 litre of the liquid was sampled and the rest was immediately returned to the rumen. The mat was weighed and thoroughly mixed in a big plastic basin. About 5% by weight were sampled, and the rest was returned into the rumen immediately. Finally the two samples were composted into their proportional weights to form two samples of 500 g each of the rumen digesta and the left over returned to their respective animal. The samples were oven dried at 60 °C spread on wide round aluminium pans (30 cm diameter) to constant weight to determine DM. Samples intended for rumen incubation were then ground through a 2.0 mm sieve and those for other chemical analyses were ground through 1 mm sieve.

Chemical analysis

Dry matter and organic matter analysis were carried out using the procedure as outlined by the AOAC (1990). All the samples analysed for NDF were done according to the methods described by Van Soest et al. (1991). In the analyses, however, sodium sulphite and α-amylase were omitted.

Allantoin in the urine samples was analysed based on use of spectrophotometer (Cecil Instruments Serial No. 125 142 Model CE 2041, Cecil Instruments Ltd. Milton Technical Centre, Cambridge, CB4 6AZ England), by the procedures outlined in FAO/IAEA (1997). Uric acid was determined by Uricase method as described by Fujihara et al. (1987). Total purine derivatives output (Y) was the sum of allantoin and uric acid as the contribution of xanthine and hypoxanthine in cattle to daily purine output is negligible (Verbic et al., 1990).

Calculations

Microbial protein synthesis from purine derivatives

Daily purine derivatives absorption (X) in mmoles per day was calculated based on the equation derived by Verbic et al. (1990):

$X = Y - (0.385W^{0.75})/0.85$

Where Y = Daily purine excretion in mmoles per day

W =Body weight in kg

X was then calculated from using the Y obtained from urine analysis and the weight (W) of the animals. Microbial N synthesis was then calculated as: Microbial N (gN/day) = X mmol/day *70/0.116*0.85*100 = 0.727X

The equation is based on four assumptions. (i) Digestibility of microbial purines of 0.85, (ii) the N content of purines is 70 mg N/mmol, (iii) Ratio of purine N to total N in mixed rumen microbes taken as 11.6:100 and (iv) Purine excretion in the cross-bred heifers will be similar to the temperate breeds from whom the equation was derived.

Metabolisable energy (ME), digestible nutrients and carbohydrates

These were done using from the chemical composition and the energy factors for protein (24.237), fat (34.116) and (17.300MJ/kg DM) for carbohydrates as was done by Weisbjerg and Hvelplund (1993).

Thus, Gross Energy (GE) was taken as the sum of individual contribution of feed components as shown below

GE CP = CP content (kg/kg DM) * 24.237MJ/kg DM

GE EE = EE content (kg/kg DM) * 34.116MJ/kgDM

GE CHO = CHO content (kg/kg DM) *17.3 MJ/kg DM

Where CP= crude protein, EE = ether extract and CHO = carbohydrates

Digestible energy was calculated from the digestibility of individual components in the feed multiplied by the respective energy factors as shown below:

Digested CP (kg/kg DM) = (93- (300/%CP in DM))* CP content (kg/kg DM)
Digested EE (kg/kg DM) = (96- (100/%EE in DM))* EE content (kg/kg DM)
Digested CHO was calculated as the difference between digested organic matter and the sum of the digested CP and digested EE
i. e. Digested CHO (kg/kg DM) = (dig OM-(dig CP + dig EE)
Thus digestible energy (DE) (MJ/kg DM) =(dig CP*24.237 +dig EE*34.116 + dig CHO*17.3)
Metabolisable energy (ME) MJ/kg DM) was obtained by multiplying the digestible energy by the factor 0.82 i.e. ME = 0.82*DE (MJ/kg DM)
Total digestible nutrients (TDN) was calculated as the sum of the digestible nutrients of all feed components as shown below
TDN (kg/kg DM) = dig CP + 2.25dig EE + dig CHO.

In sacco DM and N degradation

Degradation of DM and N from bags was calculated from the disappearance of the fractions from dacron bags after washing (zero hour) and for the respective incubation times according to the equation:

DF = (W1-WR)/W1

Where, DF = degradation of the fraction from the bags,
W1 = weight of the fraction incubated
WR = weight of the fraction in the residue

Degradation characteristics

Rumen degradability characteristics were calculated using the exponential equation by Ørskov and MacDonald (1979)

$Y(t) = a+b(1-e^{-ct})$

Where Y(t) =degradation at time t
a = water soluble part (intersection with Y-axis)
b = non-water soluble but potentially degradable fraction
c = part of b degraded per hour (rate constant)
t = incubation time in hours

The effective degradation (ED) was calculated using the equation

Y = a + (b (c/(c+k))

Where a, b and c are as explained in the equation above.
k = fractional passage rate
Y = effective degradation

Correction of particle losses from dacron bags

This was done as proposed by Weisbjerg et al. (1990) and Madsen et al. (1995) based on the assumption that the lost particles are degraded at the same rate as those remaining in the bag.

ED (corrected) = S + [(100-S)/100-L)] * (Y-L)
Where S = Water soluble fraction (%)
L = Washing losses (%)

Y = Uncorrected ED calculated from equation (%).

Metabolisable energy and protein requirements

Metabolisable energy and protein requirements were and using the following equations:
Metabolisable energy requirement for maintenance (MEm) = 8.3 + 0.091BWt (ARC, 1990)
Rumen degradable protein (RDP) (g/day) = 8.4 *ME (Topps and Oliver, 1993)
Where: MEm = ME (MJ) requirement for maintenance
BWt = BWt is the body weight in kg
ME = Metabolisable energy intake

Estimation of duodenal flow of NDF

Rate of passage of NDF from the rumen calculated from rumen evacuation data should be determined from measured rumen pool size of NDF and duodenal NDF flow. Since, the animals used in this study did not have duodenal fistulas, it was not possible to directly measure duodenal NDF flow and therefore had to be estimated based on fecal NDF flow corrected for post ruminal fibre loss using the equation below:
Duodenal NDF flow (kg/day) = Fecal flow NDF (kg per day) + (NDF intake per day *0.065) (Weisbjerg, M. R. (Personal communication)
From knowledge that duodenal flow of INDF = Fecal flow of INDF, the duodenal flow of digestible NDF was calculated as shown below:
Duodenal flow of DNDF (kg/day) = Duodenal NDF flow (kg/day) – Fecal INDF flow (kg/day).

NDF kinetics

Fractional rates of passage and digestion (referred to as rates of digestion and passage) of fibre fractions in the rumen were calculated from fibre flow and pool sizes in the rumen as previously proposed by Robinson et al. (1987) as shown below:
Rate of intake (ki) $\%h^{-1}$= 1/24 * Daily intake (kg)/rumen pool size (kg)
Rate of passage (kp) $\%h^{-1}$= 1/24 * Calculated duodenal flow (kg)/rumen pool size (kg)
Rate of digestion (kd) $\%h^{-1}$= ki – kp
Mean retention time (MRT) h = 1/kp
The model assumes first order-kinetics and in the current study it incorporated potentially digestible and indigestible fractions as described by Allen and Mertens (1988).

Rumen digestibility of NDF and DNDF were estimated using a simple one-compartment models as described by Allen and Mertens (1988) as shown below:
Rumen digestibility of NDF = digestible fraction x (kd/(kd+kp))
Rumen digestibility of NDF = kd/(kd+kp)
Where kp and kd have been described above.

Statistical analyses

Statistical analysis was be carried out by the General linear Model (GLM) to test the differences between the means of the various parameters using four models.

(I) $Y = I + T + C + P + \varepsilon$ (Model I)

(II) $Y = I + C + P + \beta_1 U + \beta_1 S + \varepsilon$ (Model II)

(III) $Y = I + C + P + \beta_1 U + \beta_2 S + \beta_3 U^2 + \beta_4 S^2 + \varepsilon$ (Model III)

(IV) $Y = I + C + P + \beta_1 N + \varepsilon$ (Model IV)

Where	Y	= dependable variable
	I	= Intercept
	T	= treatment (HO, HLU, HHU, HLS, HHS)
	C	= cow (cow 1-5)
	P	= period (period 1-5)
	U	= Urea level (0, 32, 64g/day)
	S	= Soyabean cake level (0, 210, 420g/day)
	N	= N supplementation (0, 15, 30g/day)
	$\beta_1 - \beta_4$	= regression coefficients
	ε	= Random error

Means were compared by GLM PDIF and also by Duncan Multiple Range Test. Results are reported as least square means for each treatment with standard error of the least square means. Type II test (SAS, 1988) were used implying that the mean effect of the treatments were tested without the interaction term in the model. Where applicable the data was fitted to exponential equations, regression, and comparisons between treatments made in accordance to the general linear model procedure for Latin-square design using SAS (1988).

RESULTS

Feeding and chemical composition of hay and soyabean cake

The supplements given to the animals during this trial are shown in Table 1. At the same level, soyabean cake and urea were iso-nitrogenous. The DM and chemical composition of the hay and soyabean cake used during the experiment are shown in Table 2. The hay CP and NDF (%DM) were 4.7 and 73.5 respectively. The calculated Metabolisable energy was 14.7 and 4.6 MJ/kg DM for soyabean cake and the poor quality hay respectively (Table 2). The soyabean cake CP content, EE and NDF were 43.8, 17.1 15.8% respectively. The soyabean cake had high rumen degradation of both dry matter and nitrogen.

Table 2 Chemical composition and N degradation of and soyabean cake and hay used during the experiment.

	Type of feed	
Component	Hay	Soyabean cake
%DM	93.5	93.5
Dry matter composition (%DM)		
ASH	7.9	6.4
OM	92.1	93.6
CP	4.7	43.8
EE	1.8	17.1
NDF	73.5	15.8
INDF	25.5	NA
CHO	85.6	32.7
K	1.06	NA
Ca	0.26	NA
Mg	0.14	NA
P	0.10	NA
Na	0.20	NA
IVOMD	35.6	83.5
Energy Content		
Gross Energy (MJ/kg DM)	15.4	21.2
Digestible Energy (MJ/kg DM)	5.6	17.9
Metabolisable Energy (MJ/kg DM)	4.6	14.7
Total Digestible Nutrients (kg/kg DM)	0.34	0.90
Rumen degradation (%)		
Dry matter	39.5	80.2
Nitrogen	48.7	82.4

IVOMD: In vitro organic matter digestibility; NA: not analysed

The effective degradation (at 2%h^{-1} passage rate) of DM and N for the soyabean cake was 80 and 82% respectively. The effective degradation of hay DM and N was 39.5 and 48.7% respectively.

Intake, flow and digestibility of nutrients

Hay DM, total DM and ash intake were significantly ($P<0.001$) increased with nitrogen supplementation (Table 3). At the high levels of supplementation, both urea and soyabean cake had nearly similar hay intake. Urea supplementation led to linear increase in hay intake while there was little difference between hay intake in the first and second level of soyabean cake supplementation (Figure 1). Total DM intake was very highly correlated (linear $r^2 = 0.89$ and 0.97 for soyabean cake and urea respectively) to the CP content of the diet (Figure 2). The equations defining the relationships were $Y = 0.55X +$

3.2 and Y = 0.44X + 3.7, for soyabean cake and urea respectively where Y= DM intake (kg) and X = CP content in the diet. It was clear that per unit change in diet CP content, soyabean cake had bigger impact on DM intake compared to urea.

Fecal flow of DM, OM and ash increased by supplementation, but only significant with soyabean cake supplementation which showed linear (P=0.01) increases (Table 4).

Table 3 The effect of source and levels of nitrogen supplementation on dry matter (DM), organic matter (OM) and water intakes

	Treatment						P-value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Hay DM intake (kg/day)	5.7^{b}	6.4^{a}	6.8^{a}	6.7^{a}	6.8^{a}	0.14	<0.001	<0.001	<0.0003
Total DM intake (kg/day)	5.7^{c}	6.5^{b}	6.9^{ab}	7.0^{ab}	7.3^{a}	0.14	<0.0001	<0.0004	<0.0001
DM intake (%BW)	1.87^{c}	2.09^{b}	2.21^{a}	2.25^{a}	2.27^{a}	0.036	<0.0001	<0.001	0.0001
DM intake (g/kg $W^{0.75}$)	77.8^{c}	87.5^{b}	92.8^{a}	94.2^{a}	95.9^{a}	1.54	<0.0001	<0.001	0.0001
OM intake (kg/day)	5.3^{c}	6.0^{b}	6.3^{ab}	6.5^{a}	6.7^{a}	0.13	<0.0001	<0.001	<0.0001
Ash intake (kg/day)	0.41^{c}	0.50^{b}	0.57^{a}	0.49^{b}	0.53^{b}	0.012	<0.0001	<0.0001	<0.0001
CP in diet (% DM)	4.7^{d}	6.1^{c}	7.5^{a}	5.9^{c}	7.0^{b}	0.08	<0.0001	<0.0001	<0.0001
Water intake (l/day)	22.0^{b}	26.3^{a}	29.4^{a}	26.0^{a}	29.3^{a}	1.24	0.01	<0.0004	<0.0004

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear
Means within rows with different superscripts are significantly different (P<0.05)

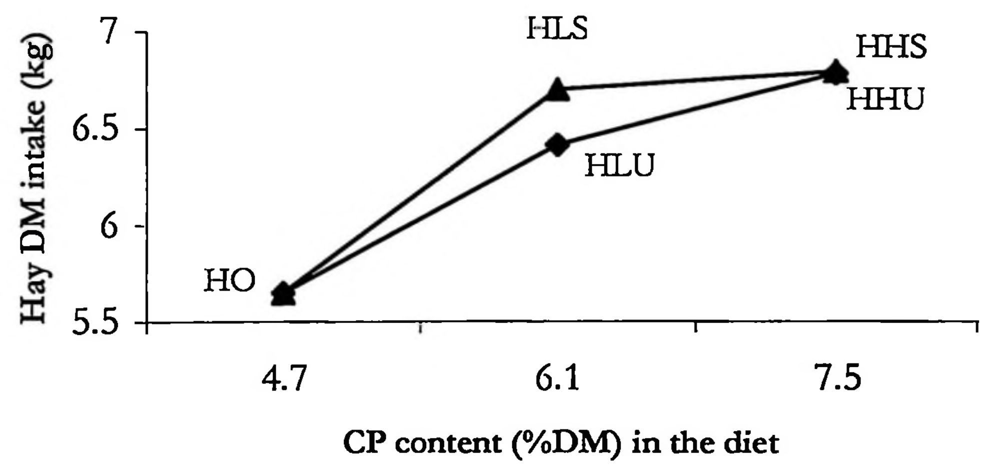

Figure 1. Relationship hay DM intake (kg/day) with the CP content (%DM) in the diet.

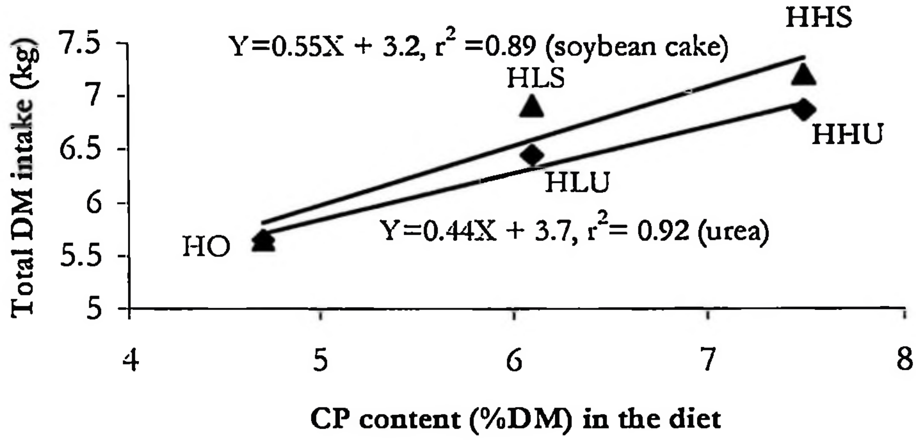

Figure 2. Relationship between total DM intake (kg/day) with the CP content (%DM) of the diet.

Fecal nitrogen flow was not affected by treatments and ranged between 29-38g/day with the highest value occurring in the control.

There was significant linear increases in apparent DM digestibility (P=0.05) with increased levels of urea and (P=0.01) with increased levels of soyabean cake (Table 4 and Figure 3).

Table 4. The effect of source and levels of nitrogen supplementation on fecal DM, OM, ash flow and apparent digestibility of components

	Treatments						P-value		
Item	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Fecal flow									
Fecal DM (kg/day)	3.11	3.40	3.44	3.53	3.64	0.126	0.1	0.1	0.01
Fecal OM (kg/day)	2.82	3.09	3.14	3.19	3.30	0.113	0.1	0.1	0.01
Fecal ash (kg/day)	0.30	0.31	0.31	0.33	0.34	0.018	0.5	0.4	0.1
Apparent digestibility (%)									
DM	45.0	47.8	50.0	49.1	49.9	1.29	0.1	0.02	0.01
OM	46.1	48.7	50.2	50.3	50.8	1.24	0.1	0.05	0.01
Ash	30.3^{b}	37.2^{b}	46.6^{a}	33.3^{b}	37.1^{b}	2.94	0.02	0.001	0.1
[1]**Digested CHO (kg)**	1.75^{c}	1.99^{b}	2.10^{ab}	2.12^{ab}	2.19^{a}	0.04	<0.001	<0.001	<0.0001
[2]**App.digested OM (kg)**	2.5^{c}	2.9^{b}	3.2^{ab}	3.3^{a}	3.4^{a}	0.10	<0.0002	<0.001	<0.001

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear

[1]Calculated from feed characteristics (Weisbjerg and Hveplund, 1993)

[2]Calculated as OM intake-Fecal OM

Means within rows with different superscripts are significantly different (P<0.05)

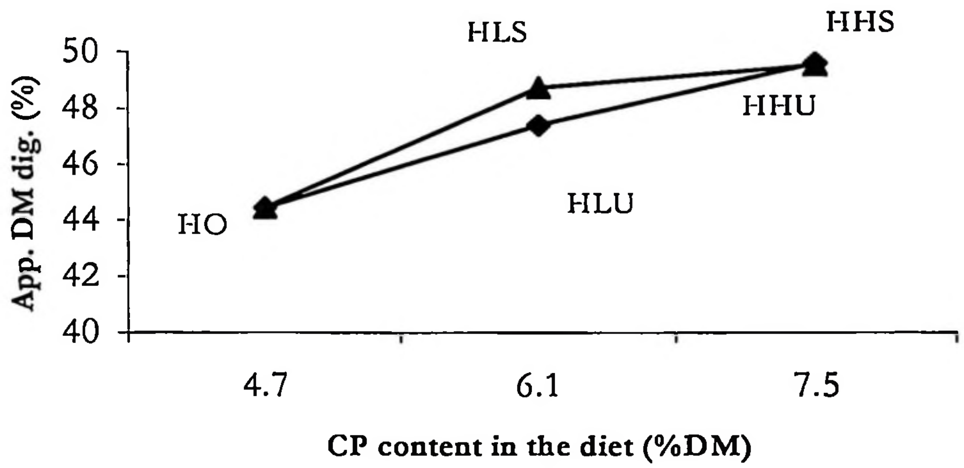

Figure 3. Relationship between the apparent digestibility of dry matter (%) with the CP content (%DM) in the diet.

Highest apparent DM digestibility was reached with the low level of soyabean cake whose value was nearly similar to that obtained with the high levels of both soyabean cake and urea (Figure 3). Nitrogen supplementation irrespective of source significantly improved both DM and OM digestibility (Model IV).

There was significant (P=0.01) increases in the apparent N digestibility with both urea and soyabean cake supplementation due to a reduction of fecal N output compared to the control (Table 10).

Both sources and levels of nitrogen supplementation led to significantly (P<0.0001) higher intake of NDF (Table 5). Calculated duodenal flow of NDF and fecal flow of NDF seemed not to be affected by treatments, though linear increases were observed with urea (P=0.03) and soyabean cake (P= 0.02) supplementation. Calculated rumen digestibility of NDF and whole tract digestibility of NDF seemed not affected by treatments though soyabean cake supplementation showed linear increases (P=0.04) in that parameter. Both levels of soyabean cake had slightly higher values for total tract NDF digestibility (Figure 4). Nitrogen supplementation irrespective of source showed significant (P=0.01) increases in the calculated rumen digestibility and whole tract digestibility of NDF (Model IV). However, the high level of urea showed numerically higher values for total tract digestible NDF digestibility (Figure 5).

Table 5. The effect of source and levels of nitrogen supplementation on neutral detergent fibre (NDF) flow and digestibility in the rumen and whole tract

	Treatments						P-values		
	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
NDF flow									
Intake (kg/day)	4.15^{b}	4.71^{a}	4.98^{a}	4.95^{a}	5.05^{a}	0.105	<0.0003	<0.0001	<0.0001
[1]Duodenal (kg/day)	2.59	2.81	2.95	2.88	2.96	0.102	0.1	0.03	0.02
Fecal (kg/day)	2.20	2.39	2.51	2.45	2.51	0.087	0.1	0.03	0.02
NDF Digestibility (%)									
[3]Rumen	40.2	42.9	43.0	43.9	43.7	1.02	0.1	0.1	0.04
Whole tract	46.7	49.4	49.5	50.4	50.2	1.02	0.1	0.1	0.04
Indigestible NDF flow									
Intake (kg/day)	1.38^{b}	1.62^{a}	1.69^{a}	1.65^{a}	1.74^{a}	0.049	0.002	0.001	<0.0003
Fecal (kg/day)	1.23^{b}	1.56^{a}	1.68^{a}	1.57^{a}	1.57^{a}	0.070	0.01	0.002	0.01
Digestible NDF flow									
Intake (kg/day)	2.77^{b}	3.09^{a}	3.29^{a}	3.31^{a}	3.32^{a}	0.074	0.001	0.003	0.001
[2]Duodenal (kg/day)	1.36	1.25	1.27	1.31	1.39	0.062	0.5	0.4	0.6
Fecal (kg/day)	0.97	0.83	0.83	0.88	0.94	0.051	0.2	0.1	0.9
Digestible NDF digestibility (%)									
[3]Rumen	54.8^{b}	63.6^{a}	64.5^{a}	63.8^{a}	61.7^{a}	1.59^{a}	0.01	0.01	0.1
Whole tract	64.6^{b}	73.4^{a}	74.3^{a}	73.5^{a}	71.6^{a}	1.51	0.004	0.01	0.04

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake *Linear

[1]Calculated as: Duodenal NDF flow (kg/day) = Fecal flow NDF (kg per day) + (NDF intake per day *0.065)

[2]Calculated as: Duodenal flow DNDF flow (kg/day) = Duodenal NDF flow (kg/day) – Fecal INDF flow (kg/day).

[3] Based on calculated duodenal flow

Means within rows with different superscripts are significantly different (P<0.05)

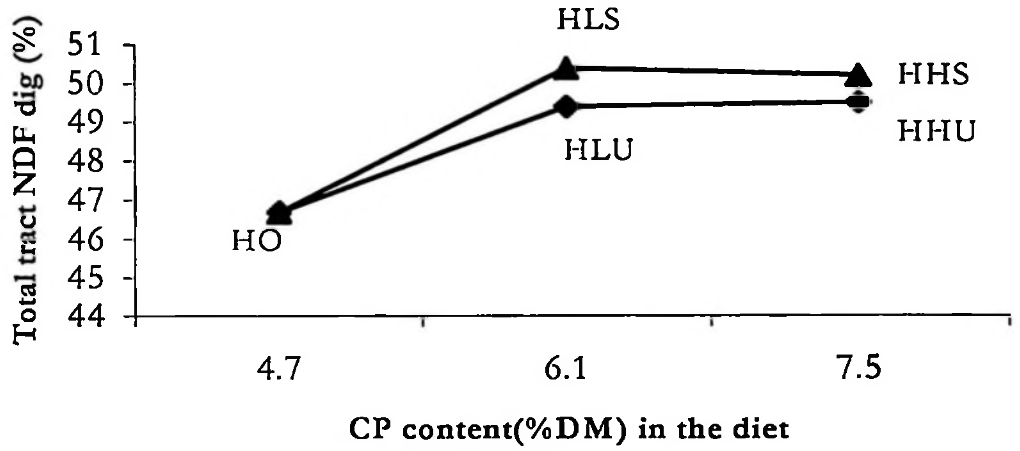

Figure 4. Relationship between total tract NDF digestibility with CP content (%DM) in the diet.

Both urea and soyabean cake supplementation significantly improved both the calculated rumen digestibility (P=0.01) and whole tract (P=0.004) digestibility of DNDF. It appeared that the high level of soyabean cake supplementation resulted in higher total tract NDF digestibility compared to urea (Figure 4). However, when INDF was deducted from the NDF, the digestibility was the same at the lower levels of N supplementation of both sources, but the high level of urea had a higher digestibility compared to the high level soyabean cake (Figure 5)

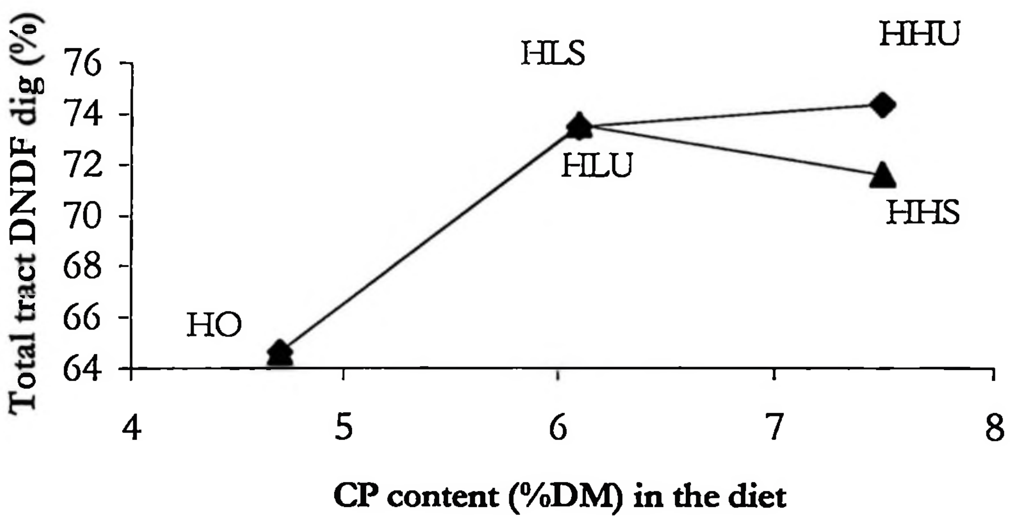

Figure 5. Relationship between total tract digestibility of DNDF and the CP content (%DM) in the diet.

Degradation characteristics of hay DM estimated from dacron bags incubated in the rumens of the animals under the various treatments showed no treatment effect (Table 6).

Table 6. In sacco dry matter degradability of hay samples incubated in dacron bags in the rumen of cows supplemented with different levels and sources of nitrogen supplements

	Treatments						P-value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Degradation constants (%DM)									
a	10.7	11.0	10.1	10.7	10.11	0.48	0.6	0.3	0.2
b	52.1	53.0	57.2	54.2	53.5	2.22	0.6	0.1	0.5
Rate constant c ($\%h^{-1}$)	2.74	2.27	1.87	1.89	3.06	0.418	0.24	0.4	0.7
Washing losses (%DM)	11.1	11.1	11.1	11.1	11.1	-	-	-	-
Degradation (% DM)									
48 hour incubation	49.0	45.2	41.8	44.8	47.7	2.5	0.3	0.1	0.6
144 hour incubation	61.5	61.4	61.4	60.8	61.1	1.23	1.0	0.9	0.8
Effective degradation (ED) (%DM)									
2 % h^{-1} passage rate	40.4	38.6	36.2	36.6	39.6	1.47	0.3	0.2	0.6
5 % h^{-1} passage rate	28.7	27.1	24.4	25.1	28.0	1.43	0.2	0.1	0.6

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear

There were no treatment effects on the degradation constants, the 48 and 144 hours and the effective degradation at 2 and 5 % h^{-1} passage rates. The rate of degradation of DM from the dacron bags ranged between 1.87 to 3.06 % h^{-1} with the lowest and highest rates occurring with the high levels of urea and soyabean cake respectively. The effective degradation of DM from the dacron bags at passage rate of 2% h^{-1} ranged between 36.2 with the high level of urea to 40.4 in the control. The degradation of DM from dacron bags at the longest time of incubation (144 hours) was nearly the same for all treatments (61-62% DM).

Rumen fermentation

Shown in Table 7 are the rumen fluid concentrations of individual and total volatile fatty acids.

Table 7. Ruminal fluid Volatile Fatty Acids (VFAs), ammonia concentration and pH under the various supplementation regime.

	Treatments						P-value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
VFAs concentration (mM)									
Acetate	27.6	33.1	35.0	33.9	37.8	3.37	0.3	0.1	0.04
Propionate	7.5	7.8	8.8	9.7	10.4	0.78	0.1	0.3	0.01
Butyrate	3.0	3.1	3.8	4.0	4.5	0.50	0.2	0.3	0.02
Total acids	38.0	44.0	47.6	47.6	52.7	4.46	0.3	0.1	0.02
Moles/100moles total									
Acetate	71.6	75.3	73.5	71.1	71.2	1.27	0.2	0.3	0.5
Propionate	20.3	17.8	18.6	20.5	20.4	1.04	0.3	0.2	0.7
Butyrate	8.1	6.9	8.0	8.3	8.4	0.47	0.2	0.8	0.3
Acetate/Propionate	3.58	4.42	3.97	3.49	3.55	0.308	0.2	0.3	0.6
Mean ruminal pH	6.9	6.8	6.8	6.9	6.9	0.04	0.42	0.1	1.0
Mean Ammonia (mgN/100ml)	1.02[a]	3.58[b]	5.62[c]	1.89[d]	1.98[e]	0.378	<0.0001	<0.0001	0.1

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear

Means within rows with different superscripts are significantly different (P<0.05)

There were significant linear increases in the concentrations of the individual and total acids with soyabean cake supplementation and also the total VFAs with urea supplementation (Table 7). The CP in the diet (%DM) and total VFAs were highly correlated (linear, r^2= 0.97 and 0.98 for soyabean cake and urea respectively). The equations relating the two parameters were Y = 5.2X + 14.2, for soyabean cake and Y = 3.4X + 22.4 for urea where Y = Total VFAs (mM) and X = CP content of diet (%DM). It was evident that for a unit change in CP content in the diet, soyabean cake caused a larger increase in the total VFAs concentration in the rumen fluid compared to urea. There was significant increases in ruminal concentration of propionate (P=0.01), butyrate (P=0.04) and total acids (P=0.03) with nitrogen supplementation (Model IV).

Ruminal fluid pH seemed not significantly affected by treatments, though urea supplementation tended to cause a slight depression of pH especially during the late night hours (Figure 7). Mean ruminal fluid ammonia concentration was significantly (P<0.0001) higher with both levels of urea compared to the levels of soyabean cake and the control (Table 7).

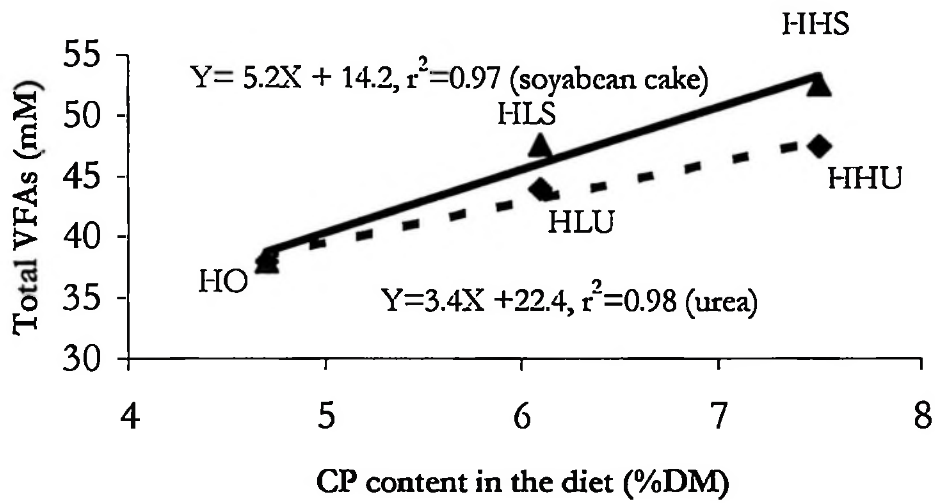

Figure 6. Relationship between total VFAs with the CP content in the diet (%DM) under the various treatments.

Figure 7 shows the diurnal variations in the ruminal fluid pH under the various supplementation regimes. The trend in pH was closely associated with the feeding cycles with a slight fall between 7.3 and 15 pm, a small rise between 15 and 18 hrs and a sharp fall between 18h and midnight. There was a sharp recovery during the early morning hours (between 3 and 8am). It appeared that urea feeding lead to a greater depression in ruminal pH with the lowest pH (6.5) occurring at midnight in HHU. Mean daily ruminal pH was not significantly different between the five treatments.

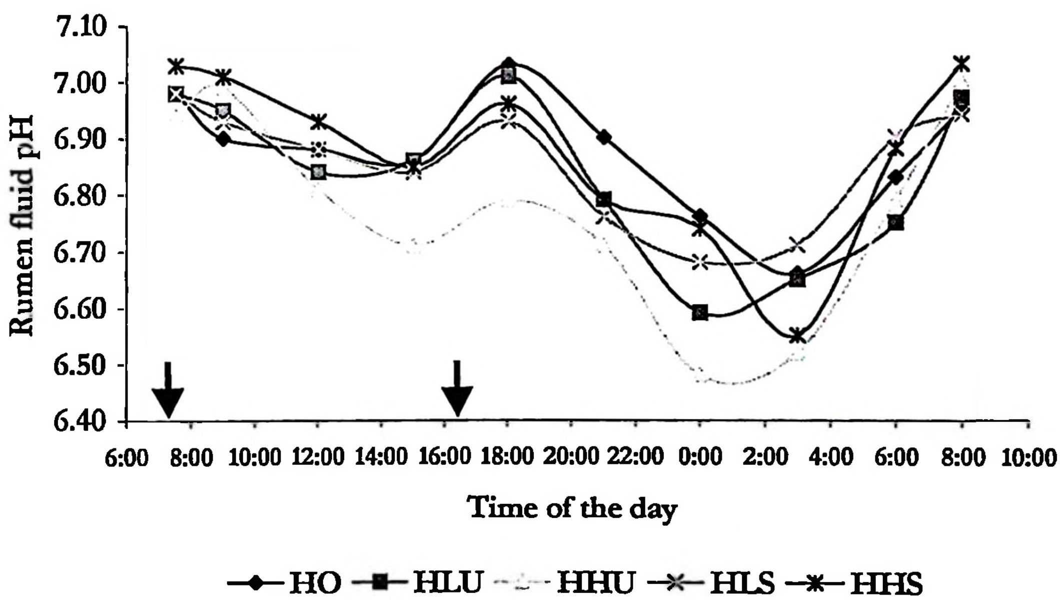

Figure 7. Diurnal variation of rumen pH. Arrows indicate the time when half of estimated daily hay, urea or soyabean cake were given. HO:hay only; HLU:hay with low urea (32g); HHU: hay with high urea (64g); HLS: hay with low soyabean cake (210g DM); HHS: hay with high soyabean cake (420g DM).

Between levels of N supplements, no significant differences in ruminal pH were observed. Except for significantly (P<0.05) depression in ruminal pH in HHU compared to HLS for ruminal samples taken at 21 hours no other significant differences were noted between urea and soyabean cake supplementation.

Diurnal trend in ruminal ammonia nitrogen is shown in Figure 8. While soyabean cake and the control had almost steady ruminal ammonia throughout the day, urea supplementation resulted into peak ammonia N levels 2-3 hours after dosing (Dosing was done at 7.30 am and 4pm). Mean daily ruminal fluid ammonia were significantly higher (P<0.001) in both levels of urea compared to HO, in HHU compared to HLS and HHS, significantly (P<0.01) higher in HLU compared to HLS and HHS. The differences were less during the night. Soyabean cake supplementation increased the rumen ammonia N, but the difference was not significant compared to the control.

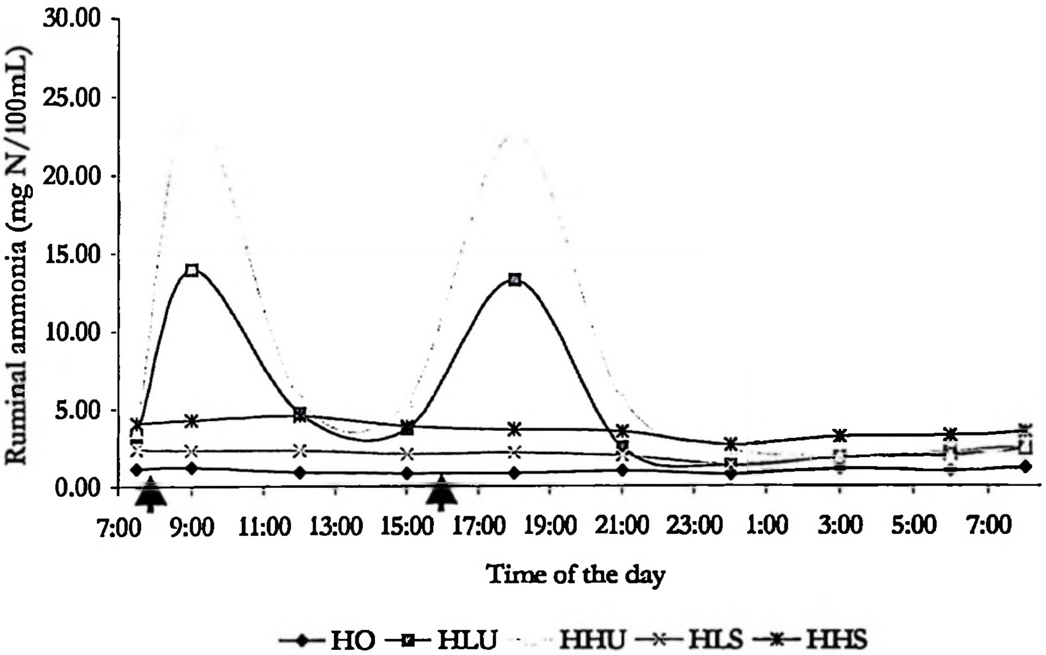

Figure 8. Diurnal variations in ruminal ammonia concentration. Arrows indicate the time when half of estimated daily hay, urea or soyabean cake were given. HO:hay only; HLU:hay with low urea (32g); HHU: hay with high urea (64g); HLS: hay with low soyabean cake (210g DM); HHS: hay with high soyabean cake (420g DM)

Urine output and composition and microbial protein synthesis

Urine output increased linearly with urea (P=0.05) and soyabean cake (P=0.04) supplementation (Table 8). The urine CP content increased linearly with urea supplementation. The concentration of allantoin in urine ranged from 7.6 to 14 mmoles/l and was significantly (P=0.01) higher with urea and soyabean cake supplementation compared the control (Table 8).

Table 8. The effect of source and levels of nitrogen supplementation on urine output and composition

	Treatments						P-value		
	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Urine output (kg per day)	6.4	6.6	8.4	6.8	8.5	0.77	0.22	0.05	0.04
Composition									
CP (%)	1.6	2.1	2.7	2.0	2.2	0.35	0.3	0.03	0.2
Allantoin (mmols/l)	7.6^{b}	13.0^{a}	10.5^{ab}	13.8^{a}	14.0^{a}	1.07	0.01	0.3	0.2
Uric acid (mmols/l)	1.8	1.7	1.4	1.3	1.6	0.15	0.1	0.03	0.2

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear
Means within rows with different superscripts are significantly different (P<0.05)

Microbial nitrogen (MN) synthesis and the efficiency of the synthesis calculated either from purine derivatives or based on carbohydrates digested in the rumen (Madsen et al., 1995) were significantly improved with both urea and soyabean cake supplementation (Table 9). The efficiency of synthesis (g MN/kg CHO) estimates from purine derivatives showed linear (P=0.01) increases with soyabean cake supplementation and curve-linearly changes (Model III) with urea supplementation (Figure 9). However, microbial protein N values calculated using the Danish AAT-PBV system (Madsen et al., 1995) were much higher compared to those obtained using the purine derivative excretion method (Verbic et al., 1990).

Protein balance in the rumen (PBV) calculated based on the Danish AAT-PBV system (Hvelplund and Madsen, 1990) showed great variations between treatments (Table 9). PBV values ranged from –184 in the control to –34g CP with high urea supplementation. There was high correlation (linear, r^2 = 0.91) between PBV (g/day) and the urine CP (g/day) defined by the equation Y= 0.59X + 203, where Y = Urine CP (g/day) and X = PBV (g/day) (Figure 10).

Table 9. The effect of source and levels of nitrogen supplementation on rumen degradable protein, microbial protein synthesis estimated from purine derivative excretion or on the basis of digested carbohydrates and the protein balance (PBV) in the rumen.

	Treatments						P-value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Rumen degradable protein (RDP)									
[1]Requirement (g/day)	229.2^{d}	260.1^{c}	275.0^{c}	297.7^{b}	327.2^{a}	5.78	<0.0001	0.001	<0.0001
Intake (g/day)	128.7^{a}	239.3^{b}	341.0^{c}	228.7^{d}	307.6^{e}	3.25	<0.0001	<0.0001	<0.0001
RDP balance (g/d)	-100.6^{d}	-20.8^{b}	66.0^{a}	-69.0^{c}	-20.0^{b}	2.54	0.0001	<0.0001	<0.0001
¶Calculations based on purine derivatives excreted in urine									
Allantoin output (mmoles/day)	47.3^{b}	79.5^{a}	81.3^{a}	85.4^{a}	99.3^{a}	6.75	0.002	0.01	0.0003
Uric acid output (mmoles/day)	11.0	12.4	11.7	8.2	13.8	2.2	0.5	0.5	0.5
Total purines (mmoles/day)	58.3^{b}	91.8^{a}	93.0^{a}	93.6^{a}	113.1^{a}	8.1	0.01	0.01	0.001
Purine absorbed (mM/day)	29.7^{b}	68.3^{a}	69.8^{a}	70.6^{a}	92.7^{a}	9.45	0.01	0.01	0.001
Microbial N (g/day)	21.6^{b}	49.7^{a}	50.7^{a}	51.3^{a}	67.4^{a}	6.87	0.01	0.01	0.001
Microbial CP (g/day)	134.6^{b}	310.6^{a}	316.9^{a}	320.6^{a}	421.2^{a}	42.25	0.01	0.01	0.001
gMN/kg CHO	12.3^{b}	25.3^{a}	24.6^{a}	24.4^{a}	32.0^{a}	3.46^{a}	0.02	0.07	0.004
¶¶Calculations based on digestible CHO									
[2]Microbial N(g/day)	50.0^{c}	56.8^{b}	60.0^{ab}	60.5^{ab}	62.5^{a}	1.26	<0.0001	<0.001	<0.0001
Microbial CP (g/day)	312.7^{c}	354.8^{b}	375.2^{ab}	378.4^{ab}	390.7^{a}	7.89	<0.0001	<0.001	<0.0001
PBV (g/day)	-184.1^{a}	-115.5^{b}	-34.2^{c}	-149.7^{d}	-83.5^{e}	4.64	<0.0001	<0.0001	<0.0001

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear.

[1]Calculated from RDP (g)=8.4ME (ARC, 1990)

[2]Calculated as digestible CHO (kg) * 28.57microbial crude N/kg dig. CHO.

¶Based on the daily excretion of purine derivatives (Verbic et al., 1990)

¶¶Based on (Madsen et al., 1995)

Means within rows with different superscripts are significantly different (P<0.05)

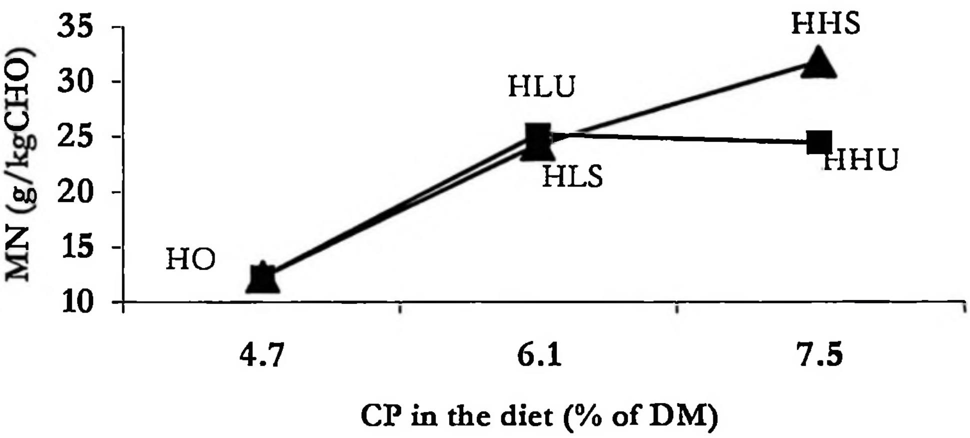

Figure 9. Relationship between the efficiency of microbial protein synthesis expressed as g microbial nitrogen per kg digested carbohydrates and the CP content (%DM).

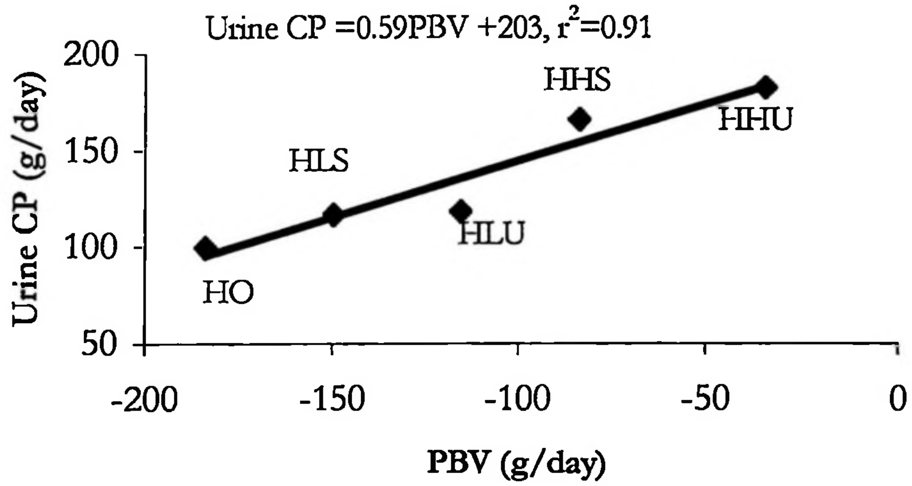

Figure 10. Relationship between urine CP and the PBV under the various treatments.

Nitrogen retention and Energy balance

Nitrogen retention was significantly (P=0.01) improved by nitrogen supplementation and it ranged from 12.8 with the low urea to 21 g/day with the high level of soyabean cake supplementation (Table 10). While there was a sharp change in N retention from the control to the first levels of supplementation, the change from the first to the second levels were more gradual with soyabean cake supplementation showing higher retention of N at all levels compared to urea (Figure 11)

Table 10. The effect of source and levels of nitrogen supplementation on nitrogen (N) metabolism

	Treatments						P-Value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Total N intake (g/day)	42.3[c]	68.9[b]	80.6[a]	64.9[b]	80.4[a]	1.07	<0.0001	<0.0001	<0.0001
Fecal N (g/day)	38.2	31.2	35.3	29.3	32.7	3.4	0.4	0.8	0.4
Urinary N (g/day)	15.9	18.9	29.2	18.6	26.5	3.21	0.5	0.01	0.01
Total N excreted (g)	54.2	50.1	64.5	48.0	59.2	5.2	0.2	0.10	0.3
N-balance (g/day)	-11.9[b]	12.8[a]	16.1[a]	17.0[a]	21.2[a]	5.55	0.01	0.01	0.002
Apparent N dig (%)	10.1[b]	50.6[a]	56.1[a]	54.7[a]	56.9[a]	7.2	0.002	0.003	0.01

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear.
Means within rows with different superscripts are significantly different (P<0.05)

Table 11. The effect of source and levels of nitrogen supplementation on Metabolisable energy (ME) intake and body weight changes

	Treatments						P-value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Metabolisable energy									
Intake (MJ/day)	27.3[d]	31.0[c]	32.7[c]	35.4[b]	39.0[a]	0.69	<0.0001	0.001	<0.0001
Maintenance (ME_m) (MJ/day)	35.8	36.6	36.5	36.4	37.2	0.28	0.1	0.8	0.001
ME balance (MJ/day)	-8.53[a]	-5.67[b]	-3.79[c]	-0.97[d]	1.8[e]	0.592	<0.0001	0.002	<0.0001
Body weight (kg)									
Initial (kg)	309.6	313.3	307.2	306.2	311.5	2.99	0.5	0.9	1.0
Final (kg)	302.4	311.3	310.2	308.9	317.1	3.11	0.1	0.1	0.001
Change (kg/28days)	-7.2	-2.0	3.10	2.7	5.6	2.80	0.1	0.03	0.001

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake; RDP: Rumen degradable protein; * Linear
Means within rows with different superscripts are significantly different (P<0.05)

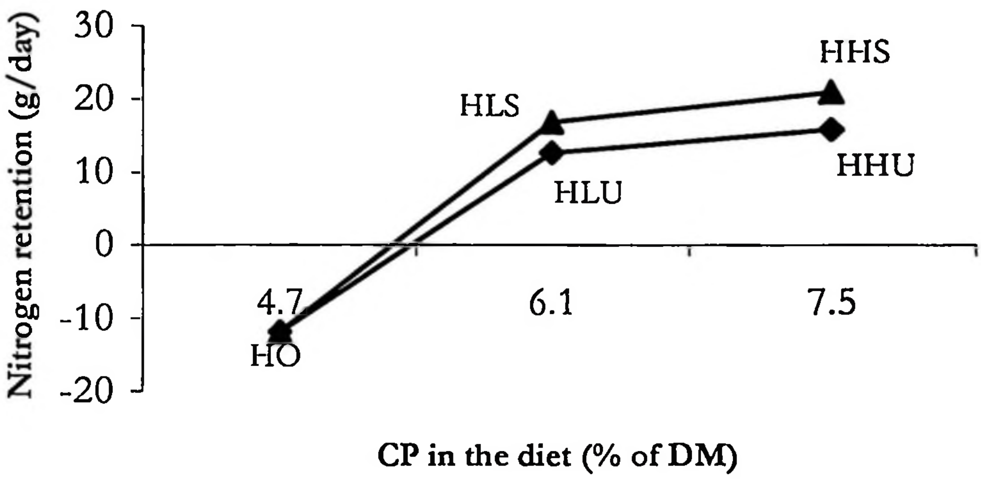

Figure 11. Relationship between N retention and the CP content (%DM) in the diet under the various treatments.

Calculations on the Metabolisable energy intake compared to the maintenance requirements of the animals used in this trial showed that except with high soyabeal meal level of supplementation, the animals were in negative energy balance ranging from –4 to –9 MJ/day in the other treatments (Table 11). However, both urea and soyabean cake supplementation significantly ($P<0.0001$) increased the energy balance (Table 11) compared to the control. Animals appeared to loose weight during the control (-7 kg) and also during low level of urea supplementation (-2 kg) periods. There was a linear increases in weight gain with urea ($P=0.03$) and soyabean cake supplementation ($P=0.001$).

Rumen pool sizes

Shown in Table 12 are the results of rumen evacuations done at 08.00, 12.00 and 17.00h and the mean values for the three evacuations. As expected, the mid-day and evening rumen evacuations showed higher values in all parameters assessed compared to the early morning evacuation due to feed consumed during the day (Table 12). There was linear increases ($P=0.05$) with both soyabean cake and urea levels in the rumen pool size of N during the early morning evacuation. The rumen pool of indigestible NDF was significantly higher with the high urea supplementation in the mid-day ($P=0.05$), evening and the average values obtained from the three evacuations ($P=0.04$) compared to other treatments. Rumen pool sizes of NDF were numerically higher with urea compared to soyabean cake supplementation due to relatively higher amounts of indigestible NDF with both levels of urea (Figure 12).

Table 12. The effect of source and levels of nitrogen supplementation rumen pool sizes of wet and dry ingesta, NDF, DNDF, INDF and N for the rumen evacuations done at 8am, 12 Noon and 17pm and the average for the three evacuations. Values are expressed in kg unless where otherwise stated.

	Treatments						P-Value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
Morning evacuation (08.00h)									
Total wet ingesta	51.9	55.8	53.1	49.2	53.7	1.52	0.1	0.3	0.8
%DM ingesta	14.4	14.2	13.8	14.4	13.7	0.41	0.6	0.2	0.2
Rumen DM load	7.5	7.9	7.3	7.1	7.4	0.32	0.5	1.0	0.5
NDF	5.6	5.9	5.4	5.3	5.5	0.35	0.4	0.7	0.4
DNDF	3.4	3.58	3.07	3.17	3.19	0.253	0.6	0.4	0.3
INDF	2.22	2.37	2.29	2.17	2.28	0.168	0.9	0.6	0.9
N	0.08	0.09	0.10	0.08	0.11	0.011	0.3	0.05	0.05
Mid-day evacuation (12.00h)									
Total wet ingesta	62.0	64.7	67.9	59.6	65.8	1.54	0.7	0.03	0.3
%DM ingesta	14.5	13.5	14.2	14.1	14.2	0.29	0.2	0.6	0.9
Rumen DM load	9.0	8.7	9.7	8.3	9.3	0.31	0.1	0.1	0.3
NDF	6.8	6.4	7.3	6.3	6.4	1.93	0.2	0.2	0.7
DNDF	4.08	3.62	3.80	3.62	3.74	0.221	0.6	0.5	0.4
INDF	2.74^{b}	2.80^{b}	3.50^{a}	2.70^{b}	2.67^{b}	0.192	0.05	0.01	0.9
N	0.10	0.09	0.13	0.09	0.11	0.012	0.2	0.04	0.3
Evening evacuation (17.00h)									
Total wet ingesta	63.8	64.7	69.7	62.0	63.7	2.12	0.2	0.03	0.9
%DM ingesta	14.1	14.3	14.4	14.3	15.1	0.37	0.44	0.46	0.1
Rumen DM load	9.0	9.2	10.1	8.9	9.6	0.34	0.2	0.03	0.2
NDF	6.8	6.9	7.7	6.7	6.7	0.40	0.4	0.1	0.9
DNDF	4.15	3.97	3.86	3.86	3.92	0.279	0.9	0.5	0.5
INDF	2.67^{b}	2.95^{b}	3.80^{a}	2.79^{b}	2.74^{b}	0.243	0.04	0.004	0.6
N	0.10	0.10	0.11	0.08	0.11	0.010	0.1	0.1	0.4
Average values for the three evacuations									
Total wet ingesta	59.2	61.7	63.6	56.9	61.0	1.51	0.1	0.02	0.5
%DM ingesta	14.3	14.0	14.1	14.3	14.3	0.22	0.8	0.5	0.8
Rumen DM load	8.5	8.6	9.0	8.1	8.7	0.24	0.2	0.1	0.5
NDF	6.4	6.4	6.8	6.1	6.2	0.28	0.5	0.3	0.5
DNDF	3.88	3.72	3.57	3.55	3.62	0.197	0.8	0.4	0.3
INDF	2.55^{b}	2.71^{b}	3.2^{a}	2.55^{b}	2.56^{b}	0.145	0.04	0.004	0.7
Rumen N	0.09	0.09	0.11	0.08	0.11	0.008	0.2	0.1	0.1

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear

Means within rows with different superscripts are significantly different ($P<0.05$)

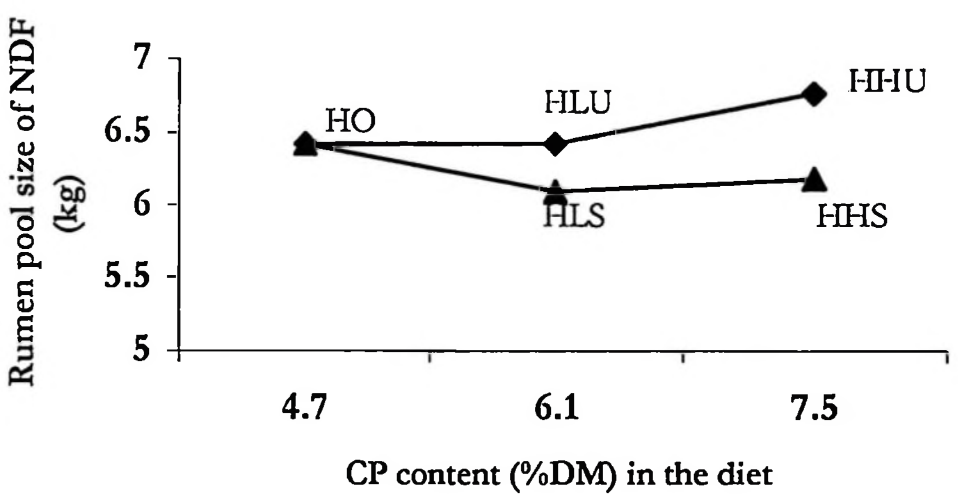

Figure 12. Relationship between the rumen pool size of NDF and the CP (% Dm) content of the diet.

Rates of digestion and passage

Rate of passage (kp) of INDF ranged between 2.0-2.6%h^{-1} and was not affected by treatments. However, passage rates numerically increased with N supplementation probably as a consequence of increased DMI. Passage rates were slightly higher with the levels of soyabean cake compared to urea (Figure 13) as rumen pools sizes of NDF were lower with soyabean cake at a nearly similar fecal outflow of INDF. As expected, the passage rate of indigestible NDF was higher than that of NDF that was turn, higher than that of digestible NDF (Table 13).

Nitrogen supplementation significantly increased (P=0.01) the rate of digestion (kd) of NDF and digestible NDF. While urea showed linear increase in the rate of digestion between the two levels, nearly similar rates were reached between the low and high levels of soyabean cake (Figure 14). This showed that soyabean cake had a greater impact on the rate of digestion of NDF at a relatively lower CP content in the diet compared to urea.

Table 13. The effect of source and levels of nitrogen supplementation on neutral detergent fibre (NDF) rates of intake, passage, digestion and mean retention time (MRT) in the rumen

	Treatments						P-Value		
Parameter	HO	HLU	HHU	HLS	HHS	SEM	Treat	*Urea	*Soya
NDF									
Rates (%h-1)									
Intake	2.72[b]	3.08[ab]	3.06[ab]	3.40[a]	3.51[a]	0.165	0.04	0.3	0.01
Passage	1.71	1.83	1.82	1.98	2.08	0.120	0.3	0.6	0.04
Digestion	1.01[b]	1.25[a]	1.24[a]	1.42[a]	1.43[a]	0.07	0.01	0.1	0.003
Indigestible NDF (INDF)									
Rates (%h-1)									
Intake	2.30[b]	2.54[ab]	2.21[b]	2.73[a]	2.85[a]	0.131	0.02	0.5	0.03
Passage	2.04	2.42	2.20	2.63	2.61	0.201	0.2	0.8	0.1
Digestible NDF (DNDF)									
Rates (%h-1)									
Intake	3.02	3.50	3.87	3.90	4.06	0.240	0.1	0.04	0.01
Passage	1.50	1.42	1.53	1.54	1.70	0.083	0.3	0.7	0.1
Digestion	1.52[b]	2.08[a]	2.34[a]	2.36[a]	2.36[a]	0.177	0.02	0.02	0.01
Mean retention time (MRT) h									
NDF	59.3	55.1	55.4	50.6	51.1	2.4	0.1	0.5	0.03
INDF	49.5	41.4	46.6	39.0	41.0	3.04	0.2	0.8	0.2
DNDF	68.7	73.6	69.1	65.1	62.2	3.54	0.2	0.9	0.1

HO: hay only; HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake * Linear
Means within rows with different superscripts are significantly different (P<0.05)

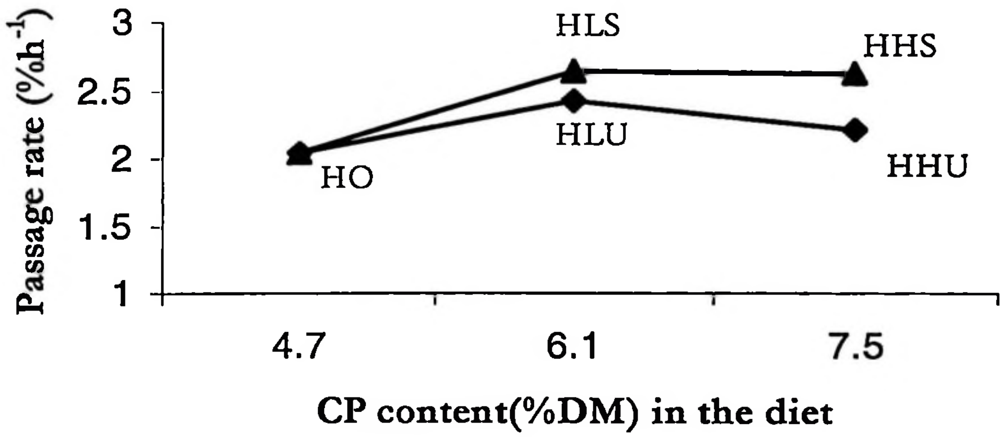

Figure 13. Relationship the passage rate of INDF and the CP content in the diet and under the various treatments.

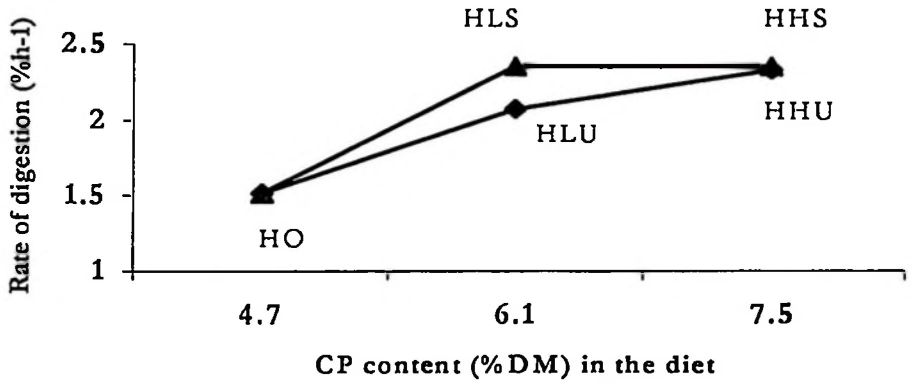

Figure 14. Relationship between the rate of digestion of DNDF and the CP content of the diet.

Summary of the major effects of nitrogen supplementation

Nitrogen supplementation caused increases in the hay and total DM intake as well as microbial protein synthesis, nitrogen retention and VFAs concentration in the rumen fluid (Table 14). Rumen fluid ammonia was also increased but to a lesser extent with soyabean cake compared to urea due to the differences of N degradability of the two sources as well as uptakes by ruminal microbes. Whereas urea N was considered 100% degraded, protein degradability of soyabean cake was 82% thereby contributing to the observed relatively low ruminal fluid ammonia with soyabean cake compared to urea.

Nitrogen digestibility and retention was greatly improved by N supplementation primarily due to increased intake but also secondarily due to increased dilution of fecal endogenous N losses.

Rumen pool size of NDF seemed unaffected by treatments. Passage rate of NDF was slightly higher with soyabean cake due to a slight increase in DM intake with that supplement. Nitrogen supplementation increased the rate of digestion and total tract NDF digestibility probably due to the improved microbial growth and cellulolytic activity in the rumen. This showed that N availability was a major limiting factor to plant fibre degradation.

Table 14. Summary of the responses due to source and levels of nitrogen supplementation of poor quality hay compared to non-supplementation.

	Intake			Fermentation products			N	NDF			
Treat	hay	T DM	App. DM dig	MN	VFA	Amm.	ret.	RumP	kp	kd	W Dig
HLU	↑	↑	↑	↑	↑	↑	↑	→	→	↑	↑
HHU	↑	↑	↑	↑	↑	↑	↑	→	→	↑	↑
HLS	↑	↑	↑	↑	↑	↗	↑	→	↗	↑	↑
HHS	↑	↑	↑	↑	↑	↗	↑	→	↗	↑	↑

HLU: hay + low urea; HHU: hay + high urea; HLS: hay + low soyabean cake; HHS: hay + high soyabean cake.
App. DM dig.: apparent DM digestibility; Wdig: whole tract digestibility; MN: microbial nitrogen synthesis; Amm.: ammonia levels; N ret.: nitrogen retention; VFA: total volatile fatty acids; Rum.: rumen; kp: rate of passage; kd: rate of digestion; Treat: treatment; DM: dry matter
↑:Increased; ↗ : slightly increased; → :unchanged.

DISCUSSION

The low CP, and ME, content in DM, low in vitro organic matter digestibility, and the high fibre content of the hay used during this trial confirms the characteristics of poor quality roughage fed to ruminants in the tropics for a big part of the year. That kind of hay if fed as sole diet to ruminants cannot meet the maintenance requirements of the animals. Therefore, to obtain a modest level of production, supplementation of the basal roughage with the deficient nutrients is essential. Since, the most limiting factor for microbial growth is N, it is most likely that when N availability is improved, more energy will be made available from the roughage. The source of nitrogen can be non-protein nitrogen or true protein. Urea and soyabean cake were good sources of ruminally available N with urea being 100% and soyabean cake 82% ruminally degradable. The chemical composition and degradability of soyabean cake used in this trial was close to those reported by Kropp et al. (1977a) with 80% N being rumen degradable.

DM and OM intake and digestibility increased with N supplementation (Tables 3 and 4). This was mainly due to the positive effect of N supplementation that enhanced microbial activities in the rumen. The observed higher microbial N synthesis was an indication that nitrogen supplementation improved microbial growth and therefore increased the digestibility and intake of the basal feed. Soyabean cake improved the DM intake and digestibility more than urea. This finding support those by Krop et al. (1977a), Krop et al. (1977b) and Robinson et al. (1998) who obtained greater responses the intake and digestibility of DM, OM and cellulose with soyabean cake compared to urea when supplemented to poor quality roughage. Driedger and Loerch (1999) reported that soyabean cake supplementation to mature steers improved the DM and OM digestibilities by 5% ($P<0.07$) compared to urea fed at an equal level to soyabean cake.

Many reports have confirmed that true protein when given with low quality roughage improves intake and digestibility (Hemsley, 1968; Church and Santos, 1981; Argyle and Baldwin, 1989; Ben-Gedalia and Yosef, 1989; Heldt et al., 1999). It is still debatable whether the greater effect of true proteins is due to specific requirement of cellullolytic microbes for pre-formed amino acids, peptides or branched long chain fatty acids, minerals and energy produced when protein are fermented in the rumen. In this study soyabean cake supplementation resulted into an extra 421g and 210g DM intake with the high and low level, respectively, as opposed to 64g and 32g at the same levels with urea. When the additional DM and energy from soyabean cake is taken into consideration, urea was possibly equally good compared to soyabean cake in promoting intake and digestibility of the poor quality forage.

The effect of nitrogen supplementation on the resultant rumen environment on the degradation of hay incubated in dacron bags did not show statistically significant differences. However, there was a numerical increase especially with soyabean cake and the low level of urea in both the rate and effective degradation at 2 and 5% passage rate (Table 6). Silva and Ørskov (1988) reported that soyabean cake supplementation had no effect on the degradation of straw DM incubated in dacron bags in sheep. As pointed out by Notziere and Michalet-Doreau (1996) the micro-environment in dacron bags incubated in the rumen is sometimes different from that found in the large reticulo-rumen compartment and that contributes to some of the variations observed. The in sacco technique is prone to many sources of factors that influence the results obtained. Variations occur between animals, within the same animal between days (periods), from one bag to another within day, and from one bag to another between days (Michalet-Doreau and Ould-Bah, 1992). Even under drastic undernutrition in Zebu cattle fed mainly rice straw, Grimaud et al. (1999) found that the in situ DM degradability was not greatly affected. Therefore, the resultant rumen environment due to feeding cannot be gauged accurately by the results of in situ degradation results alone.

The observed higher apparent N digestibility with increased N due to supplementation in this study agreed with the principle of the empirical equation $Y = 0.93X-3.6$ where Y = apparent digestibility of crude protein and X = crude protein in the diet (Van Soest, 1994). Increasing N content of the diet through supplementation with urea or soyabean cake improved the availability of ammonia thereby improving both microbial growth and cellulolytic activity in the rumen. As most tropical feeds has a big fraction of protein bound to the cell wall (Mgheni et al., 1994), an improved cellulolysis would have led to increased accessibility of protease enzymes responsible for protein degradation thereby increasing protein (N) degradability. This explains in part the lower fecal N output with nitrogen supplementation compared to the control. It could also be possible that reduced fibre digestion in the rumen of the control animals was partly compensated by increased hindgut fermentation thereby increasing fecal N of microbial origin.

The trend in pH was closely associated with the feeding cycles as also observed by Balch (1971) and Mlay (1995). Ruminal fluid pH was not greatly affected by the source or the level of supplementation, but tended to be lower for the most of the day with urea supplement compared to other treatments. This was in contradiction with the general belief that rumen alkalinity is increased with urea feeding (Robinson et al., 1998). However, Song and Kennedy (1989) reported a tendency of pH depression with high ammonia concentration in the rumen.

Diurnal variations in ruminal ammonia followed a characteristic pattern as would be expected when urea is given in dose form rather than on continuos intake (Figure 6). High peak levels were attained 1-2 hours post dosing and very low levels with advancing time from last dose. Similar trend was observed by Robinson et al. (1998) in their study involving supplementation of dairy cows fed very low protein basal diet supplemented with either soyabean cake or bloodmeal or urea. It is commonly agreed that an ammonia concentration of 5 mg N/100mL of rumen fluid is the minimum below which microbial growth is impaired, though higher values (10-20 mg/100mL) have been suggested to be preferable (Wallace, 1979; Song and Kennely, 1989; Perdok and Leng, 1990). However, it is most likely that ammonia concentrations necessary for maximal bacterial growth may differ depending on the type of feeds given to the animals. In this study, the mean rumen ammonia concentration was about 4 and 8mg N/100mL in animals supplemented with soyabean cake and urea respectively. However, with urea, ammonia availability was not equally distributed throughout the day but rather excess ammonia occurred few hours after dosing and very little during the night. Given the slow rate of plant fibre degradation, it can be argued that soyabean cake supplementation synchronised the ammonia and energy availability better than urea thereby showing an almost similar effect on digestibility at a lower ruminal ammonia concentration.

Estimates of microbial N yields have been found to differ depending on the methods used in their determination (Stern and Hoover, 1979). The observed differences between microbial N synthesis calculated from purine derivatives and on the basis of digested carbohydrates (Madsen et al., 1995) was not surprising. The two methods are based on different assumptions and there are many factors that can ultimately affect the estimates (Ørskov, 1994). Importantly, the AAT-PBV system gives the average MN synthesis based on the amount digested carbohydrates but the estimates based purine derivatives are also influenced by other factors. The most important ones are the intra-ruminal conditions (e.g. pH, ammonia, microbial profiles) and the rate of clearance of materials from the rumen (Ørskov, 1994; Owens and Weakley, 1984). Though it is assumed that all purines excreted through urine are of microbial origin after the deduction of endogenous purines, a possibility of absorption of purines of dietary origin cannot be ruled out.

The efficiency of microbial protein synthesis when the low quality hay was fed as the sole diet was indeed very low. This was partly the effect of low N deficiency and also, the general observation that tropical grasses have low efficiency of microbial protein synthesis compared to temperate grasses (King et al., 1998; Prior et al., 1998). Shem et al. (1999) obtained a range of 6-17 g MN/kg organic matter digested in the rumen for various feeds fed to dairy cattle in smallholder farms in Tanzania. This underscores the importance of provision of supplements to address to the deficiencies so common with tropical forages.

Protein balance in the rumen (PBV) expresses the difference between protein degraded in the rumen and a calculated potential need for microbial protein produced on the basis of the amount of digested carbohydrates (Madsen and Hvelplund, 1988; Madsen et al., 1995). Both urea and soyabean cake supplements improved the PBV expressed in g CP/day with the highest level of urea showing the highest ($P<0.001$) PBV compared to the control. PBV values near zero or over are considered favourable for optimal rumen functions (Madsen et al., 1995). However, in animals fed to around maintenance requirements, negative PBV values up to –70 g CP per day can still be acceptable due to some compensation that usually occurs with N recycling through entrance of urea across the rumen mucosa or via saliva. The PBV with high urea level was within this range, and for the high soyabean level, it was slightly lower (-84 g/day) (Table 9). The linear correlation between PBV and urine CP defined by the equation: Urine CP (g/day)= 0.59 *PBV (g/day)+ 203 ($r^2=0.91$) may offer a simple method of estimating the protein balance in the rumen and therefore, the N availability relative to digested carbohydrates. However, more experiments need to be done to investigate the extent the equation holds true with increasing levels of N and energy intakes. Also, since it involves total urine collection, it will be of interest to investigate the diurnal variations in CP content of spot urine samples and the possibility of using markers such as creatinine to estimate urine output.

The nitrogen supplements enabled the animals to extract more energy from the basal hay. Apparently, the animals did not meet their requirement for maintenance except for the period when they were on high soyabean cake supplement possibly due to some additional energy from the supplement. However, the results of body weight measurements indicated that there was some weight gain under situations when there was negative energy balance. The equation for determination of MEm (ARC, 1980) includes a 5% activity allowance that in stall fed animals may be a little too high.

The rumen ingesta load of mat and liquid changes according to the feeding and drinking pattern as well as the rate of disappearance of materials from the compartment through digestion and passage (Van Soest, 1994). In this experiment, most of the parameters of rumen pool sizes (mat, liquid, total weight of wet and dry materials, NDF, DNDF, INDF and nitrogen) varied within and between the sources of supplementation but not to significant extent nor was there a specific pattern. Since, nitrogen supplementation increased the intake rates, this was offset by concurrent increases in the rate of digestion and passage such that rumen pool sizes of NDF was not much affected.

In studying fibre digestibility in a ration containing different sources of fibre, it is important to put into consideration the extent to which digestion of the fractions is affected by the intrinsic qualities of the fractions (Colucci et al.,1989). In this study the obtained digestion and passage kinetics were mainly attributed to the NDF from the consumed poor quality hay. The NDF contribution from soyabean cake was very small (33 and 66 g per day for the low and high level) compared to the total NDF intake (4.5-5.0 kg/day).

Both urea and soyabean cake led to an increase in the NDF intake and digestibility through increased rate of digestion with little change in passage rate and the rumen pool (Table 13 and Figure 14). Similar trend in plant fibre kinetics was reported by Weisbjerg et al. (1998) with incremental urea supplementation (0, 86 174 and 260 g) of diets deficient in nitrogen.

Comparison of fibre kinetics using NDF is not realistic due to the confounding effect of the indigestible NDF in the total NDF (Allen and Mertens, 1988). When the INDF was deducted from the total NDF, a more realistic pattern emerged. Whereas there were no significant changes between and within the levels of N from either supplement in NDF digestibility, the high urea level showed significantly ($P<0.05$) higher digestibility of DNDF compared to the low level of urea and higher (not significant) digestibility compared to both levels of soyabean cake. This implied that cellulolytic activities were improved to similar extent by both sources of nitrogen. This finding however contradicted that of Robinson et al. (1998) who found that urea supplementation with diets very low in nitrogen did not lead to increased digestibility of fibre. However, a great deal of the deviation from this study to theirs (Robinson et al., 1998) was possibly attributed to the differences in the basal diets used.

The total intake and fecal output of indigestible NDF increased with N supplementation in accordance with the increase in hay intake with supplementation. In practice, the daily intake and fecal output of INDF should be equal. However, there was a slight fall in fecal recovery of INDF with the recovery rate of INDF being 89.1, 96.3, 99.4, 95.2, and 90.2 in HO, HLU, HHU, HLS and HHS respectively. Problems of obtaining 100% fecal recovery of INDF have been encountered in other studies (Huhtanen, et al., 1994; Stensig, et al., 1998b). In this study, it might be possible that the hand chopped hay allowed some kind of selection with animals eating more leafy parts that have less NDF content compared to the steamy portions (Jung and Allen, 1995). It was also possible that there was some loss of fecal materials during the collection. The passage rates of INDF were higher than those of NDF which were in turn higher than those of DNDF (Table 13). This agreed with other observation that particles undergoing rapid fermentation accumulates gas bubbles which increase their buoyancy thereby reducing their chances of escape from the rumen (Stensig et al.,1998a; Stensig et al., 1998b, Mgheni, 2000). Further, age dependent passage can result in an erroneous underestimation of DNDF passage, however INDF passage is correctly estimated by the rumen evacuation method.

CONCLUSION

Low nitrogen in poor quality forages was found to be a major limiting factor in their utilisation. Nitrogen supplementation improved the intake and digestibility of hay and microbial protein synthesis. Nitrogen digestibility and nitrogen balance and to some extent, energy balance were improved thereby averting weight losses in animals fed poor quality forages.

In most measured parameters, soyabean cake was superior to urea possibly due to relatively slow degradation thereby matching ammonia availability with the slow degradation of degradation of hay. Provision of pre-formed amino acids, branched chain fatty acids, energy and minerals like sulphur that cannot be supplied with non-protein nitrogen sources could have been other factors contributing to the superiority of soyabean cake over urea. However, urea was equally good in improving plant fibre degradation. As such, all N requirements of cellullolytic microbes that are essential for plant fibre degradation can be met from ammonia resulting hydrolysis of NPN.

More work remains to be done in increasing wide use of urea for improving smallholder dairy production in Tanzania. One possibility is incorporation of urea in multi-nutrient blocks containing molasses and minerals or urea spraying, or treatment of poor quality forages.

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Paper III

The effect of maize bran alone or in combination with either sunflower cake, cassava flour, molasses or "Magadi" on intake and rumen function NDF kinetics.

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Abstract

The impact on rumen function of supplements traditionally used by smallholder dairy farmers in Tanzania is reported. The supplements included sources of energy and protein (maize bran, molasses, cassava flour and sunflower cake) and an ionic feed additive called "Magadi". The experimental layout was a 5x5 Latin square with 14 days for adaptation to diets, 7 days in vivo digestibility and total urine collection and last 7 days used for rumen evacuations. Treatments were: Poor quality hay with 2.7 kg (DM) maize bran (HMB) which was the control reflecting smallholder farmers feeding practice. Others treatments were hay with 2.7 kg (DM) maize bran further supplemented with 0.25 kg DM of "Magadi" (HMG), 1.31kg (DM) sugars (molasses) (HMO) or 0.9 kg (DM) starch (cassava tuber flour) (HCA). The fifth treatment was hay supplemented with 2.8 kg (DM) of farm made concentrate mixture containing maize bran (68), sunflower cake (31) and mineral powder (1% DM) (HFC). Five mature heifers (1/2 Boran x 1/2 Friesian) were used during the trial.

DM and organic matter intake was significantly (P=0.01) higher with sugars (HMO), starch (HCA) and nitrogen (HFC) supplements compared to the control (HMB). DM and OM digestibility ranged between 49-56% and were significantly (P=0.01) higher with nitrogen (HFC) and "Magadi" (HMG) supplements and significantly (P=0.05) higher with sugars (HMO) and starch (HCA) compared to the control. Rumen fluid pH was not greatly influenced by treatments but rumen fluid ammonia was significantly (P<0.001) higher in HFC compared to other treatments. Mean total VFAs tended to increase (P<0.1) in HFC (67.0mM) compared to the other treatments. The molar proportion of acetate was significantly (P=0.05) higher in HFC (68.8), HMG (68.4) and HMB (68.0%) compared to HMO and HCA (65% each). The efficiency of microbial protein synthesis per kg digested carbohydrates was not significantly affected by treatments though it tended to increase (P<0.1) with HMG compared to the other treatments. Nitrogen retention (g N/day) was significantly (P=0.01) higher with nitrogen supplementation compared to the other treatments. Rate and extent of digestible NDF degradation was significantly (P=0.02) higher with nitrogen (HFC) (2.66%h^{-1} and 64.25% respectively) and significantly (P=0.01) lower with starch (HCA) (1.72 and 53.02% respectively) compared to the other treatments. Starch (HCA) caused a significant increases (P=0.05) in the passage rate for INDF (2.6%h^{-1}) compared to the other treatments.

It is hereby concluded that the use of sugars, starch, nitrogen supplements and feed additives like "Magadi" can have variable effects on intake and digestibility of poor quality forages and that more efficient utilisation of poor quality forages occurred with increased nitrogen availability in the rumen.

Key words: Poor quality hay, intake, digestibility, maize bran, sugars, starch, "Magadi", sunflower cake, rumen function, microbial protein, NDF kinetics

INTRODUCTION

During the long dry season, tropical forages are of low quality due to high fibre content and deficiency in important nutrients like protein that are vital for rumen microbial growth and overall animal performance (Preston and Leng, 1987; Leng, 1990). Protein supplements can increase forage intake and digestibility and improve animal performance (Poppi and McLennan, 1995). However, supplementation with protein in the absence of adequate sources of energy can lead to protein wastage (Nolan, 1990).

Moderate energy supplementation are sometimes necessary in order to increase glucose precursors thereby enhancing gluconeogenesis, acetate utilisation and overall microbial growth (Rooke et al., 1987; Khalili and Huhtannen, 1987; Cronje et al., 1991). The slow degradation of plant fibre by cellulolytic bacteria in the rumen requires a good synchrony between energy produced and ammonia N release (Beever and Siddon, 1986) though other reports do not fully ascribe to this idea.

Research on the use of various sources nitrogen to improve utilisation of poor quality roughage commonly used in Tanzania has been going on for some time (Sarwat and Mtengeti, 1990; Shem, 1996; Shayo et al., 1997; Nkya et al., 1998; Plaizier et al., 1998). However, though smallholder dairy farmers use sources of energy like maize bran, molasses and cassava, and a feed additive called "Magadi", there has been little effort to evaluate how these ingredients affect rumen fibre kinetics and overall rumen fermentation. The "Magadi" locally used in Tanzania is very close in composition to a commercial product called "Magadi"-soda naturally harvested from Lake Magadi in Kenya (Nyachoti et al., 1998). The major ingredient in Magadi soda is sodium sesquicarbonate ($NaCO_3.NaHCO_3.2H2O$). It was the aim of this paper to investigate how these supplements can affect the intake and digestibility of the poor quality hay. Such information will be valuable to smallholder farmers to make the most efficient use of the available feed resources through strategic supplementation for improved productivity.

MATERIALS AND METHODS

Animals feeds and feeding

Five-rumen fistullated, mature non-pregnant crossbred heifers (1/2 Boran x 1/2 Friesian) were used in a 5 x 5 Latin Square. The animals were weighed at the beginning of the experiment (IBW) and at the end of each period (FBW). The experimental period lasted for 28 days including 14 days of preliminary period followed by 7 days of estimation of voluntary feed intake (VFI), in vivo and in situ digestibility determinations and 7 days for rumen evacuations. After termination of the intake experiment, three (3) ruminally fistulated animals fed a standard diet (2/3 hay and 1/3 concentrate) were used for in situ INDF measurements and DM disappearance from samples in bags previously soaked for 24 hours either in water or "Magadi" suspension.

Treatments were I) Low quality hay plus maize bran to reflect normal smallholder feeding practice (HMB) which was the control. II) Hay sprayed with "Magadi" suspension and maize bran (HMG) to reflect farmers who use the locally available mineral source. III) Hay sprayed with molasses plus maize bran (HMO) to reflect farmers who has access to molasses as a sugars source. IV) Hay with maize bran plus cassava flour (HCA) to reflect farmers who could use starch sources such as cassava. V) Hay plus farm made sunflower cake-maize concentrate mixture (HFC) to reflect a situation where smallholder farmers could improve the protein content of the diet using locally available sunflower cake.

The amounts of maize bran, concentrate and cassava flour were 2.7, 2.8 and 0.9kg (DM)/animal/day divided into two portions, one fed at 7.30 am in the morning and the remaining portion fed at 16.00pm in the evening. The "Magadi" suspension was made by mixing about 250 g (DM) in one litre of tap water that was then sprayed on the amount of hay to be fed to the animal on the same day. Molasses was sprayed on the hay to be fed to the respective animal in a given day.

In all treatments, poor quality hay was used as the basal diet. The hay used during this experiment was purchased from Melela in Morogoro and was cut at advanced stage of maturity. *Urochloa spp* was the predominant grass species in the hay. The hay was chopped to small size using a hand-machete to minimise selection. The animals were fed individually *ad libitum*. Feeding was adjusted everyday to be 10-15 % in excess of the ad libitum intake using the previous day level of intake. Fresh feeds were provided twice daily at 7.30am in the morning and 16.00pm in the afternoon. All feeds and orts were weighed daily, sampled, and prepared for subsequent analyses. The DM determination was carried out everyday in both feeds and orts. Fresh and clean water was provided from automatic drinkers system equipped with flow meters where record was read at 8.00 each morning. The difference between consecutive meter readings reflected the water intake (l) in a given day by the respective animal.

Faeces and urine collection

Faecal materials were collected manually from 7 am in the morning to seven 7am the next day when it was weighed to get the amount of fresh fecal material voided per day for each animal. Then, the fecal material for each animal was thoroughly mixed in large plastic basins and a 5% sample taken. The samples were immediately deep-frozen at a temperature of –15°C. At the end of the collection period (7 days), samples were de-frozen and pooled for each animal. The pooled samples were then thoroughly mixed and a sub-sample of 500 g taken for each animal. The samples were oven dried at 60 °C spread on wide round aluminium pans (30 cm diameter) to constant weight to determine DM. Samples intended for rumen incubation were then ground through a 2.0 mm sieve and those for other chemical analyses were ground through 1 mm sieve.

Daily urine output was done by the use of special urine funnels held onto the vulva. Each funnel was linked by a pliable tube to big collecting plastic container (50 l capacity) where 500ml of 17% sulphuric acid was initially added to maintain the urine pH values below 3. Acidification of the urine was important to avoid microbial destruction of purine derivatives. Values of purine derivatives obtained in the assay were correction for the dilution effect of the acid added. About 2% of daily collection for each cow was sampled and filtered through two layers of surgical gauze to remove large particles. Daily samples were then deep frozen at –20°C and at the end of the collection period, thawed and bulked for each animal. A sub-sample of 50 ml per animal was taken and deep-frozen till the time for purine derivative assay.

Ruminal fluid Volatile Fatty Acids (VFAs) and ammonia concentration and pH

A day before the onset of rumen evacuation, 24h rumen fluid samples were taken for determination of diurnal variations in pH and ammonia concentrations.

The sampling times were at 7.30 am (before morning feeding), 10am, 12 noon, 16.00pm, 18.00 pm, 20.00 pm, 22.00 pm 0.00 (Midnight) 2.00 am, 4.00 am 6.00 am and 8 am the next day. At the indicated sampling hours, materials from the ventral rumen sac were scooped by hand and squeezed through four layers of cheesecloth into a clean beaker. About 100ml of the liquid was taken. The pH was immediately taken using a portable pH meter. Then, 30mls of the fluid was decanted into a 50ml sample bottle and acidified to pH 4.0-4.5 by adding 3mls of 5M sulphuric acid to limit loss of ammonia from the sample. Samples were put in an ice packed cool box and taken to the laboratory. In the laboratory, the samples were centrifuged at 3000 rev/min for 20 min to precipitate the feed particles and the supernatant was put into 20ml test tubes, then deep frozen at –20 °C till the time for volatile fatty acids and ammonia assay.

The concentration of ammonia was estimated by a standard procedure as described by Chaney and Marbach (1962) using alkaline hypochlorite/phenol nitroprusside.

The concentration VFAs in the ruminal fluid were determined using a gas chromatography (HP 6890 GC) coupled to peak integrator (HPGC Chemostation, Hewlett and Packard, 1990-1998) by the method by Richardson et al. (1989) with some minor modifications.

In situ degradability

The in situ degradability study was carried out simultaneously with intake and in vivo digestibility trials. Incubated feeds were the basal hay, maize bran and concentrate mixture used during the trial. The feed samples were incubated on Day 16 and the last bags taken out before rumen evacuations started. Feeding regime and water supply were therefore similar to the intake trials. Forage samples were air dried and milled to pass through a 2 mm screen. Rumen incubation times (h) were 0, 2, 4, 8, 16, 24, 48, 72, 96, 144 for hay and to a maximum of 72 h for maize bran and the concentrate mixture. Approximately 1 g of hay and 5 g for maize bran and the concentrate mixture were incubated in nylon bags (measuring 7.5 x 10 cm and pore size 36 x 36 μm) in duplicate for each incubation time for DM and nitrogen (N) degradation. All bags were inserted at the same time during morning feeding and taken out as scheduled, rinsed and frozen to arrest microbial activity. After the longest incubation time (144 for hay and 72 hours for maize bran and concentrate mixture) all samples were machine washed in cold water for 20 min. Samples for DM were filtered through N-free filter paper of known weight. The residue was dried in an oven at 100°C for 20 h. Samples for N determination were transferred to Kjeldal tubes and analysed accordingly.

In sacco long incubation was used to determine the INDF in hay, maize bran, concentrate mixture, rumen contents and faeces. Approximately 2 g of hay, rumen digesta and faecal samples and 10g of maize bran and concentrate mixture were weighed into nylon bags measuring 7.5 x 10 cm and pore size of 36 x 36 mm and incubated in the rumen of heifers for 21 days. The residues were transferred into a beaker and boiled in 100 ml of NDF solution to obtain the INDF residue. The residue was ashed in a furnace at 550 °C to obtain ash free INDF that was used to calculate the DNDF and INDF.

The effect of soaking dacron bags containing ground hay samples in either "Magadi" suspension (0.25 kg in 1 litre of tap water) or plain tap water for 24 h was measured by incubating the so treated bags in the rumen of three animals fed a standard diet as previously described. The incubation procedure was as explained above for the determination of hay DM degradability.

Measure of rumen pool size of NDF

Rumen pool size of NDF was measured by rumen evacuation method for 3 days during the last seven days of the experiments in accordance to Dado and Allen (1995) and Stensig et al. (1998). Evacuation protocols were such that a minimum time interval of 48 h between two evacuations was allowed to avoid any effect that might occur on subsequent measurements. Rumen evacuations were performed at 7.00 h (morning) on Day 24, at 12 noon (mid-day) on Day 27 and 17.00pm (afternoon) on Day 29. The rumen mat was removed from the rumen manually by hand and the material not removable by hand was removed by scooping with a cup that was small enough to pass through the rumen cannula. The mat fraction was separated from the bailable liquid and both fractions weighed. About 1 litre of the liquid was sampled and the rest was immediately returned to the rumen. The mat was weighed and thoroughly mixed in a big plastic basin. About 5 % by weight were sampled, and the rest was returned into the rumen immediately. Finally the two samples were composited into their proportional weights to form two samples of 500 g each of the rumen digesta and the left over returned to their respective animal. The samples were oven dried at 60 °C spread on wide round aluminium pans (30 cm diameter) to constant weight to determine DM. Samples intended for rumen incubation were then ground through a 2 mm sieve and those for other chemical analyses were ground through 1 mm sieve.

Chemical analyses

Dry matter and organic matter analysis were carried out using the procedure as outlined by the AOAC (1990). All the samples analysed for NDF were done according to the methods describe by Van Soest et al. (1991). In the analyses, however, sodium sulphite and α-amylase were omitted.

Allantoin in the urine samples was analysed based on use of spectrophotometer (Cecil Instruments Serial No. 125 142 Model CE 2041, Cecil Instruments Ltd. Milton Technical Centre, Cambridge, CB4 6AZ England), by the procedures outlined in FAO/IAEA (1997). Uric acid was determined by Uricase method as described by Fujihara et al. (1987). Total purine derivatives output (Y) was the sum of allantoin and uric acid as the contribution of xanthine and hypoxanthine in cattle to daily purine derivative output is negligible (Verbic et al., 1990, FAO/IAEA, 1997).

Calculations

Microbial protein synthesis from purine derivatives

Daily purine derivative absorption (X) in mmol per day was calculated based on the equation derived by Verbic et al. (1990):

X = Y- $(0.385W^{0.75})/0.85$

Where Y = Daily purine excretion in mmol per day

W =Body weight in kg

X was then calculated from using the Y obtained from urine analysis and the weight (W) of the animals. Microbial N synthesis was then calculated as: Microbial N (gN/day) = X mmol/day *70/0.116*0.85*100 = 0.727X

The equation is based on four assumptions. (i) Digestibility of microbial purines of 0.85, (ii) the N content of purines is 70 mg N/mmol, (iii) Ratio of purine N to total N in mixed rumen microbes taken as 11.6:100 and (iv) Purine excretion in the cross-bred heifers will be similar to the temperate breeds from whom the equation was derived.

Metabolisable energy (ME), digestible nutrients and carbohydrates in feeds

These were done using from the chemical composition and the energy factors for protein (24.237), fat (34.116) and (17.300MJ/kg DM) for carbohydrates as was done by Weisbjerg and Hvelplund (1993).

Thus, Gross Energy (GE) was taken as the sum of individual contribution of feed components as shown below

GE CP = CP content (kg/kg DM) * 24.237MJ/kg DM

GE EE = EE content (kg/kg DM) * 34.116MJ/kgDM

GE CHO = CHO content (kg/kg DM) *17.3 MJ/kg DM

Where CP= crude protein, EE = ether extract and CHO = carbohydrates

Digestible energy was calculated from the digestibility of individual components in the feed multiplied by the respective energy factors as shown below:

Digested CP (kg/kg DM) = (93- (300/%CP in DM))* CP content (kg/kg DM)

Digested EE (kg/kg DM) = (96- (100/%EE in DM))* EE content (kg/kg DM)

Digested CHO was calculated as the difference between digested organic matter and the sum of the digested CP and digested EE

i. e. Digested CHO (kg/kg DM) = (dig OM-(dig CP + dig EE)

Thus digestible energy (DE) (MJ/kg DM) =(dig CP*24.237 +dig EE*34.116 + dig CHO*17.3)

Metabolisable energy (ME) MJ/kg DM) was obtained by multiplying the digestible energy by the factor 0.82 i.e. ME = 0.82*DE (MJ/kg DM)

Total digestible nutrients (TDN) was calculated as the sum of the digestible nutrients of all feed components as shown below

TDN (kg/kg DM) = dig CP + 2.25dig EE + dig CHO.

In sacco DM and N degradation

DM and N degradation was calculated as the disappearance of the fractions from dacron bags after washing or after the respective incubation times according to the equation:

DF = (W1-WR)/W1

Where, DF = degradation of the fraction from the bags,

W1 = weight of the fraction incubated

WR = weight of the fraction in the residue

Degradation characteristics

Rumen degradability characteristics were calculated using the exponential equation by Ørskov and MacDonald (1979)

$$Y(t) = a+b(1-e^{-ct})$$

Where Y(t) =degradation at time t

a = water soluble part (intersection with Y-axis

b = non-water soluble but potentially degradable fraction

c = part of b degraded per hour (rate constant)

t = incubation time in hours

The effective degradation (ED) was calculated using the equation

$$Y = a + (b\ (c/(c+k))$$

Where a, b, c are explained in the equation above

k = fractional passage rate

Y = effective degradation

Correction of particle losses from dacron bags

This was done as proposed by Weisbjerg et al. (1990) and Madsen et al. (1995) based on the assumption that the lost particles are degraded at the same rate as those remaining in the bag.

$$ED\ (corrected) = S + [(100-S)/100-L)] * (Y-L)$$

Where S = Water soluble fraction (%)

L = Washing losses in particles (%)

Y = Uncorrected effective degradation (%)

Metabolisable energy and protein requirements

Metabolisable energy and protein requirements were and using the following equations:

Metabolisable energy requirement for maintenance (MEm) = 8.3 + 0.091BWt (ARC, 1990)

Rumen degradable protein (RDP) (g/day) = 8.4 *ME (Topps and Oliver, 1993)

Where: MEm = ME (MJ) requirement for maintenance

BWt = BWt is the body weight in kg

ME = Metabolisable energy intake

Estimation of duodenal flow of NDF

Rate of passage of NDF from the rumen calculated from rumen evacuation data should be determined from measured rumen pool size of NDF and duodenal NDF flow. Since, the animals used in this study did not have duodenal fistulas, it was not possible to directly measure duodenal NDF flow and therefore had to be estimated based on fecal NDF flow corrected for post ruminal fibre loss using the equation below:

Duodenal NDF flow (kg/day) = Fecal flow NDF (kg per day) + (NDF intake per day *0.065) (Weisbjerg, M. R. (Personal communication)

From knowledge that duodenal flow of INDF = Fecal flow of INDF, the duodenal flow of DNDF was calculated as shown below:

Duodenal flow of DNDF (kg/day) = Duodenal NDF flow (kg/day)– Fecal INDF flow (kg/day).

Fractional rates of passage and digestion (referred to as rates of digestion and passage) of fibre fractions in the rumen were calculated from fibre flow and pool sizes in the rumen as previously proposed by Robinson et al. (1987) as shown below:

Rate of intake (ki) $\%h^{-1}$= 1/24 * Daily intake (kg)/rumen pool size (kg)

Rate of passage (kp) $\%h^{-1}$= 1/24 * Calculated duodenal flow (kg)/rumen pool size (kg)

Rate of digestion (kd) $\%h^{-1}$= ki – kp

Mean retention time (MRT) h = 1/kp

The model assumes first order-kinetics and in the current study it incorporated potentially digestible and indigestible fractions as described by Allen and Mertens (1988).

Rumen digestibility of NDF and DNDF were estimated using a simple one-compartment models as described by Allen and Mertens (1988) as shown below:

Rumen digestibility of NDF = digestible fraction x (kd/(kd+kp))

Rumen digestibility of NDF = kd/(kd+kp)

Where kp and kd have been described above.

Statistical analysis

Statistical analysis was carried out by the General Linear Model (GLM) to test the differences between the means of the various parameters using the model:

Y = I + T + C + P + ε (Model 1)

Where Y = dependent variables
I = Intercept
T = treatment (HMG, HCA, HMO, HFC and HMB)
C = cow (cow1-5)
P = Period (period 1-5)
ε = random error

Comparison between treatment means was done by GLM PDIF and also by Duncan Multiple Range Test. Results are reported as least square means for each treatment with standard error of the least square means. Type II test (SAS, 1988) were used implying that the mean effect of the treatments were tested without the interaction term in the model.

Comparison between the means in degradation constants and effective degradation due to soaking of dacron bags either in water or "Magadi" suspension was done using the model:

$Y = T + \varepsilon$ (Model 2)

Where:

Y	=	Dependent variables
T	=	Treatments (suspension in "Magadi" or in plain water)
ε	=	Random error

RESULTS

Chemical composition of feeds

Indicated in Table 1 are the chemical composition and energy contents of feed ingredients used during the trial. DM percent ranged from 78 in molasses to 93% in the hay. The CP content of the feeds varied greatly, with the concentrate mixture having the highest followed by maize bran, hay, molasses and finally cassava flour (Table 1). The CP content in cane molasses was much lower compared to the value appearing in the Danish Feedstuff Table (5.5%) (Møller et al., 2000) but was within the range reported (1-5%) from tropical areas (Göhl, 1981). The hay had the highest ash content (10.9) followed by molasses (10.0), cassava (7.8) and 5.4 and 5.1% of DM in the concentrate mixture and maize bran respectively. As expected, the NDF content was highest in hay (75.2), medium in maize bran and concentrate (32 and 38% of DM) respectively and assumed to be none in molasses. Metabolisable energy content ranged from 9-12 in the concentrates and only 4.3 MJ/kg DM in the hay.

In vitro OM digestibility results for cassava flour from two different laboratories gave unusually very low values (33 and 39%). This was possibly due to the effects of either low nitrogen or high cyanide content that may have reduced microbial activity in the in vitro system. For cassava flour and cane molasses, energy values reported by Ghöl (1981) were used in the calculation of energy contribution from two feed ingredients.

Table 1. The chemical composition of feeds used during the trial. All values are in % unless otherwise stated.

Parameter	Type of feed				
	Maize bran	Formulated concentrate	Cane molasses	Cassava flour	Hay
DM	91.5	92.2	78.4	92.5	93.1
Components (% DM)					
ASH	5.1	5.4	9.6	7.8	10.9
OM	94.9	94.6	90.4	92.2	89.1
CP	10.9	14.8	2.1	1.4	3.4
EE	10.7	9.2	NA	0.7	3.0
NDF	31.9	38.0	NA	13.7	75.2
INDF	3.4	4.8	NA	NA	26.2
CHO	73.3	70.5	NA	90.1	82.7
K	0.8	0.7	NA	NA	1.4
Ca	0.1	0.2	NA	NA	0.4
Mg	0.3	0.3	NA	NA	0.4
P	0.8	0.7	NA	NA	0.3
Na	0.2	0.2	NA	NA	0.3
IVOMD	65.6	61.5	NA	AP	36.7
Effective degradation (%)					
DM	66.8	58.8	NA	NA	42.7
N	73.5	63.7	NA	NA	52.0
Energy content					
GE (MJ/kg DM)	17.5	17.6	*15.12	*17.80	14.9
DE (MJ/kg DM)	12.1	11.6	NA	NA	6.4
ME(MJ/kg DM)	10.7	10.2	*10.88	*11.58	5.2
TDN (kg/kg DM)	0.75	0.69	NA	NA	0.37

IVOMD: In vitro organic matter digestibility; NA: Not analysed; AP: Analysed but results from two different laboratories were unusually very low (33.4 and 39.1)
*Passage rate of 2%h^{-1}, * Source Göhl (1981)

Table 2 shows the amounts of supplements and additive given to the animals under the various treatments. About 2.7 kg DM of maize bran was offered in HMG, HCA, HMO and HMB while 2.8 kg DM of concentrate mixture containing 1.9 and 0.9kg maize bran and sunflower cake respectively, was given during HFC treatment. It was planned that animals during HMO treatment would consume about 1.4kg DM molasses. However when the final intake was calculated putting into consideration the refusals, actual molasses intake was 1.3 kg DM/day/cow. The amount of concentrates consumed

(%total DM intake) was significantly (P<0.001) higher with sugars (HMO) and starch (HCA) compared the other treatments due to the additional DM with from the two supplements and not from increased consumption of hay.

Table 2 Amounts (kg DM) of supplements/feed additive given

	Treatments				
Ingredient (kg/day)	HMB	HMG	HMO	HCA	HFC
Cane molasses	-	-	1.4	-	-
Cassava flour	-	-	-	0.9	-
*Concentrate mixture	-	-	-	-	2.8
Maize bran	2.7	2.7	2.7	2.7	1.9
"Magadi"	-	0.3	-	-	-
Total supplements	2.7	3.0	4.1	3.6	2.8

HMB: hay + maize bran; HMG: hay + maize bran + "Magadi"; HMO: hay + maize bran + molasses; HCA: hay + maize bran + cassava; HFC: hay + formulated concentrate
* Contained 1.9 and 0.9 kg of maize bran and sunflower cake respectively.

Shown in Table 3 is the mineral composition of "Magadi". The high ash content of "Magadi" (83 % of DM) indicates that the ingredient mainly contains minerals. The largest component was water-soluble bicarbonate (18 % of DM) that is also reflected by the high amount of carbon (6.7% of DM).

Table 3 Mineral composition of "Magadi"

	Proportion	
Component	% in DM	mg/kg
Ash	83.2	
Mg	2.3	
Ca	3.1	
P	0.3	
K	1.3	
Na	14.3	
C	6.7	
Cl	1.5	
Cu		35.2
Fe	3.4	
Mn		906.2
Zn		65.5
Water soluble HCO3	17.6	

Animal health

One animal died with signs of East Coast fever (ECF) at the beginning of period 4 and was replaced with another one of nearly the same weight.

Intake, flow and digestibility of nutrients

Results of intake of the various dietary components are shown in Table 4.

Table 4 The effect of "Magadi", starch, sugars and nitrogen supplements on dry matter (DM), Organic matter (OM) and water intakes, and ration composition

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Intake							
Hay (kg DM/day)	4.69	4.70	4.53	5.39	4.48	0.24	0.1
Total (kg DM/day)	7.6^{b}	8.3^{a}	8.5^{a}	8.2^{a}	7.2^{b}	0.24	0.01
Ash (kg DM/day)	0.76^{ab}	0.68^{b}	0.82^{a}	0.73^{ab}	0.60^{c}	0.03	0.003
OM intake (kg/day)	6.9b	7.6a	7.7a	7.4a	6.6b	0.12	0.01
DM intake (%BW)	2.2^{b}	2.3^{a}	2.4^{a}	2.2^{a}	2.1^{b}	0.05	0.01
DM intake (g/kg $W^{0.75}$)	93.2^{b}	101.1^{a}	102.3^{a}	97.8^{a}	88.6^{b}	2.48	0.01
Water intake (l/day)	31.3	29.9	33.5	30.1	28.3	1.68	0.3
CP diet (%DM)	6.0^{bc}	5.7^{d}	5.8^{cd}	7.4^{a}	6.3^{b}	0.10	0.01
Concentrates intake (%DM)	39.7^{cd}	43.2^{b}	47.2^{a}	34.6^{d}	38.5^{c}	1.29	<0.0001

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran; Means within rows with different superscripts are statistically different (P<0.05)

It appeared that hay DM intake was not significantly affected by treatments, though it tended to increase (P<0.1) with nitrogen supplementation compared to the other treatments. Total DM and OM intake was significantly (P=0.01) higher with sugars (HMO), starch (HCA) and nitrogen (HFC) supplementation compared to "Magadi" (HMG) and the control (HMB) (Table 4). There was no statistically significant treatment effects on fecal flow of DM and OM (Table 5). Apparent digestibility of DM and OM ranged between 49-56% and was significantly (P=0.05) higher with sugars, starch, "Magadi" and nitrogen supplementation compared to the control (Table 5).

Table 5 The effect of "Magadi", starch, sugars and nitrogen supplements on fecal DM, OM and ash flow and digestibility

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Fecal flow (kg/day)							
DM	3.4	3.9	4.0	3.7	3.6	0.13	0.1
OM	3.0	3.5	3.5	3.3	3.2	0.17	0.1
Ash	0.40^{ab}	0.43^{a}	0.43^{a}	0.40^{ab}	0.38^{b}	0.011	0.02
Apparent digestibility (%)							
DM	54.9^{a}	53.7^{a}	53.7^{a}	54.8^{a}	49.3^{b}	1.06	0.02
OM	55.8^{a}	55.2^{a}	54.3^{a}	55.7^{a}	50.6^{b}	1.08	0.03
Ash	47.3^{a}	37.1^{b}	48.1^{a}	44.6^{a}	35.5^{b}	1.80	0.001
[1]Digested CHO (kg/day)	2.9^{cb}	3.1^{b}	3.5^{a}	2.9^{cb}	2.7^{c}	0.09	<0.0002
[2]App. Digested OM (kg/day)	3.82^{b}	4.19^{a}	4.16^{ab}	4.1^{ab}	3.3^{c}	0.150	0.01

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran;
[1]Calculated based feed characteristics (Weisbjerg and Hveplund, 1993)
[2]Calculated as OM intake-Fecal OM
Means within rows with different superscripts are statistically different (P<0.05)

The intake of NDF was significantly (P=0.01) higher with nitrogen and (P=0.05) with both sugars and starch compared to the control (Table 6). "Magadi" (HMG) and the control (HMB) had similar intake of NDF (4.2 kg/day) (Table 6).

Table 6. The effect of "Magadi", starch, sugars and nitrogen supplements on neutral detergent fibre (NDF) intake, flow and digestibility

	Treatment						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Neutral detergent fibre (NDF)							
Intake (kg/day)	4.16^{c}	4.35^{bc}	4.77^{ab}	5.06^{a}	4.19^{c}	0.163	0.01
[1]Duodenal flow (kg/day)	2.28	2.74	2.70	2.60	2.47	0.123	0.1
Fecal flow (kg/day)	2.01	2.47	2.39	2.27	2.19	0.105	0.1
Digestibility (%)							
*Rumen	44.8^{ab}	36.5^{c}	44.7^{ab}	48.3^{a}	42.3^{bc}	2.10	0.02
Whole tract	51.4^{ab}	43.0^{c}	50.5^{ab}	54.8^{a}	47.8^{bc}	2.10	0.02
Indigestible neutral detergent fibre (INDF)							
Intake (kg/day)	1.20	1.34	1.45	1.53	1.28	0.078	0.1
Fecal (kg/day)	1.12^{b}	1.35^{a}	1.39^{a}	1.35^{a}	1.28^{ab}	0.053	0.03
Digestible neutral detergent fibre (DNDF)							
Intake (kg/day)	2.97^{c}	3.02^{bc}	3.34^{ab}	3.53^{a}	2.91^{c}	0.113	0.01
[2]Duodenal flow (kg/day)	1.16	1.40	1.31	1.25	1.18	0.082	0.2
Fecal flow (kg/day)	0.89	1.10	0.99	0.92	0.92	0.070	0.2
Digestibility (%)							
*Rumen	60.9^{a}	53.0b	61.4^{a}	64.2^{a}	59.6^{a}	2.44	0.02
Whole tract	70.0^{a}	62.6^{b}	71.1^{a}	73.4^{a}	68.9^{a}	4.46	0.02

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran;
^{abc}Means within rows with different superscripts are statistically different (P<0.05)
* Based on calculated duodenal flow
[1]Calculated as: Duodenal NDF flow (kg/day) = Fecal flow NDF (kg per day) + (NDF intake per day *0.065)
[2]Calculated as: Duodenal DNDF flow (kg/day) = Duodenal NDF flow– Fecal INDF flow (kg/day).

Calculated duodenal flow and fecal flow of NDF did not differ between the treatments. However, calculated rumen digestibility of NDF and whole tract digestibility was significantly lower (P =0.05) with starch and significantly higher (P=0.05) with nitrogen supplementation compared to other treatments (Table 6). Similar trend was observed with digestible NDF.

Total nitrogen intake during the experiment varied between treatments (Table 12). It ranged between 71 to 96 g/day with the highest value occurring with nitrogen supplementation (HFC) and the lowest with the control (HMB) and "Magadi" (HMG).

Fecal flow of N was highest with "Magadi" and sugars supplements (54 and 53g/day respectively) while for other treatments, it ranged between 40-43g/day). Apparent N digestibility was significantly (P=0.04) influenced by treatments; being highest with N supplementation and lowest with "Magadi" supplementation.

In situ degradation

The rate and extent of degradation of hay DM from dacron bags incubated in the rumens of the animals are shown in Table 7. Sugars and starch resulted into degradation rate constant of 1.6 and 1.8 $\%h^{-1}$ respectively which were significantly ($P<0.0004$) lower compared to the maize bran-sunflower cake concentrate mixture and also with "Magadi". The effective DM degradation from the dacron bags at both 2 and 5% h^{-1} passage rates and also the degradation at 48 hours of incubation were significantly ($P=0.02$) higher with "Magadi" and with the concentrate mixture compared to sugars and starch supplementation. The effective degradation of DM from bags soaked for 24h in "Magadi" suspension before incubation in standard cows was significantly higher ($P=0.03$) compared to those suspended in plain water (Table 8).

Table 7. The effect of "Magadi", starch, sugars and nitrogen supplements on degradation constants for DM (a, b and c) and effective degradation (ED) of hay samples incubated in dacron bags in the rumen

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Fraction a	10.0	10.0	9.7	11.0	9.6	0.34	0.1
Fraction b	52.6	55.5	56.6	51.1	53.2	2.67	0.6
Rate of degradation (C) ($\%h^{-1}$)	2.91^{a}	1.79^{cb}	1.56^{c}	2.87^{a}	2.19^{b}	0.18	<0.0004
Washing losses (% DM)	10.6	10.6	10.6	10.6	10.6	-	-
DM Degradation (% DM)							
48 hour incubation	50.1^{a}	42.1^{b}	38.0^{c}	48.31^{ab}	42.6^{ab}	2.4	0.02
144 hour incubation	62.0	59.4	59.9	62.3	59.3	2.4	0.8
Effective degradation (%DM)							
2% h^{-1} passage rate	40.7^{a}	35.4^{b}	33.3^{b}	41.1^{a}	36.0^{ab}	1.7	0.02
5% h^{-1} passage rate	28.8^{a}	23.9^{b}	22.3^{b}	29.7a	24.6^{b}	1.14	0.002

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran; Means within rows with different superscripts are statistically different ($P<0.05$)

Table 8. The effect of 24 hours soaking in "Magadi" suspension (MG) or water (WT) soaking of dacron bags with hay samples on DM degradation constants

Parameter	Treatments MG	WT	SEM	*P Value
Washing losses (%DM)	9.3	9.3	-	-
Degradation constants				
Fraction a (% DM)	10.5	9.5	0.58	0.1
Fraction b (%DM)	54.0	51.9	2.17	0.6
Rate C (%h^{-1})	2.46	1.60	0.430	0.3
Degradation (%DM)				
48 hour incubation	50.4	38.3	7.16	0.4
144 hour incubation	63.1	53.8	7.16	0.1
Effective degradation				
2%h^{-1}passage rate	41.4	29.9	0.88	0.03
5%h^{-1} passage rate	29.4	19.3	0.88	0.03

ED: Effective degradation; MG: "Magadi" suspension; WT: water suspension
*Model II

Rumen fermentation

Rumen fluid concentration of acetate, propionate, butyrate and total acids did not significantly differ between treatments (Table 9). However, the molar proportion of acetate was significantly (P=0.01) higher with nitrogen (HFC), "Magadi" (HMG) and in the control (HMB) compared to starch (HCA) and sugars (HMO). Sugars and starch supplementation had the highest molar proportion of butyrate compared to the other treatments.

While no significant effects due to treatments were observed in the rumen fluid pH, rumen fluid ammonia concentration was significantly (P<0.001) higher with nitrogen supplementation compared to the other treatments (Table 9).

Table 9. The effect of "Magadi", starch, sugars and nitrogen supplements on ruminal fluid pH, volatile fatty acids (VFAs) and ammonia concentration

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
VFAs concentration (mM)							
Acetate	43.2	36.0	37.4	46.2	40.4	5.03	0.6
Propionate	14.0	13.7	13.3	15.3	13.4	1.32	0.8
Butyrate	5.4	5.5	6.9	5.5	5.2	1.33	0.4
Total	62.6	55.2	57.6	67.0	59.0	0.69	0.8
Acetate /propionate	3.01	2.59	2.82	3.01	3.00	0.128	0.1
Moles/100 moles							
Acetate	68.4^{c}	64.8^{a}	64.8^{a}	68.8^{c}	68.0^{bc}	0.84	0.01
Propionate	23.0	25.3	23.1	23.0	23.0	0.82	0.3
Butyrate	8.6^{c}	10.0^{a}	12.2^{a}	8.2^{c}	9.1^{bc}	0.41	<0.0002
Mean ruminal ammonia (mg N/100ml)	1.75^{b}	1.58^{b}	1.09^{a}	5.70^{c}	2.24^{b}	0.515	<0.0004
Mean ruminal pH	6.7	6.7	6.8	6.5	6.6	0.08	0.2

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran; Means within rows with different superscripts are statistically different ($P<0.05$)

Figures 1 show the diurnal variations in the ruminal fluid pH under the various treatments. Nearly all treatments had a fall in ruminal pH from between 6.9-7.0 just before morning feeding to 6.6-6.8 three hours after feeding with HMB having the lowest pH. A more drastic fall in ruminal pH occurred from just after feeding concentrates at 16.00pm reaching lowest levels at 20.00pm in HFC (6.1).

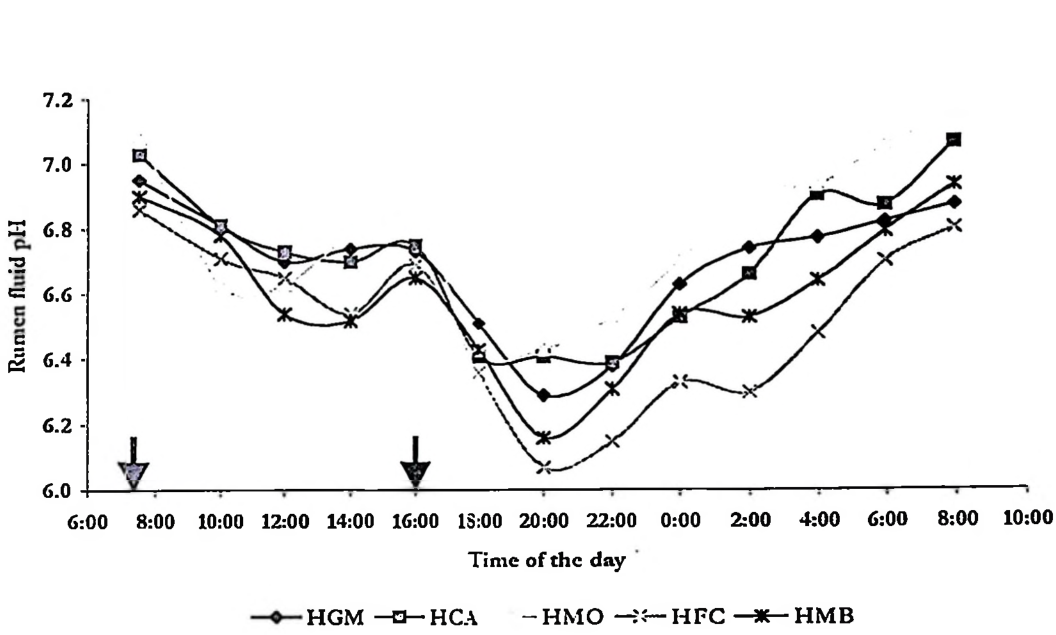

Figure 1. Diurnal variations in the rumen fluid pH under the various treatments. Arrows indicate the time when half the estimated daily amounts of hay and supplements were offered.

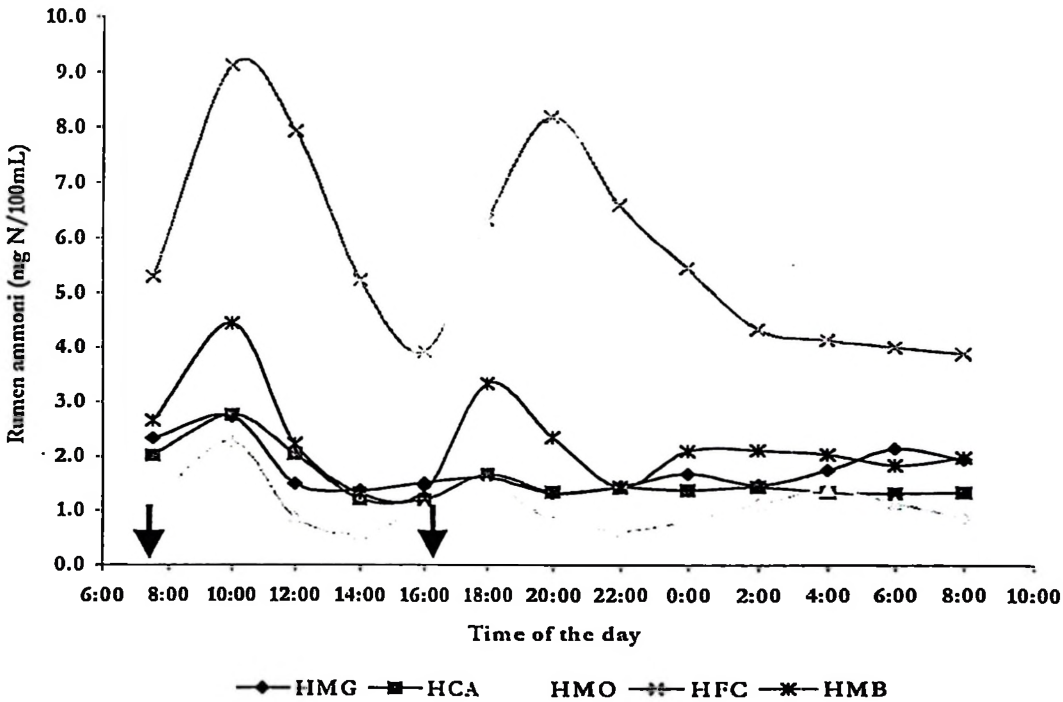

Figure 2. Diurnal variations in the rumen fluid ammonia concentration under the various treatments. Arrows indicate the time when half the estimated daily amounts of hay and supplements were offered.

Diurnal trends in ruminal fluid ammonia are shown in Figure 2. Peak ammonia levels (7.9 and 4.4mg N/100mL in HFC and HMB respectively) were attained 2 hours after morning offer of feeds while the levels in the other treatments were between 2.3-2.8 mg N/100mL ruminal fluid. The evening feeding led to a second peak ammonia (8.2 and 3.3mg N/100mL in HFC at 20.00pm and in HMB at 18.00pm respectively). Not only that there were no peak ammonia levels in the other treatments, but also the values were quite low and ranged between 1.0-3.0 in HMG and HCA, and 0.6 -2.3 mg N/100mL in HMO. Mean daily ruminal ammonia level (Table 7) were significantly (P<0.001) higher in HFC compared to the other treatments.

Urine output, composition and microbial protein synthesis

There were no significant effects of supplements on urine output, urinary allantoin and uric acid concentration (Table 10). However, urine CP content was highest with nitrogen supplementation. Microbial nitrogen (MN) synthesis estimated from purine derivatives and the efficiency of synthesis did not significantly differ between treatments, though they tended to increase with "Magadi" (P<0.1) compared to other treatments (Table 11).

Table 10. The effect of "Magadi", starch, sugars and nitrogen supplements on urine output and composition

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P-Value
Urine output (l/day)	12	9.8	9.3	9.2	9.7	0.80	0.1
CP content (%)	0.7^b	0.9^b	0.9^b	1.7^a	0.9^b	1.90	0.03
Allantoin (mmoles/l)	9.6	11.6	9.2	10.5	9.2	0.80	0.3
Uric acid (mmoles/l)	1.4	1.5	1.6	1.5	1.6	0.20	0.9

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran; Means within rows with different superscripts are statistically different (P<0.05)

The microbial crude protein synthesis and protein balance in the rumen (PBV) calculation based on Danish AAT-PBV system (Madsen et al., 1995) significantly (P<0.0001) differed between treatments relative to the differences in the calculated amounts of digestible carbohydrates intake for each treatment. Values ranged between 492 to 633g and –312 to –162g microbial crude protein per day for the synthesis and PBV respectively (Table 11).

Nitrogen retention and energy balance

Nitrogen (HFC) supplementation led to the highest nitrogen retention (32 g/day) while sugars (HMO), starch (HCA) and control (HMB) had N retention ranging between 15-25 g/day. "Magadi"(HMG) had the lowest N retention (6 g/day) (Table 12).

Table 11. The effect of "Magadi", starch, sugars and nitrogen supplements on rumen degradable protein (RDP), microbial protein synthesis estimated from purine derivatives, potential synthesis based on digested carbohydrates and the protein balance in the rumen (PBV)

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Rumen degradable protein (RDP)							
*Requirement (g/day)	348.0	343.6	349.2	346.5	341.4	2.04	0.1
Intake (g/day)	300.5[cd]	307.7[cb]	320.9[b]	358.9[a]	294.5[d]	4.68	<0.0001
Intake-requirement (g)	-47.6[c]	-35.9[b]	-28.3[b]	12.3[a]	-46.9[c]	4.41	<0.0001
[1]**Microbial N synthesis**							
Allantoin output (mmoles/day)	106.2	97.9	81.4	88.5	74	8.5	0.1
Uric acid output (mmoles/day)	16.2	14.3	16.9	14.0	11.7	3.2	0.8
Total purines (mmoles/day)	122.3	112.1	98.3	102.5	85.7	10.6	0.2
Purines absorbed (mmoles/day)	85.1	75.1	60.6	64.9	48.9	10.43	0.2
Microbial N (g/day)	61.9	54.6	44.0	47.2	35.5	7.58	0.2
Microbial CP (g/day)	386.8	341.2	275.1	295.9	221.9	47.39	0.2
Microbial N (g/kg dig. CHO)	22.2	17.4	12.7	16.9	12.8	2.60	0.1
Microbial N (g/kg DOM)	17.3	13.2	10.6	11.9	11.0	1.98	0.2
[2]**Microbial crude protein and PBV**							
[3]Microbial N (g)	83.0[c]	90.0[b]	101.2[a]	83.3[cb]	78.7[c]	2.44	<0.0003
Microbial CP (g)	518.4[c]	562.5[b]	632.5[a]	520.6[cb]	491.5[c]	15.27	<0.0003
Degradable CP int. (g)	300.5[cd]	307.7[cb]	320.9[b]	358.9[a]	294.5[d]	4.68	<0.0001
PBV (g/day)	-217.8[b]	-254.8[c]	-311.6[d]	-161.8[a]	-197.0[ab]	10.83	<0.0001

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran;
*Calculated from RDP (g/day) = 8.4*ME (ARC, 1990)
[1]According to Verbic et al. (1990)
[2]According to Madesn et al. (1995)
[3]Calculated as digestible CHO (kg) * 28.57microbial crude N/kg dig. CHO.
Means within rows with different superscripts are statistically different (P<0.05)

All supplements led to positive energy balance (Table 13). Body weights and body weight changes seemed not affected by treatments. However, there was a slight loss in weight in the control, while other treatments had weight gain ranging from 4.3 with starch, 14.6 with sugars and 21 kg/28 days with nitrogen supplementation (Table 13). Only "Magadi" and molasses treatments had the calculated body weight gain based on the energy balance close to the actual weight gain. Cassava had much less gain while the concentrate mixture had higher gain than would be expected from the energy retained.

Table 12. The effect of "Magadi", starch, sugars and nitrogen supplements on nitrogen (N) metabolism

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
N intake (g/day)	73.2[cd]	74.7[bc]	79.4[b]	95.6[a]	71.3[d]	1.44	<0.0001
Fecal N (g/day)	53.9	39.78	53.1	43.3	42.3	4.15	0.1
Urinary N (g/day	13.1[b]	10.4[b]	11.4[b]	20.1[a]	8.8[b]	1.54	0.003
Total N excreted (g/day)	67.0[a]	50.2[ab]	64.5[ab]	63.4[a]	51.1[b]	4.43	0.04
N balance (g/day)	6.13[c]	24.5[ab]	15.0[bc]	32.2[a]	20.2[ab]	4.08	0.01
Apparent N dig (%)	23.6[b]	43.8[ab]	33.1[ab]	52.9[a]	37.9[ab]	5.51	0.04

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran;
[abcd]Means within rows with different superscripts are statistically different ($P<0.05$)

Table 13. The effect of "Magadi", starch, sugars and nitrogen supplements on Metabolisable energy (ME) intake and body weights changes

	Treatments						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Metabolisable energy (MJ)							
Intake	53.1[c]	63.9[a]	66.3[a]	56.3[b]	52.0[c]	1.04	<0.0001
Maintenance (ME_m)	41.4	40.9	41.6	41.3	40.6	0.24	0.1
ME intake above maintenance	11.6[c]	23.0[a]	24.8[a]	15.0[b]	11.4[c]	0.97	<0.0001
[1]Diet Metabolizability (q_m)	0.46[dc]	0.48[b]	0.50[a]	0.44[d]	0.46[c]	0.004	<0.0001
[2]Efficiency of utilisation of ME for growth/fattening (k_g)	0.36[c]	0.38[b]	0.40[a]	0.35[c]	0.37[c]	0.003	<0.0001
[3]Expected body mass gain (kd/day)	0.20[c]	0.40[a]	0.46[a]	0.25[b]	0.19[c]	0.04	<0.0001
Body weight (kg)							
Initial	352.8	351.0	350.0	341.4	354.8	3.63	0.5
Final	357.8	355.3	364.6	362.5	352.8	2.67	0.2
Weight change (kg/28 days)	5.0	4.3	14.6	21.1	-2.0	3.93	0.1
Weight change (kg/day)	0.18	0.15	0.52	0.75	-0.07	0.23	0.1

[1]Ratio of Metabolisable to gross energy per kg DM (McDonald et al., 1995)
[2]Calculated as $k_g = 0.78q_m + 0.006$ (McDonald et al., 1995)
[3]Calculated as (ME balance $*k_g$)/EV_g where energy value of weight gain (EV_g)=20.9 MJ/kg (Topps and Oliver, 1993)
Means within rows with different superscripts are statistically different ($P<0.05$)

Rumen pool sizes

Rumen pool sizes of the different fractions were highest with the evening evacuation and lowest in the morning evacuation while the mid-day evacuation had values in between (Table 14).

Table 14. The effect of "Magadi", starch, sugars and nitrogen supplements on rumen pool sizes dry ingesta, NDF, INDF, and N during individual evacuations (8 am, 12 Noon and 17pm) and the average of the three evacuations. Unless otherwise stated, values are expressed in kg.

	Treatments						
	HMG	HCA	HMO	HFC	HMB	SEM	P-value
Morning evacuation (08.00h)							
Total ingesta	50.6	47.1	53.6	45.4	52.3	1.54	0.2
%DM ingesta	13.6	14.3	14.2	14.3	14.0	0.28	0.4
DM ingesta	6.9	6.8	7.7	6.5	7.4	0.24	0.05
NDF	4.9	4.8	5.6	4.7	5.2	0.22	0.1
DNDF	3.03^{b}	3.16^{ab}	3.72^{a}	2.82^{ab}	3.36^{ab}	0.169	0.03
INDF	1.83	1.69	1.87	1.93	1.81	0.090	0.4
N	0.08	0.09	0.08	0.08	0.09	0.007	0.7
Mid-day evacuation (12.00h)							
Total ingesta	63.6	57.0	61.9	55.5	61.4	1.93	0.1
%DM ingesta	13.9^{c}	15.5^{a}	15.0^{ab}	15.2^{ab}	14.4^{bc}	0.32	0.04
DM ingesta	8.9	8.9	9.3	8.5	8.97	0.39	0.7
NDF	6.3	5.7	6.7	5.9	6.4	0.39	0.5
DNDF	2.53	2.36	2.57	2.49	2.67	0.201	0.9
INDF	3.78	3.37	4.14	3.40	3.72	0.258	0.3
N	0.10	0.12	0.10	0.11	0.10	0.013	0.9
Evening evacuation (17.00h)							
Total ingesta	66.8	62.9	66.5	64.0	65.3	2.23	0.7
%DM ingesta	14.4^{b}	16.0^{a}	16.0^{a}	15.6^{a}	15.3^{ab}	0.37	0.04
DM ingesta	9.6	10.1	10.6	10.0	10.0	0.47	0.7
NDF	6.7	6.5	7.3	6.8	6.7	0.43	0.8
DNDF	2.76	2.56	2.72	2.78	2.62	0.223	0.9
INDF	3.96	3.97	4.58	4.04	4.09	0.284	0.5
N	0.12	0.12	0.13	0.12	0.11	0.012	0.8
Mean of the three evacuations							
Total ingesta	60.4	55.7	60.7	55.0	59.7	1.51	0.1
%DM ingesta	14.0^{c}	15.3^{a}	15.1^{ab}	15.1^{a}	14.6^{bc}	0.22	0.01
DM ingesta	8.5	8.6	9.2	8.3	8.8	0.31	0.4
NDF	6.0	5.7	6.5	5.8	6.1	0.26	0.3
DNDF	3.59	3.50	4.15	3.40	3.72	0.171	0.1
INDF	2.37	2.20	2.38	2.40	2.37	0.138	0.8
N	0.10	0.11	0.11	0.10	0.10	0.007	0.9

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran; Means within rows with different superscripts are statistically different ($P<0.05$)

Rumen pool size of DNDF was significantly higher (P=0.03) with sugar supplementation compared to other treatments in the morning evacuation. The %DM of rumen ingesta during the mid-day, afternoon and evening evacuations and the mean of the three evacuations was significantly affected by treatments to varying extents (Table 14). The other measured rumen pool parameters seemed not significantly affected by treatments. Values for the average of the three rumen evacuation showed rumen pools capacity of DM (kg) ranging between 8.3 - 9.2, with the lowest and highest value occurring with nitrogen and sugars supplementation, respectively. Mean value of rumen pool sizes ranged between 6.0-6.5 kg for NDF, 3.4-4.2 kg for DNDF and 2.2-2.4 kg for INDF (Table 14).

Rates of passage and digestion

The rate of passage of NDF ranged from 1.65-2.10%h^{-1}, that of INDF between 1.96-2.55%h^{-1} and 1.45-1.84%h^{-1} for digestible NDF (Table 15).

Table 15. The effect of "Magadi", starch, sugars and nitrogen supplements on NDF intake, passage, digestion and mean retention time (MRT) in the rumen

	Treatment						
Parameter	HMG	HCA	HMO	HFC	HMB	SEM	P value
Neutral detergent fibre (NDF)							
Intake (ki) (%h^{-1})	2.96^{b}	3.16^{b}	3.09^{b}	3.61^{a}	2.86^{b}	0.305	0.02
Passage (kp) (%h^{-1})	1.65^{b}	2.10^{a}	1.78^{b}	1.93^{ab}	1.75^{b}	0.076	0.02
Digestion (kd) (%h^{-1})	1.31^{b}	1.05^{b}	1.31^{b}	1.68^{a}	1.10^{b}	0.105	0.01
Indigestible neutral detergent fibre (INDF)							
Intake (ki) (%h^{-1})	2.09^{b}	2.53^{a}	2.53^{a}	2.65^{a}	2.24^{ab}	0.123	0.05
Passage (kp) (%h^{-1})	1.96^{b}	2.55^{a}	2.43^{a}	2.38^{ab}	2.26^{ab}	0.123	0.05
Digestible neutral detergent fibre (DNDF)							
Intake (ki) (%h^{-1})	3.61^{ab}	3.57^{b}	3.41^{b}	4.28^{a}	3.27^{b}	0.193	0.04
Passage (kp) (%h^{-1})	1.45	1.84	1.41	1.61	1.46	0.102	0.09
Digestion (kd) (%h^{-1})	2.15^{ab}	1.72^{b}	1.99^{ab}	2.66^{a}	1.81^{b}	0.182	0.02
Mean retention time (MRT)							
NDF	60.8^{a}	47.3^{b}	57.2^{a}	52.6^{ab}	56.9^{a}	2.39	0.03
INDF	50.7	39.6	42.0	43.3	45.0	2.51	0.08
DNDF	70.4	55.2	72.4	62.7	68.7	4.18	0.11

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran; Means within rows with different superscripts are statistically different ($P<0.05$)

Starch supplementation significantly (P=0.01) increased the passage of rate (kp) of NDF and also tended to increase (P=0.09) the passage rate (kp) of digestible NDF fractions compared to other treatments (Table 15). The passage rate of INDF was highest with cassava flour (2.55%h^{-1}) and lowest with "Magadi" treatment (1.96%h^{-1}). The rate of digestion (kd) of NDF and digestible NDF ranged between 1.0-1.7and 1.7-2.2%h^{-1} respectively and was significantly (P=0.05) higher with nitrogen supplementation compared to other treatments.

Major responses due to the various supplements

The major effects of the supplements used in this study on intake, rumen fermentation and nitrogen retention are summarised in Table 16.

While only the nitrogen (HFC) supplement caused an increase in hay intake, there was an increased total DM intake in all treatments except "Magadi" due to extra DM from supplements. The digestibility of DM and microbial nitrogen synthesis increased to varying extents with all the treatments compared to the control. Rumen fluid total VFAs were nearly the same with starch and sugar, but were numerically higher with "Magadi" and nitrogen supplementation compared to the control. Total tract digestibility of NDF was significantly (P=0.02) lower with starch and significantly (P=0.02) higher with nitrogen supplementation, while there was little change with "Magadi" and sugars supplementation.

Rumen fluid ammonia concentration were numerically lower with starch, and significantly (P=0.05) lower with sugars and significantly (P<0.001) higher with nitrogen supplementation compared to the control. While nitrogen retention was not significantly affected by starch, it was significantly (P=0.05) lower with "Magadi" and sugars and significantly (P=0.01) higher with nitrogen supplementation compared to the control.

Rumen pool sizes of NDF seemed not to be significantly affected by supplements. However, the rate of passage (kp) was significantly higher with starch (P=0.02) and significantly (P=0.05) higher with nitrogen supplementation compared to the control. The rate of digestion (kd) of NDF was significantly higher (P=0.02) with nitrogen and significantly (P=0.05) higher with "Magadi" and sugars while it was not much affected with starch compared to the control.

Table 16 Summary of the responses due to "Magadi", starch, sugars and nitrogen supplement compared to maize bran alone on feed intake and digestibility, nitrogen retention, fermentation products and NDF kinetics.

	Intake			Fermentation products			N	NDF			
	Hay	DM	DM dig	MN	TVFA	Amm.	ret.	RumP	kp	kd	Tdig
HMG	→	→	↑	↑	↑	→	↘	→	↘	↗	→
HCA	→	↑	↑	↑	→	↘	→	→	↑	→	↓
HMO	→	↑	↑	↑	→	↓	↘	→	→	↗	→
HFC	↑	↑	↑	↑	↑	↑	↑	→	↗	↑	↗

HMG: hay + maize bran + "Magadi"; HCA: hay + maize bran + cassava; HMO: hay + maize bran + molasses; HFC: hay + formulated concentrate; HMB: hay + maize bran DMdig: dry matter digestibility, Tdig: Total tract digestibility; MN: microbial nitrogen synthesis; Amm: ammonia levels; N ret.: nitrogen retention; TVFA: total volatile fatty acids, RumP: rumen pool; kp: rate of passage; kd: rate of digestion

↑:Increased; ↗ : slightly increased; → : unchanged; ↘ :slightly reduced ↓; reduced

DISCUSSION

Except for the higher CP (14.8%) and NDF (38.0%) most of the measured chemical parameters in maize bran and the concentrate mixture were almost similar (Table 1). This was expected due to the high proportion of maize bran in the concentrate mixture. The CP content in the mixture was improved due to the high content of CP in sunflower cake. The hay used was very poor in quality characterised with low CP content (3.4%), high NDF content (75%) and low Metabolisable energy (5.2 MJ/kg DM). The high ash content in the hay (11%) was possibly due to high silica content as frequently observed with mature dry tropical grasses and stovers (Mgheni, 2000) and also due to soil contamination during harvesting. "Magadi" was found to contain mainly minerals and very rich in water-soluble bicarbonate and may well be very similar to the Magadi soda commercially available from Lake Magadi in Kenya (Nyachoti et al., 1998).

The observed higher total DM intake with starch (cassava flour) and sugars (molasses) treatments was expected due to the extra DM from cassava flour (0.9 kg) and molasses (1.3kg). Smallholder farmers asserted that when they used "Magadi", the animals ate more and produced more milk. However, in this study, intake of hay was not increased with "Magadi". This was possibly due to the short adaptation period (14 days). Nangole et al. (1983) observed that it took over a month for cattle not used to Magadi soda soaked maize cob to adapt. And when they did, there was a dramatic increase in both DM intake and overall animal performance. The maize cobs were ground and soaked in 9% Magadi soda solution for 24 hours before feeding. Apparent DM and OM digestibility was highest with the concentrate mixture due to a positive nitrogen effect on rate of digestion of NDF (Tables 15).

It appeared that "Magadi" and nitrogen supplementation (HFC) were able to cause an increase in the rate of, and the degradation of hay DM from the dacron bags incubated in the rumen compared to other treatments. The effect of HFC can be explained in terms of high ammonia availability (Chamberlain and Choung, 1995). Since with "Magadi" the ammonia level was not improved, the effect on degradation of materials from dacron bags must be due to other reason(s). One can reason that since the disappearance of materials from the bags was mainly through digestion, then soaking in the rumen liquor rich in "Magadi" led to a greater degree of delignification (Hartley, 1985) and in the process rendering the material easier for microbial attack. This thinking is supported by the observation that prior suspension of bags containing hay samples in "Magadi" for 24 hours significantly increased the effective degradation compared to when the bags were soaked in plain water. This was consistent with the findings of Nangole et al. (1983) where Magadi soda soaking of ground maize cobs for 24 hours was superior compared to water or sodium hydroxide soaking on cell wall degradation. It was not very clear why molasses, with nearly similar ruminal pH to that due to cassava had significantly lower degradation of DM from the bags.

It was not clear why sugars and starch had a depressive effect on the DM degradation from the dacron bags at time when in vivo DM degradation was significantly higher compared to the control (see Table 5). Though the rumen pH was not seriously depressed by either sugars or starch supplementation, the micro-environment within the bags might have been quite different from that in the larger rumen compartment (Notziere and Mechelet-Doreau, 1996). It was also possible that cellulolytic microbes had preference for the soluble sugars and starch rather than obtaining them through digestion of structural carbohydrates (Mould et al., 1983; Russel, 1984), the impact of which would have been greater to the small amounts of samples in the bags.

The molar proportion of the individual VFAs is highly influenced by the activities of the dominant microbial species in the rumen (France et al., 2000). The observed higher molar proportion of acetate with nitrogen (HFC) and "Magadi" (HMG) supplementation, indicated a more cellulolytic rumen environment with those treatments (Czerkawski, 1986). Staples and Lough (1989) noted that in most reported works where bicarbonates are used as a buffering agent in the rumen, the molar proportion of acetate increases. The low molar proportion of acetate and higher proportion of butyrate and propionate with molasses and cassava flour feeding was consistent with other findings (Sutton, 1968; Kellog and Owen, 1969; Obara et al., 1991) involving high intake of rapidly fermentable carbohydrates. Increasing the intake of rapidly fermentable carbohydrates results into a fermentation pattern characterised with low molar proportion of acetate and high molar proportion of propionate or/and butyrate (Ørskov and Ryle, 1990).

The pH changes (Figure 1) after ingestion of concentrates was expected and followed closely the trend obtained by Khalili (1993) in animals fed poor quality hay supplemented with different levels of molasses and also to that obtained by Devant et al. (2000) in heifers fed high concentrate diets. Contrary to expectation, the buffering ability due to bicarbonates in "Magadi" was not observed. Ruminal fluid pH was relatively higher with sugars (molasses) compared to starch (cassava flour). This disagreed with other findings where sugars tended to depress rumen pH more than starch (Chamberlain et al. 1993; Khalili and Osuji, 1994; Chamberlain and Choung, 1995; Stensig et al., 1998). The reason for this disparity was probably in the amounts offered and the frequency of intake. Since molasses was mixed with the hay, the rate of intake was closely linked with the intake of hay and thus small amounts were consumed at a time. In this study, fermentation of plant fibre seemed not to be affected by pH since for most part of the day, rumen pH was above the critical lower limit of 6.0 (Stewart, 1977; Russel and Dombrowski, 1980; Mould et al., 1983) below which fibre digestion start to be compromised.

Peak ammonia concentration in the ruminal fluid occurred during feeding of the concentrate and also to a small extent in the control (Figure 2). This was expected bearing in mind the high amounts of protein (sunflower) in the concentrate mixture and moderate amounts in the maize bran that had high N degradation in the rumen. However, only feeding the concentrate mixture resulted in mean rumen ammonia concentration above the minimum recommended level (5mg N/100mL) for optimum microbial function, though this level is thought to vary widely (Wallace, 1979; Song and Kennelly; 1989; Perdok and Leng, 1990). The most probable cause of the low ruminal ammonia levels with "Magadi" (HMG), starch (HCA) and sugars (HMO) treatments was most likely due to higher N uptake by ruminal microbes (Driedger and Loerch, 1999).

Though fibre fermentation was optimised by the concentrate mixture, microbial protein synthesis was not. According to Ørskov and Ryle (1990), utilisation of energy for VFAs production is at the expense of microbial cell growth and so the high VFAs with the concentrate mixture (HFC) could have led to reduced microbial biomass.

Protein balance in the rumen as estimated from the potential microbial protein synthesis based on the digested carbohydrates and actual synthesis estimated from purine derivatives excreted in urine showed a big deviation. Many factors influence the efficiency of microbial synthesis (Thomas, 1977; Owen et al., 1984). Factors like rumen pH, microbial profile and especially rumen protozoa number (Eadie et al., 1970; Czerkawski, 1986; Broudiscou and Joany, 1995), synchrony of energy and nitrogen availability, fluid and particle passage rates (Hodgson and Thomas, 1975; Sniffen and Robinson, 1987) influence greatly the microbial protein that is eventually available to the animal. The population of protozoa increases tremendously with availability of rapidly fermentable carbohydrates as long as the pH does not fall below 5.5 (Mackie et al., 1978).

The positive energy and N balance enabled the animals to gain weight and maintain their body conditions throughout the experimental period except for the control where there was a slight weight loss. The lack of agreement between the expected weight gain calculated from the energy balance and the actual weight gain (Table 13) was also not clear. It might be possible that factors such as the efficiency of utilisation of ME for tissue deposition or the activity allowance used in the calculations may not have been the best for the type of animals, feeding and the environmental conditions during this study. The type of tissue deposition (fat or protein) can also influence on the extent of body weight change. Other contributory factors might be that the 28 days duration of feeding a particular supplement was too short to observe its full impact on body weight changes and the amount of rumen ingesta during weighing. The cause (s) of the relatively poor N retention and digestibility with "Magadi" was not clear. It might have been possible that high fecal N loss with "Magadi" was accentuated by increased hind gut ruminal microbial fermentation of fibre thereby causing a fall in N retention.

The magnitude of rumen pool sizes of different dietary components is influenced by the rates of intake and clearance from the rumen through passage and digestion (Van Soest, 1994). Concentrates are rapidly fermented but plant cell walls (NDF) are slowly fermented and therefore greatly contribute to rumen fill (Madsen et al., 1994). Rumen pool sizes of NDF fractions were not significantly affected by treatments due to variable effects on intake, passage and digestion rates of NDF. Therefore, observed variations in rates of intake (ki), passage (kp) and digestion (kd) of NDF were due to changes in the flow of NDF.

With "Magadi", intake and passage of NDF was slightly lower compared to the control, but the rate of digestion increased leading to an overall higher NDF digestibility compared to the control (Table 6). The cause of reduced NDF passage from the rumen with "Magadi" treatment was not very clear. It might be that the increased ionic concentration of the rumen liquor led to an increase in the buoyancy of NDF particles and therefore reduced passage out of the rumen. The apparently higher mean retention time with "Magadi" treatment may have allowed more time for NDF digestion in the rumen.

With starch (cassava flour) supplementation, intake of NDF was not much increased but passage rate (kp) was significantly increased with nearly the same rate of digestion (kd) as the control (see Table 15). This led to the observed significantly lower calculated rumen NDF digestibility and in the total tract NDF digestibility. The high passage rate of NDF with cassava flour in this study disagreed with the findings of Stensig et al. (1996) and Robinson et al. (1987) where increased starch intake tended to reduce the passage rate of NDF. Factors like sources of starch, purity, degree of processing and amounts offered could have caused the observed disparity.

The depression of NDF digestibility by cassava in this study agreed with the findings of Ahmed (1977) who found that feeding 21 and 42% cassava to Friesian bullocks fed a hay based diet reduced crude fibre digestibility from 87% (control) to 83 and 77% respectively. In this study, digestibility of NDF and DNDF fell from about 48 and 69% in the control to 43 and 63% with starch treatment respectively. Since the study of Ahmed did not include rates of passage and digestion, it was not clear whether this depression was due to the fall in pH in the rumen alone or due to increased passage as well.

The commonly observed depressive effect on fibre digestibility associated with molasses feeding (Khalili and Osuji, 1994; Kalmbacher et al., 1995) was not clearly manifested in this study. This was because molasses was sprayed on the fed hay such that the rate of intake was very slow and therefore small amounts were being consumed in unison with the hay meals per day. Also, the estimated intake of molasses in this study (1.3 kg DM/animal/day) was far below the lower limit of 1.5 kg DM/day/animal above which fibre digestibility start to be compromised (Khalili and Osuji, 1994).

Nitrogen supplementation (HFC) led to higher intake of NDF, but rate of digestion was increased with moderate rise in passage. The overall effect was higher calculated rumen NDF digestibility and total tract digestibility (Table 6). This agreed with the findings of Yan et al. (1996) that moderate supplementation of poor quality roughage with protein rich concentrates improve intake and plant fibre digestibility.

The passage rates of INDF with all the treatment in this experiment were rather high (2.0- 2.6%h-1). However, they were slightly lower than those reported by Mgheni (2000) (1.17-3.48%h-1) in heifers fed either hay, maize silage or urea treated straw under tropical conditions. Stensig (1996) obtained passage rate of INDF in cows fed either alfalfa silage or timothy silage mixture supplemented with graded levels of sugars or starch that were much lower (1.4-1.8%h^{-1}) compared to those obtained in this study. The disparity was expected bearing in mind the great differences in breed, environment, treatments, and sources of NDF between and intake levels in the reported works. However, the greatest contributory factor of the high INDF passage rate observed in this study was probably the high level of intake relative to body size (75-112g/$W^{0.75}$) of the animals used in this trial. High intake level exerts some pushing effect on passage.

The passage rate of INDF was much higher than that of NDF, that was in turn higher than that of DNDF. This was consistent with literature findings (Stensig et al., 1998;

Stensig, 1996; Huhtanen, 1998; Mgheni, 2000). Such findings agreed with the general understanding that potentially digestible fibre component undergoing fermentation has low functional specific gravity due to gases formed around and inside particles thereby making them more buoyant and less likely to pass out of the rumen (Tamminga et al., 1989). On the other hand, after long stay in the rumen, particle size decreases due digestion and mastication leading to an increase in the proportion of indigestible component while the amount of gas fall making it more dense and thus more liable to pass out of the rumen (Allen, 1996). Therefore, the simple one-compartment model on which the rumen evacuation is based is not entirely correct due to inability to take into consideration the selective retention of newly ingested NDF containing materials (Huhtanen, 1998).

As reported elsewhere (Stensig et al., 1998; Stensig, 1996) the 100% post ruminal recovery of INDF is hard to achieve. In this study % fecal recovery of INDF was 93.3, 100.8, 95.9, 88.2 and 100 with "Magadi", starch, sugars, concentrate mixture and maize bran only treatments, respectively. The poor recovery of INDF this case would appear that proper collection of the faeces from the floor was a problem especially the soft faeces when the animals are fed the concentrates.

A more realistic comparison of the kinetics of NDF is obtained when the indigestible fraction is removed from the digestible one (Allen and Mertens, 1988). Almost similar scenario to the NDF appeared. Of all treatments, the nitrogen supplementation (HFC) had the highest DNDF digestibility due to an increase in the rate of digestion, with a slight increase in the rate of passage and the intake of DNDF. This was mainly due to enhanced cellulolytic activity due to more uniform availability of N (ammonia) throughout the day compared to the other treatments where ammonia availability was limiting fibre degradation.

CONCLUSION

Feeding of energy rich concentrates, a feed additive called "Magadi" and nitrgone rich concentrates had variable effects on the intake and digestibility of poor quality roughage. Nitrogen supplementation in form of a farm made concentrate containing maize bran and sunflower cake fed to about 35% of total DM intake enhanced intake and digestibility of poor quality roughage compared to supplementing with plain maize bran as is the common practice with smallholder farmers in Morogoro. Inclusion of "Magadi" or sugars (molasses) or starch (cassava flour) in animals receiving equal amounts of maize bran produced variable results. Sugars improved OM intake and digestibility and moderately NDF digestibility. Starch improved DM and OM intake and digestibility but reduced significantly NDF digestibility due to high passage rate of NDF. "Magadi" did not improve intake but NDF digestibility and microbial protein synthesis were higher compared to maize bran alone. There was also a higher in situ DM degradation of hay samples incubated in the rumen of standard cows after prior soaking in "Magadi" suspension compared to those soaked in plain water. This showed that "Magadi" could be utilised in the treatment of poor quality hay so as to improve their intake and digestibility.

This study proved that the major limiting factor in the intake and digestibility and therefore efficient utilisation of poor quality forage was nitrogen availability in the rumen. Therefore, it is of outmost important for smallholder dairy farmers who use energy rich supplements like sugars (molasses) and starch (cassava) to concurrently provide nitrogen sources like sunflower cake which is easily available in Morogoro. However, for farmers who do not have access to sources of nitrogen, molasses and cassava can still be used provided they do not give more than 2 kg DM of either supplement per animal/day.

A lot remains to be investigated on the appropriate amounts or combinations of energy and protein supplements as well as feed additives under local feeding conditions to optimise intake and digestibility of fibre in the basal diet. The causes of poor nitrogen retention with "Magadi" need further investigation.

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Paper IV

Comparison of maize bran or maize bran sunflower meal mixture on the performance of smallholder dairy cows in urban and peri-urban area in Morogoro, Tanzania.

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Abstract

A study was conducted to determine the effect of feeding milking cows a supplement of maize bran alone (MB) or maize bran mixed with sunflower meal (MBS). The work was carried out during the dry season between November 1999 to March 2000. Eighteen smallholder farms in urban and peri-urban areas of Morogoro practising completely zero grazing with not less than two milking cows participated in the trial. Forty-eight cows of body weight 232-556 kg, previous milk yield of 3-13 L/day, body condition score of 2.5-5, parity of 2-5, and 3-6 months post calving were used. For each farm, both MBS and MB treatments were randomly distributed to the cows. Body weights were taken by heart-girth measurement before, at 6th and 12th week of treatment. Concurrent to the body weights measurements; body condition scores were taken. Daily milk production was recorded three weeks before, 12 weeks during and 3 weeks after the withdrawal of treatments. Milk samples were collected during the 12th week of treatment and analysed for butterfat (BF), crude protein (CP) and total solids (TS). The economic viability of the dairy enterprises in relation to supplementation was also assessed. MBS fed cows had significantly higher ($P<0.001$) milk yield compared to MB fed cows. No statistical significant differences were observed in milk composition parameters, body weights and body condition changes. The economic returns for sunflower meal incorporation in MBS was found to be very high.

It is therefore concluded that using sunflower meal mixed with maize bran was effective in increasing milk yield during dry season and was economically profitable compared to maize bran alone.

Key words: smallholder, dairy cows, Morogoro, supplementation, maize bran, sunflower cake, milk yield

INTRODUCTION

Smallholder dairy production in urban and peri-urban areas is a common phenomenon in Tanzania as is the case in most tropical countries (Mlozi et al., 1992; Mosha, 1991). The dairy production offers household income-generating and employment opportunities (Mlozi et al. 1992; Mlay et al., 2000). More importantly, they supply the urban dwellers with dairy products that are highly needed since rural based dairy production is very low.

This is due to the fact that the vast majority of the cattle in the traditional cattle production system in Tanzania are the zebu type that have very low genetic potential for milk production (Tanzania Agriculture, 1994). Worse still, the traditional livestock production system is faced with a lot of other problems.

One of the major production constraints in smallholder dairy sector is the dwindling both in quantity and quality of the roughage during the dry season thereby leading to drastic reduction in animal productivity (Nkya et al., 1998; Plaizeir et al., 1998; Mlay et al., 2000). Therefore, in order to sustain modest production as well as maintaining body condition, it is important to provide additional sources of energy and protein during the dry season. An adequate nitrogen (N) supply to the rumen microbes is essential for optimal fermentation of feeds as well as for enhanced microbial protein synthesis (Leng, 1984; Preston and Leng 1984; Madsen and Hvelplund 1988; Madsen et al., 1997). As most animals in this area are of medium to low milk production capability (5-15 kg/day), microbial protein supply can easily support that production level as opposed to high yield cows who may need rumen bypass protein in addition to microbial protein (Hvelplund and Madsen, 1990)

The big question is what are best ingredients for use as energy and protein supplement(s)? Factors to be considered are availability all year round, cheapness, labour involved and of course acceptance by farmers. There are several options that are possible such as inclusion of leguminous forage and shrubs (Sarwat and Mtengeti, 1990; Shem, 1996; Mero and Uden, 1997; Ndemanisho et al., 1998; Temi, 1999) and urea treatment of poor quality roughage (Mgheni, et al., 1994). Other alternatives include the use of urea molasses mixture and urea molasses mineral blocks (Leng, 1984; Sansoucy and Aarts, 1987; Preston and Leng, 1984).

The use of leguminous plants as a source of nitrogen was not considered feasible in this particular dairy production system. Being located in or around the town, there was simply no adequate land to establish the leguminous plants. The use of urea as cheap non-protein source of N was introduced by Plaizier et al. (1998). However, in a survey carried out two years later (Mlay et al., 2000) not a single farmer was found using urea either for treatment of poor quality roughage or mixed with molasses or as urea molasses mineral blocks.

Mlay et al. (2000) found, that most farmers actually fed maize bran to milking cows during milking times with the main aim of distracting the animals so as to make them calm and easy to milk. The maize bran was collected each time the farmer milled their maize grain or purchased from retailers at price of 40-50 Tsh per kilo. On farmer's view, this is very crucial since most of the animals are crosses that still bear the local zebu cattle instincts for kicking as they are not used to being milked. On the other hand, it is true that the animal gained in terms of extra energy and protein from the offered maize bran. Thus a potential source of energy acceptable to farmers and cheaply available locally was identified. The next step was to find means of improving the nitrogen content of the supplement. Here, four possibilities existed; namely cotton seedcake, sunflower seedcake, fishmeal and soyabean meal. Nkya et al. (1998) showed that cottonseed cake based farm-made concentrate was effective in improving the performance of dairy animals in

Morogoro. However considering that cotton is not a traditional crop in Morogoro and the fact that most supplies come from regions (Mwanza and Shinyanga, Tabora), very far away from Morogoro, this was not found suitable. The price of cottonseed cake was relatively high (100-120 Tsh per kg) possibly due to the transaction costs. Fishmeal and soyabean meal were even more expensive with the price levels of 1000-1500 Tsh per kilo due to scarcity.

Most villages of Morogoro grow sunflower seed crop for sale to oil processing factories as well as extracting oil for domestic use using the hand-rum press (Temi, 1999; Hayman, 1992.). In fact most local authorities at ward level are encouraging farmers to grow sunflower seed crop (Temi, 1999). Located in Morogoro Municipality, is the oil-processing factory owned by Abood group of Companies. The factory mainly extract oil from sunflower seeds. Therefore, for the Morogoro urban and peri-urban smallholder dairy farmers, sunflower seed cake can easily and cheaply be obtained from the factory. The ex-factory price during the time of this study was 70 Tsh a kilo. For the village based dairy smallholders, sunflower residues after oil extraction can be available for feeding their own animals and when in excess could be sold to other farmers. Therefore, sunflower meal was considered of great importance for the dairy industry in Morogoro.

The use of sunflower meal as protein supplement to cattle in Tanzania is not well documented. Some reports in Tanzania and elsewhere have proven that sunflower meal is a potential source of nitrogen to animals. It has been proven that sunflower meal produces similar effects compared to cotton seed cake and soyabean meal in enhancing ruminant performance (Richardson et al., 1981; Church, 1991). In their work carried in the semi-arid central Tanzania, Shayo et al. (1997) reported a significantly increased ($P<0.05$) milk yield but no effect on the milk composition in cows fed sunflower-based supplement. In work carried in Turiani, a rural area in Morogoro, Temi (1999) reported significant increase in milk yield ($P<0.05$) when sunflower meal mixed with maize bran was fed to milking cows compared to those fed maize bran alone. In another study, sunflower meal was found to be equally good to cotton seed cake in improving the performance of growing lambs (Kandylis et al., 1998) and in both growing cattle and sheep (Richardson et al., 1981).

Farm-grown sunflower based calf meals have shown to be quite suitable in the improvement of calf performance in the smallholder dairy enterprises in the communal areas of Zimbabwe (Mandibaya et al., 1999). The potential of sunflower meal as a source of rumen degradable protein, individual and total amino acids has been put to record. Mupeta et al. (1995) found that sunflower meal has higher rumen degradability of individual amino acids, total amino acids and nitrogen compared to cottonseed cake.

Therefore, it was the aim of this study to; (I) Investigate further the suitability of sunflower meal as a source of nitrogen that is cheap, effective and acceptable by farmers in Morogoro.

(II) Find out the effect if any, of added sunflower meal on milk yield, milk composition and body condition during the dry season

(III) Work with smallholder farmers as an attempt to convince them that a little more investment in their dairy enterprises may pay.

MATERIALS AND METHODS

Study area

The study was carried out in Morogoro urban and peri-urban area at an altitude of 528m above sea level with an average rainfall of 800-1200 mm per annum. Heavy rains fall between April and May. The mean maximum temperature is 32.4°C (November.-February) with lowest temperature (14.8 °C) occurring between June and October. Morogoro town is located 250 km West of Dar-es-Salaam along the Tanzania-Zambia highway. The study was carried out between November 1999 and March 2000. A total of 18 farms distributed in various wards in Morogoro (Table 1) owning a total of 48 milking cows participated in the trial.

Animals and treatments

The participating farmers owned at least two milking cows, kept under the completely zero grazing system. The selected cows were those with the following criteria: 2-6 months post calving, previous average yield of 3-13 litres per day, parity of 2-3, and body condition score between 2.5-5. The type of animals kept by farmers in this study included various crosses between the local Tanzania short horn zebu cattle and Boran with Holstein-Friesian, Ayrshire, and Jersey and to a lesser extent Simmental. The approximate exotic blood level of the animals used during the trial was 50-60%.

Treatments were either maize bran alone (MB) with crude protein (CP) of 10.9% (control) or maize bran mixed with sunflower meal (MBS) with CP of 15%. Proportions of various components in the supplements in DM and on as fed basis was as shown in Table 2. The DM composition of MBS was 31, 68 and 1% sunflower meal, maize bran and mineral powder, respectively. That of MB was 99 and 1% maize bran and mineral powder, respectively. The mineral powder (Cooper Kenya Limited, Nairobi Kenya) contained the following minerals with the % contribution of each given in brackets; NaCl (27), Ca (18.51), P (11), Mg (3), Fe (0.5), Cu (0.16), Mn (0.4), Zn (0.5), S (0.4), Co (0.02), I (0.02), Se (0.0015) Mo (0.0002) and Ca:P ratio of 1.68:1. Each cow was given 4 kg/day (as fed basis) of the respective supplement with half the amount given during morning milking time (around 6-7am) and the other half during the evening milking time (5-6pm). For a given farm, treatments were equally distributed to the milking cows so that both MBS and MB treatments were present.

Time when supplementation was done

From previous studies (Nkya et al., 1998; Mlay et al., 2000), the nutritional quality of basal forages was found to be very low during the dry season. Dry season in Morogoro stretches from July to March of the following year with occasional short rains in late October to November. Cow supplementation with the two concentrates was done from December 1999 to early March 2000 when mean the CP content, ME and organic matter digestibility of the basal forages were low (see Figure 1).

Bodyweight and condition scoring

Live weights of the animals were taken before, at 6th and 12th week of treatment by heart-girth-measurement. Concurrent with body weight measurements, body condition scores was done by the method of Edmondson et al. (1989) where 1 is severe under-conditioning and 5 being severe over-conditioning.

Roughage intake

Once every week, one farm per ward (see Table1) was used in estimating forage intake. A sample and weights of forage offered was taken each morning and the refusals were weighed and sampled the next morning. The samples and refusals were dried in an oven at 60 °C to determine DM intake.

Feed analyses

Dry matter (DM) of feed samples was determined by hot oven drying at 105 °C for 24 hours. Neutral detergent fibre (NDF) was determined according to the method of Van Soest et al. (1991). Minerals analysis including Ca, P, Na, K and Mg were determined using inductively coupled plasma spectrophotometer (AOIC, 1990). In vitro organic matter digestibility was determined by the method of Tilley and Terry (1963). Nitrogen (N) contents were analysed by the Kjeldal method (AOAC, 1990) using semi-automated N analyser (Kjeltec system 1002, Tecator AB, Hoganas, Sweden). Crude protein (CP) was derived from the N content by multiplying with a factor of 6.25.

Rumen degradability of dry matter (DM) and nitrogen (N) from maize MB and MBS were determined by the nylon bag technique (Ørskov and MacDonald, 1979) using ruminally fistulated mature crossbred heifers fed grass hay and 3kg/day of MBS. The incubation times were 0, 2, 4, 8, 16, 24, 48 and 72hrs. The residues in the bags were analysed for N by Kjeldahl method. Nitrogen degradabilities were fitted to the exponential equation $p = a + b\ (1 + e^{-ct})$ where P =degradation at time t, a =the zero time intercept of the fitted curve, a +b = the asymptote of the curve at infinate time t and c = the degradation rate constant (Ørskov and MacDonald, 1979). Corrections for particle loss from the bag were made by the equation described by Weisberg et al. (1990).

The Metabolizable energy of the supplements was determined by multiplying the calculated values of digestible energy (Hvelplund and Weisbjerg, 1998) by a conversion factor of 0.82.

Milk yield and composition

Milk recording sheets were prepared and distributed to farmers. Daily milk produced was recorded and weekly average taken thereafter. Milk yields were recorded for three weeks before treatments, 12 weeks during treatment and three weeks post treatment. Milk samples from farmers were taken in clean sample bottles (50 ml) in ice packed cool boxes in the 12th week of treatment. The samples were deep frozen in the lab and later analysed for milk butterfat (BF) percent by Gerber method while milk protein (CP) as calculated from nitrogen content from Kjeldal method analysis (AOAC, 1990) multiplied by a factor of 6.25. The percent total solids (TS) were determined by the reference method of oven drying at 105 °C in acid washed sand for 12 hours. The % solid but not fats (SNF) was calculated by the difference between %TS and %BF (i.e. %TS -%BF).

Cost-benefit analysis

The production costs were computed from the major costs of feeds and labour charges. The cost-benefits of using sunflower meal was calculated based on the extra expense incurred when it was incorporated in the diet in relation to the revenue realised from sale of the extra milk obtained due to the presence of the ingredient in the diet. No attempt was made to estimate the overall profitability of the dairy enterprises.

Statistical analyses

Analysis of variance was carried out using the SAS General linear model procedure with initial milk as a covariate with and cow and farm as independent variables according to the model shown below.

$Y = I + T + F + CM + \varepsilon$ **(Model 1)**

Where:	Y	=	Dependable variable
	I	=	Intercept
	T	=	Treatment (MB, MBS)
	F	=	Farm
	M	=	Mean initial yield for the 3 weeks pre-treatment
	ε	=	Random error

Least square means for the 3 weeks prior and after treatment were calculated using the above model but without the covariate statement i.e.

$Y = I + T + F + \varepsilon$ **(Model 2)**

Where each statement in the model is as explained in Model 1 above.

Model 2 was also used in the comparisons of the means for body weights, body condition scores and the changes body weights and body condition scores during the experimental period

RESULTS

Distribution of farmers and treatments

As shown in Table 1, 18 farms distributed in 8 wards of Morogoro Municipality participated in the trial.

Table 1. Distribution of farms and number of cows fed either maize bran-sunflower meal concentrate mixture (MBS) or maize bran alone (MB) in the various wards of Morogoro urban and peri-urban area

Ward	No. of Farms	Supplement	
		Cows on MBS	Cows on MB
Bigwa	1	2	2
Forest	2	3	2
Kihonda	3	4	3
Kichangani	2	2	2
Kilakala	3	5	3
Mazimbu	2	3	2
Mbuyuni	3	5	4
Mlimani	2	3	3
Total	18	27	21

The farm owners were contacted during an earlier survey by Mlay at al. (2000) and showed interest in participation. Farmers were visited on weekly basis for record checking, sampling and discussion on the trends they were observing. On the whole, farmers' co-operation was good.

Chemical composition and rumen degradability of the two supplements

Table 2 show the proportion of the various components in the supplements used during this trial. The target was for MBS to attain a %CP level of around 15.

Table 2. Proportions of the various components in the sunflower meal-maize bran concentrate mixture

Ingredient	%DM	CP(%in DM)	Proportion in DM	%CP contribution
Maize bran	90.3	10.9	68.0	7.4
Sunflower meal	93.2	24.8	31.0	7.7
Mineral lick			1.0	
Total			100.0	15.1

Mineral lick powder was also included to ensure that mineral supply will not be a limiting factor for optimal rumen functions and milk production. The chemical composition of sunflower (S), maize bran (MB) and maize bran mixed with sunflower meal (MBS) used in this trial is shown in table 3. The chemical composition of the maize bran was very similar to that used by Ndemanisho et al. (1998) and also by Temi (1999).

Table 3 Chemical composition of sunflower meal (S), maize bran (MB) and maize bran mixed with sunflower meal (MBS)

	Type of feed		
Parameter	S	MB	MBS
Dry matter (%)	94.2	91.5	92.2
Components (%DM basis)			
Ash	4.3	5.1	5.4
Organic matter (OM)	95.7	94.9	94.6
Crude protein (CP)	23.6	10.9	14.8
Ether extract (EE)	4.5	10.7	9.2
Neutral detergent fibre (NDF)	59.1	31.9	38.0
Carbohydrates (CHO)	67.6	73.3	70.6
Potassium (K)	NA	0.82	0.72
Calcium (Ca)	NA	0.14	0.20
Magnesium (Mg)	NA	0.32	0.29
Phosphorous (P)	NA	0.76	0.72
Sodium (Na)	NA	0.23	0.22
IVOMD (%)	58.2	64.4	62.0

NA: not analysed; IVOMD: In vitro organic matter digestibility

There was slightly higher NDF content in MBS (38.0%) compared to MB (31.9%) due to higher NDF content of sunflower meal. MBS had higher CP and less ether extract (EE) compared to MB (14.8 Vs 10.9) and (9.2 Vs 10.7%), respectively.

Table 4 shows the rumen degradability constants and effective DM and N degradation of MB and MBS. Both supplements had high potential degradability of DM and N (83-90%). Fraction of protein that was immediately degradable (a) was higher in MBS compared to MB (56.3 Vs 37.6%). Effective N degradation at 2% h^{-1} and 5% h^{-1} passage rates were higher in MB compared to MBS. While the rate of degradation of N from the two supplements was almost similar, with DM, the rate was higher in MB (5.37% h^{-1}) compared to MBS (3.02% h^{-1}).

Table 4. Degradation constants and the effective degradation of dry mater (DM) and Nitrogen (N) in MB and MBS supplements. Values expressed as %

		Degradation constants						
					C (%h^{-1})	Washing losses	*ED	**ED
MBS	DM	33.3	50.5	83.8	3.02	44.3	58.8	47.5
MBS	N	56.3	29.3	85.7	6.76	55.2	63.7	54.1
MB	DM	36.4	49.5	85.9	5.37	34.3	66.9	54.2
MB	N	37.6	52.2	89.9	6.55	35.2	73.5	63.4

DM; dry matter, N; nitrogen

*Effective degradability estimated at a passage rate of 2% h^{-1}

** Effective degradability estimated at a passage rate of 5% h^{-1}

Shown in table 5 is the relative contribution of energy, rumen degradable protein (RDP) and rumen undegraded protein (RUP) form supplementation either with maize bran alone or with the concentrate mixture. Maize bran supplied relatively higher Metabolisable energy than the concentrate mixture due to relatively low fat content in the sunflower meal mixed with maize bran.

Table 5 The energy and protein contribution from supplements given during the on farm trial

	Supplement	
Parameter	MB	MBS
ME content (MJ/kg DM)	10.7	10.2
DM (%)	91.5	92.2
Amount given (kg as fed)	4.0	4.0
Amount given (kg DM)	3.7	3.7
Energy supply (MJ)	39.6	37.6
N content (%)	1.8	2.4
N supplied (g/day)	64.1	87.4
Effective N degradation (%)	73.5	63.4
Rumen degraded N (g)	47.1	55.4
Rumen undegraded N (g)	17.0	32.0

The supply of RDP was higher with maize bran while more RUP was available from the concentrate mixture due to a relatively low rumen degradation of N from the concentrate compared to maize bran.

Time of concentrate supplementation in relation to variations in the nutritive value of basal forages

Shown in Figure 1 are the annual variations CP, NDF contents, OM digestibility and calculated energy values of mixed forage samples collected from smallholder dairy farmers in and around Morogoro Municipality between February 1999 and February 2000. The annual variations in the parameters have previously been described (Paper 1). Of importance here is the indication of the time when supplementation was carried out. This was done from late November 1999 to early March 2000 when the CP, energy contents and OM digestibility of the basal forages were low.

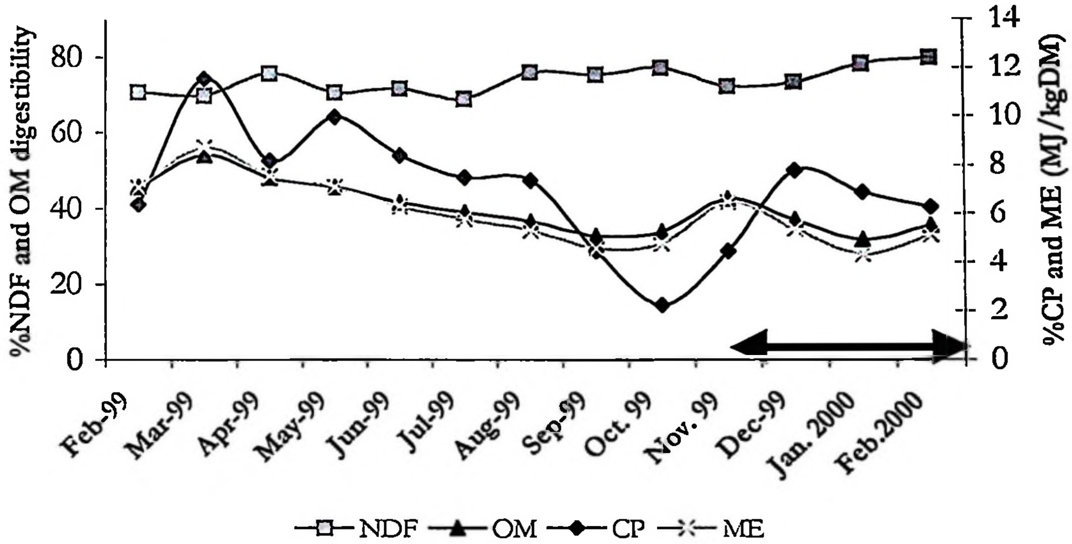

Figure 1. Annual variations in forage neutral detergent fibre (NDF), crude protein (CP), Metabolizable energy (ME) and OM digestibility. Line with arrows shows the period when supplementation with either MBS or MB was done.

Milk yield and composition

Milk yield trends 3 weeks before, 12 weeks during and 3 weeks post treatment is portrayed in Figure 2 as raw means and differences in milk yield between MBS and MB.

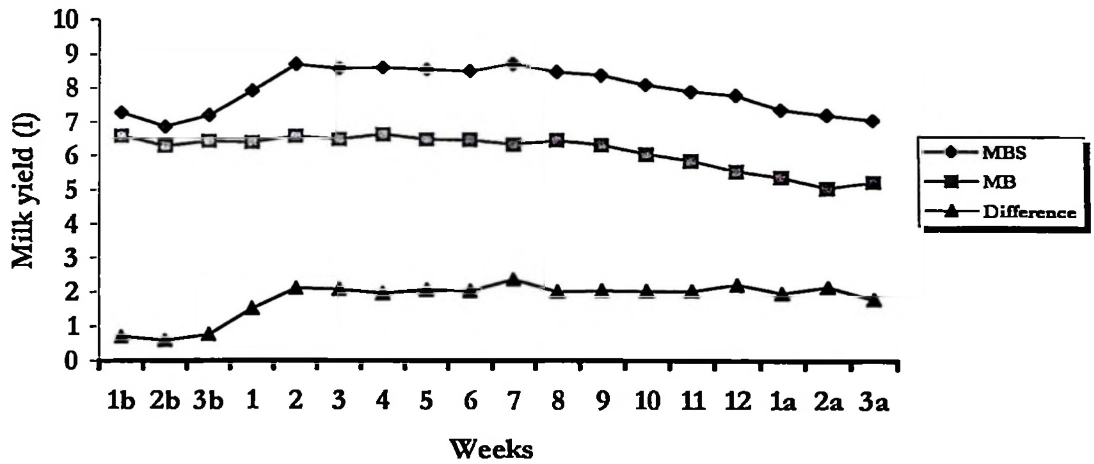

Figure 2. Mean milk yield and the difference between cows fed MBS and MB supplement three weeks before (b), 12 weeks of treatment and three weeks post treatment (a)

Apparently, MBS fed animals had higher initial milk yield compared to MB fed ones, but the difference in yield increased twice as much during treatment. From an initial mean value of 0.7 L/day in the pre-treatment period, the difference between the two groups increased to 1.5 L in the first week to 2.2 in the 12th week of treatment. Deduction of the mean difference in yield for the pre-treatment period from the differences in yield during the 12 weeks of treatment gave the extra yield due to MBS supplement. The extra yield increased from 0.84 L in the first week to a maximum value (1.68 L) in week 7 of treatment. There appeared to be a residual effect of MBS as the last three weeks post treatment showed some extra milk yield of 1.28, 1.46 and 1.12 L per day.

Results of statistical comparison in milk yield between the two groups are shown in Table 6. There was a highly significant ($P<0.001$) higher milk yield in MBS fed cows compared to MB fed ones for the whole treatment period and also for the three weeks post treatment.

Table 6 Least square means milk yield (L/day) during the on farm feeding trial with maize bran mixed with sunflower meal (MBS) or maize bran alone (MB)

	Supplements					
	MBS		MB			
Time (week)	Mean	SEM	Mean	SEM	Difference	P-value
Before treatment						
1	7.4	0.42	6.5	0.50	0.9	**0.2
2	7.0	0.43	6.2	0.51	0.8	**0.2
3	7.3	0.47	6.3	0.56	1	**0.2
During treatment						
1	7.7	0.20	6.8	0.23	0.9	*0.01
2	8.4	0.24	7.0	0.28	1.4	*<0.0003
3	8.3	0.22	6.8	0.26	1.5	*<0.0001
4	8.4	0.18	7.0	0.22	1.4	*<0.0001
5	8.3	0.22	6.8	0.26	1.5	*<0.0001
6	8.2	0.20	6.8	0.24	1.4	*<0.0001
7	8.4	0.25	6.7	0.29	1.7	*<0.0001
8	8.2	0.25	6.8	0.29	1.4	*0.001
9	8.1	0.26	6.6	0.30	1.5	*0.001
10	7.8	0.24	6.4	0.28	1.4	*<0.0004
11	7.6	0.27	6.2	0.32	1.4	*0.001
12	7.5	0.28	5.9	0.33	1.6	*<0.0004
Mean	**8.1**	**0.20**	**6.6**	**0.20**	1.5	**<0.0001**
After treatment						
1	7.4	0.44	5.3	0.52	2.1	**0.003
2	7.2	0.43	5.0	0.51	2.2	**0.002
3	7.0	0.42	5.2	0.50	1.8	**0.01

* Model 1

** Model 2

The milk composition of samples collected at the 12[th] week of treatment is also shown in Table 8. Percent BF for both groups were high (4.01 in MBS and 3.84 in MB). The percent TS, CP, SNF, were almost similar between the two groups (Table 9).

Table 7. Milk composition from the cows during the on farm feeding trial

	Supplements				
	MBS		MB		
Parameter	Lsmean	SEM	Lsmean	SEM	*P-value
Butterfat (%)	4.01	0.187	3.84	0.208	0.5
Solids not fat (%)	9.01	.210	9.03	0.234	1.0
Total solids (%)	13.02	0.254	12.86	0.283	0.7
Crude protein (%)	4.04	0.160	3.77	0.179	0.3

*Model 2.

Body weights and condition scores

Table 8 shows the means body weights and condition scores during the study period.

Table 8. Body weight and body condition scores for animals during the experimental period

	Supplement				
	MBS		MB		
	Mean	SEM	Mean	SEM	*P-value
Body weight (BW) kg					
Initial BW	381.9	13.71	358.1	15.93	0.3
BW at six weeks	384.4	13.79	361.4	16.02	0.3
BW at 12 weeks	387.1	13.71	363.2	15.93	0.3
BW change at 6 weeks	2.40	0.656	3.4	0.763	0.3
BW change at 12 weeks	5.15	1.272	5.10	1.478	0.6
Weight gain (kg/day)					
First 6 weeks	0.06	0.016	0.08	0.018	0.3
12 weeks of treatments	0.07	0.030	0.06	0.035	1.0
Condition score (BCS)					
Initial BCS	3.50	0.064	3.38	0.075	0.2
BCS at 6weeks	3.52	0.062	3.39	0.072	0.2
BCS at 12 weeks	3.56	0.059	3.41	0.069	0.3
Change in BCS at 6 weeks	0.02	0.013	0.018	0.0148	0.6
Change in BCS at 12 weeks	0.06	0.017	0.030	0.0191	0.2

*Model 2.

Mean initial body weights were 382±13.7 and 358±15.0 (mean±SEM) for MBS and MB respectively. There were no drastic weight changes during the experimental period. In the first 6 weeks of treatment both groups gained weight (0.06kg/day and 0.08kg/day) in

MBS and MB group respectively. For the12 weeks of treatment, weight gain was about 0.07 and 0.06kg/day in with the animals fed the concentrate mixture (MBS) and those fed maize bran alone respectively. Similar trend was observed in body condition score. Initial condition score was 3.5±0.06 and 3.4±0.08 (mean±SEM) in MBS and MB respectively. Both groups gained body condition with MBS having the highest gain at the end of 12 weeks of treatment (0.06Vs 0.03). The changes in body weight and condition scores did not reach statistically significant level.

Feed intake

Due to the inherent practice of group feeding by smallholder farmers, it was not possible to determine individual cow roughage intake. Average DM intake was 10.9 ± 1.04 (Mean ± SEM) kg per day. Forage intake was determined from the average intake of all mature animals in the farm including those that were not under the two treatments.

Economic implications due to supplements

The cost incurred in the purchase of ingredients for compounding the supplements is shown in Table 9. The cost per kilo of MB and MBS was about 59 and 68Tsh respectively. The additional cost to the farmers for feeding 4kg of either MB or MBS per animal per day was calculated to be 234 and 270Tsh respectively. Therefore, the extra milk due to inclusion of sunflower had to cover the extra cost above MB that was 36Tsh (Table 9). That was considered the break-even point for including sunflower meal in MBS.

Table 9. Cost of individual ingredients and overall cost of preparing 100 kg of MB and MBS supplements.

		Amount for 100 kg		Cost for ingredients	
Ingredient	Price per kg (TSH)	MBS	MB	MBS	MB
Maize bran	50.00	68.70	99.00	3435.00	4950.00
Sunflower meal	80.00	30.30	0.00	2424.00	0.00
Mineral powder	900.00	1.00	1.00	900.00	900.00
Totals		100.00	100.00	6759.00	5850.00
Cost per kg (Tsh)				67.59	58.50
Cost/day/cow (Tsh)				270.36	234.00
Break even for MBS (Tsh)				**36.36**	

No attempt was made to calculate the overall profitability of the dairy enterprises since to do that, other factors like investments in animals, houses, feeding costs of dry animals, bulls and calves would have to be considered.

Table 10 gives the breakdown of the major production costs in an already established dairy unit and the income from milk sales for two cows; one fed MBS and another fed MB. Based on the meal yields obtained in this study (Table 10) milk sales from both would have earned the farmer some 3,411Tsh per day showing that having a dairy cow in milk was highly profitable. The extra income due to the use of sunflower meal was 390 Tsh per animal per day. Again, compared to the extra cost due to sunflower meal (36 Tsh), it was highly paying to use sunflower meal.

Table 10. Estimates of production costs and income from milk sales of a farmer owning two lactating cows; one fed MBS and the other MB. Costs expressed in Tanzanian Shillings (Tsh)

	Supplement	
Item	MBS	MB
Mean yield (l/day)	8.07	6.65
*Income from sales	2421.00	1995.00
Major production costs		
Supplements	270.36	234.00
**Labour (350 Tsh/day)	175.00	175.00
Drugs 50 (Tsh/day)	25.00	25.00
[1]Forage (100Tsh/day)	50.00	50.00
Total expenses	520.36	484.00
Net income	1900.64	1511.00
Extra income due to sunflower inclusion	**389.64**	

*Based on the price of 300Tsh per litre of fresh milk

**Based on the highest pay level during that time (10,000 Tsh/month)

[1]Forage price estimated to be 4.55Tsh/kg DM

DISCUSSION

Previous studies (Kidunda, 1988) have shown a decline in nutritional value of forages with advancing dry season in Morogoro. In Morogoro, the heavy rainy season stretches from April to June, followed by the long dry season from July to November. Under normal circumstances, some short rain can fall between October and November, then followed by yet another dry season from December to March. In 1999, the short rains were very scarce leading to an unusually long dry season stretching from July 1999 to February 2000. The observed changes in the nutritional value of forages with advancing dry season conformed to characteristic features of tropical forages (Butterworth, 1967; Leng, 1990; Vesterlund, 1997). During the dry season, forages are low in essential nutrients such as nitrogen, energy, minerals and vitamins required for optimal rumen microbial growth (Preston and Leng, 1987; Preston and Leng, 1984). This in part explains the observed low in vitro organic matter digestibility of the forages collected during the dry period. The on farm trial was carried out between November 1999 to early

March 2000 which was the time when nutritive quality of the basal forages were low (see Figure 1).

The CP content of sunflower meal and maize bran used in this study (23.6 and 10.9 % respectively) was nearly of the same order as those used by Temi (1999) which were 21.9 and 11.6% respectively. The ether extract was however low (4.5%) and this could have been due to the extensive solvent extraction of oil. Reported values of EE of solvent extracted sunflower meal in the tropics ranged from 3-8 (Göhl, 1981) while according to Danish Feedstuff Table (Møllar et al., 2000) it is reported to be 3.0-3.2% of DM in partially decorticated sunflower meal. An even lower ether extract content in sunflower meal (2.67%) was obtained by Richardson et al. (1981) showing that there can be some variations in the chemical composition of feeds bearing the same name but grown in different places and also processed differently.

Surprisingly, the maize bran used in this trial had very high EE content (10.7%) compared to values reported in the Danish Feedstuff Table (3.5%) (Møller et al., 2000). The chemical composition of maize milling by-products can vary depending on the proportions of the outer skins, germ (fat rich) and the endosperm in the products. Göhl (1981) refers to the maize grain milling by-product containing the outer skins and germ as horminy feed, that with the outer skin without germ as maize bran and a product with high ether extract (9.2%) as maize oilcake. Its is possible that the by-product used in this study and the one used by Temi (1999) whose ether extract content was 8.5% had larger amounts of the fat rich germ and could possibly be close to maize oilcake (Göhl, 1981).

Sunflower meal mixing with maize bran improved the CP to 14.8 in MBS, which was close to the planned CP content of 15% (see Table 2). Based on the estimated average CP content (6.0% of DM) in the basal forage during the time when this study was done (November 1999 to February 2000) and the mean daily intake of 10.9 kg DM per day, feeding of 4 kg of MB and MBS brought the CP content of the diet to 9.6 and 11.0 respectively. This was however slightly lower than the minimum recommended CP content (13 % of DM) in what is considered a suitable ration for optimal microbial growth (Bouroughs et al., 1975; Satter and Roffler, 1977).

The observed higher effective N degradation from MB compared to MBS was most likely due to the shielding of the structural carbohydrates that were higher in MBS. Both supplements had high rumen N degradability (74 and 64% for maize bran and the concentrate mixture respectively) and therefore were a good source of rumen degradable protein to yield ammonia that is required by most rumen microbes for protein synthesis (Madsen and Hvelplund, 1988). However, it appeared that there was extremely large particle loss from dacron bags with the concentrate mixture than those with maize bran. The sunflower meal looked brittle and therefore may have yielded particles a relatively high number of smaller particles well below the sieve size during grinding thereby increasing high chances of escape from the dacron bags during washing.

Body condition score is a critical measure of dairy feeding system's effectiveness. Adequate body fat reserves promote milk production, reproductive efficiency and sustainability. At the extreme ends of the spectrum, excessively fat animals (score 5) and excessively thin ones (score 1) run higher risks of metabolic problems, lower milk yield, reproductive problems and calving complications. Body condition scoring is a very useful tool in monitoring the nutritional status of dairy cows (Edmondson et al., 1989). It is considered normal for animals, especially high yielding ones to loose a half to three-quarters body condition score in the early lactation since they will be in negative energy balance. Later on, the animals will start gaining weight. A sudden loss of one or more condition score is alarming and need immediate remedy in terms of better nutrition or treatment of the underlying other causal agent(s). The fact that most of the animals in this study maintained their body conditions and even gained condition and weight, was an indicator that the supplements supplied additional energy and protein that were deficient in the dry season poor quality roughage. One could argue that a better comparative scenario would be cows given only forage. But this would definitely not be acceptable to farmers, and would at any rate have tempted them to feed the supplements to those animals not supposed to get it. This would have led to confusing results.

In many instances, cows respond immediately to an increased energy and protein level in diets by increased yield (Schingoethe, 1996) or weight gain or both depending on the lactation phase. There is to some degree, a positive correlation between the amount of rumen degradable protein in the diet to the fibre digestibility, microbial protein synthesis and milk yield (Spörndly, 1989). The increased milk yield in the MBS fed cows compared to MB fed cow can be attributed to a nitrogen effect in the rumen and/or amount of by pass nitrogen. As it was not possible to accurately estimate the effect of the supplements on voluntary dry matter intake, at least part of the observed increase in milk yield with the concentrate mixture can be explained in terms of the N intake and degradation (Table 5). MBS had an almost double the amount of rumen bypass N (32g) compared to MB (17g) per day. The extra amino acids from digestion of the by pass protein could have led to an overall change in the pattern and efficiency of utilisation of absorbed nutrients (Oldham, 1982) and by this positively affected milk yield. Temi, (1999) supplemented dairy cows with a sunflower-maize bran mixture with 15.8% CP, and obtained a significant increase ($P<0.05$) in milk yield from animals fed 3kg of the concentrate mixture compared to those supplemented with same amounts of maize bran alone. In his study (Temi's), the sunflower-maize bran concentrate mixture increased milk yield from 3.6 L per day (maize bran only) to 5.9 L per day. In this study mean milk yield increased from 6.6 L per day (MB) to 8.1 L per day (MBS) in animals fed 4 kg of either supplements per day. The disparity between the two studies may have been mainly due to the fact that the work by Temi (1999) was carried out on station under controlled conditions and with an almost homogeneous group of animals. It must be born in mind that the response to any feeding regime by milking cows depends among other things the genetical potential for milk production and to a greater extent, the environment which influences the extent of realisation of that potential.

The increase in milk yield due to MBS in this study (1.5 L/day) was more close to that reported by Nkya et al. (1998). The workers obtained a non-significant increased milk yield of 1.6 L per day in smallholder cows in Morogoro supplemented with a cottonseed cake and maize bran mixture (CSC) compared to maize bran alone (MB). The composition of CSC was 28, and 70% of cotton seed cake and maize bran, respectively, and 1% each of mineral lick and common salt, respectively. Cows were fed 0.8 kg of CSC and 0.6 MB/l of milk produced. In comparison to the yield in this study, this was a substantially high supplementation level with an almost similar level of increase in milk yield. Urassa et al. (1999) reported significant increased milk yield (from 5.0 to 7.5 L per day) ($P<0.05$) from smallholder dairy cows supplemented with maize bran-cottonseed cake concentrate mixture compared to animals given maize bran only in Tanga region. All these studies show that there is a fairly good response in increased milk yield when the crossbred dairy cows in Tanzania are given nitrogen in addition to energy supplements. Based on the results of this study, provision of 0.5 kg of the formulated concentrate per litre of milk produced by the crossbreed cows in Morogoro is recommended provided that farmers ensure the animals are given adequate forages.

The feed given to milking cows has a strong impact on the not only on the milk yield but also the composition (Spörndly, 1989). Milk butter fat and total solids contents in this study were within the levels common for tropical dairy cattle (Chamberlain and Cowman, 1999 quoting Foley et al., 1972). However, the protein content was rather high. Similar high protein content values (4.0-4.2%) were obtained from crossbred animals supplemented with maize bran-sunflower cake concentrate mix or maize bran *Gliricidia sepium* leaf meal (Temi, 1999) in Turiani area in Morogoro, Tanzania. Chamberlain and Cowman (1999) gave a range of CP content of milk of 3.2 in Zebu cattle to 3.6 exotic Jersey cattle reared in the tropics in milk sampled 2-3 weeks after calving. Though colostrum has high CP content (21%), the variations in milk CP content with the lactation cycle for the crossbreeds in the tropics needs further investigation.

Feed costs are considered to represent up to 45-60% or even more of the total cost of producing milk depending on management. Good dairy management practices must maintain low feed costs while at the same time maintain nutrient and feed intake levels that will support optimum level of production. Improved feeding not only increases productivity but also the health status of the animal thereby reducing costs due to medication. Appropriate supplementation package to any dairy enterprise must put in consideration the costs of ingredients, their availability as well as acceptability and easy adoption by the targeted farmers (Preston and Leng, 1974). In this study, farmers commonly used maize bran as a means of making the animal calm during milking. However, most did not realise the benefit of increasing the amount of protein by mixing maize bran with other cheaply available protein source like sunflower meal. As stated earlier, sunflower meal was the cheapest and easily available both in urban and rural areas in Morogoro.

From the estimates of the costs of MB and MBS supplements, break even cost of the extra milk due to the use of sunflower was 36 Tsh. Raw data estimates showed an extra yield of 1.4 L per day which was very close to that obtained by the difference in mean yield of the two treatments from the least square means (Table 6). The amount of cash realised from the sale of the extra milk was nearly 400 Tsh, which is over ten times the break even level. Therefore, the use of sunflower meal was found to be highly profitable.

The apparently high profitability of dairy projects in general, was in part due to low transaction costs as pointed in a previous study (Mlay et al., 2000) that most farmers use bicycles for transaction of both supplies and forage and the customers collect the milk from the producers. There was also the element of cheap labour where the cattle attendants are very lowly paid relative to workload. Attendants are paid from between 5000-9000Tsh per month (Nkya et al., 1998) and can be in charge of up to 10 heads of cattle. This makes the labour cost per animal to be rather low thereby increasing the profit margin. Most dairy farm owners hold a second job either in the Government or private sector (Mlay et al., 2000). Some of them readily agreed dairy keeping was earning them more than twice the monthly salary they get from their employers. It should however be kept in mind that the real profitability has not been calculated in this study. To do so additional information is needed such as the investment in animals, houses and the cost involved to feed dry cows, calves, bull(s) etc.

CONCLUSION

It is necessary to provide energy and protein supplement to cows during dry season to arrests the fall in productivity so common during this time of the year. The solution as to what constitutes the appropriate supplementation strategy very much depends on the type of production system under consideration. The choice(s) will depend on the location, the local feed resource base, availability and prices of ingredients for use as supplements and above all, the receptivity of the farmers to non-traditional techniques.

For time to come, the use of cereal grain by-products and oil-cakes as sources of both energy and nitrogen will continue in urban and peri-urban dairy industry. Why? This is because other alternatives seem not to be practicable due to various reasons. Use of urea is still not well acceptable to farmers due to previous incident of urea toxicity. The small plots earmarked mainly for residential purposes do not offer adequate space to establish legume forages and shrubs.

This study centred on one important source of nitrogen that though a potentially source of nitrogen in Morogoro; has up to now, not received the attention it deserves. This was sunflower meal from the oil-processing factory in Morogoro. Sunflower meal is produced in the homesteads for farmers that grow sunflower seed crop and can extract oil locally using a hand-rum press. It was proved that sunflower meal is effective and economically profitable for use as dry season nitrogen supplement in combination with maize bran. With the very high marginal output in milk production obtained in this and other studies, it is likely that even higher rates of supplements are profitable. This has to be investigated in future experiments.

From the weight gain and body condition scores, is seems that supplementation with concentrates enabled the animals to meet their requirements for energy at the current level of production but the optimal level of protein inclusion need further studies.

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