Use of napier grass to improve smallholder milk production in Kenya

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Abstract

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In Kenya, dairy production is mainly in the medium and high potential agricultural areas and because of high population pressure, smallholders (2-3 ha) form 80 % of the population. Napier grass (NG) has been identified to be a suitable fodder for these areas due to its high dry matter yield. The current recommendation to feed NG to cows at a height from 60 to 100 cm (age, 6-10 weeks) does not take into account factors such as amount of rainfall which may influence yield and quality of the grass. Therefore poor quality and inadequate amount of feeds available to cows are common problems resulting in low levels of milk production (5-7 kg cow^{-1} day^{-1}). Although supplementation is advocated to improve milk production on NG based diets, concentrates are too expensive and high-protein legumes and fodder trees are not available in adequate quantities for supplementation of cows. As a consequence farmers are using poultry litter as an alternative and cheap sources of protein. Information on home-made concentrates using poultry litter as a source of protein, which amounts to supplement, what levels of milk production to expect and economics of production in the wet and dry seasons is therefore required. The overall objective of the study was to improve smallholder milk production in the medium and high rainfall areas through utilization of napier grass at optimal maturity and supplementation using poultry litter based concentrate. A review paper indicated the need to identify specific optimal stages of maturity for feeding NG to cows in the medium and high rainfall areas and that more work on milk production should establish technical and economic levels of supplementation. Digestibility was improved by supplementing NG at early maturity (120 g CP kg^{-1} DM) with soyabean meal implying that young grass will not support optimal rumen microbial protein yields. It was shown, based on crude protein: digestible organic matter ratio, that NG should be fed earlier in medium (height, 50-60 cm; age, 7-8 weeks) than high (height, 130-140 cm; age, 9-10 weeks) rainfall areas. The

digestibility of NG was accurately estimated from fibre fractions (r^2 = 0.86; rsd = 23.56; P < 0.001) or crude protein content (r^2 = 0.71; rsd =27.85; P < 0.001) while DM yield was accurately estimated from age (r^2 = 0.89; rsd = 1.27; P < 0.001) or height (r^2 =0.85; rsd = 1.54; P < 0.001) on-station. The DM yield could be estimated with some accuracy from height (r^2 = 0.51; rsd =0.77; P < 0.01) or age (r^2 = 0.39; rsd = 0.86; P < 0.01) of NG and only in the high rainfall areas on-farm. To support same level of milk production, cows fed NG at advanced maturity in dry seasons (ONG) should be offered supplements containing about 30 g kg^{-1} DM more of protein digested in the intestines than cows fed the grass at the recommended medium maturity in wet seasons (MNG). It was observed from rumen fermentation study that PLBC should be supplemented to cows fed MNG while SFBC should be used on cows fed ONG. It was not profitable, at the current market prices, to produce milk from ONG. Maximum profit was achieved when cows fed MNG were supplemented with 1 kg of dry matter of PLBC. Cows fed MNG and supplemented with PLBC produced 3.5 % less milk than cows supplemented with SFBC. However, milk production profit was 22 % higher for cows supplemented with PLBC than for cows supplemented with SFBC. Milk production profit in rural areas was 68 % lower than in areas near urban centres.

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Chapter 1

General Introduction

General introduction

Background

Kenya lies between the longitudes 34 ^{0} E and 42 ^{0} E and latitudes 5 ^{0} S and 5 ^{0} N of the equator, covering a total area of about 580, 367 Km^2. The average annual rainfall ranges from 250 to 2,500 mm with the medium and high potential agricultural areas (17 % of total land area) receiving over 750 mm. The altitude ranges from 0 m at sea level to above 3,000 m in the highlands and the annual temperature ranges from less than 10 ^{0} C to 30 ^{o} C. About 75 % of the country consist of low agricultural potential arid and semi-arid lands. The classification of land use potential is based mainly on climatic factors and to a lesser extent on soils which are generally of moderate fertility and suitable for crops and pasture production (Jaetzold and Schmidt, 1983). Due to variation in amount and distribution of rainfall, and temperatures, the flora varies from patchy grass cover in the arid areas to woodlands in the high rainfall areas (Sombroek et al., 1982).

The country's population growth rate was recently estimated at 3.4 % which would put the population by the year 2000 at about 32 million people (MoALDM, 1993). About 80 % of this population reside in the rural areas and depend on agriculture, which still remains as the main stay of the country's economy. The agricultural sector account for 28 % of the national gross domestic product (GDP), employs over 70 % of the rural workforce and generates about 64 % of the export earnings. The livestock sub-sector contributes about 10 % of the national GDP and employs over 50 % of the agricultural labour force (KARI, 1995). The livestock sub-sector comprise of over 13 million cattle, 18 million sheep and goats, over 25 million chicken and

217,000 pigs. The sub-sector provides a total of 2.4 billion litres of milk, 250,000 tonnes beef, 921 million eggs, 18, 202 tonnes poultry meat, 20,000 tonnes of honey, 2,000 tonnes beeswax and 857 tonnes of greasy wool clip (MoALDM, 1992). The dairy production sub-sector can be divided into three distinct sub-components namely:- small-scale; large-scale; and extensive (pastoral) production systems. Most of the small-scale and large-scale farms are found in the high potential agricultural areas of Kenya highlands. However, a few of these farms are located in the medium potential agricultural areas of the coastal lowlands. The pastoral production system is found mainly in the arid and semi-arid areas of the country.

The dairy (cattle) industry

The dairy industry in Kenya dates back from the 1920's when it was dominated by the large-scale farms (Jahnke, 1982). Since then, there has been a shift from large-scale milk production systems where about 80 % of the farmers are smallholders (MoALDM, 1992). Dairy production is ranked the first in priority among all other agricultural commodities (KARI, 1991). It has the potential for increased employment, particularly in the processing and distribution sector. The number of dairy cattle are estimated to be 3 million of which 80 % are owned by smallholders (MoALDM, 1992). Milk production occurs in almost all areas of the country and is primarily based on cattle. However, in some pastoral areas, cattle milk production is supplemented with sheep, goats and/or camel milk production.

The major dairy breeds in the highlands are Friesians, Ayrshire, Guernsey, Jersey and their crosses including some indigenous (zebu) cattle. In the coastal zones, Jerseys and their crosses with zebu cattle are common. It is estimated that out of the total 2.4 billion litres of milk produced, 74 % is from grade cattle and exotic crosses and about 62 % of this milk, is marketed. Ranking of dairy cattle milk production by provinces shows that Rift Valley and Central

Provinces lead with about 78 % of the total production while the North Eastern Province does not produce any milk (MoALDM, 1992). Other than milk production, the dairy industry contribute significantly to the national economy through sale of animals (culls), beef, hides, skins and manure for crop production. It was estimated that the dairy sub-sector provides income to over 400,000 smallholder dairy farmers (MoALDM, 1993; Reynolds et al., 1996).

Dairy (cattle) production constraints

The major constraints facing the dairy industry in Kenya are documented (MoLD, 1980; Abate, 1992; MoALDM, 1992; Mbogoh, 1992; Muriuki, 1992; MoALDM, 1993; KARI, 1996). These constraints are related to animal production and reproduction, animal diseases, socio-economics, research and extension.

Due to population pressure in the high agricultural potential areas, land has been fragmented into small pieces, leading to low availability of grazing land. The priority is to put more land under crop production to feed the human population. Little land is therefore available for fodder production and as a result dairy cattle are often underfed especially during the dry season when only poor quality forages and crop residues are available. Extension of dairy production to the marginal areas has been faced with animal nutrition related problems since the already established feeding practices in the medium and high potential areas are not suitable for these areas. Other than the problems related to feed resources and their utilization, animal diseases are also a major drawback to dairy production in marginal areas.

Inadequate coverage of artificial insemination services is common in small-scale farms. Furthermore, due to feed shortage, farmers keeping one or more grade cows cannot afford keeping quality bulls on their small zero-grazing units for breeding purposes (Mwangi, 1997). It

was observed that lack of genetic diversity through upgrading of indigenous low yielding zebu cattle has slowed down the expected progress to improve dairy production. Also, non-availability of suitable dairy breeds for the marginal areas is of major concern since the Sahiwal breed and their crosses with dairy cattle are inadequate to meet the demand.

Milk price was liberalised by the government in 1992 and as a result cost of inputs and price of commodities when no longer provided free or subsidised by the government are determined by marketing channels. The marketing environment has not yet stabilised mainly due to poor infrastructure, limited marketing channels, poor market information and organisation within the country. As a result of these limitations, milk and milk product prices are still low in relation to the cost of milk production and processing hence dairy production may not be as profitable as it should be at the moment especially in the rural areas.

Constraints related to the social set-up include limited credit facilities to smallholder dairy farmers due to the high risks involved in livestock production and the high interest rates charged by the lending agents. In some areas, because of communal land ownership it is difficult to improve dairy production without involving the whole community. In addition, the low levels of income and different lifestyles among the local communities may be a hindrance to dairy development. The severe draughts and floods experienced in the country have been a setback to dairy production. Other limitations to dairy development include poor planning, implementation, monitoring and evaluation by government agents. Solutions to address these pertinent issues should be sought through sound policy and research agenda for the wellbeing of dairy producers (Mbogoh, 1992).

Although agricultural research in Kenya has been conducted for many years and a substantial amount of results and technologies developed and recommended to farmers, not all these research results and recommendations have been adopted by farmers (Orodho, 1990). It was, in fact, noted during a workshop by the Kenya Agricultural Research Institute (KARI) on

agricultural research policy in Kenya that only 24 % of the research technologies developed were being applied (Koinange, 1993). It has not been common to include economic-oriented research on such issues as zero-grazing, fodder crop production and conservation, home made feed compounding, optimal utilization of crop residues and agro-forestry issues as they relate to fodder and food crop production (KARI, 1995). Furthermore, agricultural research pays little attention to the negative effect of livestock development on the environment, human health, animal welfare and equity issues including poverty and gender. All these issues are exerting a strong influence on the country's research policy and affecting donor attitude to funding of livestock activities (Ehui and Shapiro, 1995).

Research can provide technology to help achieve productivity increases but the technology need to be transferred to producers to ensure impact (Ehui and Shapiro, 1995). If farmers have to adopt the improved research technologies, there is need for close linkages between research, extension and training of farmers (KARI, 1995). Involvement of all the stakeholders is essential to ensure that the research is relevant to the needs of the targets. It has been noted with concern that the basic data related to agriculture in this country are either not available at the moment or are unreliable mainly due to the poor methodologies used to collect the data (Abate, 1992; Muriuki, 1992).

Feeding and the role of napier grass in smallholder dairy (cattle) production

The high population pressure in the high and medium potential agricultural areas has reduced farm holdings to about 2-3 hectares (Valk, 1990; Boonman, 1991). Due to this, overstocking is common with subsequent land degradation and inadequate feed supply. Intensified production is therefore a prerequisite in these areas (MoLD, 1980; MoALDM, 1993).

Some of the proposed measures to improve milk production in these areas have been stated as better feeding, supplying high yielding grade animals and upgrading the zebus.

Feeds and feeding has been indicated as the major constraint to dairy cattle production (Abate, 1992; KARI, 1995; KARI, 1996; Omore et al., 1997). This is in agreement with the report by Olaloku and Debre (1992) that inadequate feed supply is a major constraint to cattle production in general and milk production in particular in smallholder production systems throughout sub-Sahara Africa. Improving the supply of feeds is therefore a top priority and is, in fact, a prerequisite to improvements in animal health. The most important areas of research in feed resources and utilization as summarised by the various KARI documents (KARI, 1991; KARI, 1995, and KARI, 1996) are:-

- To develop cost effective forage production, processing and conservation techniques to increase dry matter intake and increase the efficiency of forage utilization.
- Characterize the available farm and agro-industrial by products, concentrates and ingredients to promote farm level low cost compounding of dairy feeds in different regions.
- Improve mineral and water availability and utilization at farm level.

The major dairy production systems in the medium and high agricultural potential areas are zero-grazing and semi-zero-grazing. The main fodder are napier grass (*Pennisetum purpureum*), Kikuyu grass (*Pennisetum clandestinum*) and other native grasses. Maize stover, banana stems and other agricultural by-products are used especially during the dry season. The high yield and the fact that napier grass can maintain its quality for a long period of growth makes it more suitable for smallholder dairy production than the other available grasses (Stotz, 1981; Van der Kamp, 1987; Wouters, 1987; Kariuki, 1989; Snijders *et al.*, 1992). The current recommendation is to feed the grass to dairy cattle at a height from 0.6 to 1.0 m or the age from 6 to 10 weeks (MoALDM, 1991). Although the recommendation is of general use, the importance

of cutting the grass at lower heights during the dry season (less moisture supply) is emphasized. Other than soil fertility and fertilizer rates (Snijders et al., 1992; Van der Kamp, 1987; Wouters, 1987), the rainfall amount and temperature have been reported to influence yields and quality of napier grass (Anindo and Potter, 1994). The current recommendation does not take into account the effects of the amount of annual rainfall on stages of maturity at which the grass should be fed to dairy cattle.

Feeding napier grass at the optimal stage of maturity would be a cheap method of dairy cattle production. However, daily milk production at farm level is often less than 10 kg per cow when the grass is fed as the sole diet (Valk, 1990; Mogaka, 1995). This yield is far below the genetic potential of dairy cattle and can be attributed to inadequate levels of feeding and the low quality of the grass. It has been shown through experimentation that high milk yields could be obtained when dairy cattle on a basal diet of napier grass are supplemented with feed resources having high energy and protein contents (Combellas and Martinez, 1982; Anindo and Potter, 1986; Muinga et al., 1995; Mukisira et al., 1995). Supplementation to calves is possible using high-protein fodders (*Ipomoea batatas* vines, *Desmodium intortum*, *Desmodium uncinatum* and *Medicago sativa*) and fodder tree leaves (*Leucaena leucocephala*, *Sesbania sesban*, *Calliandra calothyrsus* and *Gliricidia sepium*). However, the quantities of these high-protein forages are not adequate for supplementation of lactating cows (Valk, 1990; Mwangi, 1995). In addition, supplementation using commercial concentrates is at minimal levels mainly because of the high costs in relation to milk prices (Abate et al., 1990; Valk, 1990; MoALDM, 1992).

Objectives

The overall objective of this study was therefore to improve milk production in smallholder dairy farms in the high and medium rainfall areas in Kenya through utilization of napier grass at the optimal stage of maturity. The possibility to higher milk yields through supplementation with relatively cheap and locally available protein sources such as poultry litter was also investigated. The specific objectives were:-

- To determine the optimal stage of maturity for feeding napier grass to lactating dairy cows in the high and medium rainfall areas.
- To develop standard samples and regression equations for simple prediction of nutritive value of napier grass in the high and medium rainfall areas.
- To assess supplementation requirements, based on rumen degradation and fermentation data, of napier grass at the recommended and advanced stages of maturity with locally available concentrates.
- To determine the effect of quality of napier grass and protein supplement, and levels of supplementation on feed intake, live-weight changes and economics of milk production in dairy cows.

Thesis outline

The thesis determines the optimal maturity for feeding napier grass to lactating dairy cows using various methods namely:- *in vivo* digestibility; optimal CP content; yield of digestible nutrients; and CP content to digestible organic matter ratio. Regression equations for

simple prediction of yield and nutritive value of the grass are developed. The effects of amount of rainfall on optimal maturity to harvest the grass and on prediction of its nutritive value are also investigated. Opportunities to use a relatively cheap and readily available protein source (poultry litter) to improve nutritive value of NG and milk production in smallholder dairy farms are investigated. The first Chapter is a brief introduction of Kenya's agricultural sector and livestock sub-sector. This is followed by a fair coverage of the dairy (cattle) industry and constraints, the role napier grass plays in the nutrition of dairy cattle by smallholder farmers in Kenya, and finally the objectives and outline of the thesis. A review of the current research results on utilization of napier grass for milk production by dairy cows is covered in Chapter 2. The *in vivo* digestibility (Chapter 3) and the optimal CP content, yield of digestible nutrients, and CP content to digestible organic matter ratio (Chapter 4) are used to determine the optimal stage of maturity at which napier grass should be fed to lactating cows in Kenya. The influence of moisture supply to napier grass on prediction of DM yield and *in vivo* digestibility using simple techniques such as plant maturity, leaf: stem ratio or relatively expensive laboratory methods such as chemical composition and *in vitro* digestibility of the grass is investigated in Chapter 5. In Chapter 6, the rumen degradation of NG at medium (MNG) and advanced (ONG) stages of maturity, poultry litter (PL), sunflower seed meal (SFM), soyabean meal, cotton seed cake, PL (PLBC) and SFM (SFBC) based concentrates, and the locally purchased concentrate are determined. Also, their rumen microbial protein yields and intestinal protein digestion values are estimated. The data is used to suggest the appropriate supplements for animals fed the MNG or the ONG. The voluntary feed intake and rumen fermentation patterns when steers fed MNG or ONG are supplemented with PLBC or SFBC, and when steers fed MNG are supplemented with graded levels of PLBC are determined in Chapter 7. The data is also used to suggest supplementation requirements on animals fed MNG or ONG. In Chapter 8, the effect of feeding the diets in Chapter 7 to Friesian cows on

voluntary feed intake, live-weight changes and economics of milk production are determined. In Chapter 9, the results obtained in this study are discussed and conclusions made with a special reference to improvement of milk production by smallholder dairy farmers in Kenya.

References

Abate, A., Abate, A.N. and Gacugia, S., 1990. Feeding systems for milk production in the high potential areas of Kenya. On-farm trials. In: Dzowela, B.H., Said, A.N., Wendem-Agenehu, A. and Katengile J.A. (Eds.), Utilization of Research Results on Forage and Agricultural By-product Materials as Animal Feed Resources in Africa. Proceeding of the PANESA/ARNAB/ILCA joint workshop, 5-9th December, 1988, Lilongwe, Malawi. pp 264-279.

Abate, A., 1992. Analysis of the Kenya dairy industry in the last decade: Constraints and options. In: Irungu, K.R.G. and Waithaka, M.M. (Eds.), Priorities in Dairy Cattle Research. Proceeding of a KARI Workshop, 4th-9th May, NARC, Muguga, Kenya. pp 5-14.

Anindo, D.O and Potter, H.L., 1986. Milk Production from napier grass (*Pennisetum purpureum*) in a zero-grazing feeding system. East African Agriculture and Forestry Journal, 52:106-111.

Anindo, D.O. and Potter, H. L., 1994. Variation in productivity and nutritive value of napier grass at Muguga, Kenya. East African Agriculture and Forestry Journal., 59: 117 - 185.

Boonman, J., 1991. Pasture development technologies in Kenya: Achievements and future challenges. Proceeding of the 1st KARI Scientific Conference on Agricultural Research in Kenya: achievements and, challenges and prospects, 14th-16th August, 1991, Nairobi, Kenya. pp 42-49.

Combellas, J. and Martinez, N., 1982. Intake and milk production in cows fed chopped elephant grass (*Pennisetum purpureum*) and concentrate. Tropical Animal Production, 7:57-60.

Ehui, S.K. and Shapiro, B.I., 1995. Research and Technology transfer for livestock development. In: Wilson, R.T. and Mack, S. (Eds), Livestock Development Strategies for Low Income Countries. Proceeding of the joint FAO/ILRI roundtable, 27th Feb.-2nd March, 1995, Nairobi, Kenya. pp 71-80.

Jaetzold, R. and Schmidt, H., 1983. National conditions and farm management information. Farm Management Handbook of Kenya. Vol. 11, Part B. Central Kenya (Rift valley and Central province). Ministry of Agriculture, Nairobi, Kenya . 739 pp.

Jahnke, H.E., 1982. Livestock production systems and livestock development in tropical Africa. Kuler Wissenchaftverlag vank, Kiel. 253 pp.

Kariuki, J.N., 1989. Evaluation of napier grass cultivars (*Pennisetum purpureum*) under irrigation at different stages of regrowth. Msc. Thesis, University of Nairobi, Kenya. 100 pp.

KARI, 1991. Kenya Agricultural Research Priorities to the year 2000. Kenya Agricultural Research Institute (KARI), Kenya. 110 pp.

KARI, 1995. National Agricultural Research Programme (Phase II). Project preparation report, Kenya Agricultural Research Institute (KARI), Kenya. 354 pp.

KARI, 1996. Priority setting for the Kenya Agricultural Research Institute (KARI) Dairy Program. Kenya. 26 pp.

Koinange, W., 1993. The direction of agricultural research and development through the next decade. Proceeding of a Workshop on Agricultural Research Policy in Kenya held in November, *1991*. KARI/ISNAR, Nairobi, Kenya. pp 5-8.

Mbogoh, S.G., 1992. An analysis of some socio-economic aspects of dairy production and marketing in Kenya. In: Irungu, K.R.G. and Waithaka, M.M. (Eds.), Priorities in Dairy Cattle Research. Proceeding of a KARI Workshop, 4th-9th May, NARC, Muguga, Kenya. 36-53.

MoALDM, 1991. Zero-grazing. A handbook on technical aspects (Compiled by Wouters, A.P.). National Dairy Development Project (NDDP), NAHRC, Naivasha, Kenya. 75 pp.

MoALDM, 1992. Annual Report. Ministry of Agriculture, Livestock Development and Marketing, Nairobi, Kenya. 92 pp.

MoALDM, 1993. Kenya Dairy Development Policy. A strategy towards the development of a self-sustainable dairy sector. Ministry of Agriculture, Livestock Development and Marketing, Nairobi, Kenya (MoALDM), Animal Production Division, Nairobi, Kenya. 25 pp.

MoLD, 1980. National Livestock Development Policy. Ministry of Livestock Development (MoLD), Nairobi, Kenya. 60 pp.

Mogaka, L.M., 1995. Economic evaluation of zero-grazing under napier grass based system in high yielding cows at smallholder level. Proceeding of the 4th KARI Scientific Conference, Silver Springs Hotel, 25th-28th October, 1994, Nairobi, Kenya. pp 323-331.

Muinga, R. W., Thorpe W. and Topps, J. H., 1995. The effect of supplementation with *leucaena leucocephala* and maize bran on voluntary food intake, digestibility, live-weight and milk yield of *Bos Indicus* x *Bos Taurus* dairy cows and rumen fermentation in steers offered *Pennisetum purpureum ad-libitum* in the semi-humid Tropics. Animal Science, 60: 13 - 23.

Mukisira, E.A., Phillip, L.E. and Mitaru, B.N., 1995. The effect of feeding diets containing intact or partially detoxified lupin on voluntary intake and milk production by Friesian dairy cows. Animal Science, 60:169-175.

Muriuki, H.G., 1992. Diagnosis of the current situation of dairy (cattle) industry in Kenya. In: Irungu, K.R.G. and Waithaka, M.M. (Eds.), Priorities in Dairy Cattle Research. Proceeding of a KARI Workshop, 4th-9th May, NARC, Muguga, Kenya. pp 15-32.

Mwangi, D.M., 1995. Diagnostic surveys in livestock feeds, feeding and management practices in central Kenya. Proceeding of the 4th KARI Scientific Conference, Silver Springs Hotel, 25th-28th October, 1994, Nairobi, Kenya. pp 293-305.

Mwangi, J.N., 1997. Privatisation of artificial insemination services in Kenya. In: Wakhungu, J.W. (Ed), Proceeding of the Animal Production Society of Kenya (APSK) Symposium., Volume XVIII, 1995-1996, Kenya. pp 19-31.

Olaloku, E.A. and Debre, S., 1992. Research priorities for the development of appropriate feeding systems for dairy production in sub-sahara Africa. In: Stares, J.E.S., Said, A.N. and Katengile, J.A. (Eds.), The Complementarity of Feed Resources for Animal Production in Africa. Proceeding of the Joint feed Resource Network Workshop, 4th-8th March, 1991, Gaborone, Botswana. pp. 399-407.

Omore, A. McDermott, J.J. and Gitau, G.K., 1997. Factors influencing production on smallholder dairy farms in central Kenya. Proceeding of the 5th KARI Scientific Conference, 14th-16th October, 1996, Nairobi, Kenya. pp. 370-380.

Orodho, A.B., 1990. Dissemination and utilization of research technology on forages and agricultural by-products in Kenya. Dzowela, B.H., Said, A.N., Wendem-Agenehu, A. and Katengile, J.A. (Eds.), Utilization of Research Results on Forage and Agricultural By-product Materials as Animal Feed Resources in workshop, 5th-9th December, 1988, Lilongwe, Malawi. pp. 70-90.

Reynolds, L., Metz, T. and Kiptarus, J., 1996. Smallholder dairy production in Kenya. World Animal Review, 87: 66-73.

Sombroek, W.G., Braun, H.M.H and van der Pouw, B.J.A., 1982. Exploratory soil maps and agro-climatic zone map of Kenya 1980. Exploratory soil survey report No. E1. Kenya soil surveys, Ministry of Agriculture, National Agricultural Laboratories (NAL), Nairobi, Kenya. 56 pp.

Snijders, P.J.M., Orodho, A.B., Kiura, J.N. and Mogaka, L.M., 1992. Effect of nitrogen fertilizer and cutting stage on yield and quality of napier grass (*Pennisetum purpureum*). Kenya Agricultural Research Institute, NAHRC, Naivasha, kenya. 46 pp.

Stotz, D., 1981. The attractiveness of arable fodder crops for smallholder dairy farmers in Kenya. Research and Development, volume II, 75-82.

Valk, Y.S., 1990. Review reports of the Dairy Evaluation and Advice Forms (DEAF) surveys during 1989. National Dairy Development Project (NDDP/M41/200). Ministry of Livestock Development, Nairobi, Kenya. 69 pp.

Van der Kamp, A. 1987. Napier grass in Kenya. A review and a nitrogen fertilization trial. National Dairy Development project (NDDP), Ministry of Livestock Development, NAHRC, Naivasha, Kenya. pp 47.

Wouters, A.P., 1987. Dry matter yield and quality of napier grass at farm level in 1983-1986. National Dairy Development Project (NDDP/R091/143), Ministry of Livestock development, NAHRC, Naivasha, Kenya. 39 pp.

Chapter 2

The nutritive value of napier grass (*Pennisetum purpureum*) and its potential for milk production with or without supplementation: A review

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The nutritive value of napier grass (*Pennisetum purpureum*) and its potential for milk production with or without supplementation: A review

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Abstract

The existing recommendation of the maturity (age 6-10 weeks, height 60-100 cm) at which napier is fed to dairy cows is still valid as a general guideline for milk production. The use of crude protein (CP) content and digestible CP as a measure of nutritive value should be replaced by the modern protein evaluation systems. Napier-based diets supported rumen pH and ammonia N concentrations suitable for maximum rumen microbial growth and activity and for optimal organic matter digestibility and feed intake. The efficiencies of rumen microbial protein synthesis were 25, 44, and 168 g N kg^{-1} fermentable carbohydrate while the total protein digested in the intestines were 70, 90, and 80 g kg^{-1} dry matter (DM) for napier, legumes, and oil meals respectively. Napier-only diet (60-70 g CP kg^{-1} DM) supported a mean daily milk yield of 6.8 kg per cow which was accompanied by live-weight loss (- 0.44 kg $cow^{-1}d^{-1}$). The concentrate supplemented cows produced more milk (9.5 vs 6.6 kg $cow^{-1}d^{-1}$) but lost more weight (- 0.48 vs - 0.37 kg $cow^{-1}d^{-1}$) than the *Leucaena* supplemented cows. The potential for prediction of yield, nutritive value and milk yield by dairy cows, and the need for more research on dairy production from napier-based diets are discussed.

Keywords: Napier, Nutritive value, Supplementation, Milk production.

Introduction

In Kenya, the popularity of napier grass among smallholder farmers has attracted research attention to its management practices and use for dairy cattle production. The nutritive value and utilization of many Kenyan feedstuffs by ruminants has been reviewed by Abate et al. (1984) but napier was not included. There is more information on the agronomy, yield, chemical composition and *in vitro* digestibility of the fodder (Goldson 1977; Karanja 1985; Boonman 1993; Schreuder *et al.* 1993; Boonman 1997). The official recommendation (MoLD 1991) is to feed napier to dairy cows at 6 to 10 weeks (60 to 100 cm, height) at an expected annual carrying capacity of 4.0 cows ha^{-1}. The use of crude protein and digestible crude protein to estimate the nutritive value of feedstuffs has been replaced by a feeding system based on rumen degradation and intestinal protein digestion characteristics (ARC, 1984; Waldo and Glenn, 1984; NRC, 1985; Jarrige, 1989; Tamminga et al., 1994). No report brings together the available information on rumen degradation and intestinal protein digestion for napier, oil meals and legumes.

Potter and Anindo (1985) provided results on live-weight gains and milk yields by dairy cattle fed napier with concentrate supplementation. However, they did not attempt to relate dry matter intake (DMI) of the concentrate with substitution of the basal diet and the quality of the total diet with feed intake and animal performance. The potential and limitations of napier as a ruminant feed were reviewed by Kariuki (1998), but data on rumen fermentation, rumen degradation and milk production by dairy cattle were not included. Thus, there are important gaps in the information on the effective use of napier grass.

The objectives of this review are:-

(1) To use the available information on DM yield (DMY), chemical composition and *in vitro* organic matter digestibility (OMD) to re-assess optimal maturity of napier for feeding to lactating cows.

(2) To review information on rumen fermentation, rumen degradation and intestinal digestion of napier, oil meals and legumes.

(3) To review information on DMI, substitution rates, live-weight changes and milk yield by dairy cattle fed napier with either concentrate or legume supplements.

(4) To suggest areas for further research to improve milk production by dairy cows on napier-based diets.

How data in the tables were derived at

The data for napier grass in Tables 1, 2, and 5 were classified according to CP requirements for maintenance (50-70 g kg^{-1} DM), and moderate (Lower 80-100, and upper 110-130 g kg^{-1} DM), and high (140-160 g kg^{-1} DM) milk production by dairy cows (ARC, 1984). In Tables 1, 2, 3, 4, and 5 mean values were derived from experiments mostly done in Kenya (see respective sources at the footnote). The derived mean values were compared with values for other tropical or temperate forages, and values for oil meals and legumes obtained elsewhere. Some results of experiments from the source of information were used in the discussion if they gave different values than the derived means or to support statements made.

In Table 1, the CP yield (CPY) of napier was calculated from DMY and CP content and metabolisable energy (ME) content was calculated from digestible organic matter (DOM) as follows:- ME (MJ kg^{-1} DM) = DOM (g kg^{-1} DM)/1000 x 18.5 x 0.81 (AAC 1990), where DOM = OMD (g kg^{-1} OM)/1000 x OM (g kg^{-1} DM). In Table 2, mean values were fitted into the various classes of CP derived from napier and the various supplements at footnote. The mean values of rumen degradation and intestinal digestion for napier, oil meal, and legumes (Tables 3 and 4) were derived from the equations and assumptions given in the appropriate sections when

some of the required data were not available. In Table 5, the mean value for milk yield (MY) per kg of supplement (S) was calculated from total milk yield (TMY), milk yield from napier-only diet (MYN), and the DMI of the S as follows:- MY (kg kg^{-1} S) = (TMY - MYN)/S, and MY per kg CP intake (CPI) was calculated as follows:- MY (kg kg^{-1} CPI) = TMY/(TDMI x (CP of diet/1000)), where TDMI = Total DMI and the rate of substitution (SR) of the napier (N) by the S was calculated as follows:- SR (kg N kg^{-1} S) = (Napier-only DMI - DMI of supplemented N)/S. The derived mean values in Tables 1, 2, 3, 4, and 5 were fitted into regression equations for prediction purposes and the best-fit equations are shown in Table 6. The separation of means of derived values and fitting of regression equations were done by SAS (1988).

The optimal maturity to harvest napier grass

Forages remain the primary source of nutrients for ruminant animals because the rumen functions best with forage-based diets and generally the production costs are lower than for grain crops (Jung and Allen, 1995). As napier grass matured there was a decline in CP content and *in vitro* OMD while the DM yield and detergent fibres increased (Van Soest, 1982; Humphreys, 1991; Cherney et al., 1993). However, the CPY was highest when the grass was young implying that the decline in CP with maturity was faster than the increase in DMY. Due to these changes with maturity, there is a need to establish not only the stage of growth when yield and nutritive value are optimal but to also sustain the grass, soil fertility and animal production.

A CP content (Table 1) of about 60-70 g kg^{-1} DM (Wilson and Minson, 1980; ARC, 1984; Minson, 1990; Leng, 1990; Smith, 1993) and OM digestibility of about 550 g kg^{-1} DM (ARC, 1984; Smith, 1993) are required for the maintenance of ruminants. These values were achieved at 14 weeks (130 cm, height) of napier growth. This OMD is comparable to the 500-560 g kg^{-1}

DM reported for other tropical grasses by Kevelenge (1992). The CP content of 80-130 g kg^{-1} DM (ARC, 1984; Waldo and Glenn, 1984; Humphreys, 1991) and OMD of 600-700 g kg^{-1} DM (ARC, 1984) are required for moderate milk production (10-15 kg cow^{-1} d^{-1}) by dairy cows (Live-weight 450 kg, DMI 13.5 kg). These values were obtained at 6-10 weeks (60-100 cm, height) when the carrying capacity (estimated from DM yield) was between 4.0 and 4.5 cows per hectare. At this maturity, the CP (95 g kg^{-1} DM) and OMD (600 g kg^{-1} DM) were comparable to that of *Pennisetum clandestinum* at the optimal time for feeding to dairy cows (Abate and Abate, 1991). For high milk production (> 15 kg cow^{-1} d^{-1}), a CP content of about 150 g kg^{-1} DM (Broster et al., 1981; Crowder and Cheda, 1982; ARC, 1984) and OMD above 700 g kg^{-1} DM (ARC, 1984) are required. These values were achieved at 4 weeks (40 cm, height) when the quality was lower than that of temperate grasses due to low energy and high neutral detergent fibre (NDF) contents (Van Soest, 1982). At the young maturity, the CP of *Pennisetum clandestinum* (155 g kg^{-1} DM) was similar to that of napier grass but the OMD (660 g kg^{-1} DM) was lower (Hamilton et al., 1992).

At young maturity, milk yield per hectare is expected to be high because of the high CPY despite the low carrying capacity. However, the high cost of frequent harvesting and the need for more fertilizer to maintain soil fertility are likely to outweigh the benefits of the high milk yields. Furthermore, young grass is inefficiently utilized by ruminants because N is lost due to its rapid degradation in the rumen as compared to energy (ARC, 1984; Ørskov, 1982; Valk et al., 1990; Van Vuuren et al., 1991; Poppi and Maclennan, 1995).

The content of NDF above 600 g kg^{-1} DM at which grasses are classified as poor quality (Van Soest, 1982) was achieved at the age of 14 weeks. However, the young (4 wks) and medium (9 wks) aged grasses with NDF content from 500 to 600 g kg^{-1} DM could be classified as of moderate quality (Van Soest, 1982). The derived mean values of acid detergent lignin

Table 1. The mean maturity, yield and nutritive value at different levels of crude protein (CP) content of napier grass

	CP content of napier (g kg^{-1} DM)									
	140-160		110-130		80-100		50-70			
Parameters	Mean	N	Mean	N	Mean	N	Mean	N	Overall mean	SED
Age (wks)	4.3^{c}	12	7.6^{b}	18	9.0^{b}	32	14.1^{a}	30	9.8	5.88
Height (cm)	41.6^{c}	6	61.3^{bc}	11	95.0^{ab}	24	128.1^{a}	48	105.1	2.39
DM (g kg^{-1})	144.0^{c}	6	160.5^{bc}	6	174.9^{b}	7	197.4^{a}	13	175.5	2.60
OM (g kg^{-1} DM)	761.5^{c}	6	795.7^{bc}	6	811.0^{b}	9	850.9^{a}	11	812.6	2.15
NDF(g kg^{-1} DM)	535.9^{c}	7	608.2^{b}	6	631.5^{ab}	16	680.3^{a}	22	636.7	2.09
ADL (g kg^{-1} DM)	27.8^{b}	6	41.7^{a}	6	40.4^{a}	13	48.7^{a}	15	41.8	2.04
DMY (ton ha^{-1} yr^{-1})	13.7^{c}	6	19.7^{b}	8	21.8^{b}	14	28.5^{a}	25	23.7	2.48
CPY (ton ha^{-1} yr^{-1})	3.6^{a}	6	2.6^{b}	6	1.6^{c}	12	1.0 c	21	1.7	2.60
OMD (g kg^{-1} OM)	791.2^{a}	6	744.9^{b}	11	673.3^{c}	11	607.0^{d}	21	675.4	3.82
ME (MJ kg^{-1} DM)	8.9^{a}	6	8.3^{b}	11	7.7^{c}	12	7.1^{d}	30	7.6	3.05

N, number of observations; SED, standard error of difference between means; numbers within a row bearing different superscripts are significantly different ($P < 0.01$); DM, dry matter; OM, organic matter; NDF, neutral detergent fibre; ADL, acid detergent lignin; DMY, dry matter yield; CPY, crude protein yield; OMD, *in vitro* organic matter digestibility and ME, metabolisable energy content.

Source: Maher, 1936; Butterworth, 1965 and 1967; Grant et al., 1974; Odhiambo, 1974; Devendra, 1975; Mugerwa and Ogwang, 1976; Hassan and Abdi-elaziz, 1979; Muhuyi et al., 1980; Brown and Chavulimu, 1985; Wouters, 1985; Wouters and Dohmen, 1985; Anindo and Potter, 1986; Wouters, 1986; Wouters, 1987; Van der Kamp, 1987; Kariuki, 1989; Kaitho and Kariuki, 1990; Kiura, 1992; Snijders et al., 1992; Anindo and Potter, 1994; Muinga et al., 1995; Abdulrazak et al., 1996; Kariuki, 1998.

(ADL) contents were below the critical level of 60 g kg^{-1} DM above which digestibility is negatively affected (Van Soest, 1967). These values were also lower than the values (50-60 g kg^{-1} DM) reported for other tropical forages (Kevelenge, 1992). The decline in digestibility may, therefore, have been mainly due to the fibre chemistry and anatomical structure of the cell wall rather than its content (Grabber and Allison, 1992; Wilson and Hatfield, 1997). The metabolisable energy (ME) content at early maturity and the CP content at advanced maturity were likely to limit milk yield from napier-only diets. The prediction of DM yield was reliable from age and DM content ($R^2 = 0.92$) while CP yield ($R^2 = 0.79$) and *in vitro* OMD ($R^2 = 0.88$) were predicted better using CP content (Table 6).

Rumen fermentation

The ingestion feed in ruminants is fermented by microbes into volatile fatty acids (VFA), ammonia N (NH_3-N), methane and carbon dioxide. The VFA are an energy source while the NH_3-N and amino acids formed through protein hydrolysis and deamination in the rumen are the N source for microbial growth (Ørskov, 1982). The digestion of the feed (fermentation patterns) will therefore depend on the rumen environment (pH, NH_3-N and VFA concentrations) which in turn will be influenced by the characteristics of the ingested feed (Cronje, 1992).

The derived values of rumen pH (Table 2) were within the range of 6.3 to 7.0 considered optimal for rumen microbial activity and growth (Ørskov, 1982; Ørskov and Ryle, 1990: Chenost and Kayouli, 1997). High levels of supplementation with readily fermentable carbohydrates (CHO's) reduce rumen pH and often reduce salivation (Van Soest, 1982; Tamminga and Van Vuuren, 1988; Van Vuuren et al., 1992). The rumen pH was not influenced by the CP content of napier diets although it was negatively related to proportion of propionate

(Table 6). The time spent eating and ruminating when readily fermentable concentrates (e.g. cereals) are fed is less than for fibrous diets so the rumen fluid is less buffered and the rumen pH tends to be low (Ørskov, 1982). Therefore, supplementation with legumes could be associated with more ruminating time, maintaining rumen pH through increased salivation. The balance between rumen NH_3 -N concentration and supply of fermentable CHO's influences microbial activity and growth in the rumen (Lindberg, 1987). Generally, high NH_3-N concentrations are associated with increased microbial activity and rumen fermentative capacity (Nyangito et al., 1997) but different feeds require different concentrations of NH_3-N to achieve optimal microbial yield and digestion (Ørskov, 1982). For maximum microbial growth and activity, the rumen NH_3-N concentration should be between 10 and 60 mg l^{-1} (Satter and Slyter, 1974; Osuji et al., 1995). Higher concentrations (150-250 mg l^{-1}) are required for the optimal rate of digestion and feed intake (Leng and Nolan, 1984; Boniface et al., 1986). The NH_3-N concentrations (156-239 mg l^{-1}) of napier-based diets at CP of 80-160 g kg^{-1} DM were higher than requirements for maximum microbial yield and within the range for optimal rate of digestion and feed intake. At these CP levels, NH_3-N concentrations were also higher than the 150 mg l^{-1} recommended by Preston and Leng (1987) for efficient utilization of tropical forages. Lower NH_3-N concentrations were reported by Hamilton et al. (1992) (36-114 mg l^{-1}) and Khalili et al. (1993) (94-146 mg l^{-1}) when cows on other tropical grasses were supplemented with concentrates. The rumen NH_3-N levels between 120 and 190 mg l^{-1} in dairy cows fed temperate forage and supplemented with concentrates (Van Vuuren et al., 1986) were similar to values of napier-based diets containing CP content of 80-160 g kg^{-1} DM. High concentrations of NH_3-N may be due to the presence of highly degradable protein in the rumen or a high total CP content in the diet (Minson, 1990). The NH_3-N concentrations were positively related and could reliably (R^2=0.64) be estimated from CP content of napier-based diets (Table 6). Among the supplements, *Ipomea batatas* is highly degradable in the rumen (Kariuki, 1998) which could explain the increase in

NH_3-N concentration with level of supplementation. However, high levels of supplementation could result in high intake of the diet, involving large amounts of fermentable OM and resulting in increased utilization of N by rumen microbes and hence low levels of NH_3-N (Haaland et al., 1982; Russell et al., 1983; de Visser 1993).

The increase in VFA as level of CP content increased (Tables 2 and 6) suggest that more N and fermentable CHO's were available from the diet. The VFA could reliably ($R^2 = 0.79$) be predicted from CP of the diet. The relative proportions of VFA are influenced by diet, so that when a supplement consists of grain or high concentrate rations, the proportion of propionic acid is generally high while with forages it is usually lower (Tamminga et al., 1990). The molar proportions of fatty acids in Table 2 were within the reported ranges of 65-74; 15-20 and 8-16 % for acetic, propionic and butyric acids, respectively (Thomas and Rook, 1981). Lower VFA (82-89 mmol l^{-1}), acetate and acetate: propionate ratio, and higher propionate and butyrate proportions than for napier-based diets were reported by Khalili et al., (1993) for dairy cows fed a tropical grass supplemented with concentrates. Van Vuuren et al. (1986) reported an increase in rumen concentration of VFA at high rates of degradation of non-structural CHO's. A high proportion of acetic acid and low proportions of propionic and butyric acids were expected from high-protein forage supplementation (Sutton et al., 1987). However, the expected increase in intake through supplementation could be associated with some reduction in forage digestibility, so the proportions of acetic acid in the ruminal fatty acids would be expected to decrease, at the expense of propionic and butyric acids (Broster et al., 1981; Thomas and Rook, 1981). The decline in digestibility could be due to the expected high passage rate at a high level of feeding. Although there was a decline in acetic acid while the propionic and butyric acids did not change as the CP content of the diet increased, the acetic: propionic atio remained above the required ratio of 4.0:1 below which milk butter-fat is depressed (Stockdale et al., 1987; Stockdale and Trigg, 1989).

Table 2 Rumen fermentation characteristics in steers fed different crude protein contents of napier-based diets

	CP content of napier- based diets (g kg^{-1} DM)									
	140 - 160		110 - 130		80 -100		50 - 70			
Parameters	Mean	N	Mean	N	Mean	N	Mean	N	Overall mean	SED
Supplement (% TDMI)	50	6	25	6	10	6	0	6	-	-
Rumen measurements:										
pH	6.6 [a]	6	6.8 [a]	6	6.8 [a]	6	6.6 [a]	6	6.7	0.51
NH_3-N (mg l^{-1})	238.8 [a]	6	213.0 [b]	6	155.7 [c]	6	128.2 [d]	6	183.9	4.09
VFA (mmol l^{-1})	111.7 [a]	3	89.6 [b]	4	88.6 [b]	4	85.0 [b]	3	93.0	1.56
Molar percentage:										
Acetate (A)	67.1 [b]	3	69.6 [ab]	4	69.5 [ab]	4	70.5 [a]	3	69.2	1.07
Propionate (P)	17.2 [a]	3	16.2 [a]	4	16.2 [a]	4	15.8 [a]	3	16.3	0.71
Butyrate	10.1 [a]	3	10.9 [a]	4	10.5 [a]	3	10.7 [a]	3	10.6	0.60
A: P ratio	4.1 [b]	3	4.4 [a]	4	4.5 [a]	4	4.6 [a]	3	4.4	1.63

TDMI, total dry matter intake; VFA, volatile fatty acids; NH_3-N, ammonia N concentration; other abbreviations as Table 1. Supplements-*Leucaena leucocephala*, *Desmodium intortum* and Sweet potato vines (*Ipomoea batatas*)Source: Muinga et al., 1995; Abdulrazak et al., 1996 and Kariuki, 1998.

Rumen microbial protein synthesis

The rumen degradation characteristics of napier, oil meals and legumes (Table 3) were obtained from the equations:- $P = S + D(1 - e^{-Kdt})$ (Ørskov and McDonald, 1979) and $U = 1000 - (S + D)$ (Robinson et al., 1986), Where P = The fraction of the feed which is degraded at time t (g kg^{-1} DM), S = soluble fraction (g kg^{-1} DM), D = Slowly degradable fraction (g kg^{-1} DM), U = Totally undegradable fraction after 336 hours (g kg^{-1} DM), and Kd = Degradation rate of D fraction per hour.

There were no clear relationships of soluble (S) DM and CP fractions with the other rumen degradability parameters. In contrast to our derived means, soluble CP fractions were inversely related to their potential degradable fractions (Nocek and Grant, 1987; Petit and Tremblay, 1992) and the S fraction of CP in a feed influenced its susceptibility or resistance to rumen degradation (Tamminga, 1979; Aii and Stobbs, 1980; Ørskov, 1982). Furthermore, the cell wall contents (NDF and ADF) were negatively correlated with S fractions of other grasses and legumes (Seone, 1982; Nocek and Grant, 1987; Bosch, 1991). Although a feed CP content may have a high S fraction in the rumen, this does not imply that all the S fractions of the CP are degraded in the rumen (Mahadevan et al., 1980; McDonald et al., 1988). The use of the S fraction as a measure of the D fraction could, therefore, lead to serious errors if applied to feedstuffs with different properties (Satter, 1986). Our derived S, D and Kd fractions of CP and DM of napier and legumes were comparable with those reported for other tropical grasses and legumes by Mgheni et al. (1996). Stockdale (1993 a) reported S, D and Kd fractions of DM and CP content of *Trifolium resupinatum* similar to our derived means for legumes. However, because of possible differences in the detergent fibre contents, our derived degradation parameters of napier were higher than values for tropical grass straws reported by Chermiti et al. (1996). The derived

means of U fraction of CP of oil meals was lower than that reported for oil meals by Satter (1986), but value reported for coastal Bermuda grass was similar to the derived mean for napier. In a report by Castrillo et al. (1992), the S fraction was higher, the D fraction similar and the Kd value lower for oil meals compared with our derived value.

The Kd value of a forage is slower in the rumen of animals fed mainly on concentrates than in animals whose cellulose digestion is very active (Deb Hovel et al., 1986; Van Straalen and Tamminga, 1990). The small particle size of ground oil meals are expected to have a high passage rate (Kp) through the rumen than the large particles of napier and legumes (Poppi et al., 1980; ARC, 1984; Owen and Goetch, 1986; Tamminga et al., 1994). The higher Kp value of oil meals could, therefore, be the reason why its D fraction was similar to those of napier and legumes although its Kd value was higher than for the other two feeds.

There is no clear relationship between the D and the U fractions, and between U and CP of the three classes of feeds because of their different properties. A negative correlation between D and U fractions of grass silage was reported by Bosch (1991), but Van Vuuren (1993) found that the proportion of U fraction was significantly influenced by the CP of *Lolium perenne* grass possibly because they were dealing with forages at different maturity. The derived mean value of U fraction of CP for oil meals (15.4 %) was lower than the range of 20-40 % reported by Hagemeister et al. (1981) but those of napier grass (22.3 %) and legumes (25.0 %) were within the range.

The parameters related to efficiency of microbial protein synthesis were calculated (Table 4) on the following assumptions:-

Table 3. The mean DM and CP degradation characteristics of napier grass, oil meals and legumes in the rumen of steers

	DM degradation							CP degradation						
	Napier		Oil meals		Legumes			Napier		Oil meals		Legumes		
	Mean	N	Mean	N	Mean	N	SED	Mean	N	Mean	N	Mean	N	SED
General information:														
Crude protein (g kg^{-1} DM)	82.4 ^{c}	22	349.3 ^{a}	4	208.0 ^{b}	8	5.66	82.4 ^{c}	22	349.3 ^{a}	4	208.0 ^{b}	8	5.66
Organic matter (g kg^{-1} DM)	796.2 ^{c}	22	925.8 ^{a}	4	871.4 ^{b}	7	5.54	796.2 ^{c}	22	925.8 ^{a}	4	871.4 ^{b}	7	5.54
Rumen degradation parameters (g kg^{-1} DM):														
Soluble fraction (S)	200.4 ^{a}	18	238.2 ^{a}	6	273.7 ^{a}	7	0.87	289.8 ^{b}	6	457.0 ^{a}	6	282.6 ^{b}	8	1.01
Degradable fraction (D)	555.1 ^{a}	18	485.8 ^{a}	6	508.7 ^{a}	7	0.55	519.7 ^{a}	6	458.7 ^{a}	6	488.3 ^{a}	8	0.37
Degradation constant (Kd)	0.03 ^{b}	22	0.27 ^{a}	6	0.05 ^{b}	7	1.35	0.03 ^{b}	6	0.12 ^{a}	6	0.04 ^{b}	8	1.53
Undegradable fraction (U)	230.0 ^{b}	18	344.8 ^{a}	6	250.3 ^{ab}	7	1.02	222.5 ^{a}	6	154.2 ^{a}	6	249.8 ^{a}	8	0.60

Other abbreviations as Tables 1 and 2.
Source: Van Eys et al., 1986; Kariuki, 1989; Abate and Kiflewahid, 1992; Kiura, 1992; Muinga et al., 1995; Mukisira et al., 1995; Mgheni et al., 1996; Kaitho, 1997; Kariuki, 1998.

ED = S + (D(Kd / Kd+Kp)) (Ørskov and McDonald, 1979), where ED = Effective degradation (g kg^{-1} DM), and the fractional outflow rates (Kp) were 0.04, 0.03 and 0.02 per hour for oil seed meals, legumes and napier, respectively. FOM or FCP = [(Kd /Kd+Kp x D) + S] x OM or CP content (Van Vuuren et al., 1991), where FOM or FCP = Fermentable OM or CP, and D fraction of OM was the same as that of DM. FCHO = FOM - FCP - crude fat (Van Vuuren et al., 1991), where FOM = Rumen fermentable OM (g kg^{-1} DM), FCHO = Rumen fermentable carbohydrate (CHO) (g kg^{-1} DM), FCP = Rumen fermentable CP (g kg^{-1} DM), and crude fat was 18 g kg^{-1} DM (Snijders et al., 1992). RMPCHO = FCHO x 0.15 (ARC, 1984; Tamminga et al., 1994), where rumen microbial synthesis was 150 g kg^{-1} FCHO (ARC, 1984; McDonald et al., 1988; Tamminga et al., 1994). RMPCP = FCP x 0.075 (Van Vuuren et al., 1991), where FCP will yield half (75 g) the microbial protein produced from a similar quantity of FCHO (ARC, 1984; McDonald et al., 1988; Tamminga et al., 1994). TRMP = RMPCHO + RMPCP, where RMPCHO = Rumen microbial protein synthesis from FCHO (g kg^{-1} DM), RMPCP = Rumen microbial protein synthesis from FCP (g kg^{-1} DM), and TRMP = Total rumen microbial protein synthesis (g kg^{-1} DM).

The different Kp values did not significantly ($P > 0.01$) influence the rumen microbial protein (RMP) synthesis parameters probably due to the limited data. However as the Kp increased, RMP synthesis tended to decrease as observed for other tropical grasses and legumes by Mgheni et al., (1996). The Kp value is influenced mainly by the particle size, structure of the feed and feeding level (Ørskov, 1982). The rate at which feeds are hydrolysed controls the extent of digestion before they pass out of the rumen (Tamminga, 1979; Leng and Nolan, 1984). Therefore, the high value of Kd for oil meals and to a lesser extent the legumes could also have resulted in their high ED. The three feeds had at least 420 g kg^{-1} DM digested in the rumen, which indicates that the rumen environment was optimal for utilization of the feeds (Leng, 1990) and that the quality of these feeds was good and suitable for ruminant production (Preston,

1986). The derived mean value of ED of CP of oil meals at the lowest Kp value was within the reported range of 600 to 900 g kg^{-1} DM (Tamminga, 1979; Leng and Nolan, 1984).

However, the derived mean value of ED of napier and the legumes were below this range, indicating that relatively high proportion of these feeds escaped rumen fermentation. The low ED of napier could be attributed to resistance to degradation by rumen microbes at advanced stage of maturity. High detergent fibres and lignin and low CP contents also negatively affect the degradation of forages (Tamminga and Van Vuuren, 1988; Reid et al., 1988; Bosch, 1991). The derived mean values of ED were comparable to those reported for other tropical grasses and legumes (Mgheni et al., 1996). Table 4 indicates that oil meals supplied excess N in relation to energy whereas the energy and N content of napier were almost balanced. The legumes supplied more N relative to energy but some of the N was not available in the rumen. The shortage of energy in relation to N led to N fermentation and the high levels of FCP for oil meals and, to a lesser extent, the legumes. Due to the high levels of FCP, the FCHO and RMPCHO of oil meals were reduced to the level of napier. However, the TRMP was high and similar for both legumes and oil seeds while that of napier was slightly lower. The low OM and CP, and the low ED of napier, may be the reason why the grass supported low rumen microbial yields compared with the other classes of feeds.

The quantity of TRMP depends on the amount of N released in the rumen and the quantity of energy available for RMP synthesis (ARC, 1984). Low synthesis of RMP is generally found with forages or feeds containing less than 100 g CP kg^{-1} DM, possibly because there are insufficient amino acids and NH_3-N to match the energy available to rumen microbes (Minson, 1990). The FCP: FCHO ratios between 0.15 and 0.18 or 24 and 30 g N kg^{-1} FCHO are required for optimal RMP synthesis (ARC, 1984; Preston and Leng, 1987; McDonald et al., 1988; Tamminga at al., 1994; Chenost and Kayouli, 1997). The efficiency of RMP synthesis indicates that oil seeds

Table 4. Estimation of rumen microbial protein synthesis and intestinal protein digestion in ruminants at different outflow rates of napier grass, oil meals and legumes.

	Napier grass						Oil meals						Legumes						
	Kp= 0.04		Kp = 0.03		Kp = 0.02		Kp= 0.04		Kp = 0.03		Kp = 0.02		Kp= 0.04		Kp = 0.03		Kp = 0.02		
Parameters	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	SED
Rumen microbial CP synthesis (g kg^{-1} DM):																			
Effective degradation	416.2^{c}	22	428.3^{bc}	18	484.1^{abc}	18	587.7^{a}	6	619.4^{a}	5	633.2^{a}	6	559.0^{ab}	7	570.4^{ab}	7	616.3^{a}	7	1.43
Fermentable OM (FOM)	319.6^{d}	18	340.8^{d}	18	381.1^{cd}	18	553.2^{ab}	6	625.7^{a}	6	626.0^{a}	6	463.6^{bc}	7	496.0^{b}	7	535.9^{ab}	7	2.50
Fermentable CP (FCP)	50.2^{c}	6	53.7^{c}	6	58.3^{c}	6	276.0^{a}	6	288.7^{a}	6	297.7^{a}	6	114.4^{bc}	8	121.6^{c}	8	131.1^{b}	8	3.20
Fermentable CHO	284.3^{b}	6	314.7^{ab}	6	327.7^{ab}	6	260.0^{b}	4	274.8^{b}	4	308.3^{ab}	4	368.7^{ab}	7	385.4^{ab}	7	424.6^{a}	7	1.28
Synthesis from FCHO (RMPCHO)	42.7^{b}	6	47.2^{ab}	6	49.2^{ab}	6	38.8^{b}	4	41.2^{b}	4	46.2^{ab}	4	55.3^{ab}	7	57.8^{ab}	7	63.6^{a}	7	1.29
Synthesis from FCP (RMPCP)	3.8^{b}	6	4.0^{b}	6	4.4^{b}	6	21.1^{a}	4	21.8^{a}	4	22.5^{a}	4	7.4^{b}	7	8.4^{b}	7	8.3^{b}	7	3.39
Total synthesis (TRMP)	46.0^{b}	6	50.8^{ab}	6	53.0^{ab}	6	59.5^{ab}	4	63.0^{ab}	4	68.7^{a}	4	62.7^{ab}	7	66.2^{ab}	7	72.0^{a}	7	1.15
FCP: FCHO ratio	0.159^{b}	6	0.152^{b}	6	0.163^{b}	6	1.104^{a}	4	1.068^{a}	4	0.978^{a}	4	0.269^{b}	7	0.288^{b}	7	0.260^{b}	7	5.70
g N/kg FCHO	25.5^{b}	6	24.4^{b}	6	26.1^{b}	6	176.6^{a}	4	170.9^{a}	4	156.6^{a}	4	43.1^{b}	7	46.1^{b}	7	41.6^{b}	7	5.66
RMPCHO: TRMP ratio	0.927^{b}	6	0.929^{a}	6	0.925^{b}	6	0.647^{d}	4	0.653^{d}	4	0.672^{d}	4	0.882^{c}	7	0.875^{c}	7	0.885^{abc}	7	5.70
CP digestion in intestines (g kg^{-1} DM):																			
TRMP digested (TRMPI)	39.1^{b}	6	43.1^{ab}	6	45.1^{ab}	6	50.9^{ab}	4	53.5^{ab}	4	58.4^{a}	4	53.3^{ab}	8	56.3^{ab}	7	61.2^{a}	7	1.15
Digested BP (BPDI)	30.8^{ab}	6	23.1^{b}	6	22.5^{b}	6	35.6^{ab}	4	28.8^{ab}	4	20.9^{b}	4	49.1^{a}	8	42.1^{ab}	8	32.8^{ab}	8	1.21
Total CP digested (TPDI)	69.9^{a}	6	66.2^{a}	6	67.6^{a}	6	86.5^{a}	4	82.3^{a}	4	79.3^{a}	4	95.7^{a}	8	91.4^{a}	8	86.4^{a}	8	0.68
TRMPI: TPDI ratio	0.576^{ab}	6	0.676^{ab}	6	0.660^{ab}	6	0.595^{ab}	4	0.633^{ab}	4	0.737^{a}	4	1.524^{b}	7	0.576^{ab}	7	0.654^{ab}	7	1.16

BP, by-pass protein; CHO, carbohydrate; Kp, rumen outflow rate h^{-1}; napier grass (Var. French cameroon and Bana); oil meals (lupin, sunflower cake, sunflower and soyabean meals, and cotton seed cake); legumes (*Medicago sativa, Ipomoea batatas, Desmodium, Calliandra, Leucaena, Gliricidia* and *Sesbania* species); other abbreviations as Tables 1 and 2; Source:Van Eys et al. 1986; Kariuki, 1989; Abate and Kiflewahid, 1992; Kiura, 1992; Muinga, et al. 1995; Mukisira, et al. 1995; Mgheni, et al. 1996; Kaitho, 1997; Kariuki, 1998.

were used more efficiently and napier was least efficient in terms of the amount of microbial N synthesised per unit of FCHO in the rumen. The FCP: FCHO ratio and the g N kg^{-1} FCHO of napier could reliably (R^2 = 0.68) be estimated from the amount of rumen FCP whereas for the legumes, the same parameters could be estimated (R^2 = 0.60) using the S fraction of CP (Table 6). For the oil meals the same parameters could reliably (R^2 = 0.94) be predicted using D fraction of the CP.

Napier with less than 100 g CP kg^{-1} DM will require N and probably an energy source, which are readily degradable in the rumen for optimal RMP yield. An oil meal could serve as a good supplement to poor quality napier. Urea could also provide the required NH_3-N concentration in the rumen but molasses should also be added to allow utilisation of the released NH_3-N. Osuji et al. (1995) indicated that some protein feeds could also be a source of energy which is an added advantage because FCP when energy is insufficient in the rumen result in inefficient RMP synthesis (ARC, 1984; Van Vuuren, 1993; Tamminga et al., 1994).

Protein digestion in small intestines

The amount of protein digested in the small intestines (SI) for the three classes of feeds was estimated (Table 4) using the following assumptions:-

TRMPI = TRMP x 0.85 (ARC, 1984; McDonald et al., 1988; Tamminga et al., 1994)), where TRMPI = The amount of TRMP digested in the SI is 850 g kg^{-1} DM.

BPDI = [(Kp /Kd + Kp) x D] x CP content (Van Vuuren et al., 1991), where the U fraction was also indigestible in the SI, and BPDI = By-pass protein digested in the SI (g kg^{-1} DM) .

TPDI = TRMPI + BPDI, where TPDI = Total protein digested in the SI (g kg^{-1} DM).

The different Kp values did not significantly ($P > 0.01$) affect protein digestion in the SI. When expressed as a percentage of the U fraction the BPDI was 14, 23, and 20 for napier, oil meals and legumes, respectively. However, the TPDI was not significantly different for napier, oil meals and legumes ($P > 0.01$). The derived mean values of TRMPI ranged from 60 to 90 % of TPDI with a mean of 74 %, which was similar to 70 % reported by Satter (1986). The high percentage of RMPI in relation to the TPDI indicates that ruminants fed these feeds will derive most of their protein requirements from the RMP. The BPDI ($R^2 = 0.92$) and TPDI ($R^2 = 0.98$) of napier could reliably be estimated from the CP and Kd value of CP, respectively (Table 6). For oil meals the TRMPI ($R^2 = 0.98$) and BPDI ($R^2 = 0.94$) could be predicted better using the FOM and Kd value of CP respectively. The FCP and CP of legumes were the best predictors of BPDI ($R^2 = 0.68$) and TPDI ($R^2 = 0.81$) respectively.

For ruminant animals, the quantity of RMP plus U fraction of dietary protein arriving at the duodenum has a great influence on productivity (Mackie and Morrison, 1995). For high production by ruminants, a high BPDI value will be required and this can be provided by supplementation with a legume or a concentrate source with rumen by-pass protein qualities. A by-pass protein should only be used as a supplement if the basal diet provides adequate NH_3-N and energy for optimal RMP synthesis (Preston and Leng, 1987). Although the differences were not significant (probably due limited data), the derived mean value of TPDI was slightly lower for napier than for the other classes of feeds. This was possibly because of low RMP production and low ED and BPDI values, due to high cell wall passage inducing a high ileal endogenous protein loss (Van Bruchem et al., 1991).

Feed intake, live-weight change and milk yield by dairy cows

A comparison of feed intake, live-weight changes, milk yield and efficiency of milk production when dairy cows were fed a basal diet of napier supplemented with graded levels of either a concentrate or *Leucaena leucocephala* is in Table 5. For the cows given the concentrate, the protein sources were cotton and sunflower seed cakes, sunflower meal, lupin seeds, copra cake and fish meal while the energy sources were cassava meal, maize bran, maize grain and wheat bran. In some experiments the locally purchased concentrate was used.

The derived mean value of TDMI, when expressed per unit metabolic weight of the animal, increased as the level of supplementation increased although the differences were not significant ($P > 0.01$). At low levels of supplementation (0 to 15% of TDMI), both types of supplements acted as 'catalysts' in that they increased napier dry matter intake (NDMI). However, beyond the 30 % level there was a decline in NDMI due to substitution by the supplements, as reported by Broster et al., (1981), ARC (1984), Bines (1985), Dixon (1986), Preston and Leng (1987), NRC (1988), Badamana (1990), and Combellas et al. (1993). A negative substitution rate can occur when the basal diet has a low CP and the supplement alleviates this deficiency, leading to an increase in feed intake (Forbes, 1986). The lower TDMI when animals were supplemented with *Leucaena* than with concentrates may be due to the differences in the quality of the diet offered or due to breed differences among the two groups. Due to the bulkiness of legumes the negative influence on DMI of the basal diet is expected to be more than that of concentrates (Topps, 1995). Concentrates have a higher Kp value than roughage, which positively influences the DMI of the basal diet (Ørskov et al., 1981; Combellas et al., 1993). However, at high levels of concentrate supplementation, the Kd value (Cronje, 1992) and intake (Forbes, 1986) of the forage may be decreased.

The substitution rates depend mainly on quality of forage, level of supplementation and animal related factors (Broster et al., 1981; Hagemeister et al., 1981; ARC, 1984; Bines, 1985; Forbes, 1986; Deb Hovel et al., 1986; Dixon, 1986; Sutton et al., 1987; Van Eys et al., 1987; Grainger, 1990; Khalili, 1993). The rate of substitution of a forage by a concentrate for cows under confinement of 0.6 to 0.7 (Bines, 1985) is higher than mean values of 0.54 we derived for napier-based diets. The optimal concentrate to roughage ratio is about 70:30 for dairy cows (Broster et al., 1981). However, the optimal supplement to roughage ratio using high-protein forages (legumes) is not yet well established but due to rumen fill limitations, it is likely to be lower than for concentrates (Van Straalen and Tamminga, 1990).

From the mean values we derived, the *Leucaena* supplemented group (-0.23 kg cow^{-1} d^{-1}) lost less weight than the group (-0.48 kg cow^{-1} d^{-1}) supplemented with concentrates. This was possibly because of more mobilization of body reserves when lactating cows are supplemented with concentrate than legumes as was reported by Johnson (1977) and Ørskov et al. (1981). The efficiency of milk production per unit of supplement and the milk yield per kg crude protein intake (CPI) were also higher for the concentrate group than for the *Leucaena* group, for the same reasons. The majority of the animals were in the early stages of lactation, when feed intake is insufficient to meet the energy requirements for maintenance and potential milk production (Garnsworthy, 1988; NRC, 1988; Broster et al., 1993). Since milk yields were also supported by mobilisation of body tissue, it was difficult to determine the optimal level of supplementation or optimal level of CPI. Napier-only diets (70 g CP kg^{-1} DM) supported about 6.8 kg of milk per cow per day and this was accompanied by live-weight losses.

The daily milk production levels of between 9.2 and 7.2 kg per cow were obtained from napier-based diets containing a mean CP content of about 110-130 g kg^{-1} DM for concentrate and *Leucaena* supplemented groups respectively (Table 5). These milk yields were below the expected values from 10 to 15 kg cow^{-1} d^{-1} from such levels of CP content and the high genetic

potential of the animals (ARC, 1984; Waldo and Glenn, 1984). Higher NDMI (12.6 kg d^{-1}) and daily milk yield (12.1 kg cow^{-1}) than our derived values were reported by Abate and Abate (1991) when dairy cows were fed diets based on napier/*Pennisetum clandestinum* mixture. A CP content of about 150 g kg^{-1} DM should be adequate for a cow of high milk production (> 15 kg cow^{-1} d^{-1}) provided that a readily fermentable source of N is available to meet the needs of microorganisms in the rumen. Also, adequate amounts of amino acids and in the correct proportions should be supplied to meet the requirements of the cow (Broster et al., 1981; Crowder and Chheda, 1982). Stockdale and Trigg (1989) also observed a weight loss for dairy cows in their early lactation even when a supplement high in energy was offered, as the milk yields were high giving a negative energy balance. The milk yield on a maize enriched diet was significantly higher than on a beet pulp-enriched diet partly due to a high intake of energy (Valk et al., 1990).

The high milk yield response expected from a protein source with the ability to by-pass rumen fermentation such as *Leucaena* supplementation (Aii and Stobbs, 1980; Muinga et al., 1995; Abdulrazak et al., 1996) was not observed from the derived mean values for napier supplemented with the legumes. Improvements in DMI were achieved by feeding a by-pass protein source digestible in the small intestines (Preston and Leng, 1987). The inability of *Leucaena* to express the advantages associated with supplements that can escape rumen fermentation was also reported by Van Eys et al., (1986). One of the limitations seems to be insufficient energy since the concentrates supported higher milk yields at the same level of N. When maize bran (energy source) was added to *Leucaena* supplemented dairy cows, there was a positive and higher response in milk yield than the cows fed *Leucaena* as the sole supplement (Muinga et al., 1995). The napier-based diets fed to dairy cows by Mukisira et al, (1995) were balanced for both energy and N and the milk yield response was better than in experiments where energy and N contents of the napier-based diets were low. For the concentrate

Table 5. The mean parity, stage of lactation, live-weight, feed intake and milk yield by dairy cows fed diets at different crude protein content of napier grass supplemented with either concentrates (A) or *Leucaena leucocephala* (B)

	Diet crude protein content (g kg^{-1} DM)																	
	140 - 160				110 - 130				80 - 100				50 - 70					
	A		B		A		B		A		B		A		B			
Parameters	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	Mean	No	OM	SED
Supplement (% TDMI)	60	9	-	-	30	5	30	4	15	4	15	4	0	7	0	4	20	-
Breed	F+C	9	-	-	F+J+C	5	C	4	F+J	4	C+J	4	F	7	C+J	4	-	-
Parity	3	9	-	-	2	5	2	4	2	4	2	4	2	7	2	4	2	-
Lactation stage	3	9	-	-	4	5	3	4	3	4	4	4	2	7	4	4	3.3	-
LWT (kg)	430.7^{a}	9	-	-	408.6^{ab}	5	336.3^{b}	4	357.8^{ab}	4	339.3^{b}	4	429.1^{a}	7	358.5^{ab}	4	391.6	1.22
NDMI (kg d^{-1})	4.74^{b}	9	-	-	7.20^{ab}	6	7.00^{ab}	4	8.23^{ab}	4	7.10^{ab}	4	10.19^{a}	8	6.85^{ab}	4	7.3	1.38
TDMI (kg d^{-1})	12.3^{a}	9	-	-	10.73^{ab}	6	9.35^{ab}	4	9.28^{ab}	4	8.25^{ab}	4	10.19^{ab}	8	6.85^{b}	4	10.0	1.03
TDMI (g kg^{-1} $W^{0.75}$)	130.22^{a}	9	-	-	120.80^{a}	6	105.50^{a}	4	113.00^{a}	4	99.25^{a}	4	115.00^{a}	7	83.25^{a}	4	113.1	0.83
Milk yield (kg d^{-1})	12.38^{a}	9	-	-	9.23^{ab}	6	7.15^{b}	4	8.58^{ab}	4	6.50^{b}	4	7.62^{b}	9	6.05^{b}	4	8.7	1.36
Milk yield (kg kg^{-1} S)	0.53^{a}	9	-	-	0.72^{a}	6	0.33^{a}	4	0.88^{a}	4	0.30^{a}	4	-	8	-	4	0.6	0.63
Milk yield (kg kg^{-1} CPI)	6.53^{b}	9	-	-	7.88^{b}	5	6.78^{b}	4	9.76^{ab}	4	8.38^{b}	4	10.52^{ab}	8	13.76^{a}	4	8.9	1.36
SR (kg N kg^{-1} S)	0.54^{a}	9	-	-	0.27^{ab}	6	-0.02^{b}	4	-0.12^{b}	4	-0.22^{b}	4	-	5	-	4	0.2	1.38
LWC (kg $cow^{-1}d^{-1}$)	0.08^{a}	9	-	-	-0.10^{a}	6	0.15^{a}	4	0.02^{a}	4	0.01^{a}	4	-0.48^{a}	5	-0.39^{a}	4	-0.1	0.88

F, Friesian; J, Jersey; C, Ayrshire/Brown swiss x Sahiwal cross; LWT, live-weight; NDMI, napier dry matter intake; LWC, live-weight change, N, Napier grass; S, supplement; CPI, crude protein intake of diet; SR, substitution rate; $W^{0.75}$, metabolic weight; OM, overall mean; other abbreviations as tables 1, and 2.

Source: Irungu and Mbugua, 1978; Muhuyi et al., 1980; Combellas and Martinez, 1982; Mukisira and Kiruiro, 1982; Wouters and Dohmen, 1985; Anindo and Potter, 1986; Muia et al., 1991; Muinga et al., 1992; Muinga et al., 1993; Muinga et al., 1995; Mukisira et al., 1995.

Table 6. Best-fit regression equation for prediction of yield, *in vitro* organic matter digestibility and rumen fermentation of napier grass, rumen and intestinal digestion of napier grass, oil meals and legumes, and milk yield by supplemented dairy cows

Dependent variable	Regression equation	R^2	RSD	N
Napier grass yield (tons ha^{-1} yr^{-1}):				
	DMY =-10.46 + 2.61 AGE + 0.08 DM	0.92	0.05	25
	CPY = - 1.52 + 0.04 CP	0.79	0.62	25
Napier digestibility (g kg^{-1} DM):				
	OMD = 548.54 + 1.61 CP	0.88	20.57	25
Rumen fermentation:				
	A: P = 8.80 - 0.27 P	0.81	0.09	9
	VFA =78.09 + 0.11 CP	0.79	0.98	9
	NH_3 = 3.75 + 1.76 CP	0.64	24.16	9
	pH = 9.18 - 0.15 P	0.48	0.11	9
Napier rumen degradation (g kg^{-1} DM):				
	FCP: FCHO = 0.07 + 0.002 FCP	0.68	0.03	6
	g N kg^{-1} FCHO = 10.46 + 0.30 FCP	0.67	5.07	6
Napier intestinal digestion (g kg^{-1} DM)				
	BPDI = 61.69 - 0.14 CP	0.92	4.49	6
	TPDI = 107.14 - 365.33 KdCP	0.98	2.33	6
Milk yield (kg $cow^{-1}d^{-1}$):				
Napier + concentrate	MY = 0.98 + 0.87 TDMI	0.67	1.72	17
Napier + *Leucaena*	MY = 0.18 + 0.77 TDMI	0.85	0.68	5
Oil meals rumen degradation (g kg^{-1} DM):				
	FCP: FCHO = 2.56 - 0.003 DCP	0.94	0.06	4
	g N kg^{-1} FCHO = 408.33 - 0.55 DCP	0.94	9.61	4
Oil meals intestinal digestion (g kg^{-1} DM):				
	TRMPI = - 1.71 + 0.09 FOM	0.98	1.86	4
	BPDI = 62.65 - 197.21 KdCP	0.94	3.68	4
Legumes rumen degradation (g kg^{-1} DM):				
	FCP: FCHO = 0.01 + 0.001 SCP	0.60	0.05	7
	g N kg^{-1} FCHO = 1.49 + 0.19 SCP	0.59	7.47	7
Legumes intestinal digestion (g kg^{-1} DM):				
	BPDI = 20.17+ 0.25 FCP	0.68	10.09	7
	TPDI = 12.26 +0.44 CP	0.81	13.03	7

R^2, variation in dependent variable accounted for by the dependent variable (S); RSD, residues standard deviation; MY, milk yield (kg cow^{-1} d^{-1}); DCP, rumen degradable CP; KdCP, degradation rate of CP; SCP, rumen soluble CP. Regression equations significant at $P < 0.05$; other abbreviation as Tables 1, and 2.

supplemented cows the milk yield was also low in relation to the N content of the diet, probably due to the inability of its protein to by-pass rumen fermentation. Another reason may be deficiencies in amino acids essential for milk synthesis by the dairy cows. Amino acids likely to limit milk production are lysine and methionine (Satter, 1986). Nutrient imbalances have been reported to be the main cause of low productivity of livestock in the tropics and sub-tropics (Preston and Leng, 1987) as these could lead to inefficient utilization of the nutrients (Leng, 1990 and 1993). Mineral deficiencies could not have been a serious problem since these nutrients were offered in all the experiments. The milk yield could be estimated from TDMI of the diets for the concentrate (R^2 = 0.67) and *Leucaena* (R^2 = 0.85) supplemented cows. In a report by Stockdale (1993 b), milk yield at different stages of lactation of dairy cows fed irrigated Persian clover (*Trifolium resupinatum*) could be predicted from the DMI (R^2 = 0.78-0.82).

Areas for further research

The use of DM yield and CP content to determine the maturity at which napier should be fed to dairy cows needs to be replaced with parameters related to ruminant production such as yield of digestible nutrients and the degradable protein: fermentable organic matter ratio. When *in vitro* digestibility has to be used as a measure of nutritive value, the calculations should be standardised using *in vivo* digestibility of similar forages. More information is required on OM and CP degradation, and intestinal digestion of the grass to replace the use of CP and digestible CP as a measure of nutritive value. There should be specific recommendations for the maturity of the grass for the high and medium rainfall areas. More work on milk production from napier-

based diets should establish the technical and economic optimal levels of supplementation. The levels of supplementation at which the grass is substituted by either concentrate or legumes need more attention. Studies should be conducted on utilization by dairy cows of napier with readily available and inexpensive supplements such as poultry waste, urea and molasses. Hay could be made from young napier in the wet seasons, and use of overgrown napier should be tried as a dry season feed. To minimise the cost of experimentation, models need to be developed from the generated data set for prediction of nutrient yields, nutritive value, digestion, feed intake and milk yield by dairy cows.

Conclusions

Information on yield, chemical composition and *in vitro* digestibility alone is insufficient to predict animal performance. Napier-based diets supported rumen pH and NH_3-N concentration at optimal levels for rumen microbial growth, activity and feed intake. The napier and legumes were less efficient in microbial protein synthesis and had less amount of total protein digested in intestines than the oil meals. The grass was substituted above the 30 % level of supplementation with either concentrates or legumes. Napier-only diets supported daily yield of about 6.8 kg of milk per cow which was accompanied by live-weight losses. The mean daily milk yields of the concentrate supplemented cows was about 28 % higher than that of *Leucaena* supplemented cows, but the latter lost less weight. Further research with readily available and inexpensive supplements to make dairy production from napier-based diets profitable.

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References

AAC, 1990. Feeding Standards for Australian Livestock. Australian Agricultural Council. Ruminant sub-committee CSIRO. Eastern Melbourne, Australia.

Abate, A. and Abate, A.N., 1991. Wet season nutrient supply to lactating grade animals managed under different production systems. East African Agriculture and Forestry Journal, 57:33-39.

Abate, A., Kayongo-male, H., Abate, A.N. and Wachira, J.D., 1984. Chemical composition, digestibility, and intake of Kenyan feedstuffs by ruminant. A review. Nutritional Abstracts and Reviews, (Series B). Commonwealth Agricultural Bureaux, 54:1-13.

Abate, A. and Kiflewahid, B., 1992. Use of the nylon-bag technique in determining the complementarity of feedstuffs for dairy cattle rations. In: Stares J.E.S., Said A.W. and Katengile J.A. (Eds.), The Complementarity of Feed Resources for Animal Production in Africa. Proceedings of the Joint Feed Resource Network Workshop, 1991. Gaborone, Botswana. pp 225-231

Abdulrazak, S.A., Muinga, R.W., Thorpe, W. and Ørskov, E.R., 1996. The effects of supplementation with *Gliricidia sepium* or *Leucaena leucocephala* forage on intake, digestion and live-weight gains of *Bos Taurus* x *Bos Indicus* steers offered Napier grass. Animal Science, 63: 381-388.

Aii, T. and Stobbs, T.H., 1980. Solubility of the protein of tropical pastures and the rate of its digestion in the rumen. Animal Feed Science and Technology, 5: 183-192.

Anindo, D.O. and Potter, H, L., 1986. Milk production from napier grass (*Pennisetum purpureum*) in zero-grazing feeding systems. East African Agriculture and Forestry Journal, 52: 106-111.

Anindo, D.O. and Potter, H.L., 1994. Variation in productivity and nutritive value of napier grass at Muguga, Kenya. East African Agriculture and Forestry Journal, 59: 117-185.

ARC, 1984. The nutrient requirements of ruminant livestock (Suppl. No. 1). Agricultural Research Council. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

Badamana, M.S., 1990. The effect of level of protein in the concentrates on performance of dairy goat. Proceedings of the Small Ruminant Collaborative Research Support Programme Scientific Workshop, ILRAD, Nairobi, Kenya. pp 232-234.

Bines, J.A., 1985. Feeding and food intake by housed dairy cows. Proceedings of Nutritional Society, 44: 355-362.

Boniface, A.N, Murray, R.M. and Hogan, J.P., 1986. Optimum level of ammonia in the rumen liquor of cattle fed tropical pasture hay. Proceedings of Australian Society of Animal Production 16: 151-154.

Boonman, J.G., 1993. East African's grasses and fodders: their ecology and husbandry. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Boonman, J.G., 1997. Farmers success with tropical grasses: crop-pasture rotation in mixed farming in East Africa. Ministry of Foreign Affairs. The Netherlands.

Bosch, M. W., 1991. Influence of stage of maturity of grass silage on digestion processes in dairy cows. PhD thesis, Wageningen Agricultural University, The Netherlands.

Broster, W.H., Broster, V.J. and Clements, A.J., 1993. Feed utilization by the dairy cows over multiple lactations. A review. Livestock Production Science, 34: 1-21

Broster, W.H., Sutton, J.D. and Bines, J. A., 1981. Concentrate: forage ratios for high yielding dairy cows. In: Haresign W. and Cole D.J.A. (Eds.), Recent Development in Ruminant Nutrition. Butterworth, London. pp 325-352.

Brown, D.L. and Chavulimu, E., 1985. Effect of ensiling or drying of fibre forage species in Western Kenya. *Zea mays* (Maize stover), *Pennisetum purpureum* (Pakistan grass), *Pennisetum* species (Bana grass), *Ipomea batatas* (sweet potato vines) and *Cajanus cajan* (Pigeon pea leaves). Animal Feed Science and Technology, 13: 1-6

Butterworth, M. H., 1965. Some aspects of the utilization of tropical grasses. I. Green elephant grass at various stages of growth. Journal of Agricultural Science (Camb.), 65: 233-239.

Butterworth, M. H., 1967. The digestibility of tropical grasses. Nutritional Abstracts and Reviews, 37: 349-368.

Castrillo, C., Lainez, M., Gasa, J. and Guada, J.A., 1992. The effect of increasing the proportion of barley straw in pelleted concentrate diets given to lambs on rumen outflow rate and degradation of protein supplements. Animal Production, 54: 59-66.

Chenost, M. and Kayouli, C., 1997. Roughage utilization in warm climates. Animal production and Health paper No. 135, FAO, Rome.

Chermiti, A., Nefzaoui, A., Teller, E., Vanbelle, M., Ferchichi, H. and Rokbani, N., 1996. Prediction of the voluntary intake of the low quality roughages by sheep from chemical composition and rumen degradability characteristics. Animal Science, 62: 57-62.

Cherney, D.J.R., Cherney J.H. and Lucey R.F., 1993. *In vitro* digestion Kinetics and quality of perennial grass as influenced by forage maturity. Journal of Dairy Science, 76: 790- 797.

Combellas J. and Martinez W., 1982. Intake and milk production in cows fed chopped elephant grass (*Pennisetum purpureum*) and concentrate. Tropical Animal Production, 7: 57-60.

Combellas, J., Priore, F., Peratha, J. and Zavarce, O., 1993. Influence of the addition of fish meal to diets of roughage and concentrate on the consumption and live-weight gain of growing cattle. Animal Feed Science and Technology, 42: 319-331.

Cronje, P.B., 1992 Effects of dietary roughage: concentrate ratio and rumen ammonia concentration on *in situ* feedstuff degradation in the rumen of sheep. South African Journal of Animal Science, 22: 207-213.

Crowder, L.V. and Chheda, H.R., 1982. Tropical grassland husbandry. Longman. London, U.K.

Deb Hovel, F.D., Ngambi, J.W.W., Barber, W.P. and Kyle, D.J., 1986. The voluntary intake of hay by sheep in relation to its digestibility in the rumen as measured in nylon bags. Animal Production, 42: 111-118.

Devendra, C., 1975. The intake and digestibility of Napier grass (*Pennisetum purpureum*) at four, five and six weeks of growth by goats and sheep in Trinidad. Turrialba, 25: 226 -231

Dixon, R.M. (Ed.), 1986. Ruminant feeding systems utilising fibrous agricultural residues. IDP AVC. Canberra, A.C.T. pp 59-75.

Forbes, J.M., 1986. The voluntary food intake of farm animals. Butterworth, London, U.K. pp 86-113.

Garnsworthy, P.C. (Ed.), 1988. Lactation and nutrition in the dairy cow. Butterworth, London, U.K. pp 157-170.

Goldson, J.R., 1977. Napier grass in East Africa. A review. Technical report No.24. Pasture Research Project. National Agricultural Research Station, Kitale, Kenya. 126 pp.

Grabber, J.H. and Allison, D.W., 1992. Anatomical structure and digestibility of reed canary grass cultivars and hybrid rye grass. Grass and Forage Science, 47: 400-404.

Grainger, C., 1990. Effect of stage of lactation and feeding level on milk yield response by stall fed dairy cows to change in pasture intake. Australian Journal of Experimental Agriculture, 30: 495-501.

Grant, R. J., Van Soest, P.J., McDowell, P. J. and Perez, C.B., 1974. Intake, digestibility and metabolic loss of napier grass by cattle and buffaloes when fed witted, chopped and whole. Journal of Animal Science, 39: 423 - 434.

Haaland, G.L., Tyrell, H. F., Moe, P.W. and Wheeler, W.E., 1982. Effect of crude protein level and limestone buffer in the diet fed at two levels of intake on rumen pH, ammonia nitrogen, buffering capacity and volatile fatty acid concentration of cattle. Journal of Animal Science, 55: 943 - 950.

Hagemeister, H., Lupping, W. and Kaufmann, W., 1981. Microbial protein synthesis and digestion in the high yielding dairy cows. In: Haresign W. and Cole D.J.A. (Eds.), Recent Developments in Ruminant Nutrition. Butterworth, London, U.K. pp 31-48.

Hamilton, B.A., Ashes, J.R. and Carmichael, A.W., 1992. Effect of formaldehyde-treated sunflower on milk production of grazing dairy cows. Australian Journal of Agricultural Research, 43: 379-387.

Hassan, N. I. and Abdi-Elazi, H.M., 1979. Evaluation of some forages introduced to newly-reclaimed areas in Egypt. World Review of Animal Production, 15: 31 - 35

Hoover, W. H., 1986. Chemical factors involved in ruminal fibre digestion. Journal of Dairy Science, 69: 2755-2766.

Humphreys, L.R., 1991. Tropical pasture utilization. Camb. University press. Great Britain.

Irungu, K.R.G. and Mbugua, P.N., 1978. Milk production from napier grass. Annual Report, National Animal Husbandry Research Centre, Naivasha, Kenya. pp 68-71.

Jarrige, R., 1989. Ruminant nutrition: recommended allowance and feed tables, INRA,John Libbey, London.

Johnson, C.C., 1977. The effect of the plane and pattern of concentrate feeding on milk yield and composition in dairy cows. Journal of Agricultural Science (Camb.), 88: 79-94.

Jung, H.G. and Allen, M.S., 1995. Characteristics of plant cell-wall affecting intake and digestibility of forage ruminants. Journal of Animal Science, 73: 2774 - 2790.

Kaitho, R.J., 1997. Nutritive value of browses as supplements to poor quality roughages. PhD thesis, Wageningen Agricultural University, The Netherlands.

Kaitho, R.J. and Kariuki, J.N., 1990. Nutrient intake by Friesian heifers fed napier grass (*Pennisetum purpureum*). Proceedings of the 2nd Kenya Agricultural Research Institute Scientific Conference. Nairobi, Kenya. pp 111-115.

Karanja, G.M., 1985. Napier grass for dry season use. Proceedings of the Animal Production Society of Kenya, 17: 1-6.

Kariuki, J.N., 1989. Evaluation of two napier grass cultivars (*Pennisetum purpureum*) under irrigation at different stages of regrowth. MSc. Thesis, University of Nairobi, Kenya.

Kariuki, J.N., 1998. The potential of improving napier grass under smallholder dairy farmer's condition in Kenya. PhD thesis, Wageningen Agricultural University, The Netherlands.

Kevelenge, J.E.E., 1992. Nutrient intake, *in vivo* digestibility and performance of wether sheep fed on non traditional fodders in Kenya. East African Agriculture and Forestry Journal, 58: 65-72.

Khalili, H., 1993 Supplementation of grass hay with molasses in crossbred (*Bos taurus x Bos Indicus*) non-lactating cows: effect of level of molasses on feed intake, digestion, rumen fermentation and rumen pool size. Animal Feed Science and Technology, 41: 23-38.

Khalili, H., Varvikko, T. and Osuji, P.O., 1993. Supplementation of grass hay with molasses in crossbred (*Bos taurus x Bos Indicus*) non-lactating cows: effect of timing of molasses supplements on feed intake, digestion, dry matter degradability and rumen fermentation. Animal Feed Science and Technology, 41: 39-50.

Kiura, J.N., 1992. Evaluation of protein digestibility of napier grass (*Pennisetum purpureum*) and green leaf desmodium (*Desmodium intortum*). MSc. thesis Wageningen Agricultural University, The Netherlands.

Leng, R.A., 1990. Factors affecting the utilization of poor quality forages by ruminants particularly under tropical conditions. Nutritional Research Reviews, 3: 277-303.

Leng, R.A., 1993. Quantitative ruminant nutrition - a green science. Australian Journal of Agricultural Research, 44: 363-380.

Leng, R.A. and Nolan, J.V., 1984. Nitrogen metabolism in the rumen. Journal of Dairy Science 67: 1072-1089.

Lindberg, J.E., 1987. Measurement of feed degradability by *in sacco* and other methods. In: Jarrige R. and Alderman G. (Eds,), Feed Evaluation and Protein Requirement Systems for Ruminants. Commission of the European Community, Luxembourg. pp 85-96.

Mackie, R.I. and Morrison, M., 1995. Nitrogen metabolism in the rumen: biotechnological problems and prospects. In: Wallace, R.J. and Lahlou-Kassi, A. (Eds.), Rumen Ecology Research Planning. Proceedings of a Workshop, ILRI, Kenya. pp 25-42.

Mahadevan, S., Erfle, J.D. and Sauer, F.D., 1980. Degradation of soluble and insoluble protein by *bacteroides amylophilus* protease and by rumen micro-organisms. Journal of Animal Science, 50: 723-728

Maher, C., 1936. Elephant grass (*Pennisetum purpureum*) as a cattle fodder in Kenya. East African Agriculture and Forestry Journal, 1: 310-342.

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D., 1988. Animal nutrition. 4th Edition. Longman UK group, Essex. England.

Mgheni, D.M., Hvelplund, T. and Weisbjerg, M.R., 1996. Rumen degradability of dry matter and protein in tropical grasses and legume forages and their value expressed in the AAT-PBV protein evaluation system. In: Ndikumana, J. and Deleeuw, P. (Eds.), Sustainable feed production and utilization for smallholder livestock enterprises in sub-sahara Africa. Proceedings of the 2nd African Feed Resource Network (AFRNET) Workshop, 1993, Harare, Zimbabwe. pp 77-84.

Minson, D.J., 1990. Forage in ruminant nutrition. Academic press, Inc. San Diego.

MoLD, 1991. Zero-grazing: A handbook on technical aspects. Ministry of Livestock Development (MoLD). Nairobi, Kenya.

Mugerwa, J.S. and Ogwang, B.H., 1976. Dry matter production and chemical composition of elephant grass hybrids. East African Agriculture and Forestry Journal, 42: 60-65.

Muhuyi, B.W., Kevelenge, J.E.E., Kiruiro, E.M. and Mukisira, E.A., 1980. Evaluation of two napier fodders by lactating Friesian cows under zero-grazing system. Annual report, National Agricultural Research Station, Kitale, Kenya. pp 82-85.

Muia, J.M.K., Irungu, K.R.G., Kariuki, J.N. and Duyn, S.P.J., 1991. Milk production by Friesian cows fed napier grass (*Pennisetum purpureum)* and supplemented with commercial dairy meal. Technical Report, Kenya Agricultural Research Institute, NAHRC, Naivasha, Kenya. 18 pp.

Muinga, R. W., Thorpe, W. and Topps, J. H., 1992. Voluntary food intake, live-weight change and lactational performance of crossbred dairy cows given ad-libitum *Pennisetum purpureum* (napier grass var. Bana) supplemented with *leucaena* forage in the lowland semi-humid tropics. Animal Production, 55: 331-337.

Muinga, R. W. Thorpe, W. and Topps, J. H., 1993. Lactational performance of Jersey cows given napier grass (*Pennisetum purpureum*) with and without protein concentrates in the semi-humid tropics. Tropical Animal Health and Production 25: 118 - 128.

Muinga, R.W., Thorpe, W. and Topps, J.H., 1995. The effects of supplementation of *leucaena leucocephala* and maize bran on voluntary intake, digestibility, live-weight change and milk yield of *Bos Indicus* X *Bos Taurus* dairy cows and rumen fermentation in steers offered *Pennisetum purpureum ad-libitum* in the semi-humid tropics. Animal Science, 60: 13-23.

Mukisira, E.A., Phillip, L.E. and Mitaru, B.N., 1995. The effect of feeding diets containing intact or partially detoxified lupin on voluntary intake and milk production by Friesian dairy cows. Animal Science, 60: 169-175.

Mukisira, E.A. and Kiruiro, M., 1982. A comparative effect of dry season forage feeding on grazed fodders and ley pastures. Annual Report, National Agricultural Research Station, Kitale, Kenya. pp 62-65.

Nocek, J.E. and Grant, A.L., 1987. Characterisation of *in situ* nitrogen and fibre digestion and bacterial nitrogen contamination of hay crop forages preserved at different dry matter percentages. Journal of Animal Science, 64: 552 - 564.

NRC, 1985. Ruminant nitrogen usage. National Research Council (NRC), Academic press, Washington. D.C.

NRC, 1987. Nutrient requirement of dairy cattle. 6th Edition. National Research Council (NRC), Washington, DC.

Nyangito, M.M., Ngungi, K.R. and Musimba, N.K.R., 1997. Effect of poultry waste and grain sorghum supplements on utilization of forage hay by small East African goats. Proceedings of the 5th Kenya Agricultural Research Institute Scientific Conference, 1996, Nairobi, Kenya. pp 700-710.

Odhiambo, J.F., 1974. The nutritive value of various growth stages of *Pennisetum purpureum.* East African Agriculture and Forestry Journal, 39: 325-329.

Ørskov, E.R., Hughes-Jones, M. and McDonald, I., 1981. Degradability of protein supplements and utilization of undegraded protein by high producing dairy cows. In: Haresign W. and Cole, D.J.A. (Eds.), Recent Development in Ruminant Nutrition. Butterworth, London. pp 17-30.

Ørskov, E.R. and McDonald, I., 1979. The estimation of protein degradability in the rumen from incubation measurements weighed according to rate of passage. Journal of Agricultural Science (Camb.), 92: 499 - 503.

Ørskov, E.R. (Ed.), 1982. Protein nutrition in the ruminants. Academic press, Inc., London.

Ørskov, E.R. and Ryle, M. 1990. Energy nutrition in ruminants. Elsevier Science publishers, London, U.K.

Osuji, P.O., Fernandez-Rivera, S. and Odenyo, A., 1995. Improving fibre utilization and protein supply in animals fed poor quality forages. In: Wallace, J. and Lahlou-Kassi, A. (Eds.), Rumen Ecology and Research Planning. Proceedings of a Workshop at the International Livestock Research Institute, Nairobi, Kenya. pp 1-22.

Owens, F.N. and Goetch, A.L., 1986. Digesta passage and microbial protein synthesis. In: Milligan, L.P., Grovum, W.L. and Dobson, A. (Eds.), Control of Digestion and Metabolism in Ruminants. Proceedings of 6th International Symposium on Ruminant Physiology. Englewoodscliffs, Canada. pp 196-223.

Petit, H.V. and Tremblay, G.F., 1992. *In situ* degradability of fresh grass and grass conserved under different harvesting methods. Journal of Dairy Science, 75: 774 - 781.

Poppi, D.P., Norton, B.W., Minson, D.J. and Handricksen, R.E., 1980. The validity of the critical size theory for particles leaving the rumen. Journal of Agricultural Science (Camb.), 94: 275-280.

Poppi, D.P. and Maclennan, S.R., 1995. Protein and energy utilization by ruminants at pasture. Journal of Animal Science, 73: 278-290.

Potter, H.L. and Anindo, D.O., 1985. Animal performance on napier grass diets. Proceedings of Animal Production Society of Kenya, 17: 7-13.

Preston, T.R., 1986. Better utilization of crop residues and by-products in animal feeding: research guidelines. 2. A practical manual for research workers. Animal production and Health paper No. 50 (2), FAO, Rome.

Preston, T.R. and Leng, R.A., 1987. Matching ruminant production systems with available resource in the tropics and sub-tropics. Penambul Books, Armidale.

Reid, R.C., Jung, G.A. and Thyne, M.V., 1988. Relationship between nutritive quality and fibre components of cool season and warm season forages: A retrospective study. Journal of Animal Science, 66: 1275 - 1291.

Robinson, P.H., Fadel, J.G. and Tamminga, S., 1986. Evaluation of mathematical model to describe neutral detergent residue in terms of its susceptibility to degradation in the rumen. Animal Feed Science and Technology, 15: 249-271.

Russell, J.B., Sniffen, C.J. and Van Soest, P.J., 1983. Effect of carbohydrate limitation on degradation and utilization of casein by mixed rumen bacteria. Journal of Dairy Science, 66: 763 - 775

SAS, 1988. SAS/STAT User's Guide, release 6.03 Edition. Statistical Analysis System Institute, Inc. Carry, NC.

Satter, L.D., 1986. Protein supply from undegraded dietary protein symposium: protein and fibre digestion, passage and utilization in lactating cows. Journal of Dairy Science, 69: 2734-2749.

Satter, L.D. and Slyter, L.L., 1974. Effect of ammonia concentration on rumen microbial protein production *in vitro*. British Journal of Nutrition, 32: 199-208.

Schreuder, R, Snijders, P.J.M., Wouters, A.P. Steg, A. and Kariuki, J.N., 1993. Variation in OM digestibility crude protein content, yield and ash content of napier grass (*Pennisetum purpureum*) and their prediction from chemical and environmental factors. Kenya Agricultaral Research Institute, NAHRC, Naivasha, Kenya. 62 pp.

Seone, J.R., 1982. Relationship between the physico-chemical characteristics of hays and their nutritive value. Journal of Animal Science, 55: 422 - 431

Smith, O.B., 1993. Feed resources for intensive smallholder systems in the tropics. The role of crops residues. In: Baker M.J. (Ed.), Grasslands for Our World. Sir publishing, Wellington, New Zealand. pp 740-747.

Snijders, P.J.M., Kariuki, J.N., Orodho, A.B., Kiura, J.N. and Mogaka, L.M., 1992. Effect of nitrogen fertilization and cutting stage on yield and quality of napier grass (*Pennisetum purpureum*). Kenya Agricultaral Research Institute, NDDP, NAHRC. Naivasha, Kenya . 46 pp.

Stockdale, C.R., 1993 a. The nutritive value of Persian clover (*Trifolium resupinatum*) herbage grown under irrigation in northern Victoria. Australian Journal of Agricultural Research, 44: 1557-1576.

Stockdale, C.R., 1993 b. The productivity of lactating cows fed irrigated Persian clover (*Trifolium resupinatum*). Australian Journal of Agricultural Research, 44: 1591-1608.

Stockdale, C.R., Callaghan, A. and Trigg, T.E.. 1987. Feeding high energy supplements to pasture fed dairy cows. Effect of stage of lactation and level of supplementation. Australian Journal of Agricultural Research, 38: 927 - 940.

Stockdale, C.R. and Trigg, T.E., 1989. Effect of pasture feeding level on response of lactating dairy cows to high energy supplements. Australian Journal of Experimental Agriculture, 29: 605-611.

Sutton, J.D., Bines, J.A., Morant, S.V. Napper, D.J. and Given, D.I., 1987. A comparison of starchy and fibrous concentrates for milk production, hay utilization and energy intake by Friesian cows. Journal of Agricultural Science (Camb.), 109: 375-386.

Tamminga, S., 1979. Protein degradation in the fore-stomachs of ruminants. Journal of Animal Science, 49: 1615 - 1630.

Tamminga, S. and Van Vuuren, A.M., 1988. Formation and utilization of end products of lignocellulose degradation in ruminants. Animal Feed Science and Technology, 21: 141-159.

Tamminga, S., Van Vuuren, A.M., Van der Koelen, C.J., Ketelaar, R.S. and Van der Togt, P.L., 1990. Ruminal behaviour of structural carbohydrates, non-structural carbohydrates and crude protein from concentrate ingredients in dairy cows. Netherlands Journal of Agricultural Science, 38: 513 - 526.

Tamminga, S., Van Straalen, W.M., Subnel, A.P.J., Meijer, R.G.M., Steg, A., Wever, C.J.G. and Blok, M.C., 1994. The Dutch protein evaluation system: the DVE/OEB system. Livestock Production Science, 40: 139-155.

Thomas, P.C and Rook, J.A.F., 1981. Manipulation of rumen fermentation. In: Haresign W. and Cole D.J.A (Eds.), Recent Development in Ruminant Nutrition. Butterworth. London. pp 157-183.

Topps, J. H., 1995. Forage legumes as protein supplements to poor quality diets in the semi-arid tropics. In: Wallace, R.J. and Lahlou-Kassi, A. (Eds.), Rumen Ecology Research Planning. Proceedings of a Workshop at the International Livestock Research Institute, Nairobi, Kenya. pp 183-190.

Valk, H., Klein Poelhuis, and Wentink, H.J., 1990. Effect of fibres and starchy carbohydrate in concentrate as supplements in herbage based diet for high yielding dairy cows. Netherlands Journal of Agricultural Science, 38: 475-486.

Van Bruchem, J., Oosting, S.J., Bongers, D.C. J. M. G., Lammers-Wienhoven, T.S.C.W. and Gurses, C., 1991. Treatment of wheat straw with ammonia: the effect of energy and protein supplements on intestinal available amino acids in sheep. In: Ibrahim, N.M.N., de Jong R., Van Bruchem, J. and Purnomo, A. (Eds.), Livestock and Feed Development in the Tropics. Proceedings of an International Seminar, Brawijaya University, Malang, Indonesia. pp 98-105.

Van der Kamp, A., 1987. Napier grass in Kenya-a review. A nitrogen fertilization trial. Ministry of Agriculture and Livestock Development, NDDP, Naivasha, Kenya. 47 pp.

Van Eys, J. E., Mathius, I.W. Pongsapan, P. and Johnson, W.K., 1986. Foliage of the tree legume *Gliricidia, Leucaena* and *Sesbania* as supplements to napier grass diets for growing goats. Journal of Agricultural Science (Camb.), 107: 227 - 233.

Van Eys, J.E., Pulungan, H., Rangkuti, M. and Johnson, W.C., 1987. Cassava meal as supplement to napier grass diets for growing sheep and goats. Animal Feed Science and Technology, 18: 197 - 207.

Van Straalen, W.M. and Tamminga, S., 1990. Protein degradation of ruminant diets. In: Wiseman, J. and Cole, D.J.A. (Eds.), Feedstuff Evaluation. Butterworth, London. pp 55-72.

Van Soest, P.J., 1967. Development of a comprehensive system of feed analysis and the application to forages. Journal of Animal Science, 26: 119-128.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B books, Corvallis, Oregon, USA.

Van Vuuren, A.M., 1993. Digestion and nitrogen metabolism of grass fed dairy cows. PhD thesis, Wageningen Agricultural University, The Netherlands.

Van Vuuren, A.M., Van der Koelen, C.J. and Vroons-de Bruin, J., 1986. Influence of level and composition of concentrate supplements on rumen fermentation patterns of grazing dairy cows. Netherlands Journal of Agricultural Science, 34: 457-467.

Van Vuuren, A.M., Tamminga, S. and Ketelaar, R.S., 1991. In *sacco* degradation of organic matter and crude protein of fresh grass (*Lolium perenne*) in the rumen of grazing dairy cows. Journal of Agricultural Science (Camb.), 116: 429-436.

Van Vuuren, A.M., Krol-Kramer, F., Van der Lee, R.A. and Corijn, H., 1992. Protein digestion and amino acids in dairy cows fed fresh *Lolium perenne* with different nitrogen contents. Journal of Dairy Science, 75: 2215-2225.

Visser, H. de, 1993. Influence of carbohydrate on feed intake, rumen fermentation and milk performance in high yielding dairy cows. PhD thesis, Wageningen Agricultural University. The Netherlands.

Waldo, D.R., and Glenn, B.P., 1984. Comparison of new protein systems for lactating dairy cows. Journal of Dairy Science, 67: 1115-1133.

Wilson, J.R. and Minson, D.J., 1980. Prospects for improving the digestibility and intake of tropical grasses. Tropical Grasslands, 14: 253-259.

Wilson, J.R. and Hatfield, R.D., 1997. Structural and chemical change of cell-wall types during stem development: consequences of fibre degradation by rumen microflora. Australian Journal of Research, 48: 165-180.

Wouters, A.P., 1985 Uninterrupted growth of napier grass (var. bana) at two levels of N application. Ministry of Livestock Development, NDDP, NAHRC, Nairobi, Kenya. 18 pp.

Wouters, A.P., 1986. The productivity and quality of napier grass (var. bana) during the dry season at three levels of N application. Ministry of Livestock Development, (NDDP/R10/10), NAHRC, Nairobi, Kenya. 17 pp.

Wouters, A.P., 1987. Dry matter yield and quality of napier grass on farm level from 1983-1986. Ministry of Livestock Development (NDDP/RO9/143), Nairobi, Kenya. 39 pp.

Wouters, A.P. and Dohmen, C., 1985. The feed intake of napier grass (var. bana) at two growth stages by lactating dairy cows. Ministry of Agriculture and Livestock Development, NDDP, NAHRC, Naivasha, Kenya. 27 pp.

Chapter 3

Effect of moisture supply, maturity and supplementation with soyabean meal on digestibility of napier grass (*Pennisetum purpureum*) fed to sheep.

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Effect of moisture supply, maturity and supplementation with soyabean meal on digestibility of napier grass (*Pennisetum purpureum)* fed to sheep

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Abstract.

An experiment was conducted to investigate the effect of moisture supply, age at harvesting and supplementation with a protein and energy source on *in vivo* digestibility of napier grass (*Pennisetum purpureum* var. Bana). The digestibility was determined weekly from 3 to 15 weeks of growth of the grass under two watering regimes to simulate annual precipitation in the medium (800 mm) and high (1200 mm) rainfall areas of Kenya. The watering regime, maturity and supplementation affected digestibility of the grass ($P < 0.05$). The mean organic matter digestibility was 0.64 and 0.63 and crude protein digestibility was 0.62 and 0.63 for the high- and low-watered grass, respectively. The mean organic matter digestibilities was 0.65 and 0.61 whilst crude protein digestibility was 0.67 and 0.59 for the supplemented and non-supplemented grass, respectively. The difference between digestibility of the supplemented and non-supplemented grass increased as it matured. Nutrient deficiencies significantly limited digestibility from the age of 5 and 6 weeks of growth for the low- and high-watered grass, respectively. It was concluded that napier grass should be fed as a sole diet to lactating dairy cows at 3-11 weeks and 3-10 weeks in the medium and high rainfall areas of Kenya, respectively when digestibility does not limit production.

Keywords: Napier grass, Moisture, Maturity, Supplementation, *In vivo* digestibility

Introduction

Napier grass is one of the major roughage fed to dairy cows on smallholder farms in Kenya. The current recommendations in Kenya is to harvest the grass at 6-10 weeks of growth when crude protein (CP) content is optimal (100-120 g kg^{-1} DM) for moderate dairy production (ARC, 1984). Yield of forage is a measure of its carrying capacity whereas its chemical composition is an indication of the potential to supply nutrients to animals. The first step towards estimating nutritive value of forage is to determine its digestibility. Numerous studies to evaluated the nutritive value of the grass have been based on *in vitro* digestibility (Mislevy et al., 1989; Boonman, 1993; Schreuder et al., 1993) a method which give less reliable estimates of nutritive value than are *in vivo* digestibility determinations (McDonald et al., 1988). The available information on *in vivo* digestibility of the grass were obtained from limited stages of maturity and at varying feeding levels (Hassan and abdi-Elaziz, 1979; Thomas et al., 1980; Abour-Ashour et al., 1984; Muinga et al., 1995). However, digestibility of a forage is known to vary even at the same stages of maturity when determined at a different levels of feeding (Zemmelink, 1986). Therefore, for comparison purposes and for estimation of metabolisable energy (ME), it is recommended that digestibility be determined at maintenance level of intake (ARC, 1980).

In Kenya, napier grass is mainly grown in the high and medium potential agricultural areas receiving about 1200 mm and 800 mm yr^{-1} of rainfall, respectively. Temperature, light and availability of water are associated with maturation process of plants and will affect yield and nutritive value of forage (Van Soest, 1982; Anindo and Potter, 1994). While recommending stage of maturity for harvesting the grass, these factors were not taken into account. Therefore, for efficient

utilization of napier grass specific recommendation should be developed for the high and medium rainfall areas of Kenya and other parts of the world with similar precipitation.

The suitable maturity for feeding napier grass for milk production would be at young stages of growth when CP content and ME concentration are high. However, at these stages of maturity, yield and carrying capacity are low. On the other hand, at advanced maturity when yield and carrying capacity are high, the protein and energy contents are often low. When intake of nutrients by ruminants is below the requirements of rumen microbes, digestibility of the food will be reduced (ARC, 1980). Supplementation with high protein concentrates has been shown to enhance digestibility of a roughage low in protein (ARC, 1980; Matejovsky and Sanson, 1995; Phillips et al., 1995). There is, therefore, need to determine the stage of maturity at which low CP content would limit its digestibility and how supplementation would influence digestibility of the grass.

The objectives of this study were to determine:-

(i) The effect of watering regime on apparent digestibility of napier grass.

(ii) The critical maturity at which nutrient deficiencies would limit digestibility and hence the need for supplementation.

(iii) The maturity at which digestibility of the grass would limit dairy cattle production.

Materials and methods

Study site

The study was conducted at the National Animal Husbandry Research Centre (0° 40' S, 36° 26' E, altitude, 1940 m), Naivasha, Kenyan. The mean annual rainfall is 620 mm which is not adequate for improved forage and fodder production. Although the mean temperature is 16.3 °C wide daily variation ranging from 7 to 26 °C does occur particularly in the dry months. The soils are dark greyish to dark brown, very deep and slightly to moderately alkaline (Jaetzold and Schmidt, 1983).

Management of napier grass

Napier grass (var. Bana) was established on the fields A and B, each measuring 1.36 hectares, using root-splits spaced at 60 and 90 cm within and between rows, respectively. A preliminary trial indicated that the fertility of the soil was better for field A than B. For this reason, compound fertilisers (NPK -20:10:10) were applied only to the grass in field B at an annual rate of 500 kg ha^{-1} and top-dressed at a rate of 50 kg ha^{-1}, using CAN (26 % N) after harvesting the grass. Because of fertiliser application in field B, analyses of soil samples at 5 weeks of growth of the grass indicated that fertility status of the fields was comparable. Napier grasses in field A and B was irrigated fortnightly for 24 and 8 h, respectively in addition to rainfall. The total amount of water supply to field A was 1200 mm and that in field B was 800 mm which was aimed at simulating annual precipitation in the high and medium rainfall areas in Kenya, respectively. The mean temperature

over the growing period of grass was 17 ± 3.5 °C. The grass was harvested manually at a stubble height of 5 cm using a Machete.

Animal experimentation

Twelve wither sheep of the Doper breed, aged 17.5 ± 1.4 months and weighing 42.7 ± 3.8 kg were fed in metabolism cages which allowed separate feeding, watering and total faecal collection. Feeding was done near maintenance level of intake. The animals were weighed on three consecutive days to obtain mean live-weight and dewormed against internal parasites at the start of the experiment. For each watering regime, digestibility of the grass was determined weekly starting from the 3rd week and ending at the 15th week of growth (13 digestibility trials). For each stage of growth, enough grass to feed the 12 sheep for 14-day adaptation and 5-day faecal collection periods was harvested. The grass was chopped using a motorised chaff-cutter to a size of 2.5 cm to minimise selection by sheep, weighed into plastic bags and stored at –20 °C. Prior to feeding, the grass was thawed to room temperature. At each stage of maturity, digestibility of the high-watered grass was determined 19 days earlier than that of the low-watered grass using the same sheep. Feeding was done 3 times per day at 8.00, 13.00 and 18.00 h. Supplementation (6 sheep) was done at a daily rate of 100 g soyabean meal head $^{-1}$ and 2.5 g head $^{-1}$ of minerals was provided. Clean water was available *ad-libitum*.

Total collection and weighing of faeces were done for each individual sheep before feeding and representative samples (20 % of total collection) were preserved using 20 ml formalin solution (10 % V/V) and stored in plastic bottles at 3-5 °C. Digestibility coefficients of the grass were calculated by difference according to methods of Close and Menke (1986). It was assumed that the

forage and the supplement had no associative effects and digestibility of the supplement was constant at all stages of maturity. The digestibility of organic matter in dry matter (DOMD) was estimated from the determined organic matter digestibility (OMD) of napier grass as follows:-

DOMD % = 0.92 OMD % - 1.2 (MAFF, 1984)

The metabolisable energy (ME) concentration was also estimated from the DOMD of the grass as follows:-

ME (MJ kg^{-1} DM) = DOMD % x 0.15 (MAFF, 1984)

Sampling and Laboratory analyses

Representative food samples were taken before weighing napier grass to be fed to the sheep for digestibility trials. Food and faecal samples were bulked for the 5-day collection period. Representative sub-samples of the bulk were taken according to procedures of Van Soest and Robertson (1985).

Dry matter (DM) content of the food and faeces were determined by drying them at 105 °C for 24 h while ashing was done at 450 °C for 6 h. Samples for chemical composition were dried at 70 ° C for 24 h and then ground through a 1 mm screen. The neutral-detergent fibre (NDF), acid-detergent fibre (ADF) and acid-detergent lignin (ADL) were determined according to procedures of Van Soest and Robertson (1985). The CP content of food was determined according to Association of Official Analytical Chemists procedures (A.O.A.C., 1990). The CP content of faeces was, however, determined from the fresh material as described by Van Soest and Robertson (1985).

Statistical analysis

The data was analysed in a completely randomised design using the general linear model (GLM) procedures of Statistical Analyses Systems (SAS, 1988). The watering regimes (2 levels), maturity (13 levels) and supplementation (2 levels) of napier grass were the treatments. Analysis of variance included the effect of treatments on chemical composition, digestibility and estimated ME concentration of the grass. The effect of the interaction of maturity with supplementation on the study parameters and the maturity stages at which digestibility of supplemented and non-supplemented grass were significantly different were determined.

Results

Effect of moisture supply

The means of chemical composition, nutrient intake and digestibility by sheep and estimated ME concentration of napier grass under the two watering regimes are shown in Table 1. The CP, ADF and ADL, and nitrogen (N) intake by sheep were significantly higher for the high than the low watered grass. The NDF content and digestible organic matter (OM) intakes were similar for the two watering regimes. The OM and NDF digestibilities, and ME concentration were significantly lower for the high- than the low-watered grass. However, the CP digestibility was higher for the high- than the low-watered grass.

Effect of maturity of napier grass

The changes in chemical composition, nutrient intake and digestibility by sheep, and estimated ME concentration as napier grass matured under the two watering regimes are shown in Table 2. Stages of maturity of the grass had a significant ($P < 0.05$) influence on chemical composition, nutrient intake, digestibility and estimated ME concentrate of the grass. The rate of decline in CP content as the grass matured were comparable for the high (7.60 g kg^{-1} DM $week^{-1}$) and low watering regimes (7.44 g kg^{-1} DM $week^{-1}$). The rate of increase in ADL content with maturity was higher for the high- (1.20 g kg^{-1} DM $week^{-1}$) than the low-watered grass (0.41 g kg^{-1} DM $week^{-1}$). Generally, the N intake declined faster than digestible OM intake as the grass matured for the two watering regimes. The rates of decline in N intake were comparable whereas digestible OM intake declined faster for the low- than the high-watered grass. On the other hand, the rate of decline with maturity, of OM digestibility was higher for the high- (0.02 $week^{-1}$) than the low-watered grass (0.01 $week^{-1}$). However, the decline in CP and NDF digestibilities, and ME concentration were comparable for the two watering regimes.

Effect of supplementation

Table 3 shows the effect of supplementing sheep with soyabean meal on nutrient intake, digestibility and estimated ME concentration of napier grass. The nutrient intake, digestibility and ME concentration were higher ($P < 0.001$) for the supplemented than non-supplemented grass. The N and digestible OM intakes by sheep were 36 % and 17 % higher, respectively for the supplemented than non-supplemented grass. On the other hand, the OM, CP and NDF digestibilities

Table 1. Means of chemical composition, nutrient intake and digestibility by sheep, and estimated metabolisable energy concentration from 3 to 15 weeks of growth of napier grass under two watering regimes.

Variable	Napier grass (1200 mm yr^{-1})	Napier grass (800 mm yr^{-1})	s.e.d.	Sign.
N	156	156		
Chemical composition (g kg^{-1} DM)				
Dry matter (g kg^{-1})	142.539	165.640	0.501	***
Ash	195.385	199.846	0.741	***
Crude protein	103.359	90.231	0.790	***
Neutral - detergent fibre	598.308	598.077	1.022	NS
Acid - detergent fibre	376.077	281.615	0.720	***
Acid - detergent Lignin	37.000	36.231	0.177	***
Nutrient intake (g kg^{-1} $W^{0.75}$)				
Nitrogen	38.112	32.373	0.514	***
Digestible organic matter	27.235	26.665	0.305	NS
In vivo digestibility coefficient				
Organic matter	0.628	0.637	0.003	**
Crude protein	0.631	0.623	0.004	*
Neutral - detergent fibre	0.584	0.609	0.004	***
Metabolisable energy (*MJ* kg^{-1} DM)	8.484	8.615	0.044	**

s.e.d., standard error of difference; N, number of observations; NS, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 2. Regression equations to estimate chemical composition, nutrient intake and digestibility by sheep and metabolisable energy concentration from 3 to 15 weeks of growth of napier grass under two watering regimes.

Dependent variable (y)	Regression equation	r.s.d.	r^2	Sign
Napier grass receiving 1200 mm yr^{-1} of water (N=13).				
Chemical composition (g kg^{-1} DM)				
Dry matter (g kg^{-1})	y = 118.951 + 2.621 x	3.632	0.882	***
Ash	y = 242.325 - 5.212 x	4.282	0.954	***
Crude protein	y = 169.516 - 7.604 x	4.411	0.977	***
Neutral - detergent fibre	y = 467.264 + 14.560 x	8.631	0.976	***
Acid - detergent fibre	y = 290.082 + 9.555 x	8.330	0.950	***
Acid - detergent Lignin	y = 26.220 + 1.198 x	2.192	0.811	***
Nutrient intake (g kg^{-1} $W^{0.75}$)				
Nitrogen	y = 55.649 - 2.576 x	5.160	0.782	***
Digestible organic matter	y = 26.529 - 0.160 x	2.369	0.062	*
In vivo digestibility coefficient				
Organic matter	y = 0.745 - 0.015 x	0.029	0.798	***
Crude protein	y = 0.841 - 0.029 x	0.035	0.907	***
Neutral - detergent fibre	y = 0.710 - 0.014 x	0.032	0.748	***
Metabolisable energy (MJ kg^{-1} DM)	y = 10.108 - 0.208 x	0.397	0.798	***
Napier grass receiving 800 mm yr^{-1} of water (N=13).				
Chemical composition (g kg^{-1} DM)				
Dry matter (g kg^{-1})	y = 137.874 + 3.005 x	5.148	0.850	***
Ash	y = 249.262 - 5.488 x	8.284	0.863	***
Crude protein	y = 157.187 - 7.440 x	5.174	0.967	***
Neutral - detergent fibre	y = 521.429 + 8.516 x	9.530	0.920	***
Acid - detergent fibre	y = 220.495 + 6.791 x	3.567	0.981	***
Acid - detergent Lignin	y = 32.571 + 0.407 x	0.419	0.931	***
Nutrient intake (g kg^{-1} $W^{0.75}$)				
Nitrogen	y = 52.646 - 2.825 x	3.822	0.887	***
Digestible organic matter	y = 32.449 - 0.859 x	2.990	0.543	***
In vivo digestibility coefficient				
Organic matter	y = 0.756 - 0.012 x	0.028	0.936	***
Crude protein	y = 0.826 - 0.028 x	0.030	0.926	***
Neutral - detergent fibre	y = 0.687 - 0.011 x	0.036	0.560	***
Metabolisable energy (MJ kg^{-1} DM)	y = 9.885 - 0.171 x	0.389	0.736	***

r.s.d., residue standard deviation; r^2, variation in the dependent variable (y) that can be explained by the independent variable (x); N, number of observations; x, age of the grass in weeks; NS, not significant; *** $P < 0.001$.

Table 3. Effect of supplementation with soyabean meal and the interaction of age of napier grass with supplementation on average nutrient intake and digestibility by sheep, and the estimated metabolisable energy (ME) concentration of the grass from 3 to 15 weeks of growth.

Variable	Napier + SBM	Napier alone	s.e.d.	Significance	
				Sup.	Age x Sup.
N	156	156			
Nutrient intake ($g\ kg^{-1}\ W^{0.75}$).					
Nitrogen	40.642	29.842	0.514	***	NS
Digestible OM	29.000	24.900	0.305	***	NS
In vivo digestibility.					
Organic matter	0.651	0.614	0.003	***	*
Crude protein	0.669	0.585	0.004	***	***
NDF	0.608	0.585	0.004	***	NS
ME ($MJ\ kg^{-1}$ DM)	8.810	8.290	0.044	***	*

N, number of observations; SBM, Soyabean meal; s.e.d., standard error of difference; Sup., Supplementation; NS, not significant; OM, Organic matter; NDF, Neutral-detergent fibre; *, $P < 0.05$; ***, $P < 0.001$.

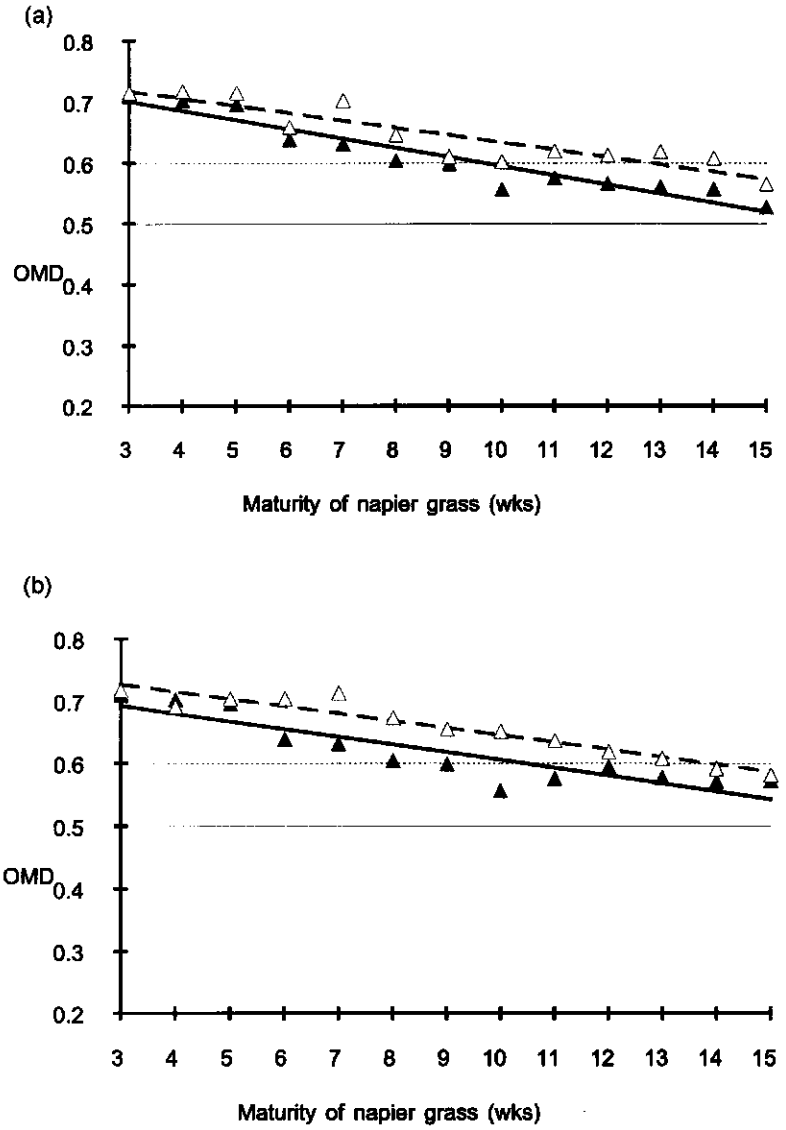

Figure 1. Organic matter digestibility (OMD) coefficient of non-supplemented (—) and supplemented (- - -) napier grass receiving (a) 1200 mm and (b) 800 mm of water. Organic matter digestibility requirements for maintenance (—) and production of 10 kg of milk cow^{-1} day^{-1} (.....).

and ME concentration were 6 %, 14 %, 4 % and 6 % higher, respectively for the supplemented than non-supplemented grass.

There was an interaction ($P < 0.05$) of maturity with supplementation on OM and CP digestibilities, and ME concentration of the grass. The interaction of the two, however, did not affect NDF digestibility of the grass. For OM and CP digestibilities, the difference between the supplemented and non-supplemented grass increased as the grass matured (OM digestibility shown in Figure 1). The digestibility of the supplemented and non-supplemented grass were significantly ($P < 0.05$) different from 5 weeks and 6 weeks for the low- and high-watered grass, respectively.

Discussion

The OM digestibility and ME concentration from 3 to 15 weeks of growth of the grass were above the levels of 0.50 and 6.72 MJ kg^{-1} DM, respectively which are required for maintenance of a 450 kg cow (ARC, 1984). However, the CP level of 60-70 g kg^{-1} below which voluntary intake would decline (Wilson and Minson, 1980; ARC, 1984; Minson, 1990) occurred at 13 and 12 weeks of napier growth for the high and low watering regimes, respectively. The fact that nutritive value of the grass could be maintained for a long period of growth implied that excess grass in the wet season would possibly be suitable for maintaining livestock during the dry season.

The OM digestibility coefficient value of 0.60 required for daily milk yields of about 10 kg cow^{-1} (Heaney, 1979; ARC, 1984) was realised at 3-11 weeks and from 3-10 weeks for the low- and high-watered grass, respectively. The difference in harvesting intervals was due to high digestibility

values of the low- than the high-watered grass. At these stages of maturity, the ME concentration ranged from 9.48 to 8.03 MJ kg^{-1} DM and from 9.37 to 8.17 MJ kg^{-1} DM for the high and low watering regimes, respectively. These levels of ME concentration were adequate for daily milk yield of about 10 kg for a 450 kg cow (ARC, 1984). At the same stages of maturity, the CP content ranged from 146.70 to 93.47 g kg^{-1} DM and from 134.87 to 82.79 g kg^{-1} DM for the grass receiving high and low moisture levels, respectively. At about 10 weeks of growth of the grass, the CP content would limit milk yields in excess of 10 kg cow^{-1} (ARC, 1984). Although the digestibility of napier grass was higher at early than advanced stages of growth, harvesting at young maturity may not be practical due to reduced persistency, low DM yield, and high labour and fertiliser requirements among other factors.

High moisture supply to napier grass is associated with high rates of growth and maturation hence less concentration of CP and ash due to "dilution effect" and a high cell wall content (Humphreys, 1991). Since fertility status of the soils in fields A nad B was similar (Muia et al, 1999), the higher CP concentration for the high than low watered grass was unexpected. The higher CP digestibility of the high- than the low-watered grass may be due to the higher CP content and a higher N intake. The high ADF and ADL contents of the grass receiving high levels of moisture may be the reason why the OM and NDF digestibilities were lower than digestibility values for the grass receiving low levels of moisture. Anindo and Potter (1994) reported high DM digestibility of napier grass in the wet than in the dry season, which was contrary to findings from the current study. However, their results may have been influenced by variations in soil fertility and seasonal temperature in addition to moisture supply. Wilson et al. (1986) and Ducrocq and Duru (1997) observed that DM digestibility of tropical and sub-tropical grasses tended to increase with water

stress. Seasonal differences in digestibility of forages were reported by Van Soest (1982) and Minson (1990) to be caused by changes in temperature and water availability to the forage.

The decline in digestibility as napier grass matured may be attributed to the observed declines in CP content and ME concentration, and an increase in detergent fibres and degree of lignification. Under high temperatures in the tropics, there is rapid growth and development of grasses resulting to a high rate of decline in the proportion of leaves in relation to stems which reduce CP content and digestibility (Van Soest, 1982; Mannetje, 1983). A similar decline in digestibility of napier grass as it matured was also reported in Kenya (Thomas et al., 1980, Muinga et al., 1995) and elsewhere (Hassan and Abdi-Elaziz, 1979; Abour-Ashour et al., 1984; Njwe and Chiffon, 1991). Cherney et al., (1993) and Givens et al., (1993) also reported a decline in digestibility with advancing maturity of temperate grasses.

Lignin content was reported by Broster et al (1981), Van Soest (1982) and Van Soest and Robertson, (1979) to affect digestibility of forage more than any other chemical component. Van Soest (1982) reported a lignin content value above 60-g k^{-1} DM to affect digestibility of forage negatively. In the current study, digestibility of napier grass was affected negatively although lignin content values were below this critical level. The reason may be due to the recent observations that variation in the anatomical structure and chemistry of the fibre fractions are closely related to digestibility of forage rather than the fibre content (Jung and Allen, 1995; Wilson and Hatfield, 1997).

The high digestibility of supplemented as compared to non-supplemented napier grass may be attributed to supply of essential nutrients from soyabean meal which were limiting rumen microbial activity and growth when the grass was fed alone. The difference in digestibility was higher at advanced stages of maturity when non-supplemented grass was likely to be more deficient in

essential nutrients for optimal rumen fermentation. The amount and quality of protein and energy intake by ruminants influence rumen degradability and intestinal digestion and consequently the absorbed protein to energy ratio hence efficiency of production (Preston and Leng, 1987). Matejovsky and Sanson (1995) reported an increase in DM, OM and CP digestibility by lambs when grass hay was supplemented with a protein source. In contrast, NDF digestibility was not affected by supplementation in their study. Minimal supplementation has been reported to enhance digestibility of forages and the effect is more pronounced the low the protein content of the forage (ARC, 1984; Matejovsky and Sanson, 1995). However, supplementation with protein and energy source did not affect NDF digestibility of wheat forage in a study by Phillips et al. (1995).

Adequate levels of protein and energy are required for optimal rumen microbial activity and growth although sulphur and phosphorus are also essential (Stern and Hoover, 1979; ARC, 1980; Thomas and Rook, 1981; Ørskov, 1982; Van Soest, 1982). The CP content of 60-70 g kg^{-1} DM is the minimum required by rumen microbes for digestion of food (ARC, 1984). Low nutrient status particularly that of CP content in pastures consumed by ruminants were reported to be associated with low digestibility (Leng, 1980; Ørskov, 1982). However, supplementation improved OM digestibility of napier grass in the current study from the 5 th week and the 6 th week for the low and high watering regimes, respectively when CP content was as high as 120 g kg^{-1} DM. In agreement with current results, napier grass containing high CP content (90-120 g kg^{-1} DM) was inefficiently utilized in the rumen and supplementation with a rumen fermentable protein source improved food intake and performance by ruminants (Van Eys et al., 1986; Njwe and Chiffon, 1991; Mgheni et al., 1996). Furthermore, Preston and Leng (1987) have recommended that tropical forages be supplemented with a protein source which is degradable in the rumen to ensure that ammonia levels are maintained above 150 mg l^{-1} to maximise intake and rumen digestion. After supplementation,

the 0.60 level of OM digestibility required for daily milk production of about 10 kg cow^{-1} (Heaney, 1979; ARC, 1984) was realised at 3-13 weeks and at 3-14 weeks for the high- and low-watered grass, respectively. This implies that minimal supplementation to optimise rumen fermentation would improve OM digestibility of a 13 and 14 week old napier grass to the same level as that of non-supplemented 10 and 11 week old grass in the high and medium rainfall areas of Kenya, respectively.

The energy content is low as compared to CP content at young stages of growth of napier grass. Therefore, enhanced digestibility after supplementing the grass at early maturity may be due to supply by soyabean meal of the required energy in the rumen. Alternatively, at advanced maturity digestibility of the grass was very low because supply of both energy and CP contents was not adequate for optimal rumen microbial growth. As a result, supplementation improved both the energy and protein status in the rumen hence the big difference in digestibility between supplemented and non-supplemented grass.

Use of sheep or cows to determine digestibility gave similar values for silage and grassland products (Aerts et al., 1984). For DM digestibility values exceeding 0.55, the differences between the two species of animals tend to be minimal and can safely be ignored (Heaney, 1979). Therefore, the digestibility values obtained in the current study ranging from 3 to 10 weeks of growth of the grass would, therefore, be used reliably for cows.

Conclusions

The digestibility of napier grass declined with maturity and relatively lower OM digestibility values were obtained for the high- than the low-watered grass. The digestibility was limited at CP content as high as 120-g kg^{-1} DM, which occurred at the 5^{th} week and the 6^{th} week of maturity of the low- and high-watered grass, respectively. Therefore, supplementation with an energy and protein source in the rumen enhanced digestibility from these stages of maturity. The difference between digestibility of the supplemented and non-supplemented grass increased as it matured. For the purpose of milk production, harvesting should be done at 3-10 weeks and 3-11 weeks of growth for the grass in the high and medium rainfall areas of Kenya, respectively.

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References

Abour-Ashour, A. M., Saleh Youssef, M. S., El-Kashab, S. H. and Bendary, M. M., 1984. Evaluation of the nutritive value of napier grass. Word Review of Animal Production, 20: 13 -17.

Aerts, J.V. De Boever, J. L. Cottyn, B.G., De Brabander, D.L. and Buysse, F. X., 1984. Comparative digestibility of feedstuffs by sheep and cows. Animal Feed Science and Technology, 12: 47-56.

Anindo, D. O. and Potter, H. L., 1994. Variation in productivity and nutritive value of napier grass at Muguga, Kenya. East African Agriculture and Forestry Journal, 59: 117-185.

AOAC, 1990. Official methods of analysis (15th Ed). Association of Official Analytical Chemistry, Vol.1, Washington, D.C.

ARC, 1980. Nutrient requirements of ruminant livestock. Agricultural Research Council. Commonwealth agricultural Bureaux, Farnham, Royal, U.K.

ARC, 1984. Nutrient requirements of ruminant livestock. Supplement 1. Agricultural Research Council. Commonwealth Agricultural Bureaux, Farnham, Royal, U.K.

Boonman, J. G., 1993. East Africa's grasses and fodder: Their Ecology and Husbandry. Kluwer Academic Publishers, Dordecht, The Netherlands.

Broster, W. H., Sutton, J. D. and Bines, J. A., 1981. Concentrate: Forage ratios for high yielding dairy cows. In: Haresign, W. and Cole, D.J.A. (Eds.), Recent Development in Animal Nutrition. Butterworth, London. pp. 325-352

Close, W. and Menke, K. H., 1986. Selected topics in animal nutrition. A Manual Prepared for the 3rd Course on Animal Nutrition in the Tropics and Sub-tropics. 2nd Edition, University of Hohenheim, Germany, pp 1-170.

Cherney, D. J. R., Cherney, J. H. and Lucey, R. F., 1993. *In vitro* digestion kinetics and quality of perennial grasses as influenced by forage maturity. Journal of Dairy Science, 76: 790-797.

Ducrocq, H. and Duru, M., 1997. *In vitro* digestibility of green lamina of Cocksfoot (*Dactylis glomerata L.*) in relation to water deficit. Grass and Forage Science, 52: 432-438.

Givens, D. I., Moss, A. R. and Adamson, A. H., 1993. Influence of growth stage and season on the energy value of the herbage. 1. Change in metabolisable energy content. Grass and Forage Science., 48: 166-174.

Hassan, N. I. and Abdi - Elaziz, H. M., 1979. Evaluation of some forages introduced to newly reclaimed areas in Egypt. World Review of Animal Production. 15: 31- 35.

Heaney, D. P., 1979. Sheep as a Pilot Animal. In: Pigden, W.J., C.C. Balch and Michael Graham (Eds.), Standardisation of Analytical Methodology For Feeds. Proceeding of a Workshop, 12th - 14th March, Ottawa, Canada. pp. 44 - 48

Humphreys, L.R., 1991. Tropical pasture utilization. Cambridge university, Great Britain.

Jaetzold, R. and Schimidt, H., 1983. National Conditions and Farm Management Information. East Africa, 2c, Ministry of Agriculture, Nairobi, Kenya.

Jung, H.G. and Allen, M. S., 1995. Characteristics of plant cell wall affecting intake and digestibility of forage by ruminants. Journal of Animal Science, 73: 2774-2790.

Leng, R. A., 1980. Factors affecting the utilization of poor quality forages by ruminants particularly under tropical conditions. Nutritional Research Review, 3: 277-303.

McDonald, P., Edwards, R. A. and Greenhalgh, J. F. D., 1988. Animal nutrition. 4th Edition. London, New York.

Mannetje, C. T., 1983. Nutritive value of topical and sub-tropical pastures with special reference to protein and energy deficiency in relation to animal production. In: Gilchrist, F. M. C. and Mackie, R.I. (Eds.), Herbivore Nutrition in the Sub-tropic and Tropics. Science Publication, Pretoria. pp. 55-66

Matejovsky, K. M. and Sanson, D. W., 1995. Intake and digestion of low -, medium - and high - quality grass hays by lambs receiving increasing levels of corn supplementation. Journal of Animal Science, 73: 2156-2163.

MAFF, 1984. Energy allowances and feeding systems for ruminants. No. 433. Her majesty's stationary office, London.

Mgheni, D. M., Hvelplund, T. and Weisberrg, M. R., 1996. Rumen degradability of dry matter and protein in tropical grasses and legume forages and their protein value expressed in the AAT-PBV protein evaluation system. In: Ndikumana, J. and P. Deleeuw (Eds.), Sustainable Feed Production and Utilization for Smallholder Livestock Enterprises in Sub-Sahara Africa. Proceeding of the 2nd African feed Resource Network (AFRNET) Workshop, 6^{th}-10^{th} December, 1993, Harare, Zimbabwe. pp 77-84.

Mislevy, P. Martin, F. G. and Adjei, M. B., 1989. Changes in elephant grass components with maturity. 1. Percentage Dry yields. Proceeding of the 16th International Grassland Congress, Nice, France. pp 951 - 952.

Minson, D. J., 1990. Forage in ruminant nutrition. Academic Press, Inc. Australia.

Muia, J.M.K, Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 1999. Optimal stage of maturity for feeding napier grass (*Pennisetum purpureum*) to dairy cows in Kenya. Tropical Grasslands, 33:182-190.

Muinga, R. W., Thorpe W. and Topps, J. H., 1995. The effect of supplementation with *leucaena leucocephala* and maize bran on voluntary food intake, digestibility, live-weight and milk yield of *Bos Indicus* x *Bos Tauras* dairy cows and rumen fermentation in steers offered *Pennisetum purpureum ad-libitum* in the semi-humid Tropics. Animal Science, 60: 13-23.

Njwe, R. M. and Chiffon, M. K., 1991. Performance of dwarf sheep fed Elephant grass (*Pennisetum purpureum*) and concentrate supplements containing rubber seed as substitute for cotton seed cake. World review of Animal Production, 16: 43-45.

Ørskov, E. R., 1982. Protein nutrition in ruminants. Academic press, London.

Phillips, W.A., Horn, G.W. and Smith, M. E., 1995. Effect of protein supplementation on forage intake and nitrogen balance of lambs fed freshly harvested wheat forage. Journal of Animal Science, 73: 2687-2693.

Preston, T.R. and Leng, R. A., 1987. Matching ruminant production systems with available resources in the tropics and sub-tropics. Penambul Books, Armidale, Australia. 245 pp.

SAS, 1988. SAS/STAT user's guide. 6.03 Edition, Cary, N C.

Schreuder, R., Snijders, P. J. M., Wouters, A. P. Steg, A. and Kariuki, J. N., 1993. Variation in organic matter digestibility *(in vitro)*, yield, crude protein and ash content of napier grass (*Pennisetum purpureum*) and their prediction from chemical and environmental parameters. Kenya Agricultural Research Institute, NAHRC, Naivasha, Kenya. 62 pp.

Stern, M. D. and Hoover, W. H., 1979. Methods for determination and factors affecting rumen microbial synthesis. A review. Journal of Animal Science, 49: 1590-1603.

Thomas, G., Njoroge, P. K. and Fenlon, J. G., 1980. Prediction of digestibility in three tropical grasses. Tropical Agriculture (Trinidad), 57: 75-81.

Thomas, P.C. and Rook, J.A.F., 1981. Manipulation of rumen fermentation. In: Haresign, W. and D.J.A, Cole (Eds.), Recent Development in Ruminant Nutrition. Butterworth, London. pp 157-183.

Van Eys, J.E., Mathius, I.W., Pongsapan, P. and Johnson, W.L., 1986. Foliage of the tree legumes *Gliricidia, Leucaena* and *Sesbania* as supplements to napier grass diets for growing goats. Journal of Agricultural Science, Cambridge, 107: 227-233.

Van Soest, 1982. Nutritional ecology of the ruminant. O & B Books Msc., Corvallis, Oregon, USA.

Van Soest, P.J. and Robertson, J.B., 1979. Systems of analysis for evaluating fibres feed. In: Pigden, W.J., C.C. Balch and Michael Graham (Eds.), Standardisation of Analytical Methodology for Feeds. Workshop proceeding, 12-14 March, Ottawa, Canada. pp. 49-60

Van Soest, P.J. and Robertson, J.B., 1985. Analysis of forage and fibrous foods. A Laboratory Manual for Animal Science 613, Cornell University.

Wilson, J. R. and Minson, D. J., 1980. Prospects for improving the digestibility and intake of tropical grasses. Tropical grasslands, 14: 253-259.

Wilson, J. R., Jones, P.N. and Minson, D. J., 1886. Influence of temperature on the digestibility of and growth of *Macroptilium atropurpureum* and *Panicum maximum* var. *Trichoglume* in sub-tropical and tropical Australia. Tropical Grasslands, 20: 145-165.

Wilson, J. R. and Hatfield, R. D., 1997. Structural and chemical changes of cell-wall types during stem development: consequences for fibre degradation by rumen microflora. Australian Journal of Research, 48: 165-180.

Zemmelink, G., 1986. Evaluation and utilization of tropical forages. In: Ibrahim, M.N.M. and J.B. Schiere (Eds.), Rice Straw and Related Feed in Ruminant Rations. Proceeding of the International Workshop, 24th-28th March, Kandy, Sri Lanka. pp 285-298.

Chapter 4

Optimal stage of maturity for feeding napier grass (*Pennisetum purpureum*) to dairy cows in Kenya.

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Optimal stage of maturity for feeding napier grass (*Pennisetum purpureum*) to dairy cows in Kenya

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Abstract

Two experiments were conducted to determine the maturity at which napier grass (*Pennisetum purpureum* var. Bana) should be fed to dairy cows in Kenya. The grass was grown in two fields to irrigated to simulate precipitation in the high (1200 mm yr^{-1}) and medium (800 mm yr^{-1}) rainfall areas in Kenya. The height, chemical composition and yields (Experiment 1) and *in vivo* digestibility (Experiment 2) of the grass were determined weekly from week 3 to week 15 of growth. Optimal maturity for feeding was determined using crude protein concentration, yields of digestible organic matter and crude protein, and crude protein: digestible organic matter ratio methods. Height and yield increased and *in vivo* digestibility and nutrient ratio declined as the grass matured ($P < 0.001$). Although the height and yields of high-watered grass were 3 times those of low-watered grass, organic matter digestibility was higher on low-watered grass ($P < 0.001$). The optimal ages for feeding obtained using these methods were within the 6-10 weeks but the heights were different from the 60-100 cm ranges that are recommended in Kenya. Further, the recommended maturity was different and more specific for each watering regime. The nutrient ratio method was preferred since it considered the interrelationship between protein and energy concentrations. This method indicates that napier grass should be fed to dairy cows at 50-60 cm (7-8 wk) and 130-140 cm (9-10 wk) in the medium and high rainfall areas in Kenya, respectively.

Keywords: Napier grass; Maturity; Feeding Dairy cows.

Introduction

Dairy production in Kenya is concentrated mainly in the medium and high potential areas receiving annual rainfall of about 800 mm and 1200 mm, respectively. Napier grass (*Pennisetum purpureum* var. Bana) is the main feed resource in these areas due to its high yields of dry matter (Stotz, 1981). As napier grass matures, yields of dry matter (DM) increase whereas the crude protein (CP) concentration declines (Boonman, 1993). In Kenya, it is recommended that the grass be fed to dairy cows at a height of 60-100 cm or at 6-10 weeks of growth (MLD, 1991). This general recommendation is based on the optimal CP concentration (100-120 g kg^{-1} DM) for moderate milk production by dairy cows (ARC, 1984). The average carrying capacity based on yields of DM at these levels of CP was estimated to be 3.8 cows per hectare (Snijders, 1989). However, for better utilisation and performance, more precise recommendations on maturity at which to harvest the grass and the corresponding carrying capacities are required for napier grass in areas with varying levels of precipitation.

Chemical composition is a measure of the potential to supply nutrients, whereas the yields of DM indicate the carrying capacity of forage. The first step in evaluating the nutritive value of a feed is to measure digestibility. Available information on *in vivo* digestibility of napier grass was determined on material at limited stages of growth and at *ad libitum* feeding levels (Thomas et al., 1980; Anindo and Potter, 1994; Muinga et al., 1995). Therefore, most data on digestibility of napier grass has been based on *in vitro* digestibility which is a less reliable estimate of nutritive value than *in vivo* digestibility (McDonald et al., 1988). However, information on changes in yields of digestible nutrients as the grass matures is scarce. Furthermore, the optimal maturity to harvest the grass in the medium and high rainfall areas, based on yields of digestible nutrients, need to be determined.

Although energy and protein concentration of a feed could influence performance of animals, their interrelationship is important (Tamminga, 1982; Nocek, 1988; Oldham, 1988). The protein: energy (nutrient) ratio of the ingested diet has an influence on the nature and extent of rumen fermentation on one hand and utilisation of energy, microbial protein and undegraded protein in the small intestines on the other (Van Es, 1980). The nutrient ratio method is, therefore, closely related to utilisation of a diet and animal performance and would be a useful method for determining the optimal maturity at which napier grass should be fed to dairy cows in Kenya.

The objectives of this study were to:

- ★ compare the estimated optimal maturity for harvesting napier grass using the optimal CP concentration, yields of digestible nutrients and nutrient-ratio methods with the current recommendations in Kenya;
- ★ compare the estimated optimal maturity for harvesting the grass using the 3 methods; and
- ★ determine the specific maturity for harvesting the grass in the medium and high rainfall areas.

Materials and methods

Study site

The study was conducted at the National Animal Husbandry Research Centre (0^0 40' S, 36^o 26' E, altitude 1940 m), Naivasha, Kenya. Mean annual rainfall of 650 mm is received mainly in late March - June and October - December for the long and short rains, respectively. Irrigation is, therefore, required for improved forage and

fodder production. Although the mean temperature is 17.8 ^{0} C, daily values range from 7-26 $^{\circ}$ C, particularly in the dry months. The soils are dark grey - dark brown with humic top - soil, and are very deep and slightly - moderately alkaline (Jaetzold and Schmidt, 1983).

Management of napier grass

Napier grass (var. Bana) was established on 2 fields (A and B), using root-splits spaced at 60 and 90 cm within and between rows, respectively. A preliminary study indicated that field A was more fertile than field B (Table 1). Compound fertiliser (N: P: K, 20:10:10) was applied to field B only at 500 kg ha^{-1} $annum^{-1}$ and top-dressing was done using C.A.N. (26 % N) at a 50 kg ha^{-1} after harvesting the grass. Because of fertiliser application to field B, analyses of soil samples at 5 weeks of growth of the grass indicated that fertility status of the two fields was comparable (Table 1). The grass in fields A and B was irrigated fortnightly for 24 h and 8 h, respectively. The total amount of water available was 1200 mm in field A and 800 mm in field B, which was aimed at simulating annual precipitation in high and low rainfall areas of Kenya, respectively.

Experiment 1

Each field of 1.36 ha was divided into 7 equal plots (70 m x 27.7 m) which were further sub-divided into 13 equal sub-plots (10 m x 14.9 m). The grass was cut at weekly intervals from week 3 to week 15. The different harvesting ages of the grass were allocated randomly to the various sub-plots within each plot. At each stage of growth, height of 50 randomly selected plants was measured using a 2-m stick, as the distance from ground level to the apex of the

majority of the leaves. Height was considered to be a more appropriate measure than age for determining maturity of napier grass at farm level. At each maturity, the grass was harvested from the respective sub-plots, weighed and yields per hectare extrapolated.

Experiment 2

The harvested grass from Experiment 1 was used to determine *in vivo* digestibility. Six Dorper withers, aged 16.2 (*s.e* ± 1.7) months and weighing 40.4 (*s.e.* ± 3.2) kg, were fed in metabolism cages which allowed separate watering, total faecal collection and feeding at about a maintenance level of intake. The animals were weighed on 3 consecutive days to obtain mean live-weight and drenched to control internal parasites at the start of the experiment. For each stage of growth, enough grass to feed the 6 sheep for 14-day adaptation and 5-day faecal-collection periods was harvested. The grass was chopped using a motorised chaff-cutter to a size of 2.5 cm to minimise selection by sheep, weighed into plastic bags and stored at – 20 ° C. Prior to feeding, the grass was thawed to room temperature. At each maturity stage, *in vivo* digestibility of the high-watered grass was determined 19 days earlier than that on the low-watered grass using the same sheep. The sheep were fed 3 times per day at 08.00, 13.00 and 18.00 h. Minerals (Nacl, 270.0; Ca, 185.1; P, 110.0; Mg, 30.0; Fe, 5.0; Cu, 1.6; Mn, 4.0; S, 4.0; Zn, 5.0; Co, 0.2; Se, 0.015; and Mo, 0.002 g kg^{-1} DM; Ca: P ratio, 1.68:1) and clean water were available *ad libitum*.

Faeces of each sheep were weighed before feeding and representative samples (20 % of total collection) were preserved using 20 ml formalin solution (10 % V/V) and stored in plastic bottles at 3-5 ° C. Organic matter (OM) and CP digestibility coefficients were calculated according to procedures of Close and Menke (1986).

Sampling and chemical analyses

Soil samples were randomly taken from each field at a depth of 15 cm and 15-30 cm for top- and sub-soil, respectively. The pH and fertility status of the soil were determined using the procedures in a manual by Hinga et al. (1980). Representative samples of napier grass were taken before feeding to the sheep. Feed and faecal samples were bulked for the 5-day collection period. Representative sub-samples of the bulked material were taken according to procedures of Van Soest and Robertson (1985).

The DM concentration in feed and faeces was determined by drying at 105 ° C for 24 h while total ash was obtained at 450 ° C for 6 h. Samples for chemical composition were dried at 70 ° C for 24 h and then ground through a 1-mm screen. The CP concentration in feed was determined according to the procedures of AOAC (1990). The CP concentration in faeces was determined on fresh material as described by Van Soest and Robertson (1985).

Calculation of parameters

The yield of digestible nutrients (YDN) was calculated from the yields of nutrients (YN) in Experiment 1 and their respective digestibility (ND) coefficients in Experiment 2 as follows:

YDN (tonnes ha^{-1}) = YN (tonnes ha^{-1}) x ND (%)/100.

The CP: digestible organic matter (nutrient) ratios (NR) were calculated from yields of CP (YCP) and yields of digestible organic matter (YDOM) as follows:

NR (g CP kg^{-1} DOM) = YCP (g ha^{-1})/ YDOM (kg ha^{-1}).

Statistical analyses

The data from Experiment 1 were analysed using a split-plot design with 7 replications. The main plots were the experimental units to determine the effect of watering regimes (2 levels) on height, chemical composition and yield of the grass whereas the sub-plots were the experimental units to determine the effect of age (13 levels) on these study parameters.

The data from Experiment 2 were analysed using a completely randomised design replicated 6 times (sheep). The watering regimes and stages of maturity of the grass were the treatments. The analysis of variance and mean separation for the determined and calculated parameters were done using the general linear model (GLM) procedures of the Statistical Analyses Systems (SAS, 1988).

Results

Extractable nutrients and pH of the soil in the two field

Before the experiment was started, the fertility status (K, P and N) of the soil in field A was better but after application of fertilizer to field B the fertility of both fields was comparable (Table 1).

Height, chemical composition, yield and *in vivo* digestibility

The changes in height, chemical composition, yield and *in vivo* digestibility of napier grass with time under the 2 watering regimes are shown in Table 2. Height, concentrations of DM and

ash, yields of OM and CP, and OM digestibility were affected by both watering regime and age ($P < 0.001$). The CP digestibility was affected only by age and not watering regime ($P < 0.001$).

The average height was about 70 % greater for the high-watered grass and increased by 11.53 cm wk^{-1} compared to an increase of 6.38 cm wk^{-1} for the low-watered grass. Although the DM concentration was increasing at a similar rate (3.00-g kg^{-1} DM wk^{-1}), the average was 16 % higher for the low- than the high-watered grass. The mean yields of OM and CP on the high-watered grass were 3 times those on the low-watered grass. As the grass matured, rates of increase in yields of OM was 3 times higher (0.907 vs 0.304 t ha^{-1} wk^{-1}) on the high- than low-watered grass. The yield of CP increased to a maximum (high, 1.03; low, 0.36 t ha^{-1}) at 13 weeks of grass growth for both watering regimes. The average ash concentration on the low-watered grass was slightly higher (2.3 %) than that on the high-watered grass. However, their rates of decline as the grass matured were similar (5.0-g kg^{-1} DM wk^{-1}). The average CP digestibility (high, 58.31; low, 58.53 %) and rate of decline (high, 2.87; low, 2.68 % units wk^{-1}) were similar for both watering regimes. Average OM digestibility was higher (64.47 vs 60.98 %) for the low- than the high-watered grass. However, the rate of decline in OM digestibility on the high-watered grass was faster (1.51 vs 1.24 % units wk^{-1}) than that on the low-watered grass.

Level of crude protein and yield of dry matter

The influence of watering regime on yield of DM and CP concentration as napier grass matured is shown in Figure 1. Both parameters were affected significantly ($P < 0.001$) by watering regime and age of the grass. The average CP concentration was 12 % higher for the high- than the low-watered grass but their rates of decline were similar (high, 7.60; low, 7.44 g kg^{-1} DM wk^{-1}). The following equations describe changes in CP concentration

Table 1 Extractable nutrients and pH of soil in fields A and B before experiment and at 5 weeks of napier grass growth

	Before experiment				At 5 weeks of napier growth			
	Field B		Field A		Field B		Field A	
	Top-soil	Sub-soil	Top-soil	Sub-soil	Top-soil	Sub-soil	Top-soil	Sub-soil
pH	7.73	7.89	7.59	7.69	7.82	7.78	7.61	7.66
Na (me%)	2.37	2.63	2.47	2.58	2.29	2.51	2.46	2.39
K (me%)	3.26	2.53	1.67	0.92	3.10	2.06	2.93	2.16
Ca (me%)	20.50	21.52	19.67	18.97	18.41	17.32	18.91	17.34
Mg (me%)	2.21	3.12	2.50	3.74	2.11	3.02	2.34	3.50
Mn (me%)	0.71	0.51	0.63	0.47	0.65	0.47	0.58	0.42
P (ppm)	125.36	128.41	78.42	71.30	120.42	111.70	116.41	99.72
C (%)	3.59	2.53	1.82	1.67	3.07	2.32	2.87	2.41
N (%)	0.36	0.25	0.18	0.17	0.31	0.23	0.29	0.24

pH, Hydrogen potential; Na, Sodium; K, Potassium; Ca, Calcium; Mg, Magnesium; Mn, Manganese; P, Phosphorus; C, organic Carbon; and N, Nitrogen.

Table 2 Changes in height, chemical composition, yields and *in vivo* digestibility of napier grass from 3 to 15 weeks of growth under two watering regimes

Watering regime	Regression equation	r^2	rsd	Sign
1200 mm yr^{-1}				
	$y_1 = 23.800 + 11.531\ x$	0.982	4.439	0.001
	$y_2 = 118.951 + 2.621\ x$	0.882	3.632	0.001
	$y_3 = 242.325 - 5.212\ x$	0.954	4.282	0.001
	$y_4 = -0.785 + 0.907\ x$	0.999	0.138	0.001
	$y_5 = -0.014 + 0.158\ x - 0.006\ x^2$	0.975	0.033	0.001
	$y_6 = 74.551 - 1.508\ x$	0.909	1.947	0.001
	$y_7 = 84.135 - 2.870\ x$	0.969	2.083	0.001
800 mm yr^{-1}				
	$y_1 = 10.112 + 6.381\ x$	0.957	1.957	0.001
	$y_2 = 138.874 + 3.005\ x$	0.850	5.148	0.001
	$y_3 = 249.262 - 5.488\ x$	0.863	8.284	0.001
	$y_4 = -0.097 + 0.304\ x$	0.995	0.085	0.001
	$y_5 = 0.005 + 0.053\ x - 0.002\ x^2$	0.950	0.013	0.001
	$y_6 = 75.638 - 1.241\ x$	0.923	1.462	0.001
	$y_7 = 82.645 - 2.680\ x$	0.933	2.919	0.001

r^2, variation in dependent variable (y) accounted for by age of napier grass (x) in weeks; rsd, residue standard error; y_1, height of napier (cm); y_2, dry matter concentration (g kg^{-1}); y_3, total ash concentration (g kg^{-1} DM); y_4, yield of organic matter (t ha^{-1}): y_5, yield of crude protein (t ha^{-1}); y_6, *in vivo* organic matter digestibility (%); y_7, *in vivo* crude protein digestibility (%); Sign., significance level.

(y, g kg^{-1} DM) with age (x, weeks) of the grass: $y = 169.516 - 7.604\ x$ ($r^2 = 0.977$; rsd = 4.411; $P < 0.001$), and $y = 157.187 - 7.440\ x$ ($r^2 = 0.967$; rsd = 5.174; $P < 0.001$) for the high- and low-watered grass, respectively. The average yield of DM on the high-watered grass was about 3 times that on the low-watered grass. The changes in yields of DM (y, tonnes ha^{-1}) with age (x, weeks) of the grass are described by the following equations: $y = -0.540 + 1.069\ x$ ($r^2 = 0.997$; rsd = 0.221; $P < 0.001$), and $y = 0.013 + 0.361\ x$ ($r^2 = 0.995$; rsd = 0.105; $P < 0.001$) for the high- and low-watered grass, respectively.

Yields of digestible organic matter and digestible crude protein

The changes in yields of digestible OM and digestible CP as napier grass matured under the two watering regimes are shown in Figure 2. Yields on the high- watered grass were 3 times those on the low-watered grass. Changes in yields of digestible OM (y, tonnes ha^{-1}) with age (x, weeks) of the grass could be described using the equations: $y = 0.233 + 0.453\ x$ ($r^2 = 0.992$; rsd = 0.163; $P < 0.001$), and $y = 0.189 + 0.162\ x$ ($r^2 = 0.962$; rsd = 0.131; $P < 0.001$) for the high- and low-watered grass, respectively. In contrast, the changes in yield of digestible CP (y, tonnes ha^{-1}; x, age in weeks) were described by the quadratic equation, $y = 0.066 + 0.097\ x - 0.005\ x^2$ ($r^2 = 0.859$; rsd = 0.031; $P < 0.001$) for the high-watered grass. Also, the quadratic equation, $y = 0.024 + 0.033\ x - 0.002\ x^2$ ($r^2 = 0.815$; rsd = 0.013; $P < 0.001$) described changes in yield of digestible CP for the low-watered grass.

For both watering regimes, yields of digestible CP of the grass increased to a maximum at 8-10 weeks of growth and declined thereafter. At maximum yields of digestible CP, the height was 115-140 cm and 60-75 cm for the high- and low-watered grass, respectively. Yields of DM at these stages of growth were 8.0-10.0 t ha^{-1} for high- and 3.0-3.5 t ha^{-1} for low-watered grass.

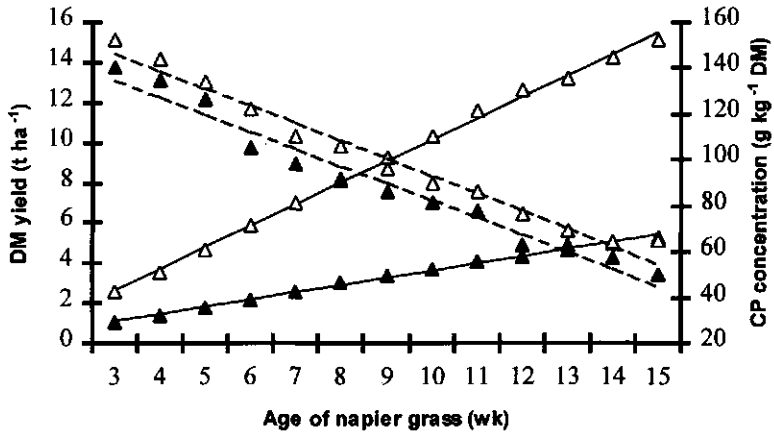

Figure 1 Yield of dry matter (–) and crude protein concentration (--) at various ages of napier grass receiving 1200 mm/yr (Δ) and 800 mm/yr (▲) of water.

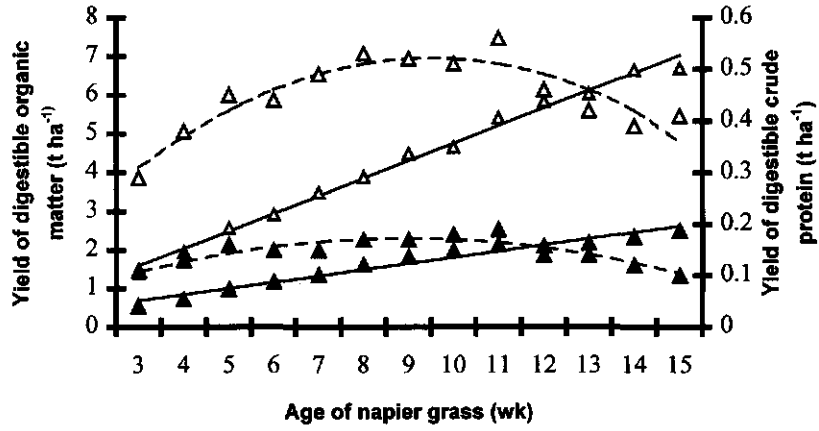

Figure 2 Yields of digestible organic matter (–) and digestible crude protein (--) at various ages of napier grass receiving 1200 mm/yr (Δ) and 800 mm/yr (▲) of water.

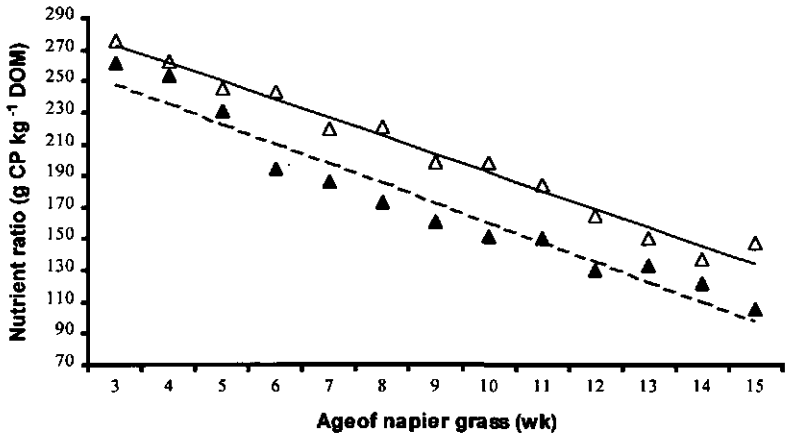

Figure 3 Crude protein: digestible organic matter ratio at various ages of napier grass receiving either 1200 mm yr^{-1} (–) or 800 mm yr^{-1} (--) of water.

Crude protein concentration: digestible organic matter ratio

Figure 3 shows the changes in nutrient ratio for napier grass under the two watering regimes. The nutrient ratios were affected significantly ($P< 0.001$) by watering regime and age of the grass. The average nutrient ratio was about 17.5 % higher for the high- than the low-watered grass although rates of decline as the grass matured were similar (high, 11.60; low, 12.47 g CP kg^{-1} DOM wk^{-1}). Linear equations were used to describe changes in nutrient ratio (y, g CP kg^{-1} DOM) with age (x, weeks) of the grass: $y = 307.948 - 11.595\ x$ ($r^2 = 0.979$; rsd = 6.846; $P< 0.001$), and $y = 285.500 - 12.466\ x$ ($r^2 = 0.943$; rsd = 12.444; $P< 0.001$) for the high- and low-watered grass, respectively.

Discussion

Crude protein concentration and yield of dry matter

The CP concentration for maintenance of a cow fed a medium quality forage of about 60-70 g kg^{-1} DM (ARC, 1984) occurred at 12-13 weeks of growth of the grass for both watering regimes. In contrast, the CP concentration for moderate milk production by dairy cows is about 100-120 g kg^{-1} DM (ARC, 1984). Using these levels of CP (conventional method), the current recommendation in Kenya is to feed grass at 60-100 cm or 6-10 weeks of growth (MLD, 1991). We achieved these concentrations at 100-120 cm (7-9 wk) and 40-55 cm (5-7 wk) for the high- and low-watered grass, respectively. At these maturity stages, the ages were within but the heights were outside the recommended ranges.

Owing to the high yields of DM, the carrying capacity on the high-watered grass (10 cows/ha) was 2.7 times that on the low-watered grass (3.7-cows ha^{-1}). Annual yields of DM and the carrying capacity on the low-watered grass were similar to the recommended 20.0 t ha^{-1} (MLD, 1991) and 3.8-cows ha^{-1} (Snijders, 1989) in Kenya. However, the use of CP concentration to determine the appropriate stage for feeding the grass to dairy cows may be limited by lack of information on rumen degradability of the protein which determine its usefulness for ruminants (Ørskov, 1982; ARC, 1984).

DM yields of napier grass increased over time due to accumulation of structural carbohydrates while CP concentration declined due to the dilution effects which occur as forages mature (Humphreys, 1991). The higher yield on field A than B could probably be attributed to the higher water supply since the fertility of the soil was comparable (Table 1). Water supply is highly associated with nutrient uptake and accumulation of biomass because of accelerated

maturation process when other factors such as temperature, soil fertility and light intensity are not limiting forage growth (Van Soest, 1982; Humphreys, 1991). Results from this study agreed with those of Anindo and Potter, (1994) and Ndikumana (1996) that yields of napier grass in the tropics are closely related to amounts of rainfall. The high rate of elongation on the high- than the low-watered grass could have also contributed to the reported high DM yields. Also, a close association was found between height and yield of napier grass by Boonman (1993).

Yields of digestible organic matter and digestible crude protein

Yield of digestible OM increased as the grass matured because the rate of increase in yield of OM was greater than the rate of decline of OM digestibility (Table 2). Although yield of CP increased to a maximum at 13 weeks as the grass matured, yield of digestible CP increased to a maximum at a height of 115-140 cm (8-10 wk) and 60-75 cm (8-10 wk) on the high- and low-watered grass, respectively. The observed changes in yield of digestible CP as the grass matured reflect the slow rate of increase in yield of CP to the age of 13 weeks and a decline thereafter, and the faster rate of decline in CP digestibility. Maximum yields of digestible CP were obtained within the recommended ages of 6-10 weeks for the grass under both watering regimes. However, at these stages of maturity, the heights for the high-watered grass were outside the 60-100 cm range recommended in Kenya. Although use of digestible nutrients may be superior to the conventional method, the interrelationship of protein and energy was not considered.

Crude protein concentration: digestible organic matter ratio

The nutrient ratio requirement for moderate milk yield by dairy cows is 194 g CP kg^{-1} DOM (Tamminga, 1989). This ratio occurred at 130-140 cm (9-10 wk) and 55-60 cm (7-8 wk) for the

high- and low-watered grass, respectively. At these stages of maturity, the CP concentration in the grass under both watering regimes was 90-100 g kg^{-1}. Van Vuuren et al. (1990) obtained an optimal protein: energy ratio at a wider range of CP (69-100 g kg^{-1} DM) concentration in fresh temperate grass than in the current study. At these stages of maturity, the ages were within but the heights were outside the recommended ranges. The obtained stages of maturity to harvest the grass were more specific and different for the two watering regimes than from the other two methods. For each watering regime, the yields of DM and carrying capacities were comparable to the values obtained using the other two methods.

The use of this method indicated that a well managed napier grass could be utilised as a maintenance diet even at advanced maturity since the 130 g CP kg^{-1} DOM ratio required for optimal rumen microbial growth (ARC, 1984) was achieved at about 14-15 weeks for both watering regimes. However, the high CP concentration at young ages implied that the grass could not be utilised efficiently for milk production since the nutrient ratios were higher than the critical value of 210 g CP kg^{-1} DOM (Poppi and Mclennan, 1995). This critical nutrient ratio level occurred at 122-128 cm (8.5-9.0 wk) and 50 cm (6 wk) for the high- and low-watered grass, respectively. When nutrient ratios of fresh grass are above the critical level, there are losses of protein or incomplete net transfer of protein from the rumen to the intestine (Poppi and Mclennan, 1995).

Nitrogen in fresh grass is highly digestible in the rumen and results in low efficiency of microbial protein synthesis and energy utilisation (Ørskov, 1982; ARC, 1984). Therefore, utilisation of this grass at a maturity below 120 cm (8.5 wk) and 50 cm (6 wk) in the high and medium rainfall areas, respectively should be accompanied by a readily fermentable energy source (*e.g.* molasses) to maximise rumen microbial activity and growth. This would lead to a better supply of protein of microbial origin in the small intestines. However, for high milk

yields, a source of undegradable protein in the rumen (*e.g. Leucaena leucocephala*) should be incorporated in the diets (NRC, 1988). Alternatively, for high milk yields, supplements high in energy and protein should be provided when the grass is fed to dairy cows at 130-140 cm (9-10 wk) and at 55-60 cm (7-8 wk) in the high and medium rainfall areas, respectively.

At the stages of maturity suitable for milk production, the average CP concentration (90-100 g kg^{-1} DM) and OM digestibility (60 %) of the grass could support daily milk yields of about 10-12 kg cow^{-1} (ARC, 1984). At similar CP concentrations, daily milk yields varied and were lower (5 -10 kg cow^{-1}) when dairy cows were fed a napier grass only diet (Anindo and Potter, 1986; Muinga et al., 1992; Muinga et al., 1995). Also, from their reports and results obtained by Combellas and Martinez (1982) supplementing napier grass with either concentrates or fodder trees (120-140 g CP kg^{-1} DM of diet) gave low milk yields (8 -15 kg cow^{-1}) than the 15 - 20 kg cow^{-1} expected from similar CP concentrations (ARC, 1984). Our results indicated that the critical CP concentration for milk production by dairy cows was 90-g kg^{-1} DM, a level below which the grass should be supplemented with a rumen degradable nitrogen source.

The CP concentration recommended for maintenance and production in ruminants by ARC (1984) are based on temperate forages and may not be appropriate when dealing with tropical forages. Tropical forages are more fibrous than temperate forages and a higher proportion of their nitrogen is not available to ruminants because it is bound within the indigestible vascular bundles (Van Soest, 1982). Furthermore, the high levels of non-protein nitrogen in tropical forages is an indication that the true protein is low suggesting that the CP concentration value (N x 6.25) tend to overestimate the value of protein to ruminants (Reeves et al., 1996). It may be because of these characteristics that Hennessy (1980) suggested a higher critical CP concentration for tropical forages (81.3 g kg^{-1} DM) than the quoted value of 68.8 g kg^{-1} for temperate forages (ARC, 1984).

The soil fertility status and management of napier grass were better than in most farms in Kenya. It is, therefore, expected that when fertility of soil is lower than in the current study, the grass be harvested at young ages or lower heights when the quality is good (protein: energy ratio) for milk production by dairy cows. Feeding the grass at young ages implies less carrying capacity but more milk yield per animal. It is only in exceptional farms that fertility of soil and management of napier grass will be better than in the current study. In such circumstances, it is expected that the grass be harvested at a more advanced maturity and at a higher carrying capacity than our recommendations. In addition to soil fertility, the amount of rainfall as was observed in this study, is expected to influence harvesting stage and yields of napier grass.

The nutrient ratio method takes into account the interactions of energy and protein, which are known to have a major influence on performance of animals (Tamminga, 1982; Nocek, 1988; Oldham, 1988). This method, therefore, has advantages over the previous two methods in determining the suitable maturity for feeding the grass to dairy cows. However, the importance of the quality of the protein which determine the extent of degradability in the rumen and the ability to escape rumen digestion (Tamminga, 1982; Nocek, 1988; Oldham, 1988) is one of the drawbacks in the use of this method.

Conclusions

The optimal harvesting ages determined using optimal CP concentration, yields of digestible OM and CP, and CP concentration: digestible organic matter ratio methods were within the 6-10 weeks range whereas the heights were outside the 60-100 cm range that are recommended in Kenya. The CP concentration: digestible organic matter ratio method was preferred to either

optimal CP concentration or optimal yields of digestible nutrient method since the interrelationship between protein and energy concentrations in the grass was considered. The use of this method indicated that grass in medium rainfall areas should be harvested earlier (55-60 cm; 7-8 wk) and that in high rainfall areas later (130-140 cm; 9-10 wk) than currently recommended.

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References

Anindo, D. O. and Potter, H. L., 1986. Milk production from napier grass in zero-grazing feeding system. East African Agriculture and Forestry Journal, 52: 106 - 111.

Anindo, D. O. and Potter, H. L., 1994. Variation in productivity and nutritive value of napier grass at Muguga, Kenya. East African Agriculture and Forestry Journal, 59: 117-185.

AOAC, 1990. Official methods of analysis. 15th Edn. Association of Official Agricultural Chemist, Washington, DC.

ARC, 1984. The nutrient requirements of ruminant livestock. Supplement No. 1. Agricultural Research Council. Commonwealth Agricultural Bureaux: Farnham Royal, UK.

Boonman, J. G., 1993. East Africa's grasses and fodder: their ecology and husbandry. Cluwer Academic Publishers: Dordrecht, The Netherlands.

Close, W. and Menke, K. H., 1986. Selected topics in animal nutrition. A Manual Prepared for the 3 rd Course on Animal Nutrition in the Tropics and Semi-tropics. 2 nd edn. University of Hohenheim: Germany.

Combellas, J. and Martinez, N., 1982. Intake and milk production in cows fed chopped elephant grass (*Pennisetum purpureum*) and concentrate. Tropical Animal Production, 7: 57-60.

Hennessy, D.W., 1980. Protein nutrition of ruminants in tropical areas of Australia. Tropical Grasslands, 14: 200-265.

Hinga, G., Muchena, F.N. and Njihia, C.M., 1980. Physical and chemical methods of soil analysis. National Agricultural Laboratories Manual. Ministry of Agriculture, Kenya.

Humphreys, L.R., 1991. Tropical pasture utilization. Cambridge University Press: Great Britain.

Jaetzold, R. and Schmidt , H., 1983. National conditions and farm management information. East Africa, 2 c. Ministry of Agriculture: Nairobi, Kenya.

McDonald, P., Edwards, R. A. and Greenhalgh, J. F. D., 1988. Animal nutrition. 4th Edition. Longman group publishers: London.

MLD, 1991. Zero-grazing (Updated version). A handbook on technical aspects (compiled by A. P. Wouters, October 1986). Ministry of Livestock Development, NDDP, Nairobi, Kenya.

Muinga, R. W., Thorpe, W. and Topps, J.H., 1992. Voluntary feed intake, live-weight change and lactation performance of crossbred dairy cows given ad libitum *Pennisetum purpureum* (napier grass var. Bana) supplemented with *Leucaena* forage in the lowland semi-humid tropics. Animal Production, 55: 311 - 337.

Muinga, R. W., Thorpe, W. and Topps, J. H., 1995. The effect of supplementation with *Leucaena leucocephala* and maize germ on voluntary food intake, digestibility, live-weight and milk yield of *Bos indicus* x *Bos taurus* dairy cows and rumen fermentation in steers offered *Pennisetum purpureum* ad-libitum in semi-humid tropics. Animal Science, 60: 13-23.

Ndikumana, J., 1996. Multi-locational evaluation of napier and *Pennisetum* hybrids: highlights of research results from the Addis Ababa. The Africa Feed Resources Network Newsletter (AFRNET), 6: 2-8..

Nocek, J. E., 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. Journal of Dairy Science, 71: 2070-2107.

NRC, 1988. Nutrient requirements of dairy cattle. 6th revised Edition. National Research Council. National Academic Press: Washington, DC.

Oldham, J. D., 1988. Protein - energy interrelationships in dairy cows. Journal of Dairy Science, 67: 1090 - 1114.

Ørskov, E. R., 1982. Dynamics of nitrogen in the rumen. In: Ørskov, E. R. (Ed.), Protein Nutrition in the Ruminants. Academic Press Inc: London. pp 40-84.

Poppi, D. P. and McLennan, S. R., 1995. Protein and energy utilization by ruminants at pasture. Journal of Animal Science, 73: 278-290.

Reeves, M. Fulkerson, W.J. and Kellaway, R.C., 1996. Forage quality of Kikuyu grass (*Pennisetum clandestinum*): the effect of time of defoliation and nitrogen fertiliser application and in comparison with perennial rye grass (*Lolium perenne*). Australian Journal of Agricultural Research, 147: 1349-1359.

SAS, 1988. SAS/START User's guide. Release 6.03 Edition. Statistical analysis systems institute Inc.: Cary, NC, USA.

Snijders, P. J. M., 1989. Feeding and fertilizer requirements of zero-grazing under good management. Ministry of Livestock Development, NDDP, Naivasha, Kenya. 18 pp.

Stotz, D., 1981. The attractiveness of arable fodder crop systems for smallholder dairy farms in Kenya. In: Research and Development, Volume 11: 75 - 82.

Tamminga, S., 1982. Energy-protein relationships in ruminant feeding: similarities and differences between rumen fermentation and post-ruminal utilization. In: Miller, E. L., Pike, I. H. and Van Es, A. J. H. (Eds.), Protein Contribution of Feedstuffs for Ruminants. Butterworth: London. pp 4-17.

Tamminga, S., 1989. Supplementation and fermentation of ruminant diets based on crop residues. IVVO report, No. 204. Lelystad, The Netherlands.

Thomas, G., Njoroge, P. K. and Fenlon, J. G., 1980. Prediction of digestibility in three tropical grasses. Tropical Agriculture (Trinidad), 57: 75-81.

Van Es, A. J. H., 1980. Recent advances on the nutrition of farm animals. In: Verde, L. S. and Fernandez, A. (Eds.), Proceedings of the 4 th Annual Conference on Animal Production, Buenos Aires. pp 336-423.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B books: Corvallis, Oregon, USA.

Van Soest, P. J. and Robertson, J. B., 1985. Analysis of forage and fibrous foods. A Laboratory Manual for Animal Science, No. 613.

Van Vuuren, A.M., Tamminga, S. and Ketelaar, R.S., 1990. Ruminal availability of nitrogen and carbohydrate from fresh and preserved herbage in dairy cows. Netherlands Journal of Agricultural Science, 38: 499-512.

Chapter 5

Prediction of yield and digestibility of napier grass *(Pennisetum purpureum)* from maturity, leaf: stem ratio and laboratory analyses

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Abstract

Simple or multiple linear and quadratic regressions were developed by pooling weekly data on maturity, leaf: stem ratio and laboratory analyses parameters (independent variables) to predict dry matter (DM) yield and digestibility (dependent variables) of napier grass under two watering regimes on-station. The accuracy of these regressions were assessed using data obtained at different periods on-station and on-farm. The dry matter (DM) yield could be accurately estimated using age or height whereas *in vitro* organic matter digestibility (OMD) was predicted better from detergent fibres, lignin and crude protein content. Prediction of DM yield was more accurate than that of *in vitro* OMD. Multiple regression equations accounted for more variations in DM yield, *in vitro* OMD and *in vivo* digestible organic matter than equations derived from single independent variables. Some of the regression equations could accurately predict DM yields and *in vitro* OMD on-station at different years. However, prediction of DM yield on-farm was less accurate and possible only for the high rainfall districts.

Keywords: Napier grass, Yeld, Digestibility, Prediction

Introduction

Napier grass is an important fodder crop for smallholder dairy farmers in the high and medium rainfall areas of Kenya (Valk, 1990). Information on yields, chemical composition and *in vitro* digestibility of this grass under research conditions exist (Boonman, 1993). However, animal performance at farm level is often poor mainly due to insufficient quantity and low quality fodder (Wouters, 1987).

Attempts have been made to develop relationship of yield and *in vitro* digestibility with maturity, leaf: stem ratio, and chemical composition (Schreuder et al., 1993). However, the value of regression equations developed on-station for on-station and on-farm is uncertain. Simple and inexpensive methods for estimating yield and nutritive value would enable farmers to minimise overstocking and improve animal performance. Also, the earlier prediction equations lacked data on *in vivo* digestibility, which is a more accurate measure than *in vitro* digestibility (McDonald et al., 1988). This study sought to develop linear and quadratic regression equations for prediction of DM yield, *in vitro* OMD and *in vivo* DOM of napier grass from maturity, leaf: stem ratio (LSR) and laboratory analyses on-station. The accuracy of these prediction equations in estimating DM yield and digestibility at different occasion on-station and on-farm was also assessed.

Materials and methods

The study was at Naivasha (1940-m altitude, 620-mm annual rainfall, 18 ° C mean temperature) from May 1994 to February 1995. Napier grass (var. Bana) was established in two fields at a spacing of 60 cm in the rows and 90 cm between rows. Fertilization was with

100:100:150 kg/ha of N: P_2O_5; K_2O respectively. The two fields A and B were irrigated to simulate annual precipitation in the high (1200 mm) and medium (800 mm) rainfall areas respectively. The DM yield, *in vivo* DOM, *in vitro* OMD, height, LSR and chemical composition under the two irrigation regimes were determined at weekly intervals as the grass matured from the 3 rd to the 15 th week. Height of the grass was estimated from the ground level to the apex of most leaves using a calibrated 2-m stick. The DM yield per ha was extrapolated from the yield of the harvested material. The LSR was determined by drying at 105 $^{\circ}$C for 24 h.

At each stage of maturity, *in vivo* DOM was determined by feeding the grass to 6 mature Dorper wethers (Age 16.2 ± 1.7 month, and body weight 40.4 ± 3.2 kg) in individual metabolism cages to allow separate feeding (at maintenance level), watering and total faecal collection. Adequate grass was harvested at respective maturity stages and chopped to 2.5 cm (to minimise selection), weighed and stored at -20 $^{\circ}$C, to be fed during the 14-day and 5-day adaptation and faecal collection periods respectively. Since all the 6 sheep were used in each trial, the digestibility of the grass from field A was determined first and that from field B, 19 days later. Feeding was done 3 times a day (8.00; 13.00 and 18.00 h). Mineral salts were offered at a daily rate of 25 g per sheep and clean water was available all the time. Total collection and weighing of faeces were done for each sheep before the morning feeding and representative samples (20 % of total collection) were preserved with formalin solution (10 % l.c) and stored in tightly closed plastic containers at 3-5 $^{\circ}$C. The *in vivo* DOM was calculated according to Close and Menke (1986).

Three samples were obtained from the *in vivo* DOM trial. The first was used to determine *in vitro* OMD (Tilley and Terry, 1963). Rumen liqour was obtained from 4 fistulated sheep fed 1 kg of *Medicago sativa* (lucerne) hay (145 g CP kg^{-1} DM; 450 g NDF kg^{-1} DM) and *Chloris gayana* (Rhodes grass) hay, (76 g CP kg^{-1} DM; 610 g NDF kg^{-1} DM) mixture

at 3:1 ration. Each sheep was supplemented with 100-g calf pellets (205 g CP kg^{-1} DM). The second sample was used to determine DM content of the grass (105 ° C for 24 h). For chemical analysis, the third sample was dried at 70 ° C for 24 h and ground through a 1-mm sieve of a Wiley mill. Total ash was obtained by ashing at 450 ° C for 6 h. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) contents were determined according to Van Soest and Robertson (1985). The crude protein (CP) content of the grass was determined by the AOAC method (1990) whereas that of the wet faecal samples was determined by the method of Van Soest and Robertson (1985). Data from the two irrigation regimes were pooled and correlation coefficients for all variables were obtained. Simple or multiple linear and quadratic regression equation were developed using either single or different combinations of age, height, LSR, DM, ash, CP, NDF, ADF and ADL contents, and *in vitro* OMD (independent variable) to predict DM yield, *in vivo* DOM and *in vitro* OMD (dependent variables). The best-fitting multiple regression equations were obtained using the step-wise selection criteria. The equations were ranked starting with the more precise (lowest RSD) and those accounting for more variation (highest Adj R^2) in the dependent variables. Independent variables determined on-station at Naivasha (Wouters, 1985; Wouters, 1986; Van der Kamp, 1987; Kariuki, 1989), Kakamega and Kisii (Snijders et al., 1992) and on-farm in various districts (Wouters, 1987) were fitted into these equations to predict DM yield and *in vitro* OMD. The relationship of observed (Y) and predicted (x) DM yield and *in vitro* OMD were developed to assess the reliability of the regression equations developed on-station in prediction of these dependent variables at different periods either on-station or on-farm. The correlation and regression equations were developed by SAS (1988). Although DM yield data was available both on-station and on-farm the *in vitro* OMD data was only available on-station.

Table 1 Correlation coefficients of parameters of napier grass when data were pooled for the two watering regimes

	Age	HT	LSR	DM	ASH	CP	NDF	ADF	ADL	DMY	DOM	OMD
Age	1.00***											
HT	0.82***	1.00***										
LSR	-0.95***	-0.74***	1.00***									
DM	0.52**	0.02NS	-0.52**	1.00***								
ASH	-0.81***	-0.65***	0.79***	-0.48*	1.00***							
CP	-0.94***	-0.69***	0.92***	-0.55**	0.78***	1.00***						
NDF	0.89***	0.67***	-0.85***	0.58**	-0.76***	-0.80***	1.00***					
ADF	0.56**	0.88***	-0.44*	0.17NS	-0.39*	-0.40*	0.44*	1.00***				
ADL	0.95***	0.77***	-0.93***	0.52**	-0.78***	-0.91***	0.88***	0.52**	1.00***			
DMY	0.64***	-0.92***	-0.56**	0.17NS	-0.48*	-0.53**	0.52**	0.94***	0.65***	1.00***		
DOM	-0.90***	-0.90***	0.83***	-0.26NS	0.71***	0.82***	-0.79***	-0.76***	-0.85***	-0.83***	1.00***	
OMD	-0.90***	-0.90***	0.81***	-0.23NS	0.69***	0.81***	-0.78***	-0.70***	-0.85***	-0.79***	0.91***	
	1.00***											

Age (weeks); HT, height (cm); LSR, leaf: stem ratio; DM, dry matter (g kg^{-1} DM); ash (g kg^{-1} dm); CP, crude protein (g kg^{-1} DM); NDF, neutral detergent fibre (g kg^{-1} DM); ADF, acid detergent fibre (g kg^{-1} DM); ADL, acid detergent lignin (g kg^{-1} DM); DMY, dry matter yield (tons ha^{-1}); DOM, *in vivo* digestible organic matter (g kg^{-1} DM) and OMD, *in vitro* organic matter digestibility (g kg^{-1} OM); ***, **, and *, significant at $P < 0.001$, $P < 0.01$, and $P < 0.05$ respectively; NS, not significant at $P > 0.05$.

Table 2 Ranking of equations for predicting DM yield of napier grass

	On-station								On-farm (N = 14)			
Ranking (N = 26)	AdR^2	RSD	sign.	Relationship	AdR^2	RSD	N	sign.	Relationship	AdR^2	RSD	sign.
y = - 21.75 - 0.64 AGE + 0.05 HT + 0.04 ADF + 0.47 ADL	0.95	1.04	***	Y = 3.13+0.53 x	0.68	2.38	19	***	-	-	-	-
y = - 11.27 + 0.04 HT+ 0.4 ADF	0.92	1.24	***	Y = 1.28+0.72 x	0.17	3.50	30	NS	-	-	-	-
y = -1.39 - 0.37 AGE + 0.11 HT + 0.04 LSR	0.89	1.15	***	Y = 1.20 +1.31x	0.59	2.51	30	***	-	-	-	-
y = -1.20 - 0.38 AGE + 0.11 HT	0.89	1.47	***	Y = 1.17+1.29 x	0.59	2.52	30	***	y = 2.58 + 0.32 x	0.44	0.83	**
y = - 16.40 + 0.07 ADF	0.88	1.48	***	Y = 0.45+0.75 x	0.34	3.13	11	**	-	-	-	-
$y = 1.61 + 0.0004\ HT^2$	0.86	1.62	***	Y = -0.78+1.48x	0.84	1.56	30	***	y = 1.14 + 0.52 x	0.49	0.80	**
y = - 2.12 + 0.08 HT	0.85	1.68	***	Y = 0.33+1.26 x	0.85	1.54	30	***	y = 1.63 + 0.46 x	0.51	0.77	**
y = 38.52 - 0.05 OMD	0.60	2.68	***	Y = 1.46+1.16 x	0.58	2.55	30	***	-	-	-	-
y = - 0.26 + 0.72 AGE	0.41	3.33	***	Y = -1.36 +1.33 x	0.89	1.27	11	***	y = 7.75 + 0.53 x	0.39	0.86	**
y = - 15.21 + 0.61 ADL	0.40	3.30	***	Y = 2.01+ 0.58 x	0.64	2.53	30	***	-	-	-	-
y = 11.45 - 2.22 LSR	0.28	3.60	**	Y = -5.30 +1.61 x	0.78	1.85	30	***	-	-	-	-
y = 13.73 - 0.08 CP	0.27	3.67	**	Y = -0.36 +1.00 x	0.47	2.84	17	***	y = 2.56 + 0.14 x	-0.07	1.15	NS
y = - 20.65+ 0.05 NDF	0.24	3.71	**	Y = 0.49 + 0.71 x	0.32	3.18	17	*	-	-	-	-
y = 21.96 - 0.08 ASH	0.19	3.82	*	Y = 0.51 +1.00 x	0.47	2.97	20	***	y = 2.90 + 0.10 x	-0.01	1.12	NS
y = 12.79 - 0.04 DM	0.03	4.28	NS	Y = 19.39 -2.35 x	0.66	2.47	19	***	-	-	-	-

AdR^2, variation in the dependent variable accounted for by the independent variable (s) when adjusted for the number of variables in the model; RSD residue standard error; N, number of observations; y, dry matter (DM) yield (tons ha^{-1}); Y, observed DM yield; x, predicted DM yield; sign., significance level of fit; other abbreviations and symbols as Table 1.

Table 3 Ranking of equations for prediction of *in vitro* OMD of napier grass

				On-station				
Ranking (N = 26)	AdR^2	RSD	sign.	Relationship	AdR^2	RSD	N	sign.
y = 771.875 - 26.567 AGE - 29.096 LSR + 1.236 DM	0.91	21.31	***	Y = 314.54 + 0.55 x	0.44	43.03	19	**
y = 903.722 - 15.450 AGE - 0.616 HT - 21.128 LSR	0.90	22.49	***	Y = 308.65 + 0.57 x	0.62	31.92	30	***
y = 802.985 - 9.138 AGE - 0.681 HT	0.89	23.02	***	Y = 249.01 + 0.66 x	0.65	30.49	30	***
y = 797.110 - 16.016 AGE	0.82	29.36	***	Y = 320.15 + 0.57 x	0.64	31.23	30	***
y = 1138.367 - 0.409 ADF -10.095 ADL	0.82	30.04	***	Y = 357.42 + 0.51 x	0.86	23.56	11	***
y = 791.917 - 1.534 HT + 0.001 HT^2	0.81	30.98	***	Y = 108.82 + 0.85 x	0.59	33.16	30	***
y = 781.038 - 1.286 HT	0.80	30.44	***	Y = 74.12 + 0.90 x	0.59	33.22	30	***
y = 720.916 - 0.006 HT^2	0.76	33.99	***	Y = -32.98 + 1.07 x	0.55	34.76	30	***
y = 1099.825 - 12.810 ADL	0.72	35.90	***	Y = 382.94 + 0.47 x	0.85	25.14	11	***
y = 530.314 + 51.408 LSR	0.65	40.01	***	Y = 185.29 + 0.79 x	0.58	33.77	30	***
y = 470.982 + 1.802 CP	0.64	40.43	***	Y = 258.51 + 0.67 x	0.71	27.85	30	***
y = 1294.375 - 1.100 NDF	0.59	43.07	***	Y = 320.26 + 0.58 x	0.58	37.51	17	***
y = 919.154 - 0.817 ADF	0.47	49.38	***	Y = -43.60 + 1.13 x	0.50	41.20	17	***
y = 291.063 + 1.866 ASH	0.45	50.10	***	Y = 341.50 + 0.52 x	0.37	43.20	20	***
y = 797.623 - 0.943 DM	0.05	67.07	NS	Y = -232.18 + 1.45 x	0.67	32.99	19	***

y, *in vitro* OM digestibility (g kg^{-1} OM); Y, observed *in vitro* OM digestibility; x, predicted *in vitro* OM digestibility; other abbreviations and symbols as Tables 1 and 2.

Table 4 Ranking of equations for prediction of *in vivo* digestible organic matter of napier grass

Ranking (N = 26)	AdR^2	RSD	sign.
y = 683.15 - 6.53 AGE - 0.60 HT	0.91	16.69	***
y = 708.62 - 8.12 AGE - 0.58 HT - 5.34 LSR	0.91	16.97	***
y = 436.17 + 0.70 CP - 0.34 ADF + 0.26 OMD	0.91	17.13	***
$y = 692.76 - 1.61 HT + 0.003 HT^2$	0.85	21.57	***
y = 667.48 - 1.03 HT	0.83	21.92	***
y = 96.90 + 0.72 OMD	0.82	22.28	***
y = 677.99 - 12.57 AGE	0.82	23.25	***
$y = 618.39 - 0.004 HT^2$	0.76	26.52	***
y = 916.03 - 10.07 ADL	0.72	28.25	***
y = 466.65 + 41.16 LSR	0.68	30.28	***
y = 420.75 + 1.43 CP	0.65	31.34	***
y = 1080.99 - 0.89 NDF	0.62	32.57	***
y = 793.18 - 0.70 ADF	0.56	35.14	***
y = 268.67 + 1.53 ASH	0.49	37.89	***
y = 690.25 - 0.82 DM	0.07	52.41	NS

y, *in vivo* digestible organic matter (g kg^{-1} DM); other abbreviations and symbols as Tables 1, 2, and 3.

Results

The DM yield was highly correlated with age, height, ADF, ADL and *in vitro* OMD whereas *in vitro* OMD and *in vivo* DOM were highly correlated with age, height, LSR, Ash, CP, NDF, ADF and ADL contents (Table 1). Also, *in vivo* DOM was highly correlated with *in vitro* OMD. Multiple equations derived from age, height, LSR, CP and detergent fibre and lignin contents explained more variations in DM yield (Table 2), *in vitro* OMD (Table 3), and *in vivo* DOM (Table 4) than single independent variables. The ADF content and height accounted for more variations in DM yield than any other independent variable. Among the single variables, age and height explained more variation in *in vitro* OMD whereas age, height and *in vitro* OMD accounted for more variation in *in vivo* DOM. The DM yield was accurately predicted (R^2 > 85 %) using age or height on-station (Table 2). A multiple linear equation derived from ADF and ADL contents, and the use of ADL or CP contents as single independent variables were more accurate (R^2 > 70 %) predictors of *in vitro* OMD on-station than the other equations (Table 3). Among all the developed equations, only those derived from age or height could be used with some accuracy (R^2 = 50) to estimate DM yield on-farm (Table 2).

Discussion

In this study, prediction of DM yield (highest R^2 = 89 %; lowest RSD = 1.27) of napier grass was more accurate than that of *in vitro* OMD (highest R^2 = 86 %; lowest RSD = 23.56). This was probably because digestibility is a lot more complex than yield and is influenced by many factors, the major ones being food and animal related (Minson, 1990; Humphreys, 1991).

The *in vitro* OMD is therefore, more closely correlated to *in vivo* DOM than chemical and other plant related factors because, it tends to eliminate most of the animal related variations (McDonald et al., 1988). Multiple regression equations accounted for more variations in DM yield, *in vitro* OMD and *in vivo* DOM than equations derived from single variables, in agreement with Snijders et al. (1992) and Schreuder et al. (1993). However, since regressions derived from single variables predicted DM yield and *in vitro* OMD better than multiple equations, the accuracy of prediction equations has probably been influenced by other non-plant related factors such as meteorological parameters (Minson, 1990). The multiple regression equations obtained using chemical composition parameters were not accurate estimators of digestibility of Bermuda grass (*Cynodon dactylon* (L.) pers.) even when they exhibited a high R^2 and low RSD values. As was the case in our study, the chemical composition may not necessarily cover all the components, which affect forage digestibility (Golding et al., 1976).

Our observation that in napier grass height accounted for more variations in DM yield than age agreed with work by Mislevy et al. (1989), Snijders et al. (1992), and Schreuder et al. (1993). Age and height are reasonable measures of maturity for forage such as napier grass with an erect growth habit (Van Soest, 1982). Although most forages exhibit a sigmoidal growth pattern, there is usually a positive and high correlation between DM yield and maturity at the active growth phase (Humphreys, 1991). Napier grass is usually harvested at the active phase of growth, so prediction of DM yield using age or height should be more reliable than LSR, chemical composition or i*n vitro* OMD. Age or height could accurately estimate DM yield during different years on-station possibly because of better fertilizer application, management and water supply. The prediction of DM yield on-farm was less accurate as on-station mainly because of the differences in soil fertility, growth period and farmers' management practices and in some cases, the weather. These factors are associated with

variations in yield of napier grass (Wouters, 1987; Anindo and Potter, 1994). Consequently, DM yields on-farm could only be predicted if most of the relevant variables are included in the prediction equations. However, use of age or height is simple and cheaper, so that may outweigh their reduced accuracy on-farm.

The detergent fibres, lignin and CP content were not highly correlated and so they could not explain the variations in *in vitro* OMD as in previous studies with napier grass (Hassan and Osman, 1984; Kariuki, 1989; Snijders et al., 1992). This may be because the correlation coefficients and regression equations in our study were developed after pooling data from the two irrigation regimes. The variations accounted for by detergent fibres, lignin and CP content when estimating *in vitro* OMD were comparable to those reported by Thomas et al. (1980) for napier and other tropical grasses. As plants mature, there is a decline in CP content and digestibility but the detergent fibres and the degree of lignification increase (Van Soest, 1982; Cherney et al., 1993). Thus the digestibility of forages is negatively affected by detergent fibres and the degree of lignification (Wilson et al., 1991; Reeves et al., 1996; Wilson and Hatfield, 1997) as we observed. The CP content is related to digestibility through its influence on microbial protein synthesis and rumen degradability (Matejovsky et al., 1995), which may be why this independent variable can reasonably predict *in vitro* OMD.

The use of *in vitro* OMD to predict *in vivo* DOM is complicated by differences in the digestive efficiency of the rumen liquor which can result in variations within and between batch runs (Ayres, 1991). Most of these problems can be overcome by including in each run samples of known *in vivo* digestibility as similar as possible to the samples being tested. The cost of the two-stage *in vitro* digestibility and chemical composition analysis limit application of these methods for prediction of digestibility of napier grass at farm level.

Conclusion

The prediction of DM yield was more accurate than that of *in vitro* OMD. Age or height was more accurate in prediction of DM yield whereas detergent fibres, lignin and CP contents were better in estimation of *in vitro* OMD on-station. Prediction of DM yield was less accurate on-farm.

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References

Anindo, D.O. and Potter, H.L., 1994. Variation in productivity and nutritive value of napier grass at Muguga, Kenya. East African Agriculture and Forestry Journal, 59:117-185.

AOAC, 1990. Official methods of analysis, 15th Edition. Association of Official Analytical Chemists Washington, DC.

Ayres, J.F., 1991. Sources of error with *in vitro* digestibility assay of pasture feeds. Grass and Forage Science, 46: 89 - 97.

Boonman, G.J., 1993. East African's grasses and fodder: their ecology and husbandry. Kluwer Academic Publishers. Dordrecht, The Netherlands.

Cherney, D.J.R., Cherney J.H. and Lucey R.F., 1993. *In vitro* digestion kinetics and quality of perennial grasses as influenced by forage maturity. Journal of Dairy Science, 76: 790-797.

Close, W. and Menke, K. H., 1986. Selected topics in animal nutrition. A Manual for Course on Animal Nutrition in the Tropics and Semi-tropics, 2nd Edn. University of Hohenheim.

Golding, E.J., Moore, J.E., Franke, D.E., and Ruelke, O.C., 1976. Formulation of hay grass diets for ruminants. 1. Evaluation of multiple regression equations for predicting of Bermuda grass hay quality from laboratory analysis. Journal of Animal Science, 42: 710-716.

Hassan, N I and Osman, A.F., 1984. Relationship among agronomic characters, chemical composition and *in vitro* digestibility parameters of napier grass. World Review of Animal Production, 20: 45-50.

Humphreys, R.L., 1991. Tropical pasture utilization. Cambridge University Press, Great Britain.

Kariuki, J.N., 1989. Evaluation of two cultivars of napier grass (*Pennisetum purpureum*) under irrigation at different stages of regrowth. Msc. Thesis, University of Nairobi, Kenya.

Matejovsky, K.M. and Sanson, D.W., 1995. Intake and digestion of low-, medium- and high-quality grass hays by lambs receiving increasing levels of corn supplementation. Journal of Animal Science, 73: 2156-2163.

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D., 1988. Animal nutrition, 4th Edition. Bath Press, Avon, Great Britain.

Minson, D.J., 1990. Forage in ruminant nutrition. Academic Press, Inc. San Diego.

Mislevy, P., Martin, F.G. and Adjei, M.B., 1989. Changes in Elephant grass plant components with maturity. 1. Percentage dry matter. 16th grassland congress, Nice, France. pp 951 -952.

Reeves, M., Fulkerson, W.J. and Kellaway, R.C., 1996. Forage quality of Kikuyu grass (*Pennisetum clandestinum*): the effect of time of defoliation and nitrogen fertilizer application and in comparison with perennial ryegrass *(Lolium perenne)*. Australian Journal of Agricultural Research, 47: 1349-1359.

Schreuder, R., Snijders, P.J.M., Wouters, A.P., Steg, A. and Kariuki, J.N., 1993. Variation in organic matter digestibility (*in vitro*), yield, crude protein and ash content of napier grass (*Pennisetum purpureum*) and their prediction from chemical and environmental parameters. Kenya Agricultural Research Institute, Naivasha, Kenya. 62 pp.

Snijders, P.J.M., Orodho, A.B., Kiura, J. N. and Mogaka, L.M., 1992. Effect of nitrogen fertilizer and cutting stage on yield and quality of napier grass (*Pennisetum purpureum*). Kenya Agricultural Research Institute, Naivasha, Kenya. 46 pp.

SAS, 1988. SAS/STAT user's guide, release 6.03 Edition. Statistical Analysis System Institute Inc. carry, N.C.

Thomas, C. Njoroge, P.K. and Fenlon, J.S., 1980. Prediction of digestibility in three tropical grasses. Tropical Agriculture (Trinidad) 57: 75-81.

Tilley, J.M.A. and Terry, R.A., 1963. A two-stage technique for the *in vitro* digestion of forage crops. Journal of British Grassland Society, 18: 104-111.

Valk, Y.S., 1990. Review reports of the DEAF surveys during 1989. Ministry of Livestock Development, NDDP/M41/200, Nairobi, Kenya. 69pp.

Van der Kamp, A., 1987. Napier grass in Kenya. A review and nitrogen fertilization trial. Ministry of Livestock Development, NDDP, NAHRC, Nairobi, Kenya. 47 pp.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B Books, Corvallis, OR, USA.

Van Soest, P.J. and Robertson, J.B., 1985. Analysis of forage and fibrous foods. A Laboratory Manual for Animal Science 613. Cornell University.

Wilson, J.R., Deinum, B. and Engels, F.M., 1991. Temperature effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. Netherlands Journal of Agricultural Science 39: 31-48.

Wilson, J.R and Hatfield, R.D., 1997. Structural and chemical change of cell wall types during stem development: consequences of fibre degradation by rumen microflora. Australian Journal of Agricultural Research, 48: 165-180.

Wouters, A.P., 1985. Uninterrupted growth of napier grass (var. Bana) at two levels of nitrogen application. Ministry of Livestock Development, NDDP, NAHRC, Nairobi, Kenya. 18 pp.

Wouters, A.P., 1986. The productivity and quality of napier grass (var. Bana) during the dry season at three levels of nitrogen application. Ministry of Livestock Development, NDDP/ R10/10, NAHRC, Nairobi, Kenya. 17 pp.

Wouters, A.P., 1987. Dry matter yield and quality of napier grass on farm level from 1983-1986. Ministry of Livestock Development, NDDP/R09/143, NAHRC, Nairobi, Kenya. 39 pp.

Chapter 6

Rumen degradation and estimation of microbial protein yield and intestinal digestion of napier grass *(Pennisetum purpureum)* and various concentrates

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Abstract

A study was conducted in a randomized complete block arrangement using 4 steers to determine rumen degradation and estimate rumen microbial protein (RMP) yield and total protein digestion in the intestines (TPDI) for poultry litter (PL), sunflower seed meal (SFM), soyabean meal (SBM) and cotton seed cake (CSC) in Trial 1, and for PL based concentrate, SFM based concentrate, a commercial concentrate, and medium (MNG) and old (ONG) maturity napier grass (*Pennisetum purpureum*) in Trial 2. The data was used to suggest appropriate supplements for animals fed MNG or ONG diets. Optimal efficiency of RMP synthesis were obtained in concentrates (26-27 g N kg^{-1} fermentable OM (FOM)) but the protein ingredients had higher (37-88 g N kg^{-1} FOM) and napier grass lower (10-19 g N kg^{-1} FOM) values. The estimated values of RMP yield and TPDI using rumen degradation data were comparable to determined values in other studies. Estimated yields of RMP (44 vs 52 g kg^{-1} DM) and TPDI (49 vs 79 g kg^{-1} DM) were lower for ONG than MNG ($P < 0.05$). Among the protein ingredients, estimated yields of RMP (58 vs 87 g kg^{-1} DM) and TPDI (89 vs 219 g kg^{-1} DM) were lowest for PL and highest for SBM ($P < 0.05$). Comparison of concentrates showed that PL based concentrate had the lowest while the commercial concentrate had the highest estimated yields of RMP (75 vs 84 g kg^{-1} DM) and TPDI (96 vs 118 g kg^{-1} DM) ($P < 0.05$). Supplementing animals with SBM, SFM or CSC would support high performance while moderate levels of production would be obtained from SFM based concentrate or the local commercial concentrate. However, supplementing animals with PL or PL based concentrate will result in low levels of production. To sustain same levels of production, animals fed ONG should be offered supplements containing about 30 g kg^{-1} DM more TPDI than animals fed MNG.

Keywords: Napier; Concentrates; Rumen degradation, Estimation of microbial protein yield and intestinal protein digestion

Introduction

In Kenya, napier grass (*Pennisetum purpureum*) is among the major feed resources for smallholder dairy production. The current recommendation (MoLD, 1991) is to feed napier grass (NG) to dairy cows from 6 to 10 weeks (60-100 cm, height) of maturity but this is possible only in the wet seasons when soil moisture is in adequate amounts for rapid growth of the grass. Farmers therefore feed NG to animals at the recommended early to medium maturity during the wet seasons while NG at advanced maturity is offered during the dry seasons. However, feeding forages at early maturity is usually associated with loss of nitrogen (N) due to it higher degradation in the rumen relative to energy resulting in low animal performance (ARC, 1984; NRC, 1988). At advanced maturity, forages are characterised by high content of detergent fibres and lignin, low total N content and high proportion of bound N within the indigestible vascular bundles (Van Soest, 1982; Sniffen et al., 1992) resulting in low digestibility, low nutrient intake, and consequently low animal performance.

Supplementation of NG with fodder trees, high protein legumes and high energy and protein concentrates has been advocated to improve milk production in Kenya (Muinga et al., 1995; Kariuki, 1998). However, commercial concentrates are too expensive for the smallholder and because of problems of establishment and persistency, the existing fodder trees and legumes are not available in adequate quantities for livestock production (Mwangi, 1995). As a consequence, farmers use alternative sources of protein such as poultry litter (i.e. poultry excreta contaminated with bedding materials) and the practice is common because the majority of dairy farmers also keep poultry for either commercial or home consumption purposes.

To improve on ration formulation and efficient utilisation of feeds, the nutritive value of NG and the available supplements should be evaluated using information on protein degradation in the rumen, microbial protein synthesis and intestinal digestion. This new protein evaluation system has been adopted to replace crude protein (CP) or digestible CP in

feeding standards (Jarrige, 1989; Tamminga et al., 1994). Data on rumen degradation of NG at early and medium maturity, fodder trees and legumes (Kiura, 1992; Muinga et al., 1995; Mgheni et al., 1996; Kariuki, 1998) exist. Data is also available on rumen degradation of conventional protein ingredients (McDonald et al, 1988; NRC, 1988; Jarrige, 1989; Hvelplund and Madsen, 1990; Tamminga et al, 1990; Sniffen et al, 1992). Information on rumen degradation of NG at advanced maturity, locally compounded concentrates and PL is, however, non-existent. Furthermore, although data obtained using the new protein evaluation system is essential in animal nutrition, the methods used to determine rumen microbial protein yield and digestion in the intestines are sophisticated and expensive. Therefore these methods are not commonly used to evaluate nutritive value of tropical feedstuffs. However, estimation of these parameters using rumen degradation data would be useful for comparing nutritive value of locally available feed resources and for better formulation of rations to improve animal production.

The objectives of this study were (1) to compare rumen degradation of PL with those of conventional protein ingredients, PL based concentrate with those of concentrates compounded using conventional protein sources and NG at the recommended medium stage of maturity (MNG) with NG at advanced stage of maturity (ONG), (2) to estimate and compare rumen microbial protein synthesis and intestinal digestion of these feedsuffs, and (3) to use the data to suggest appropriate supplements for the MNG and the ONG .

Materials and methods

Climate and site of study area

This study was conducted at the National Animal Husbandry Research Station (0 ° S; 36 ° E; altitude, 1940 m), Naivasha, Kenya. Average annual rainfall of 630 mm is received mainly from March-June and October-December for the long and short rains, respectively. Average

temperature is 18 °C with daily variations of 7-26 ° C, particularly in the dry months. The soils are of moderate fertility and slightly to moderately alkaline (Jaetzold and Schmidt, 1983).

Trial 1

Four Friesians steers (447.3 ± 29.5 kg, live-weight), fitted with large cannulas (10-cm internal diameter), were used in a randomised complete block design to determine rumen degradation, estimate rumen microbial protein synthesis and intestinal protein digestion of poultry litter (PL) and other conventional protein ingredients (sunflower seed meal (SFM), soyabean meal (SBM), and cotton seed cake (CSC). The Trial was conducted in four periods (blocks) in a year from January to February, April to May, July to August, and November to December and PL (from layers) was in the deep litter system for a period ranging from 6 to 18 months. In each period, the PL was collected from the deep litter system, sun-dried for 3 days, sieved and stored in bags while the other protein ingredients were purchased locally in quantities sufficient to last the 14-days adaptation and 14-days rumen degradability periods. The MNG (10 wk) and the ONG (15 wk), managed according to current recommendations (MoLD, 1991) were mixed on a 50:50 DM basis (CP, 68.5; neutral detergent fibre (NDF), 577.8 g kg^{-1} DM; gross energy (GE), 16.2 MJ kg^{-1} DM) and fed *ad libitum* to the steers. The steers were supplemented at a daily rate of 3.65 kg of DM with a mixture of the SFM and PL based concentrates on a 50:50 DM basis (CP, 150.2; NDF, 260.0; g kg^{-1} DM; GE, 8.5 MJ kg^{-1} DM) and clean water was available all the time.

The PL based concentrate was compounded using maize germ meal (360-g kg^{-1} DM), PL (400-g kg^{-1} DM), SFM (230-g kg^{-1} DM) and a mineral premix (10-g kg^{-1} DM). The SFM based concentrate was compounded using maize germ (630-g kg^{-1} DM), SFM (360-g kg^{-1} DM) and a mineral premix (10-g kg^{-1} DM). The chemical composition of the maize germ was 920.2, 990.3, 90.8, 283.7 g kg^{-1} DM and 18.5 MJ kg^{-1} DM, respectively. The mineral premix consisted of 270.0, 185.1, 110.0, 30.0, 5.0, 1.6, 4.0, 4.0, 5.0, 0.2, 0.015, 0.002 g kg^{-1} DM and 1.68:1 of Nacl, Ca, P, Mg, Fe, Cu, Mn, S, Zn, Co, Se, Mo and Ca:P ratio, respectively. The

concentrates were formulated to be iso-nitrogenous (24.0 g N kg^{-1} DM) and with a calorific value of 17.0 to 19.0 MJ kg^{-1} DM of metabolisable energy (ME). The chemical components, gross energy (GE) and estimated ME content for the protein ingredients and concentrates are in Table 1.

Rumen degradation was determined using the nylon bag (nybold, Switzerland, porosity 26 %, mesh size 40 μm; bag size 6 cm x 12 cm) technique. After oven drying at 70 ° C and grinding to pass a 3-mm screen, 5 g of each sample was placed in the bags, sealed with an adhesive and closed by means of draw-strings. The bags were introduced progressively in the rumen and incubated for 336, 96, 48, 24, 16, 12, 6 and 3 h. Three bags per time interval were incubated for the 336 and 96 h while 2 bags per time interval were incubated for the other periods. All the bags were removed from the rumen at the same time, rinsed in tap water until the water was clear, dried in the oven at 70 °C for 24 h and weighed. A zero hour disappearance was estimated by washing 2 bags in tap water and oven dried in a similar way to the incubated samples.

Trial 2

After Trial 1 in each period, the same steers were used (similar design) to determine rumen degradation, and estimate rumen microbial protein synthesis and intestinal protein digestion of MNG, ONG, PL and SFM based concentrates and a locally available commercial concentrate. The commercial concentrate was purchased at the same time as the protein ingredients while PL and SFM based concentrates were compounded and prepared as in Trial 1. The NG samples were prepared like the other samples and incubated for 336, 96, 48, 24, 12 and 6 h while the concentrate samples were incubated at time intervals similar to those of the protein ingredients in Trial 1. Feeding of steers was as described for Trial 1.

Rumen degradation

Organic matter (g kg $^{-1}$ M) and crude protein (g kg^{-1} CP) disappearance were expressed as the proportion of the original sample incubated and the results fitted to the Ørskov and McDonald (1979) exponential model:-

$P = A + B (1 - e^{-kdt})$

Where, P = nutrient disappearance at time t; A = solubility in water; B = degradability of water insoluble but slowly degradable fraction; U = non-degradability of the feed at 336 h; and kd = the rate of degradability of fraction B per hour.

ED = A + B (kd/(kd + kp)) (Ørskov and McDonald, 1979)

Where, ED = effective degradability assuming an outflow rate (kp) of 0.04 and 0.06 per h for NG and the concentrates, respectively.

The contents of degradable and undegradable OM and CP in the rumen were estimated using the following equations:-

ACP = (A/1000) * CP, where ACP = content of water soluble CP (g kg^{-1} DM).

AOM = (A/1000) * OM, where AOM = content of water soluble OM (g kg^{-1} DM).

BCP = (B/1000) * CP, where BCP = content of water insoluble but slowly degradable CP (g kg^{-1} DM).

BOM = (B/1000) * OM, where BOM = content of water insoluble but slowly degradable OM (g kg^{-1} DM).

UCP = (U/1000) * CP, where UCP = content of non-degradable CP after 336 h (g kg^{-1} DM).

UOM = (U/1000) * OM, where UOM = contents of non-degradable OM after 336 h (g kg^{-1} DM)

FCP = (ED of CP/1000) * CP, where FCP = content of fermentable CP (g kg^{-1} DM).

FOM = (ED of OM/1000) * OM, where FOM = content of fermentable OM (g kg^{-1} DM).

INFCP = FCP – ACP, where INFCP = content of water insoluble but effectively fermented CP (g kg^{-1} DM).

INFOM = FOM – AOM, where INFOM = content of water insoluble but effectively fermented OM (g kg^{-1} DM).

The degradation values for carbohydrates (CHO) were obtained by subtracting values of CP from those of OM (CHO = OM – CP).

Rumen microbial protein yield

It was assumed that 150-g of rumen microbial protein are synthesised per kg of fermentable OM and that a kg of fermentable CP will yield half of rumen microbial protein as a kg of fermentable CHO (ARC, 1984; NRC, 1988; Tamminga et al, 1994), then the equation, $Yx + Z/2x = 150$ (where Y and Z are the proportions in each feed of fermentable CHO and CP, respectively) gave actual rumen microbial protein yields per kg of fermentable CP (x/2) or fermentable CHO (x) of the various feeds:-

Rumen microbial yield from fermentable CHO (RMPCHO) = (amount of fermentable CHO/1000) x rumen microbial yield per kg of fermentable CHO (g kg^{-1} DM).

Rumen microbial yield from fermentable CP (RMPCP) = (amount of fermentable CP/1000) x rumen microbial yield per kg of fermentable CP (g kg^{-1} DM).

The total rumen microbial protein yield (TRMP) = RMPCHO + RMPCP (g kg^{-1} DM).

The total rumen microbial protein digested in the intestines (TRMPI) = TRMP x 0.85, since rumen microbial protein is assumed to be digested in the intestines with an efficiency of 85 % (Tamminga et al, 1994).

Intestinal digestion

The digestion in the intestines was estimated using the equations:-

BP = CP – fermentable CP, where BP is amount of rumen by-pass protein (g kg^{-1} DM).

BPDI = BP – undegradable CP, where BPDI is amount of BP digested in the intestines (g kg^{-1} DM).

TPDI = TRMPI + BPDI, where TPDI is total protein digested in the intestines (g kg^{-1} DM).

Energy content

Gross energy was determined in a bomb calorimeter (adiabatic; Gallencamp, England). The digestible OM (DOM, g kg^{-1} DM) and content of ME (MJ kg^{-1} DM) of NG were estimated using the equations:-

DOM = 677 – (12.57 * Age of NG in wk) (Muia et al., 2000 a)

ME = DOM/1000 * 18.5 * 0.81 (AAC, 1990).

The OM digestibility (OMD g kg^{-1} DM)) and ME (MJ kg^{-1} DM) of protein ingredients and concentrates were estimated using the equations:-

OMD = 919 – (0.355 * NDF) + (0.387 * ADF) – (2.17 * ADL) – (0.39 * EE) (Jarrige, 1989), where, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL =acid detergent lignin and EE = ether extract (crude fat).

DOMD (g kg^{-1} DM) = (0.92 * OMD %) - 12 (MAFF, 1984).

ME = DOMD * 0.015 (MAFF, 1984).

Laboratory analyses

The DM level of feeds were determined at 105 °C for 24 h and the ash content at 500 °C for 6 h. After drying at 70 ° C for 24 h, samples were ground to pass a 1 mm screen and analysed for EE content by extracting in a soxhlet using diethyl ether and for CP content using a micro-Kjedahl procedure (AOAC, 1990). The NDF, ADF and ADL contents were determined using procedures by Van Soest and Robertson (1985).

Statistical analysis

The statistical analysis was conducted in a randomised complete block arrangement using the model:-

$Yij = \mu + Pi + Fj + eij$, where Y = dependent variable; μ = overall mean; P = period effect; F = feed effect; and e = error term. The analysis and separation of means of the study parameters by the least significance difference method were done using the general linear model in SAS (1988).

Results

Chemical composition and estimated energy content

The chemical composition and energy content of all feeds are in Table 1. The chemical composition of all feeds differed across the periods. However, there were more variations in composition of the PL than the other protein ingredients, ONG than the MNG but variations in composition of the concentrates were similar. The CP content in PL was 0.3-times while the ADL content was 3.8-times the values in SBM. As compared to the MNG, the CP content of ONG was 0.6-times and the ADL content 1.4-times. Content of ADL in PL based concentrate was 1.1-times the commercial concentrate value and 1.3-times the SFM based concentrate value. Although the PL and SFM based concentrates were formulated to be of similar CP and ME contents, the ME content of the SFM based concentrate was higher. AS compared to the PL and SFM based concentrates, the CP and ME contents of the commercial concentrate were higher.

Rumen degradation

The degradability characteristics of OM and CP contents of the various feeds are in Table 2. The periods did not affect rumen degradability of all the feeds. However, there were more

variations in degradability of the PL as compared to the other protein ingredients, the ONG than the MNG, and the PL based concentrate than the other concentrates. In Trial 1, rumen degradability of OM and CP contents was lowest in PL and highest in SBM. In Trial 2, degradability parameters were higher on the MNG vs the ONG while among the concentrates, the PL based concentrate had the lowest and the locally available commercial concentrate the highest values. The effective degradability values of OM and CP in PL were 0.8 and 0.8-times, respectively while their non-degradability values were 3.0 and 2.7-times, respectively the values in SBM. Also, their rates of degradability (kd) were lower in PL than in SBM. As compared to MNG, the effective degradability of OM and CP in ONG were 0.6 and 0.7-times, respectively while their non-degradability values were 3.1 and 3.4-times, respectively. Also, the kd values of the ONG were lower than the values for the MNG. For the PL based concentrate, the effective degradability values of OM and CP were 0.9 and 0.9-times, respectively while their non-degradability values were 2.3 and 2.3-times, respectively the values in the commercial concentrate. However, the kd values were highest in the PL based concentrate and similar for the other concentrates.

The contents of rumen degradable and undegradable CP and CHO for the various feeds are in Table 3. Amounts of water soluble, fermentable, and non-degradable CHO and amount of non-degradable CP in PL were higher while values of water soluble and fermentable CP were lower than in SBM. As a result, the S ratio (water soluble CP: water soluble CHO), D ratio (water insoluble but rumen fermentable CP: water insoluble but rumen fermentable CHO) and the efficiency of rumen microbial protein synthesis values were 0.2, 0.3 and 0.4-times, respectively the values in SBM. As compared to the MNG, the fermentable CHO and CP values in the ONG were lower while the non-degradable CHO and CP values were higher. The S ratio, D ratio and the efficiency of rumen microbial protein synthesis values in ONG

were 0.5, 0.5 and 0.5-times, respectively the values in MNG. A comparison of the concentrates indicated similar fermentable CHO and CP values in PL and SFM based concentrates and higher values in the commercial concentrate. However, the non-degradable values of CHO and CP in PL based concentrate were higher than in the other concentrates. Although the S and D ratios were similar in the concentrates, the efficiency of rumen microbial protein synthesis was lower in the SFM based concentrate.

Estimated rumen microbial protein yield and protein digestion in the intestines

The estimated rumen microbial protein yields and the intestinal protein digestion for the various feeds are in Table 4. Amount of total rumen microbial protein yield in PL was 0.7-times the value in SBM and the proportion of the total rumen microbial protein yield originating from fermentable CP was lowest in PL (13 %) and highest in SBM (38 %). Amount of total protein digested in the intestines in PL was 0.4-times the value in SBM and the proportion of this protein originating from microbial protein was highest in PL (55 %) and lowest in SBM (34 %). Yield of total rumen microbial protein in ONG was 0.8-times the value in MNG and the proportion of this protein yield originating from fermentable CP was lower in ONG (3 %) than in MNG (6 %). The total protein digested in the intestines in ONG was 0.6-times the amount in MNG and the proportions of this protein originating from microbial protein was higher in ONG (65 %) than in MNG (61 %). Among the concentrates, the PL based concentrate had 0.9-times the total rumen microbial protein yield in the commercial concentrate whereas the proportion of this protein originating from fermentable CP (9 %) was similar. The PL based concentrate had 0.8-times total protein digested in the intestines as the value in the commercial concentrate and the proportion of this protein originating from rumen microbes was highest in the PL based concentrate (65 %) and lowest in the commercial concentrate (62 %).

Table 1 The mean chemical composition and estimated metabolisable energy content of sunflower seed meal, soyabean meal, poultry litter, napier grass at medium and old maturity, commercial concentrates, and sunflower and poultry litter based concentrates

	Trial 1(N=16)					Trial 2 (N=16)					
	SFM	SBM	PL	CSC		MNG	ONG	SFBC	PLBC	CC	
Parameters	M±SD	M±SD	M±SD	M±SD	SED	M±SD	M±SD	M±SD	M±SD	M±SD	SED
Dry matter (g kg^{-1})	929.5^{ab}±8.5	934.7^{a}±6.9	923.1^{b}±16.5	923.9^{b}±5.83	3.703	179.6^{d} ± 3.5	240.1^{c} ± 1.5	900.4^{b} ± 8.0	908.2^{a} ± 4.9	901.5^{b} ± 2.1	1.193
Chemical Composition (g kg DM^{-1}):											
Organic matter	953.9^{a}±3.6	961.4^{a}±5.3	768.9^{b}±14.8	951.9^{a}±5.2	2.854	783.6^{e}±2.9	880.2^{d}±3.3	934.7^{a}±2.9	905.5^{c}±6.4	923.4^{b}±3.5	0.744
Crude protein	242.6^{b}±2.6	508.4^{a}±10.7	169.0^{d}±9.7	234.6^{c}±3.0	2.656	82.5^{c}±1.9	52.9^{d}±1.9	151.2^{b}±1.7	150.3^{b}±3.8	155.6^{a}±1.1	0.588
NDF	318.3^{c}±6.5	297.8^{d}±11.4	411.9^{a}±20.2	329.6^{b}±8.1	4.592	540.6^{b}±0.4	633.2a±2.1	243.2c±2.0	282.6c±2.1	252.4d±2.5	0.585
ADF	126.5^{c}±3.7	115.4^{d} ±5.7	163.1^{a}±8.9	152.3^{b}±2.6	2.073	303.4^{b}±2.1	357.4^{a}±4.4	111.5^{e}±1.6	142.2^{c}±3.6	122.9^{d}±2.2	0.644
ADL	12.4^{b}±1.7	12.4^{b}±2.1	46.8^{a}±4.1	13.4^{b}±1.9	0.942	36.2^{d} ±1.2	51.2^{a}±1.2	36.8^{d}±1.9	46.5^{b}±3.0	43.5±4.2	0.672
Crude fat	92.9^{a}±9.6	79.8^{b}±7.0	11.6^{d} ±2.9	33.8^{c}±3.2	1.813	36.5^{c}±1.7	26.3^{d}±1.8	65.2^{a}±2.5	20.4^{e}±1.4	48.8^{b}±2.7	0.294
Energy content (MJ kg^{-1} DM):											
Gross energy (GE)	20.3^{a}±2.1	18.1^{b}±1.7	15.8^{c}±1.4	18.6^{b}±1.5	0.589	15.7^{d}±0.4	16.7^{c}±0.4	19.1^{a}±0.7	18.0^{b}±1.2	17.7^{b}±0.4	0.183
Estimated ME	11.7^{a}±1.1	11.1^{a}±1.5	8.2^{b}±1.5	11.8^{a}±1.60	0.518	8.3^{d}±0.4	7.3e±0.4	10.4^{b}±0.4	9.9^{c}±0.5	10.6^{a}±0.90	0.108

SFM, sunflower seed meal; SBM, soyabean meal; PL, poultry litter; CSC, cotton seed cake; MNG, napier at medium maturity (age, 10 wk; height, 1.3 m); ONG, napier at old maturity (age, 15 wk; height, 2.0 m); SFBC, sunflower seed meal based concentrate; PLBC, poultry litter based concentrate; CC, commercial concentrate; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; ME, metabolisable energy content; M, mean; SD, standard deviation; SED, standard error of difference between means; superscripts, a, b, c, d and e within a row in each Trial indicate significant ($P < 0.05$) difference.

Table 2 The rumen degradability of sunflower seed meal, soyabean meal, poultry litter, cotton seed cake, napier grass at medium and old maturity, commercial concentrate, and sunflower seed meal and poultry litter based concentrates in steers

	Trial 1 (N = 16)					Trial 2 (N = 16)					
	SFM	SBM	PL	CSC		MNG	ONG	SFBC	PLBC	CC	
Degradability	M ± SD	M±SD	M±SD	M±SD	SED	M±SD	M±SD	M±SD	M±SD	M±SD	SED
Organic matter (g kg^{-1} OM):											
A	288.7^{a}±5.5	251.7^{c}±4.9	290.1^{a}±10.8	265.6^{b}±9.3	2.637	198.0^{d}±1.9	182.0^{e}±3.9	235.9^{c}±2.7	254.6^{b}±6.1	336.4^{a}±2.8	1.333
B	605.3^{b}±7.3	653.0^{a}±6.5	427.5^{d}±13.4	570.0^{c}±11.9	3.322	673.4^{a}±2.7	414.2^{e}±6.2	649.5^{b}±3.0	530.5^{d}±7.8	571.4^{c}±3.8	1.813
kd	0.06^{b}±0.02	0.07^{a}±0.01	0.06^{b}±0.11	0.06^{b}±0.01	0.004	0.03^{e}±0.01	0.01^{d}±0.01	0.06^{b}±0.01	0.08^{a}±0.01	0.06^{b}±0.01	0.002
U	106.0^{c}±5.5	95.3^{d}±3.6	282.4^{a}±9.2	164.4^{b}±6.5	2.244	128.6^{c}±1.7	403.8^{a}±3.6	114.6^{d}±2.1	214.9^{b}±4.4	92.3^{e}±3.4	1.101
ED	579.9^{b}±39.2	602.5^{a}±26.8	502.0^{d}±19.3	551.0^{c}±20.2	9.718	466.5^{c}±31.2	282.0^{d}±26.7	545.9^{b}±15.1	553.3^{b}±9.7	616.7^{a}±15.7	7.581
Crude protein (g kg^{-1} CP):											
A	351.2^{a}±6.1	289.0^{c}±9.7	320.8^{b}±12.1	276.1^{d}±10.9	3.303	212.8^{d}±5.2	183.9^{e}±4.5	246.0^{c}±3.2	258.2^{b}±6.1	340.0^{a}±1.8	1.594
B	553.4^{c}±7.5	624.9^{a}±11.0	445.1^{d}±15.9	578.3^{b}±10.1	3.621	671.8^{a}±5.4	422.1^{e}±7.8	646.8^{b}±4.3	531.8^{d}±8.0	570.6^{c}±3.9	2.184
kd	0.06^{b}±0.01	0.07^{a}±0.01	0.05^{c}±0.01	0.06^{b}±0.01	0.004	0.04^{c}±0.01	0.01^{d}±0.01	0.06^{b}±0.01	0.08^{a}±0.01	0.06^{b}±0.01	0.002
U	95.4^{c}±2.9	86.1^{d}±5.2	234.1^{a}±14.5	145.7^{b}±4.0	2.821	115.4^{c}±2.1	394.0^{a}±4.3	107.3^{d}±3.1	210.0^{b}±5.5	89.4^{e}±3.1	1.291
ED	631.3^{a}±24.2	627.2^{a}±26.9	527.4^{c}±30.0	561.7^{b}±14.0	8.766	427.7^{c}±26.0	282.3^{d}±26.7	554.7^{b}±16.0	561.5^{b}±12.9	617.7^{a}±20.3	7.609

N, number of observations; SED, standard error of difference between means: A, water solubility of OM or CP; B, slow degradability of OM or CP; kd, degradability constant per hour; U, non-degradability of OM or CP; ED, effective degradability of OM or CP; SFM, sunflower seed meal; SBM, soyabean meal; PL, poultry litter; CSC, cotton seed cake; MNG, napier at medium maturity (age, 10 wk; height, 1.3 m); ONG, napier at old maturity (age, 15 wk; height, 2.0 m); SFBC, sunflower seed meal based concentrate; PLBC, poultry litter based concentrate; CC, commercial concentrate; superscripts, ^{a}, ^{b}, ^{c}, ^{d} and ^{e} within a row in each Trial indicate significant ($P < 0.05$) difference; M, mean; SD, standard deviation.

Table 3. The rumen degradation of sunflower seed meal, soyabean meal, poultry litter, cotton seed cake, napier grass at medium and old maturity, commercial concentrate, and sunflower seed meal and poultry litter based concentrates in steers.

	Trial 1 (N = 16)					Trial 2 (N =16)					
Degradation (g kg^{-1} DM)	SFM	SBM	PL	CSC	SED	MNG	ONG	SFBC	PLBC	CC	SED
Crude protein (CP):											
ACP	85.2^{b}	146.9^{a}	54.2^{d}	64.8^{c}	1.176	17.6^{d}	9.7^{e}	37.2^{c}	38.8^{b}	52.9^{a}	0.268
BCP	134.3^{b}	317.8^{a}	75.2^{c}	135.7^{b}	2.021	55.4^{d}	22.3^{e}	97.8^{a}	79.9^{c}	88.8^{b}	0.381
UCP	23.1^{d}	43.7^{a}	39.6^{b}	34.2^{c}	0.871	9.5^{e}	20.9^{b}	16.2^{c}	31.6^{a}	13.9^{d}	0.212
FCP	153.2^{b}	318.8^{a}	89.0^{d}	131.8^{c}	2.790	43.5^{c}	14.9^{d}	83.8^{b}	84.4^{b}	96.1^{a}	0.892
Carbohydrate (CHO):											
ACHO	190.2^{a}	95.1^{c}	168.9^{b}	188.0^{a}	2.660	137.6^{d}	150.5^{c}	183.3^{b}	191.7^{b}	257.7^{a}	1.196
BCHO	443.2^{a}	310.0^{c}	253.5^{d}	406.9^{b}	3.950	472.2^{b}	342.2^{e}	509.3^{a}	400.4^{d}	438.8^{c}	1.715
UCHO	78.0^{c}	47.9^{d}	177.5^{a}	122.3^{b}	2.452	91.2^{e}	334.6^{a}	90.9^{c}	163.0^{b}	71.3^{d}	1.005
FCHO	400.0^{a}	260.5^{c}	297.0^{b}	392.6^{a}	9.050	322.0^{c}	233.2^{d}	426.4^{b}	416.6^{b}	473.3^{a}	6.148
Ratios:											
S (ACP: ACHO)	0.45^{b}	1.56^{a}	0.32^{c}	0.35^{c}	0.032	0.13^{b}	0.07^{c}	0.20^{a}	0.20^{a}	0.21^{a}	0.002
D (INFCP: INFCHO)	0.33^{b}	1.06^{a}	0.28^{b}	0.33^{b}	0.036	0.14^{c}	0.07^{d}	0.19^{a}	0.20^{a}	0.20^{a}	0.005
g N kg^{-1} FOM	44.5^{b}	88.2^{a}	37.0^{d}	40.3^{c}	1.121	19.1^{c}	9.7^{d}	26.3^{b}	27.0^{a}	27.0^{a}	0.308

N, *number of observations*; SED, standard error of difference between means: ACP and ACHO, water soluble CP and CHO contents, respectively; BCP and BCHO, slowly degradable CP and CHO contents, respectively; UCP and UCHO, non-degradable CP and CHO contents, respectively; FOM, FCP and FCHO, rumen fermentable OM, CP and CHO contents, respectively; SFM, sunflower seed meal; SBM, soyabean meal; PL, poultry litter; CSC, cotton seed cake; MNG, napier at medium maturity (age, 10 wk; height, 1.3 m); ONG, napier at old maturity (age, 15 wk; height, 2.0 m); SFBC, sunflower seed meal based concentrate; PLBC, poultry litter based concentrate; CC, commercial concentrate; INFCP or INFCHO are the amounts of water insoluble but slowly fermentable CP or CHO, respectively; superscripts, ^{a}, ^{b}, ^{c}, ^{d} and ^{e} within a row in each Trial indicate significant ($P < 0.05$) difference.

Table 4 Estimated rumen microbial protein synthesis and total protein digestion in small intestines of sunflower seed meal, soyabean meal, poultry litter, cotton seed cake, napier grass at medium and old maturity, commercial concentrate, and sunflower seed meal and poultry litter based concentrates.

	Trial 1(N = 16)					Trial 2 (N = 16)					
Parameters	SFM	SBM	PL	CSC	SED	MNG	ONG	SFBC	PLBC	CC	SED
RMP synthesis (g kg^{-1} DM):											
From FCHO	69.2^{a}	53.7^{b}	50.3^{c}	67.3^{a}	1.625	49.3^{d}	42.3^{e}	72.2^{b}	68.1^{c}	75.9^{a}	0.396
From FCP	13.3^{b}	32.8^{a}	7.5^{d}	11.3^{c}	0.274	3.0^{d}	1.4^{e}	7.1^{b}	6.8^{c}	7.7^{a}	0.022
Total	82.5^{b}	86.5^{a}	57.9^{d}	78.6^{c}	1.614	52.2^{d}	43.6^{e}	79.2^{b}	74.9^{c}	83.6^{a}	0.403
By-passs protein (BP)	89.5^{c}	189.6^{a}	80.0^{d}	102.9^{b}	3.307	44.4^{d}	37.1^{e}	67.3^{b}	63.7^{c}	71.0^{a}	0.586
Protein digested in SI (g kg^{-1} DM):											
From TRMP (TRMPI)	70.1^{b}	73.5^{a}	49.2^{d}	66.8^{c}	1.372	44.5^{d}	37.2^{e}	67.4^{b}	63.7^{c}	71.0^{a}	0.343
From BP (BPDI)	66.3^{b}	145.9^{a}	40.4^{c}	68.7^{b}	3.091	34.7^{b}	11.9^{d}	47.1^{a}	32.0^{c}	46.6^{a}	0.930
TPDI	136.4^{b}	219.4^{a}	89.5^{c}	135.5^{b}	3.126	79.1^{d}	49.0^{e}	114.5^{b}	95.7^{c}	117.6^{a}	0.896
Percentage TRMPI in TPDI	51.4^{b}	33.7^{c}	55.1^{a}	49.3^{b}	1.133	61.1^{b}	64.8^{a}	56.0^{c}	65.1^{a}	61.5^{b}	0.905

N, number of observations; SFM, SBM and CSC, sunflower, soyabean and cotton seed meals, respectively; PL, poultry litter; MNG and ONG, napier at medium (age, 10 wk; height, 1.3 m) and old (age, 15 wk; height, 2.0 m) maturities, respectively; SFBC and PLBC, SFM and PL based concentrates, respectively; CC, commercial concentrate; SI, small intestines; SED, standard error of difference between means; RMP, rumen microbial protein; FCP and FCHO, fermentable CP and CHO, respectively; TRMP, total RMP; TRMPI, TRMP digested in the SI; BP, by-pass protein; BPDI, BP digested in the SI; TPDI, total protein digested in the SI; different superscripts ^{a}, ^{b}, ^{c}, ^{d}, and ^{e} within a row in each Trial indicate significant ($P < 0.05$) difference.

Discussion

The rumen degradation parameters decreased with maturity of NG which is consistent with other reports (Kiura, 1992; Muinga et al, 1995; Kariuki, 1998). This is mainly caused by an increase in indigestible detergent fibres and acid detergent lignin (ADL) content and a low CP content due to a decline in leaf: stem ratio (Van Soest, 1982; Minson, 1990). The PL had lower rumen degradability and estimated intestinal protein digestion parameters than the other protein ingredients because of lower CP and ME contents and higher detergent fibre and ADL contents due to contamination with bedding materials. The non-protein N (NPN) in PL may be assumed to have a low digestion while amino acid N in the other protein ingredients has a high digestion in the lower tract (Tamminga et al, 1994). The lower estimated total protein digested in the intestines in the PL based concentrate than in other concentrates can be explained by the presence of NPN from PL and the higher ADL content.

At similar qualities, the rumen degradation parameters for NG in our study were comparable to values reported by Kiura (1992) and Kariuki (1998) but lower than values reported by Mgheni et al (1996). Rumen degradation parameters for SBM, SFM and CSC were higher, comparable or lower than values in various reports (McDonald et al, 1988; NRC, 1988; Jarrige, 1989; Hvelplund and Madsen, 1990; Tamminga et al, 1990; Sniffen et al, 1992). The values we obtained of estimated total protein digested in the intestines for MNG was similar to the determined value for the same grass by Kariuki (1998) but higher than determined value reported by Jarrige, (1989). The determined values of total protein digested in the intestines for SFM, SBM and CSM quoted by Hvelplund and Madsen, (1990) and Jarrige (1989) were higher than values in our study. The SBM, SFM and CSC had a higher estimated total protein digested in the intestines than that of NG because leaf protein is largely

degraded in the rumen and the by-pass protein is encrusted within the indigestible cell wall fibre fractions (Tamminga et al., 1990). However, the by-pass protein of protein ingredients is mainly storage protein, which is not protected by cell wall fractions and is therefore highly digested in the lower tract (Tamminga et al, 1990). Factors that may influence rumen degradation and hence the parameters estimated from these values include the nutritive value of the basal diets, the feed sample, assumed rates of passage (kp), processing methods, incubation periods in the rumen, levels and frequency of feeding, and environmental temperature (ARC, 1984; Satter, 1986; Hvelplund and Madsen, 1990, Sniffen et al, 1992).

The solubility of CP content of NG, concentrates, SFM and CSC were generally higher the higher the CP content and the lower the ADL content which is consistent with a report by Nocek and Grant (1987). Also, higher solubility values of CP contents of these feeds resulted in higher fermentable CP values. This relationship was however not consistent for the SBM and the PL mainly because of their difference in physical and chemical properties as was also suggested for other feeds by Satter (1986). The fermentable CP values for SBM, SFM and CC were within the range from 60 to 90 % reported for dietary proteins which are highly degradable in the rumen (Tamminga, 1979). However, although the other feeds had lower rumen degradability values, this did not necessarily result in high amounts of dietary by-pass protein which is digested in the intestine, as was reported by Sniffen et al (1992) and Tamminga et al (1994). This was possibly due to their low CP content or high proportion of CP encrusted within the indigestible vascular bundle. The optimal efficiency of rumen microbial protein yield ranging from 24 to 30g N kg^{-1} of fermentable OM (ARC, 1984; McDonald et al, 1988; NRC, 1988; Tamminga et al, 1994) were achieved only for the concentrates. The protein ingredients had higher estimated values than this range indicating less efficiency of rumen microbial protein synthesis because energy was deficient in relation to N content. Lower values than optimal rumen microbial protein synthesis were estimated for

NG with a CP content of less than 100 g kg^{-1} of DM, possibly because there was insufficient N to match the energy available to the rumen microbes (Minson, 1990).

Milk production in dairy (Anindo and Potter, 1986; Muinga et al, 1993; Muia et al, 2000 b) or dual purpose (Muinga et al, 1992; Muinga et al, 1995) cattle fed NG only diets range between 5 and 10 kg per cow per day. This milk production range is much lower than the genetic potential of the animals and therefore for higher milk production, supplementation is essential. For improved animal performance, a supplement should enhance fermentation of the basal diet, improve rate and extent of particle size reduction and thus increase the passage rate of digesta out of the rumen leading to increased feed intake (Osuji et al, 1995). Since microbial protein cannot meet the requirements of high producing animals (Ørskov, 1982; ARC, 1984), supply of certain amount of dietary by-pass protein which is digested in the lower gut is also required. For high milk yields (> 15 kg cow^{-1} day^{-1}), animals fed NG should therefore be supplemented using SBM, SFM and CSC with high rumen microbial protein yields and total protein digested in the intestines. Moderate milk yields (10-15 kg cow^{-1} day^{-1}) could be achieved using the commercial and SFM based concentrates with high rumen microbial protein yields and moderate total protein digested in the intestines. Moderate rumen microbial protein yields and low total protein digested in the intestines values for the PL based concentrate and the PL imply that these feeds would only support low milk yields (< 10 kg cow^{-1} day^{-1}) when supplemented to animals fed NG.

The difference in estimated yields of rumen microbial protein yields was lower (16 %) while that of estimated total protein digested in the intestines was higher (38 %) on the MNG vs the ONG. This was an indication that much of the variations in milk yields when dairy cattle are fed NG only diets would mainly be attributed to the total amount of protein digested in the intestines. Animals fed ONG would therefore require a supplement containing about 30

g kg^{-1} DM more of total protein digested in the intestines to sustain same level of production as animals fed MNG. For Example animals fed ONG and MNG should be supplemented with SBM and SFM, SBM and CSC, SFM and PL, or CSC and PL, respectively. Alternatively, when animals are offered same supplement, the quantity should be about 38 % higher for ONG diet to support same level of production as MNG diet. However, in such a situation, high levels of supplementation should not result in high rates of substitution of the inexpensive ONG basal diet.

Although PL is inexpensive and readily available, it may not be the appropriate supplement to NG because of the high detergent fibres and ADL content hence high rates of substitution of the basal diet at high levels of inclusion. The expected high levels of animal production when NG is supplemented with the conventional protein ingredients may be outweighed by the high costs of production. The use of these conventional protein ingredients for RMP yields when supplemented to NG may not be beneficial because high quality dietary protein will be fermented (AAN deaminated) and less energy will be produced from CP fermentation (Preston and Leng, 1987). However, their high total protein digested in the intestines is expected to be an advantage for the high yielding animals. The higher kd values of OM and CP contents of the PL based concentrate as compared with the other concentrates would result in higher rates of passage through the rumen and an expected higher feed intake (Owens and Goetsch, 1986). Further, the expected low cost for PL based concentrate than the other concentrates may outweigh the disadvantage of low quality and thus play an important role to support livestock production on NG basal diets.

Conclusions

Rumen degradation data could be used to estimate rumen microbial protein yield and intestinal protein digestion of feeds. The low content of CP, rumen degradation, estimated protein digestion in the intestines was an indication that NG when fed to ruminants could not support high animal production without supplementation. For high milk yields, dairy cattle fed NG should be supplemented with conventional protein ingredients (SBM, SFM or CSC), while supplementation with sunflower seed meal based concentrate and the local commercial concentrates would support moderate levels of production. However, supplementing animals fed NG with poultry litter and poultry litter based concentrates as a protein source would support low levels of milk yield. To obtain same levels of production, animals fed ONG should be offered supplements containing about 30 g kg^{-1} DM more total protein digested in the intestines than animals fed MNG.

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References

Australian Agricultural Council (AAC), 1990. Feeding standards for Australian livestock. Australian Agricultural Council. Ruminant sub-committee CSIRO. Eastern Melbourne, Australia.

Anindo, D.O. and Potter, H.L., 1986. Milk production from napier grass (Pennisetum purpureum) in a zero-grazing feeding system. East African Agriculture and Forestry Journal, 52:106-111.

Association of Official Analytical Chemists (AOAC), 1990. Official method of analysis. 14th Edition. Association of Official Analytical Chemists, Washington, D.C:

Agricultural Research Council (ARC), 1984. The nutrient requirements of ruminant livestock (Suppl. No. 1). Commonwealth Agricultural Bureaux, Farnham Royal, UK.

Hvelplund, T. and Madsen, J., 1990. A study of the quantitative nitrogen metabolism in the gastro-intestinal tract and the resultant new protein evaluation system for ruminants. The AAT-PBV system. 215 pp.

Jaetzold, R. and Schmidt, H., 1983. Farm Management Information. Handbook of Kenya, vol. 11 a. Ministry of Agriculture, Nairobi, Kenya.

Jarrige, R., 1989. Ruminant nutrition: Recommended Allowance and Feed Tables, INRA, John Libbey, London.

Kariuki, J.N., 1998. The potential of improving napier grass under smallholder dairy farmer's condition in Kenya. PhD thesis, Wageningen Agricultural University, The Netherlands.

Kiura, J.M., 1992. Evaluation of protein digestibility of napier grass (*Pennisetum purpureum*) and green leaf Desmodium (*Desmodium intortum*). Msc. thesis, Wageningen Agricultural University. The Netherlands.

MAFF, 1984. Energy allowances and feeding systems for ruminants. Ministry of Agriculture Fisheries and Food, Department of Agriculture and Fisheries for Scotland, Department of Agriculture for Northern Ireland. Reference book 433. Her Majesty's Stationary Office, London.

McDonald, P. Edwards, R.A. and Greenhalgh, J.F.D., 1988. Animal nutrition. 4th Ed. Longman U.K. group, Essex, England.

Mgheni, D.M., Hvelplund, T. and Weisbjerg, M.R., 1996. Rumen degradability of dry matter and protein in tropical grasses and legume forages and their value expressed in the AAT-PBV protein evaluation system. In: J. Ndikumana and P. Deleeuw (Eds.), Sustainable Feed Production and Utilisation for Smallholder Livestock Enterprises in Sub-Sahara Africa. Proc. 2nd Afr. Feed Resource Network (AFRNET) Workshop, 1993, Harare, Zimbabwe. pp 77-84.

Minson, D.J. (Ed.), 1990. Forage in ruminant nutrition. Academic press, Inc. San Diego.

MoLD, 1991. Ministry of Livestock Development (MoLD). Zero-grazing: A handbook on technical aspects. Nairobi, Kenya.

Muia, J.M.K., Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 2000 a. Prediction of yield and digestibility of napier grass (*Pennisetum purpureum*) from maturity, leaf; stem ratio and laboratory analyses. Tropical Science, (in press).

Muia, J.M.K., Tamminga, S., and Mbugua, P.N., 2000 b. Effect of supplementing napier grass (*Pennisetum purpureum*) with sunflower or poultry litter based concentrates on feed intake, live-weight changes and economics of milk production in Friesian cows. Livestock Production Science (accepted).

Muinga, R.W., Thorpe, W. and Topps. J.H., 1992. Voluntary feed intake, live-weight change and lactation performance of crossbred dairy cows given *ad libitum Pennisetum purpureum* (napier grass var. Bana) supplemented with *Leucaena* forage in lowland semi-humid tropics. Animal Production, 55: 311-337.

Muinga, R.W., Thorpe, W. and Topps. J.H., 1993. Lactation performance of Jersey cows given napier fodder (*Pennisetum purpureum*) with and without protein concentrates in semi-humid tropics. Tropical Animal Health and Production, 25: 118-128.

Muinga, R.W., Thorpe, W. and Topps. J.H., 1995. The effects of supplementation of *Leucaena leucocephala* and maize bran on voluntary intake, digestibility, live-weight change and milk yield of *Bos Indicus* X *Bos Taurus* dairy cows and rumen fermentation in steers offered *Pennisetum purpureum ad-libitum* in the semi-humid tropics. Animal Science, 60: 13-23.

Mwangi, D.M., 1995. Diagnostic survey in livestock feeds, feeding and management practices in central Kenya. In: P.O. Fungoh, G.C.O. Mbadi and H. Ondatto (Eds.), Proceeding of the 4th Kenya Agricultural Research Institute Scientific Conference, 1994, Nairobi, Kenya. pp. 293-305.

National Research Council (NRC), 1988. Nutrient requirement of dairy cattle. 6th Edition. Washington, DC.

Nocek, J.E. and Grant, A.L., 1987. Characterisation of in situ nitrogen and fibre digestion and bacterial nitrogen contamination of hay crop forages preserved at different dry matter percentages. Journal of Animal Science, 64: 552-564.

Ørskov, E.R. and McDonald, I., 1979. The estimation of protein degradability in the rumen from incubation measurements weighed according to rate of passage. Journal of Agricultural Science (Camb.), 92: 499 - 503.

Ørskov, E.R. (Ed.), 1982. Protein nutrition in ruminants. Academic press, Inc., London.

Osuji, P.O., Fernandez-Livera, S. and Odenyo, A., 1995. Improving fibre utilisation and protein supply in animals fed poor quality roughage: ILRI nutrition research plans. In: Wallace, R.J. and Lalhou-Kassi, A. (Eds), Rumen Ecology Research Planning. Proc. Workshop at ILRI, Addis Ababa, Ethiopia. ILRI, Nairobi, Kenya. pp. 1-22.

Owens, F.N. and Goetsch, A.L., 1986. Digesta passage and microbial protein synthesis. In: Milligan, L.P., Grovum, W.L. and Dobson, A. (Eds), Control of Digesta and Metabolism in Ruminants. Prentice-hall, Englewood Cliff, NJ. 196-226 pp.

Preston, T.R. and Leng, R.A., 1987. Matching ruminant production systems with available resources in the tropics and sub-tropics. Penambul Books, Armidale. 245 pp.

Satter, L.D., 1986. Protein supply from undegraded dietary protein. Symposium: protein and fibre digestion, passage and utilisation in lactating cows. Journal of dairy Science, 69: 2734-2749.

Sniffen, C.J., O'Connor, J.D., Van Soest, P.J., Fox, D.G. and Russell, J.B., 1992. A net carbohydrate and protein system for evaluating cattle diets. II. Carbohydrate and protein availability. Journal of Animal Science, 70: 3562 - 3577.

Statistical Analysis Systems Institute, 1988. SAS User's guide: Release 6.03 Edition. SAS Institute, Carry, NC.

Tamminga, S., 1979. Protein degradation in the fore-stomachs of ruminants. Journal of Animal Science, 49: 1615 - 1630.

Tamminga, S., Van Vuuren, A.M., Van der Koelen, C.J., Ketelaar, R.S. and Van der Togt, P.L., 1990. Ruminal behaviour of structural carbohydrates, non-structural carbohydrates and crude protein from concentrate ingredients in dairy cows. Netherlands Journal of Agricultural Science, 38: 513-526.

Tamminga, S., Van Straalen, W.M., Subnel, A.P.J., Meijer, R.G.M., Steg, A., Wever, C.J.G. and Blok, M.C., 1994. The Dutch protein evaluation system: the DVE/OEB system. Livestock Production Science, 40: 139-155.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B books, Corvallis, Oregon, USA.

Van Soest, P.J. and Robertson, J.B., 1985. Analysis of forage and fibrous foods. AS 613 Manual, Department of Animal Science, Cornell University, Ithaca.

Chapter 7

Effect of supplementing napier grass (*Pennisetum purpureum*) with poultry litter and sunflower meal based concentrates on feed intake and rumen fermentation in Friesian steers

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Abstract

Nutrient intake and rumen fermentation patterns were determined when four fistulated Friesian steers (4 x 4 Latin square) fed medium (MNG) or old (ONG) maturity napier grass *(Pennisetum purpureum)* were supplemented with equal amounts of sunflower seed meal (SFBC) or poultry litter (PLBC) based concentrates (Trial 1), and when the steers were fed MNG only diet or supplemented with graded levels of the PLBC (Trial 2). In Trial 1, intake of crude protein (CPI) (15.3 vs 11.1 g kg^{-1} $W^{0.75}$, $P < 0.001$) and organic matter (OMI) (127.1 vs 124.7 g kg^{-1} $W^{0.75}$, $P < 0.05$) were higher on MNG vs ONG diets. The CPI and OMI were 3 % higher on SFBC vs PLBC diets ($P < 0.01$). The MNG had higher concentrations of rumen ammonia (NH_3-N) (101.0 vs 51.2 mg l^{-1}) while pH (6.7 vs 7.1) and acetate (A) to propionate (P) ratio (3.7 vs 3.9) were lower than values for the ONG diets ($P < 0.001$). The rumen concentration of NH_3-N (70.9 vs 81.3 mg l^{-1}) and pH (6.8 vs 7.0) were lower while the A:P ratio (3.8 vs 3.7) was higher for the SFBC than the PLBC diets ($P < 0.05$). In Trial 2, the CPI (186.2 vs 100.7 g kg^{-1} $W^{0.75}$) and OMI (15.1 vs 10.6 g kg^{-1} $W^{0.75}$) of the supplemented MNG were higher than for the MNG only diet ($P < 0.001$). The rumen pH (6.7 vs 6.1) and A:P ratio (3.8 vs 3.6) were higher while concentration of NH_3-N (56.56 vs 87.5 mg l^{-1}) was lower for the MNG only diet than for the supplemented MNG ($P < 0.001$). To improve feed intake and digestion, PLBC should be supplemented to animals fed MNG while SFBC should be used on animals fed ONG.

Keywords: Napier; Poultry litter; Sunflower seed meal; Steers; Intake; Rumen fermentation

Introduction

In Kenya, napier grass (*Pennisetum purpureum*) is among the major feed resources for smallholder dairy production. Feeding napier grass to dairy cows at the recommended maturity (MoLD, 1991) of 6 to 10 weeks (60-100 cm height) is possible only during the wet seasons when amount of soil moisture is adequate for rapid growth of the grass. In contrast, during the dry seasons, adequate amounts of the grass can only be available to animals when the grass is harvested at advanced maturity. However, feeding forages at an early maturity is associated with relatively high degradation in the rumen of protein than energy hence inefficient utilisation of liberated N resulting in low animal performance (ARC, 1984). At advanced maturity, forages are characterised by high content of fibre, low total N level and a relatively high proportion of bound N within the indigestible vascular bundles (Van Soest, 1982; Sniffen et al., 1992) resulting in low digestibility, low nutrient intake and consequently low animal performance.

Supplementation of napier grass with high-protein fodder trees and legumes, and high-energy and -protein concentrates have been advocated to improve animal production (Anindo and Potter, 1986; Muinga et al., 1995; Kariuki, 1998). However, commercial concentrates are too expensive for the smallholder and because of problems of establishment and persistency, the existing high-protein forages are not available in adequate quantities for supplementing livestock (Mwangi, 1995). As a consequence, farmers use alternative sources of protein such as poultry litter (i.e. poultry excreta contaminated with bedding materials). This has become a common practice because the majority of dairy farmers also keep poultry for either commercial or home consumption purposes. Considerable data on the use of poultry litter (PL) as a ruminant feedstuff exists (Ayangbile et al., 1993; Kato et al., 1994). Several processing methods have

been examined and recommended to minimise or eradicate harmful pathogens from PL (Patil et al., 1993; Kaur et al., 1997).

The end products of rumen fermentation are volatile fatty acids (VFA), ammonia nitrogen (NH_3-N), and gases such as methane and carbon dioxide (Baldwin and Allison, 1983; Van Houtert, 1993). The VFA are a source of energy to the host animal while NH_3-N and amino acids formed as a result of hydrolysis and deamination of proteins in the rumen are a source of N for microbial growth (Ørskov, 1982). Actual digestion of a feed and the amount of VFA produced as well as the proportion of the individual acids, depends on the condition of the rumen environment (such as pH and NH_3-N) which in turn is influenced by characteristics of the ingested feeds (Van Houtert, 1993). Level of intake can also influence the end products of rumen fermentation (Robinson et al., 1986). Information is available on rumen fermentation patterns when napier grass is supplemented with high-protein forages (Muinga et al., 1995; Abdulrazak et al., 1996; Kariuki, 1998). However, data on rumen fermentation patterns when medium (MNG) or most (ONG) mature stage of maturity of the grass is supplemented with PL based protein/energy concentrate (PLBC) is non-existent.

The objectives of this study were (1) to determine intake of nutrients and rumen fermentation patterns when steers fed MNG or ONG maturity were supplemented with equal amounts of either sunflower seed meal based concentrate (SFBC) or PLBC, (2) to determine intake of nutrients and rumen fermentation patterns when steers fed the recommended MNG maturity were supplemented with graded levels of the PLBC, and (3) to suggest, using the obtained data, the appropriate supplements for the MNG and ONG.

Materials and methods

Climate and site of study area

This study was conducted at the National Animal Husbandry Research Station (0 ° S; 36° E; altitude, 1940 m), Naivasha, Kenya. Average annual rainfall of 630 mm is received mainly from March to June and October to December for the long and short rains, respectively. Average temperature is 18 ° C with daily variations ranging from 7 to 26 ° C, particularly in the dry months. The soils are of moderate fertility and slightly to moderately alkaline (Jaetzold and Schmidt, 1983).

Trial 1

Four fistulated steers (Average live-weight, 445.1 ± 26.4 kg) were used in a 4 x 4 Latin square design study to examine feed intake and rumen fermentation parameters when MNG or ONG was supplemented with either SFBC or PLBC at a daily rate of 3.65 kg of DM per steer. The PL, collected from a deep litter system, where layers were kept for an average period of 12 months, was sun-dried for 3 days, sieved and stored in bags. Sunflower seed meal, maize germ meal and a mineral premix were purchased locally in quantities sufficient for the study. The PLBC was compounded using 360, 400, 230 and 10-g kg^{-1} of DM of maize germ, PL, sunflower seed meal and the mineral premix, respectively. Ingredients of the SFBC were 630, 360 and 10 g kg^{-1} of DM of maize germ, sunflower seed meal and the mineral premix, respectively. The sunflower seed meal consisted of 931.3 g of DM per kg of original material, 954.8, 240.8 and 11.9 g kg^{-1} of DM of organic matter (OM), crude protein (CP) and acid detergent lignin (ADL)

contents, respectively and 10.7 MJ kg^{-1} of DM of estimated metabolisable energy (ME). The PL consisted of 900.2 g of DM per kg of original material, 772.0, 164.8 and 54.2 g kg^{-1} of DM of OM, CP and ADL contents, respectively and 9.6 MJ kg^{-1} of DM of ME. Maize germ meal had 920.2 g of DM per kg of original sample, 990.3, 90.8 and 283.7 g kg^{-1} of DM of OM, CP and neutral detergent fibre (NDF) contents, respectively while composition of the mineral premix was 270.0, 185.1, 110.0, 30.0, 5.0, 1.6, 4.0, 4.0, 5.0, 0.2, 0.015, 0.002 g kg^{-1} of DM of Nacl, Ca, P, Mg, Fe, Cu, Mn, S, Zn, Co, Se, Mo, Nacl, Ca, P, Mg, Fe, Cu, Mn, S, Zn, Co, Se and Mo, respectively and 1.68:1 of Ca: P ratio. Concentrates were formulated to be iso-nitrogenous (24 g N kg^{-1} DM) and to have a calorific value of 17.0 to 19.0 MJ kg^{-1} DM. Chemical composition and estimated content of ME for the diets are shown in Table 1.

The management of napier grass was according to recommendations (MoLD, 1991). Each 28 day experimental period consisted of a 14 days of adaptation, a 3 days of rumen fluid sampling, and a 10 days of feed intake measurement. Napier grass was fed *ad libitum* (120 % of the previous days measured intake) and clean water was available all the time. Grass was offered twice daily (08.00 and 17.00 h) and the concentrates once daily (07.30 h). Grass was chopped using an electric chaff-cutter to a mean particle length of 2.5 cm to avoid selection.

Steers were fitted with large ruminal cannulas (10 cm inner diameter) through which a plastic tube (50 cm long; 15 mm, inner diameter) closed at one end with a cork and perforated with approximately 120 holes of 2 to 5 mm in diameter was inserted. The tube was positioned in the ventral sac of the rumen and about 200 ml of rumen fluid was drawn first before feeding using a hand vacuum apparatus. A portion of the rumen fluid was acidified (1 ml 20 % H_2SO_4 per 5 ml of rumen fluid) to stop fermentation and frozen (-20 °C) in tightly capped containers for subsequent ammonia analysis. The second portion was acidified with metaphosphoric acid (1 ml

25 % H_3PO_4 per 5 ml of rumen fluid) and frozen (-20 ^{o} C) for subsequent analysis of VFA. The third portion of rumen liquor was transported to the laboratory for pH determination, within 30 minutes. Rumen samples were withdrawn at 4-h intervals over a 24 h day at 07.00, 11.00, 15.00, 19.00, 23.00, 03.00 and 07.00 h. The same sampling schedule was followed for 3 consecutive days in each period.

Trial 2

The 4 fistulated steers used in Trial 1 were fed four dietary treatments namely, non-supplemented MNG diet (T0) or MNG diet supplemented with either 0.91 (T1), 3.65 (T2) or 6.35 (T3) kg of DM of the PLBC. The management of napier grass, compounding of the PLBC, sampling procedures and determination of feed intake levels and rumen fermentation patterns (similar design) were as described for Trial 1. The nutritive profiles of the diets are in Table 1.

Estimation of energy content

Gross energy was determined in a bomb calorimeter (adiabatic; Gallencamp, England). Digestible OM (DOM, g kg^{-1} DM) and the content of ME (MJ kg^{-1} DM) of napier grass were estimated using the relationships:

DOM = 677 – (12.57*age of the grass in wk) (Muia et al., 2000 a).

ME = DOM/1000*18.5*0.81 (AAC, 1990).

The OM digestibility (OMD %) and ME (MJ kg^{-1} DM) content of the SFBC and the PLBC were estimated using the equations:

OMD = 91.9 – (0.355*NDF %) + (0.387*ADF %) – (2.17*ADL %) – (0.39*EE %) (Jarrige, 1989).

Where, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent lignin, and EE = ether extract (crude fat).

DOM % = (0.92*OMD %) - 1.2 (MAFF, 1984).

ME = DOM %*0.15 (MAFF, 1984).

Laboratory analysis

The DM level of feeds was determined at 105 $^{\circ}$C for 24 h and the ash content at 500 ^{0}C for 6 h. After drying at 70 $^{\circ}$C for 24 h, samples were ground to pass a 1 mm screen and analysed for EE using the soxhlet extraction in diethyl ether after Hcl hydrolysis and for CP content using the micro-Kjeldahl procedure (AOAC, 1990). The NDF, ADF and ADL contents were determined using the procedure by Van Soest and Robertson (1985).

The pH of rumen fluid was determined using a pH meter (Ion analyser, 255 Corning). Frozen rumen fluid was thawed, left to settle, and about 5 ml obtained from the clear upper layer. This was mixed with 10 ml of NaOH (40 %) and steam heated using a micro-Kjeldahl for determination of NH_3-N (Markhan still assembly, 46 Mc, Griffins and George, Leicestershire, England). After thawing the third sample, it was centrifuged (1300 g, size 2, model head 250 A) for 10 minutes and the VFA separated and quantified using gas liquid chromatography (Varian series 3300/3400; 10% SP-1200/1% H_3PO_4 on chromosorbs WAW; Supelco Inc., Bellfonte, USA).

Statistical analyses

A 4 x 4 Latin square design (with steers as the rows and periods as the columns) was used to determine the effect of treatments on feed intake and rumen fermentation parameters for both Trials. The following statistical model was used:

$Y_{ijk} = \mu + P_i + S_j + Trt_k + e_{ijk}$. Where Y, nutrient intake or rumen fermentation parameter ; μ, overall mean; P, period effect; S, steer effect; Trt, treatment effect and e, the error term. Contrasts were made on MNG vs ONG and SFBC vs PLBC for Trial 1 and T0 vs others for Trial 2.

Effects of treatments, periods, steers and time of feeding on rumen fermentation parameters were analysed using the repeated measure analysis of variance for both Trials. The multivariate test included both between (period, steer and treatment) and within (time, time*period, time*steer and time*treatment) subject effects. Orthogonal contrasts (linear, quadratic and cubic) of study parameters with change in time of sampling for period, steer and treatments were also obtained by including the polynomial option in the repeated statement. The two analyses and separation of treatment means by the least significance difference method were done using the general linear model procedures of SAS (1988).

Results

The nutritive characteristics of the feeds in both trials are in Table 1. Among these feeds, the lowest contents of CP and estimated ME, and the highest ADL content were recorded for the ONG. The contents of CP and estimated ME were similar in the concentrates, but the

PLBC had a higher content of ADL. The amounts of fermentable CP and CHO were lower in ONG than in MNG while values in the PLBC and SFBC were similar.

For Trial 1, feed intake results are in Table 2 while the rumen fermentation results are in Tables 2 and 4, and Figure 1. The periods, steers and treatments affected all feed intake parameters (Table 2). Although the total intake of OM for the MNG diet was only 2 % higher, that of CP was 38 % higher than for the ONG diet. However, the total intake of either OM or CP for the SFBC diet was about 3 % higher than for the PLBC diet. The periods, steers and treatments affected most of the rumen fermentation parameters (Table 2). The rumen pH was 6 % and acetate: propionate ratios 8 % lower while the concentration of VFA was 22 %, ammonia N (NH_3-N) 97 %, percentage acetate 1.2 % and percentage propionate 9 % higher on the MNG vs ONG diets. As compared to the PLBC diet, the concentration of VFA, percentage acetate and acetate: propionate ratios in SFBC diet were 2.5, 1 and 3.5 % higher, respectively while its rumen pH, concentration of NH_3-N, and percentage propionate values were 2, 13, and 3 % lower, respectively. The time of feed offer and its interaction with periods, steers and treatments affected most of the rumen fermentation patterns (Table 4). The interaction of time of feed offer with treatments had quadratic relationships with rumen pH, concentration of VFA, and percentage acetate and propionate.

The rumen pH ranged from 6 to 7 for the MNG diets and from 6.5 to 7.5 for the ONG diets (Figure 1). For the SFBC diet, the rumen pH ranged from 6 to 7.3 while the range for the PLBC diet was from 6 to 7.5. Lowest levels of rumen pH occurred 8-16 h post-morning feeding while the highest levels were recorded 16-20 h post-afternoon feeding. Concentration of NH_3-N ranged from 80 to 150 mg l^{-1} for the MNG diets and from 40 to 80 mg l^{-1} for the ONG diets. Concentration of NH_3-N ranged from 40 to 130 mg l^{-1} for the SFBC diets while that for the

PLBC diets ranged from 40 to 150 mg l^{-1}. Highest levels of NH_3-N concentrations occurred 2-6 h post-morning feeding and 8-12 h post-afternoon feeding. Lowest level of NH_3-N concentration was recorded 8-18 h post-morning feeding. Concentration of VFA ranged from 110 to 140 mmol l^{-1} for MNG diets while values for the ONG diets ranged from 80 to 120 mmol l^{-1}. The concentration of VFA in SFBC diet ranged from 85 to 145 mmol l^{-1} while the range for the PLBC diet was from 80 to 140 mmol l^{-1}. Highest concentration of VFA occurred 12-16 h post-morning feeding while the lowest levels were recorded 16-20 h post-afternoon feeding. The percentage acetate had a similar diurnal pattern as the concentration of VFA while diurnal changes of percentage propionate were similar to changes in rumen pH.

For Trial 2, feed intake results are in Table 1 while the rumen fermentation results are in Tables 1 and 2, and Figure 2. There was a negative substitution rate at low levels of supplementation, an increase in substitution rate of napier grass and an increase in intake of total nutrients as level of PLBC was increased (Table 2). However, the substitution rate of 25 % at the common levels of supplementation (20-25 % of total intake of DM) was lower than what is reported in literature. The periods, steers and treatments affected all nutrient intakes. As compared to non-supplemented MNG, intake supplemented MNG was 10 % lower while intakes of total OM and CP were 23 and 42 % higher, respectively. Although all the rumen fermentation parameters were affected by treatments, the periods and steers affected only some of the parameters (Table 2). The rumen pH, percentage butyrate and acetate: propionate ratio were 8.6, 14 and 4.2 % lower, respectively while the concentrations of NH_3-N and VFA, and percentage acetate and propionate were 54.7, 16.9, 1 and 4.8 % higher, respectively for the supplemented than the non-supplemented MNG. Time of feed offer and its interaction with period, steers and treatments affected most of the rumen fermentation parameters (Table 4). The interaction of time of feed offer with treatments had quadratic relationships with concentration of VFA and percentage acetate.

Table 1 Chemical composition and estimated metabolisable energy content and rumen degradation of medium and old maturity napier grass, and sunflower seed meal and poultry litter based concentrates

	Trial 1				Trial 2	
Parameters	MNG	ONG	SFBC	PLBC	MNG	PLBC
Dry matter (g kg^{-1})	182.7	238.6	904.4	900.4	177.5	902.7
Chemical Composition (g kg DM^{-1}):						
Organic matter	784.4	878.5	934.4	910.2	785.4	909.4
Crude protein	81.8	53.3	153.4	150.7	82.6	150.9
Neutral detergent fibre	542.1	633.7	240.1	250.1	539.8	249.8
Acid detergent fibre	305.2	360.1	114.9	142.4	304.7	139.2
Acid detergent lignin	37.4	51.6	38.3	46.4	38.6	45.4
Crude fat	36.4	27.4	65.4	20.9	38.4	26.9
Energy content (MJ kg^{-1} DM):						
Gross energy	15.4	16.9	19.5	17.2	15.8	17.3
Estimated metabolisable energy	8.3	7.3	10.4	10.5	8.3	10.5
Rumen degradation (g kg^{-1} DM)*						
FCHO	322.0	233.2	426.4	416.6	322.0	416.6
FCP	43.5	14.9	83.8	84.4	43.5	83.2

MNG, medium maturity napier (age, 10 wk; height, 1.3 m); ONG, old maturity napier (age, 15 wk; height, 2.0 m); SFBC, sunflower seed meal based concentrate; PLBC, poultry litter based concentrate; FCHO, rumen fermentable carbohydrate; FCP, rumen fermentable CP; *, data obtained from Muia et al. (2000 b).

Table 2 Feed intake and rumen fermentation patterns in Friesian steers fed napier grass at medium or old maturity with either sunflower seed meal or poultry litter based concentrates (Trial 1)

	Treatments					Between subject effects			Contrasts	
	MNG + SFBC	MNG + PLBC	ONG + SFBC	ONG + PLBC	SED	Period	Steer	Trt	MNG vs ONG	SFBC vs PLBC
Feed intake:										
Observations (n)	40	40	40	40						
NDMI (kg cow^{-1} d^{-1})	11.94^{a}	11.32^{b}	10.20^{c}	10.09^{c}	0.183	**	***	***	***	**
TDMI (kg cow^{-1} d^{-1})	15.59^{a}	14.97^{b}	13.85^{c}	13.74^{c}	0.183	**	***	***	***	**
TDMI (g kg^{-1} W$^{0.75}$)	158.56^{a}	152.37^{b}	140.35^{c}	139.72^{c}	1.873	***	***	***	***	**
TOMI (g kg^{-1} W$^{0.75}$)	129.95^{a}	124.19^{b}	125.37^{b}	123.94^{b}	1.564	***	***	***	*	**
TCPI (g kg^{-1} W$^{0.75}$)	15.63^{a}	15.02^{b}	11.20^{c}	11.07^{d}	0.128	***	***	***	***	***
Rumen parameters:										
Observations (n)	84	84	84	84						
pH	6.64^{c}	6.73^{c}	6.99^{b}	7.20^{a}	0.090	*	***	NS	***	*
NH_3-N (mg l^{-1})	94.33^{b}	107.68^{a}	47.38^{d}	54.93^{c}	3.739	***	***	NS	***	***
VFA (mmol l^{-1})	124.94^{a}	122.55^{b}	103.35^{c}	100.22^{d}	0.730	NS	***	*	***	**
Molar % of VFA:										
Acetate (A)	69.46^{a}	69.05^{ab}	68.80^{b}	68.01^{c}	0.241	NS	**	***	**	**
Propionate (P)	19.04^{b}	19.34^{a}	17.23^{d}	17.92^{c}	0.128	NS	***	NS	**	**
Butyrate	9.79^{d}	10.01^{c}	11.86^{b}	12.11^{a}	0.111	NS	***	*	**	NS
★Others	1.71^{ab}	1.60^{b}	2.11^{a}	1.96^{ab}	0.212	NS	***	NS	**	NS
A:P ratio	3.68^{c}	3.61^{d}	4.06^{a}	3.88^{b}	0.032	***	*	***	***	**

MNG, medium maturity napier (age, 10 wk; height, 1.25 m); ONG, old maturity napier (age, 15 wk; height, 1.85 m); NDMI, napier DM intake; TDMI, total DMI; TOMI, total OM intake; TCPI, total CP intake; SFBC, sunflower seed meal based concentrate (3.65 kg DM cow^{-1} d^{-1}); PLBC, poultry litter based concentrate (3.65 kg DM cow^{-1} d^{-1}); TRT, treatments; NH_3-N, ammonia nitrogen; VFA, volatile fatty acids, SED, standard error of difference between means; different superscripts ^{a}, ^{b}, ^{c}, and ^{d} within a row indicate significant difference ($P < 0.05$); *. $P < 0.05$; ***, $P < 0.001$; NS, no significance ($P > 0.05$); ★, include valeric, iso-valeric and iso-butyric fatty acids.

Table 3 Feed intake and rumen fermentation patterns in Friesian steers fed napier at medium maturity with graded levels of poultry litter based concentrate supplementation (Trial 2)

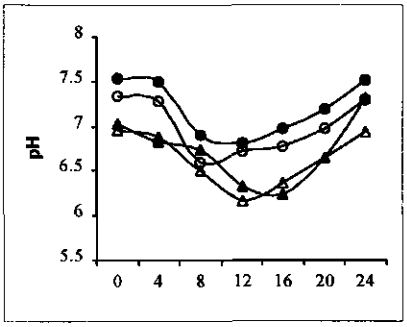
	Treatments					Between subject effects			Contrasts
	T0	T1	T2	T3	SED	Period	Steer	Trt	T0 vs Others
Feed intake:									
Observations	40	40	40	40					
NDMI (kg cow^{-1} d^{-1})	12.76^{b}	13.09^{a}	12.06^{c}	9.41^{d}	0.082	***	***	***	***
TDMI (kg cow^{-1} d^{-1})	12.76^{c}	13.99^{b}	15.71^{a}	15.76^{a}	0.082	***	***	***	***
TDMI (g kg^{-1} W$^{0.75}$)	128.27^{c}	140.63^{b}	157.90^{a}	158.40^{a}	0.809	***	***	***	***
TOMI (g kg^{-1} W$^{0.75}$)	100.74^{d}	111.59^{c}	128.57^{b}	132.32^{a}	0.635	***	***	***	***
TCPI (g kg^{-1} W$^{0.75}$)	10.60^{d}	12.24^{c}	15.55^{b}	17.45^{a}	0.067	***	***	***	***
SR (%)	0.00^{c}	-13.28^{d}	24.91^{b}	56.02^{a}	3.211	***	***	***	***
Rumen parameters:									
Observations	84	84	84	84					
pH	6.65^{a}	6.20^{b}	6.05^{c}	5.99^{c}	0.048	*	***	***	***
NH_3-N (mg l^{-1})	56.56^{c}	62.46^{c}	88.80^{b}	111.22^{a}	5.068	***	***	***	***
VFA (mmol l^{-1})	97.90^{d}	102.91^{c}	118.97^{b}	121.33^{a}	0.604	NS	***	***	***
Molar percentage of VFA:									
Acetate (A)	69.33^{c}	68.81^{c}	70.80^{a}	70.43^{a}	0.220	***	NS	***	***
Propionate (P)	18.57^{c}	19.40^{b}	19.10^{b}	19.92^{a}	0.181	***	NS	***	***
Butyrate	10.09^{a}	9.65^{b}	8.35^{c}	8.02^{d}	0.102	NS	**	***	***
★Others	2.01^{a}	2.13^{a}	1.75^{b}	1.63^{b}	0.119	NS	NS	***	NS
A:P ratio	3.79^{a}	3.58^{b}	3.75^{a}	3.57^{b}	0.043	***	*	***	***

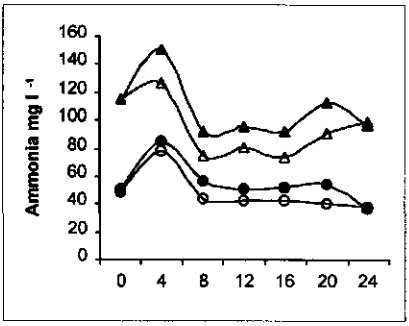
NDMI, napier grass DM intake; TDMI, total DM intake; TOMI, total OM intake; TCPI, total CP intake; T0, medium maturity (MNG) napier grass only diet or when MNG was supplemented with 0.91 (T1), 3.65 (T2) and 6.35 (T3) kg of DM cow^{-1} d^{-1} of poultry litter based concentrate (PLBC); NH_3-N, ammonia nitrogen; VFA, volatile fatty acids, TRT, treatment; SED, standard error of difference between means; different superscripts ^{a}, ^{b}, ^{c}, and ^{d} within a row indicate significant difference ($P < 0.05$); *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; NS, no significance ($P > 0.05$); ★, include valeric, iso-valeric and iso-butyric fatty acids; others, mean of T1, T2 and T3 diets.

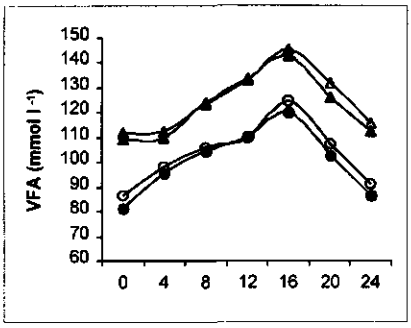
Table 4 The within-subject effects and contrasts of treatments with time of feeding on rumen fermentation parameters for Trials 1 and 2

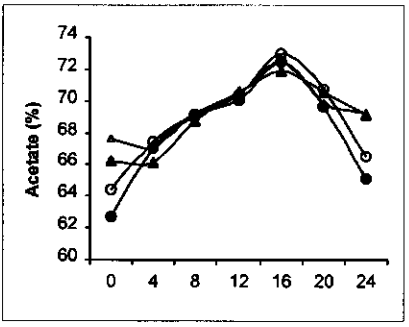
	Within subject effects				Contrasts		
Parameters	Time	Time*Period	Time*Steer	Time*Trt	Linear	Quadratic	Cubic
Trial 1							
PH	***	*	NS	NS	NS	*	NS
NH_3-N	***	**	**	NS	NS	NS	NS
VFA	***	***	***	*	NS	*	NS
Acetate	***	***	***	***	NS	*	NS
Propionate	***	***	***	NS	NS	*	NS
Butyrate	***	***	***	*	NS	NS	NS
Others	**	*	NS	NS	NS	NS	NS
A:P ratio	***	**	*	***	NS	NS	NS
Trial 2							
PH	***	*	NS	NS	NS	NS	NS
NH_3-N	***	***	*	***	NS	NS	NS
VFA	***	NS	**	***	NS	**	NS
Acetate	***	**	*	**	NS	**	NS
Propionate	***	*	NS	NS	NS	NS	NS
Butyrate	***	NS	*	NS	NS	NS	NS
Others	NS	**	NS	*	NS	NS	NS
A:P ratio	***	**	*	**	NS	NS	NS

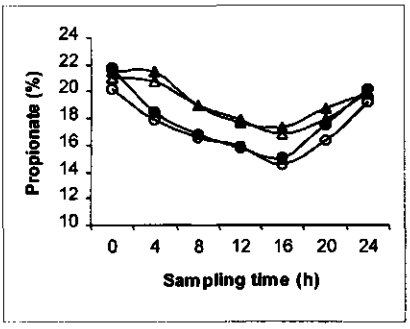
Trt, tretments; *, ** and *** significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; NS, no significant difference at $P > 0.05$.

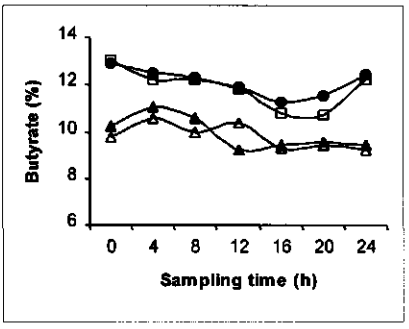

pH
8
7.5
7
6.5
6
5.5
0 4 8 12 16 20 24

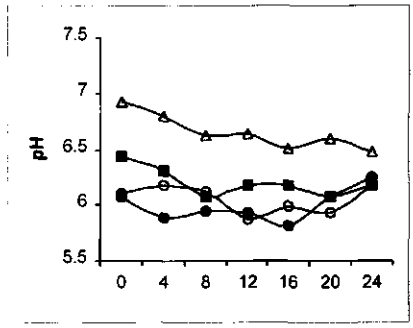

Ammonia mg l -1
160
140
120
100
80
60
40
20
0
0 4 8 12 16 20 24

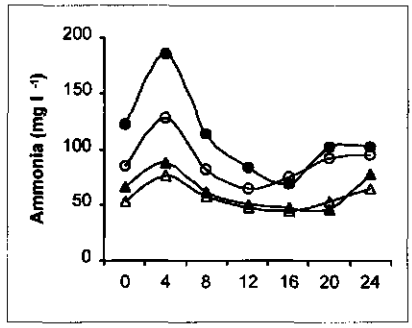

VFA (mmol l -1)
150
140
130
120
110
100
90
80
70
60
0 4 8 12 16 20 24

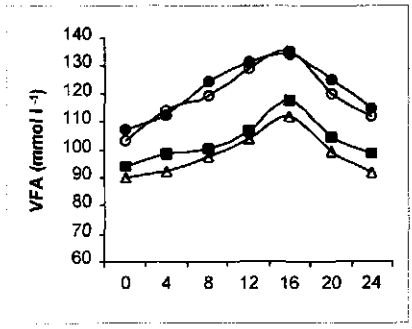

Acetate (%)
74
72
70
68
66
64
62
60
0 4 8 12 16 20 24

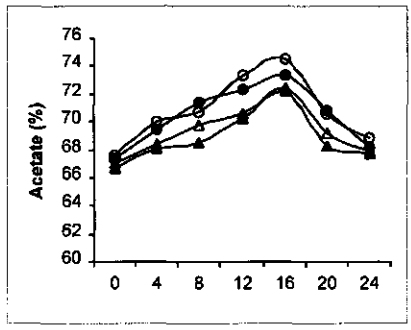

Propionate (%)
24
22
20
18
16
14
12
10
0 4 8 12 16 20 24
Sampling time (h)

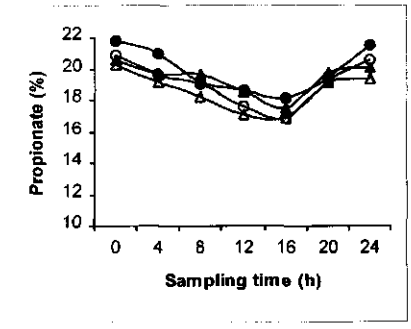

Butyrate (%)
14
12
10
8
6
0 4 8 12 16 20 24
Sampling time (h)

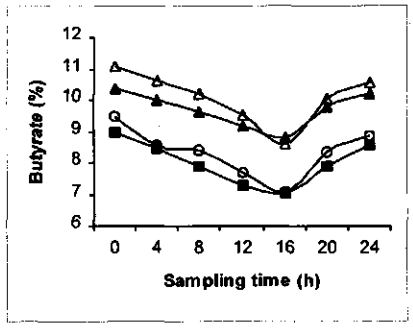

pH
7.5
7
6.5
6
5.5
0 4 8 12 16 20 24


Ammonia (mg l -1)
200
150
100
50
0
0 4 8 12 16 20 24


VFA (mmol l -1)
140
130
120
110
100
90
80
70
60
0 4 8 12 16 20 24


Acetate (%)
76
74
72
70
68
66
64
62
60
0 4 8 12 16 20 24


Propionate (%)
22
20
18
16
14
12
10
0 4 8 12 16 20 24
Sampling time (h)


Butyrate (%)
12
11
10
9
8
7
6
0 4 8 12 16 20 24
Sampling time (h)

The rumen pH of the non-supplemented MNG ranged from 6.5 to 6.9 while the range for the supplemented MNG was from 5.9 to 6.4 (Figure 2). Highest rumen pH occurred 12-16 h post-afternoon feeding while the lowest level was recorded 6-14 h post-morning feeding. There were minimal fluctuations in rumen pH over the 24 h period. Concentration of NH_3-N ranged from 50 to 190 mg l^{-1} for the supplemented MNG while the range for the non-supplemented MNG was from 50 to 75 mg l^{-1}. Highest concentration of NH_3-N occurred 2-4 h post-morning feeding and 10-14 h post-afternoon feeding while the lowest level was recorded 2-8 h post-afternoon feeding. Concentration of VFA ranged from 90 to 100 mmol l^{-1} for the non-supplemented MNG while that of supplemented MNG ranged from 90 to 130 mmol l^{-1}. Highest concentrations of VFA were recorded 10-18 h post-morning feeding while the lowest levels occurred 14-16 h post-afternoon feeding. Changes in percentage acetate were similar to changes in concentration of VFA with time of feed offer. Also, similar changes were observed for percentage propionate and rumen pH with time of feed offer.

Discussion

When the rumen degradation is higher as was the case with the MNG in relation to the ONG and the SFBC as compared with the PLBC (Muia et al, 2000 b), intake is elevated because of the shorter feed residence period in the rumen (Ørskov, 1982; Russell et al., 1992). The higher intake of CP than OM for the MNG diet (211 vs 89 g CP intake kg^{-1} OM intake) implied that animals fed ONG diet should be supplemented with concentrates containing more CP than OM to attain similar levels of intake as the animals fed the MNG diet. The intake data also

suggested that when animals are fed napier grass diets, the amount of PLBC supplement should be about 3 % higher than the amount of SFBC to achieve similar levels of feed intake. The improved feed intake for MNG supplemented with the PLBC than the MNG only diet would be attributed to an enhanced digestion. The contents of CP and ME in MNG were adequate for moderate milk production (8 kg cow^{-1} day^{-1}) and maintenance of a 450 kg cow (ARC, 1984). Therefore increasing the ratio of CP intake from 105 g per kg OM intake for the MNG only diet to 122 g per kg OM intake for the MNG supplemented with PLBC would be expected to result in improved milk production.

The negative substitution rate at low levels of supplementation (6 % of total DM intake) with the PLBC indicating that the supplement alleviated some deficiencies in the basal diet resulting in increased intake. But at high levels of PLBC supplementation (23-40 % of total DM intake), there was a decline in intake of MNG due to substitution of the forage by the supplement. Since the substitution rate was lower than 100 %, increasing the PLBC increased total feed intake as was reported for napier grass supplemented with concentrates (Anindo and Potter, 1986; Combellas and Martinez, 1982) or high-protein forages (Abdulrazak et al.,1996; Kariuki,1998). However, napier grass intake was not depressed by supplementation with high-protein forages (Muinga et al., 1995) possibly due to the lower levels of supplementation or lower quality of the grass used. At similar levels of concentrate supplementation, substitution rate values from 28 to 34 % reported by Combellas and Martinez (1982) were lower than in our study probably due to differences in quality of the napier grass in relation to the concentrate. However, substitution rate of 39 % obtained by Anindo and Potter (1986) by supplementing napier grass with cotton seed cake based concentrate was comparable to our results. Although intake of nutrients was higher than is expected for steers of similar live-weight (MAFF, 1984), intake values in the current study were comparable to values when napier grass was supplemented with concentrates (Anindo and Potter, 1986; Muia et al., 2000 c).

The higher rumen pH for the ONG than the MNG, PLBC than the SFBC and for the MNG than the mean of supplemented MNG were possibly because of their higher fibre content. The time spent eating and ruminating when high fibre diets are fed is more than for low fibre diets and as a result the buffering capacity of the rumen fluid is more resulting in high pH (Ørskov, 1982; Feng et al., 1993). Also, high feed intake results in overall increase in digested nutrients and hence a lowered rumen pH (Robinson et al., 1986; Clark et al., 1992). The pH values for these diets ranging from 6 to 7.5 was an indication that the rumen environment was optimal for microbial protein growth (Durand and Kawashima, 1980) and cellulolysis (Mould and Ørskov, 1983). However, the frequent fluctuations of rumen pH for the PLBC supplemented diets as compared to that of the SFBC supplemented diets would be associated with unstable rumen environment which might have a negative influence on the rumen microbes and feed digestion. A higher rumen pH was also reported for diets containing PL than those without PL in a study by Ayangbile et al. (1993). In contrast, pH levels were not affected by supplementing napier grass with high-protein forages (Muinga et al, 1995; Abdulrazak et al, 1996; Kariuki, 1998) probably because of the high fibre content of the diets inducing more salivation and a higher buffering capacity (Russell et al., 1992). The variations in rumen pH in relation to time of feeding in our study were consistent with a report where low levels were achieved 9 and 24 h after feeding high cellulose diets (Dehority and Tirabasso, 1998). In contrast, the rumen pH was high pre-feeding but declined rapidly a few hours after feeding readily fermentable starchy concentrates (Robinson et al., 1986).

The rumen NH_3-N levels below 50 mg l^{-1} when ONG was supplemented with SFBC was an indication that the diet could not support optimal rumen microbial growth (Satter and Slyter, 1974). The PLBC was a better supplement as compared to the SFBC, based on NH_3-N

concentration because it attained the minimum concentration requirements for optimal rumen microbial growth even when supplemented to animals fed ONG diet. The MNG supplemented with at least 3.65 kg of DM of the PLBC or the SFBC attained the required minimum NH_3-N concentration of 100 mg l^{-1} for optimum digestion/or feed intake (Preston and Leng, 1987). This could be among the reasons for the higher increase in feed intake from 0.91 to 3.65 kg of DM of the PLBC in Trial 2. The higher concentration of NH_3-N on the MNG vs ONG and on supplemented MNG vs MNG only diet was because of their higher CP content as suggested by Minson (1990) and their higher fermentable CP in relation to fermentable OM (Table 1). However, the higher NH_3-N concentration on the PLBC vs SFBC could be attributed to the rapid degradation of PL as compared to sunflower seed meal (Muia et al 2000 b) as was the case with non-protein N in other reports (Baldwin and Allison, 1983; Van Houtert, 1993). The high NH_3-N concentrations with increased levels of supplementation in our study were consistent with other reports on napier grass supplemented with high-protein forages (Muinga et al., 1995; Abdulrazak et al., 1996; Kariuki, 1998). Also, the lowest and highest concentrations of NH_3-N in relation to time of feeding were comparable to other reports on napier grass diets (Muinga et al., 1995; Kariuki, 1998). As compared to the current study, higher concentration of NH_3-N for napier grass supplemented with high-protein forages (Muinga et al., 1995; Kariuki, 1998) suggest more fermentable N than OM resulting in loss of N in form of NH_3-N as was reported for other diets by Russell et al. (1992). Alternatively, the high levels of concentrate supplementation in our study may have supplied more fermentable N and OM resulting in an enhanced rumen microbial growth and thus an increased utilization of NH_3-N leading to a lower concentration in the rumen in consistent with a report by de Visser, (1993).

The higher concentration of VFA on the MNG vs ONG, SFBC vs PLBC and mean of supplemented MNG vs MNG only diet would be attributed to their higher degradation in the

rumen (Muia et al., 2000 b) leading to higher rumen microbial growth as reported McCarthy et al. (1989). Also their higher intake resulted in higher concentration of VFA in agreement with other reports on napier grass diets (Muinga et al., 1995; Kariuki, 1998). The concentration of VFA we obtained was higher than values reported when napier grass was supplemented with high-protein forages (Muinga et al., 1995; Kariuki, 1998) because concentrates have a higher passage rate through the rumen hence a higher intake (Owens and Goetsch, 1986). The percentage of the individual acids were within the reported range of 65 to 74 %, 15 to 20 %, and 8 to 16 % for of acetate, propionate and butyrate, respectively (Thomas and Rook, 1981). The higher acetate: propionate ratio on the ONG vs MNG and on MNG only diet vs the mean of supplemented MG were due to the higher percentage acetate because of the higher fibre content. However, the higher acetate: propionate ratio on SFBC vs PLBC was not expected. The higher rate of degradation in the rumen of PLBC than the SFBC (Muia et al., 2000 b) may have increased the feed intake and passage rate of the basal diet resulting in a higher percentage of propionate hence a lower acetate: propionate ratio. The lower acetate: propionate ratio on the supplemented MNG vs MNG only diet was consistent with reports on napier grass supplemented with high-protein forages (Muinga et al., 1995; Kariuki, 1998). The acetate: propionate ratios for napier grass supplemented with PLBC or SFBC were below the minimum level of 4.0: 1 for maintenance of milk butter fat content (Russell et al., 1992). Using the same diets gave low milk butter fat content (3.6-3.9 %) in a different study (Muia et al., 2000 c) in consistent with the low acetate: propionate ratio values in the current study.

The concentrations of VFA in the rumen were inversely related to the pH in agreement with reports on other diets (Robinson et al., 1986; Tamminga and Van Vuuren, 1988). Diurnal changes in rumen pH followed the same pattern as the concentration of NH_3-N in our study but in contrast, high rumen pH enhanced absorption of NH_3-N, resulting in reduction of its

concentration in the rumen for other diets (Harmeyer and Mertens, 1980). The decrease in NH_3-N concentration was accompanied by an increase in VFA concentration suggesting that the NH_3-N was utilised by rumen microbes resulting in production of VFA. The concentrations of VFA and NH_3-N are expected to rise when degradation of a diet in the rumen increases. Alternatively, when the rate of rumen microbial growth is increased, the fermentable metabolites (VFA and NH_3-N) in the rumen are expected to decrease. Also, absorption of these metabolites through the ruminal epithelium is expected to result in decrease of their concentrations in the rumen. The concentrations of these metabolites in the rumen at different periods may therefore differ depending on the rates of production, absorption, utilisation, rumen pH, and rumen outflow (Tamminga, 1992; Feng et al., 1993; Van Houtert, 1993).

At similar stages of maturity, the chemical composition of the MNG and the ONG in the current study were comparable to values obtained in the highlands of Kenya (Snijders et al., 1992; Kariuki, 1998; Muia et al., 1999). However, mainly because of soils and weather differences, the values were higher than those reported at the coastal areas of Kenya (Muinga et al., 1995; Abdulrazak, et al., 1996). The nutritive value of the ingredients used to compound the concentrates (sunflower seed meal, cotton seed cake and maize germ) were similar to values reported in literature (Mcdonald et al., 1988; NRC, 1988; Sniffen et al., 1992) and the quality of the PL was similar to values reported by Ayangbile et al (1993). The CP content of the PL was lower than in others reports (Patil et al., 1993; Kato et al., 1994) probably because of contamination with bedding materials. The nutritive value of PL can vary depending on factors such as type of bird and their feeds, time before collection, and processing methods (kayongo and Muinga, 1986) but the possibility for maintaining its quality by ensilage exist (Patil et al., 1993; Kaur et al., 1997).

Conclusions

Intake of nutrients and hence the concentration of VFA in the rumen were higher for MNG than ONG, and for SFBC than PLBC. However, the difference in intake of CP was higher than OM on MNG vs ONG but similar on SFBC vs PLBC. Although the rumen pH was optimal for microbial growth and cellulose digestion for all diets, there were more fluctuations in rumen pH of the PLBC than the SFBC diets. The higher feed intake resulted in higher concentrations of NH_3-N on the MNG vs ONG but PLBC had higher NH_3-N concentration values than SFBC. However, at NH_3-N concentration levels below the critical value of 100-mg l^{-1}, feed intake was higher than expected. All the diets gave acetate: propionate ratio values lower than the levels required for maintenance of milk butter fat content. To improve feed intake and digestion, animals fed MNG should be supplement with PLBC while SFBC should be used for animals fed ONG.

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References

AAC, 1990. Australian Agricultural Council. Feeding standards for Australian livestock. Ruminant sub-committee CSIRO. Eastern Melbourne, Australia.

Abdulrazak, S.A., Muinga, R.W., Thorpe, W. and Ørskov, E.R, 1996. The effects of supplementation with *Gliricidia sepium* or *leucaena leucocephala* forage on intake, digestion and live-weight gains of *Bos Taurus* x *Bos Indicus* steers offered napier grass. Animal Science, 63: 381 - 388.

Anindo, D.O. and Potter, H.L., 1986. Milk production from napier grass (*Pennisetum purpureum*) in a zero-grazing feeding system. East African Agriculture and Forestry Journal, 52: 106-111.

AOAC, 1990. Official method of analysis. Association of Official Analytical Chemists. 14th Edition, Washington, D.C.

ARC, 1984. The nutrient requirements of ruminant livestock (Suppl. No. 1). Agricultural Research Council. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

Ayangbile, O.A., Tallam, S.K. and Sultan, M.S., 1993. Processing of slaughter house blood and poultry litter and the effects on nutrient digestibility by steers. Animal Feed Science and Technology., 40: 153 -164.

Combellas, J. and Martinez, N., 1982. Intake and milk production in cows fed chopped elephant grass (*Pennisetum purpureum*) and concentrates. Tropical Animal Production, 7: 57-60.

Baldwin, R.L., and Allison, M.J., 1983. Rumen metabolism. Journal of Animal Science, 57: 461-477.

Clark, J.H., Klusmeyer, T.H. and Cameroon, M.R., 1992. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. Symposium: Nitrogen metabolism and Amino Acid Nutrition in Dairy Cattle. Journal of Dairy Science, 75: 2304 - 2323.

Dehority, B.A. and Tirabasso, P.A., 1998. Effect of ruminal cellulolytic bacterial concentration on *in situ* digestion of forage cellulose. Journal of Animal Science, 76: 2905-2911.

Durand, M., and Kawashima, R., 1980. Influence of minerals in rumen microbial digestion. In: Ruckebusch, Y., and Thivend, P. (Eds.), Digestive Physiology in Ruminants. MTP Press, Lancaster, UK, pp.375-408.

Feng, P. Hoover, W.H., Miller, T.K. and Blauwie, R., 1993. Interaction of fibre and non structural carbohydrates on lactation and ruminal function. Journal of Dairy Science, 76: 1324-1333.

Harmeyer, J. and Martens, H., 1980. Aspects of urea metabolism in ruminants with reference to the goat. Journal of Dairy Science, 63: 1707-1728.

Jaetzold, R. and Schmidt, H., 1983. Farm Management Information. Handbook of Kenya, vol. 11a. Ministry of Agriculture, Nairobi, Kenya.

Jarrige, R., 1989. Ruminant nutrition: recommended allowance and feed tables, INRA, John Libbey, London.

Kariuki J.N., 1998. The potential of improving napier grass under smallholder dairy farmer's condition in Kenya. PhD thesis, Wageningen Agricultural University, The Netherlands.

Kato, H., Bareeba, F.B. and Mugerwa, J.S., 1994. Fermentation characteristics and nutritive value of broiler litter derived from coffee husks and ensiled with maize forage. East African Agriculture and Forestry Journal, 59: 253 -260.

Kaur, B., Wadhwa, M., Singh, N., Bakshi, M.P.S. and R.P. Gupta, R.P., 1997. Processing and evaluation of poultry droppings as livestock feed. Indian Journal of Animal Science, 67: 716 -719.

Kayongo, S.B. and Irungu, K.R.G., 1986. Evaluation of broiler waste in formulation of concentrate for lactating Friesian heifers grazing irrigated pastures. East African Agriculture and Forestry Journal, 52: 9 - 15.

McCarthy, R. D. Jr, Klusmeyer, T.H., Vicini, J.L., Clark, J.A. and Nelson, D.R., 1989. Effect of source of protein and carbohydrates on ruminal fermentation and passage of nutrients to the small intestines of lactating cows. Journal of Dairy Science, 72: 2002 -2016

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D. 1988. Animal nutrition. 4th edition. Longman group publishers: London, New York.

MAFF, 1984. Energy allowances and feeding systems for ruminants. Ministry of Agriculture Fisheries and Food, Department of Agriculture and Fisheries for Scotland, Department of Agriculture for Northern Ireland. Reference book 433. Her Majesty's Stationary Office, London.

Minson, D.J. (Ed.), 1990. Forage in Ruminant Nutrition. Academic press, Inc. San Diego.

MoLD, 1991. Zero-grazing: A handbook on technical aspects. Ministry of Livestock Development (MoLD), Nairobi, Kenya.

Mould, F.L., and Ørskov, E.R., 1983. Manipulation of rumen fluid pH and its influence on cellulolysis, *in sacco* dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. Animal Feed Science and Technology, 10: 1-14.

Muia, J.M.K., Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 1999. Optimal stage of maturity for feeding napier grass (*Pennisetum purpureum)* to dairy cows in Kenya. Tropical Grasslands., 33: 182-190.

Muia, J.M.K., Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 2000 a. Prediction of yield and digestibility of napier grass (*Pennisetum purpureum*) from maturity, leaf; stem ratio and laboratory analyses. Tropical Science, (in press).

Muia, J.M.K., Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 2000 b. Rumen degradation and estimation of microbial protein yield and intestinal digestion of napier grass (*Pennisetum purpureum*) and various concentrates. Animal Feed Science Technology. (submitted).

Muia, J.M.K., Tamminga, S.,and Mbugua, P.N. 2000 c. Effect of supplementing napier grass (*Pennisetum purpureum*) with sunflower meal or poultry litter based concentrate on feed intake, live-weight change and economics of milk production in Friesian cows. Livestock Production Science (accepted).

Muinga, R.W., Thorpe, W. and Topps. J.H., 1995. The effects of supplementation of *leucaena leucocephala* and maize bran on voluntary intake, digestibility, live-weight change and milk yield of *Bos Indicus* X *Bos Taurus* dairy cows and rumen fermentation in steers offered Pennisetum purpureum *ad-libitum* in the semi-humid tropics. Animal Science, 60: 13-23.

Mwangi, D.M., 1995. Diagnostic survey in Livestock feeds, feeding and management practices in central Kenya. In: Fungoh, P.O., Mbadi, G.C.O. and Ondatto. H., (Eds.), Proceeding of the 4th Kenya Agricultural Research Institute Scientific Conference, 1994, Nairobi, Kenya. pp. 293-305.

NRC, 1988. Nutrient requirements of dairy cattle. 6th revised Edition. National Academic press: Washington, DC.

Owens, F.N., and Goetsch, A.L., 1986. Digesta passage and microbial protein synthesis. In:Milligan, L.P., Grovum, W.L, and Dobson, A. (Eds.), Control of Digesta and Metabolism in Ruminants. Prentice-hall, Englewood Cliff, NJ, pp. 196-226.

Ørskov, E.R. (Ed.), 1982. Protein nutrition in ruminants. Academic press, Inc., London.

Patil, A.R., Goetch, A.L., Galloway, D.L. Sr., Forster, L.A. Jr., 1993. Intake and digestion by Holstein Steer calves consuming grass hay supplemented with broiler litter. Animal Feed Science and Technology, 44: 251 -263.

Preston, T.R. and Leng, R.A. (Ed.), 1987. Matching ruminant production systems with available resource in the tropics and sub-tropics. Penambul Books, Armidale.

Robinson, P.H., Tamminga, S. and Van Vuuren, A.M., 1986. Influence of declining level of feed intake and varying the proportion of starch in the concentrate on rumen fermentation in dairy cows. Livestock Production Science, 15: 173 - 189.

Russell, J.B., O'Connor, J.D., Fox, D.G., Van Soest, P.J. and Sniffen, C.J., 1992. A net carbohydrate and protein system for evaluating cattle diets. 1. Ruminal fermentation. Journal of Animal Science, 70: 3551 - 3561.

SAS, 1988. User's guide. Release 6.03 Edition. Statistical Analysis Systems Institute (SAS/START). Carry, NC.

Satter, L.D. and Slyter, L.L., 1974. Effect of ammonia concentration on rumen microbial protein production *in vitro*. British Journal of Nutrition, 32: 199-208.

Sniffen, C.J., O'Connor, J.D., Van Soest, P.J., Fox, D.G. and Russell, J.B., 1992. A net carbohydrate and protein system for evaluating cattle diets. II. Carbohydrate and protein availability. Journal of Animal Science, 70: 3562 - 3577.

Snijders, P.J.M., Orodho, A.B., Kiura, J.N. and Mogaka, L.M., 1992. Effect of nitrogen fertilizer and cutting stage on yield and quality of napier grass (*Pennisetum purpureum*). Research report, Kenya Agricultural Research Institute, Naivash, Kenya. 46 p.

Tamminga, S., 1992. Nutrition management of dairy cows as a contribution to pollution control. Journal of Dairy Science, 75: 345 - 357.

Tamminga, S. and Van Vuuren, A.M., 1988. Formation and utilization of end products of lignocellulose degradation in ruminants. Animal Feed Science Technology, 21: 141-159.

Thomas, P.C and Rook, J.A.F., 1981. Manipulation of rumen fermentation. In: Haresign, W. and Cole, D.J.A (Eds.), Recent development in ruminant nutrition. Butterworth. London. pp. 157- 183.

Van Houtert, M.F.J., 1993. The production and metabolism of volatile fatty acids by ruminants fed roughage: A review. Animal Feed Science and Technology, 43, 189-225.

Van Soest, P.J., 1982. Nutritional Ecology of the Ruminant. O & B books, Corvallis, Oregon, USA.

Van Soest P.J. and Robertson, J.B. 1985. Analysis of forage and fibrous foods. AS 613 Manual, Department of Animal Science, Cornell University, Ithaca.

Visser de, H., 1993. Influence of carbohydrate on feed intake, rumen fermentation and milk performance in high yielding dairy cows. PhD thesis, Wageningen Agricultural University. The Netherlands.

Chapter 8

Effect of supplementing napier grass (*Pennisetum purpureum*) with sunflower meal or poultry litter based concentrates on feed intake, live-weight changes and economics of milk production in Friesian cows

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Effect of supplementing napier grass (*Pennisetum purpureum*) with sunflower meal or poultry litter based concentrates on feed intake, live-weight changes and economics of milk production in Friesian cows

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Abstract

A study was conducted using a randomized complete block design to determine feed intake, live-weight changes (LWC), milk yield and cost of milk production in Friesian cows fed supplemented napier grass at 10 (MNG) or 15 (ONG) weeks of maturity. The MNG or ONG was supplemented with equal amounts of sunflower (SFBC) or poultry litter (PLBC) based concentrates in Experiment 1 while in Experiment 2, the MNG was fed either as a sole diet or supplemented with graded levels of the PLBC. In Experiment 1, the intakes of total organic matter (TOMI) was lower (135.9 vs 137.7 g kg $W^{0.75}$) while intake of total crude protein (TCPI) was greater (16.6 vs 12.0 g kg $W^{0.75}$) for MNG than ONG diets ($P < 0.001$). The TOMI (137.8 vs 135.8 g kg $W^{0.75}$) and TCPI (14.3 vs 14.2 g kg $W^{0.75}$) were higher for SFBC than PLBC diets ($P < 0.05$). The yield of milk corrected for butter fat (FCM) was higher (11.0 vs 5.7 kg cow^{-1} day^{-1}) for MNG than ONG diets ($P < 0.001$). In Experiment 2, the TOMI (112.8 vs 130.6 g kg $W^{0.75}$) and the TCPI (12.2 vs 16.1 g kg $W^{0.75}$) were lower for MNG only diet than the mean of the supplemented MNG ($P < 0.001$). The MNG only diet supported lower yields of FCM (7.7 vs 10.7 kg cow^{-1} day^{-1}) than the mean of the supplemented MNG ($P < 0.001$). Although supplemented cows fed MNG diets gained weight, those fed supplemented ONG diets or MNG only diet lost weight. Feeding of supplemented ONG resulted in loss of revenue while supplementing with PLBC had higher profits than SFBC. We concluded that use of the PLBC would lower costs and improve milk production in dairy cows fed NG-based diets.

Keywords: Napier; Sunflower meal; Poultry litter; Dairy cattle feeding and nutrition; Live-weight; Milk; Economics

Introduction

In Kenya, napier grass (*Pennisetum purpureum*) is among the major feed resources for dairy cows in the medium and high rainfall areas. The official recommendation (MoLD, 1991) is to feed napier grass (NG) at a height of 60 to 100 cm. Feeding NG at these stages of maturity is possible during the wet seasons when there is adequate growth. Alternatively, dairy farmers could opt to use other feeds during the wet seasons and thus use NG at an advanced stage of maturity during the dry seasons. However, at advanced maturity forages are characterized by high cell wall content, low N content, low digestibility, and low intake resulting in low performance by ruminants (Van Soest, 1982).

Since feeding a NG only diet at the recommended stage of maturity does not support high animal performance, supplementation with either concentrates (Anindo and Potter, 1986; Muinga et al., 1993) or fodder trees (Muinga et al., 1995) resulted in improved milk yield in dairy cows. However, commercial concentrates are too expensive for the small-holder and because of establishment and persistency related problems, the existing fodder trees are not adequate for supplementing livestock at the farm level (Mwangi, 1995). Consequently, farmers are using alternative sources of protein such as poultry litter (i.e. poultry excreta contaminated with bedding materials). Poultry litter (PL) is readily available and inexpensive as compared to the other conventional sources of protein like cotton seed cake and sunflower cake.

Considerable data on use of poultry litter (PL) for beef production exist (McCann and Martin, 1997; Jordan et al., 1997). There is scarce information on milk yield when dairy cows fed forages other than NG are supplemented with PL based concentrates (Kayongo and Irungu, 1986; Odhuba, 1989). However, data on milk yield in high yielding cows fed NG and supplemented with PL based concentrate is however non-existent. Farmers need to know how to make inexpensive home-made concentrates using PL as a protein source and the advantages

of feeding such concentrates in terms of milk yield and cost of milk production by dairy cows during the wet and dry seasons.

The objectives of this study were to determine the effects of feeding medium (MNG) or old (ONG) stage of maturity NG and supplemented with either sunflower meal (SFBC) or PL (PLBC) based concentrate on feed intake, live-weight changes, milk yield and composition, and costs of milk production in dairy cows. The effects of feeding dairy cows on the MNG supplemented with graded levels of the PLBC on the study parameters were also investigated.

Materials and methods

This study was conducted at the National Animal Husbandry Research Station (0 ° S; 36 ° E, altitude, 1940 m), Naivasha, Kenya. Average annual rainfall of 630 mm, falls mainly from March-June and October-December for the long and short rains, respectively. Average temperature is 18 ° C and the soils are of moderate fertility and slightly to moderately alkaline (Jaetzold and Schmidt, 1983).

Experiment 1

Thirty two multiparous (2 to 4 lactation), Dutch Friesian cows (live-weight 438.8 ± 38.8 kg) were selected from a large herd at the research station based on their live-weight, milk yield and body condition. The animals previously grazed mixed pastures of Kikuyu grass *(Pennisetum clandestinum)*, Rhodes grass (*Chloris gayana*) and Kenya white clover (*Trifolium semipilosum*). At the beginning of the trial the cows were drenched to control internal

parasites and sprayed weekly with acaricide to control ticks. The cows were blocked into two equal groups based on stage of lactation; early- (45; SD, 10 days) and mid-(102; SD, 11 days) lactation. The cows in each block were divided into 4 similar groups based on live-weight and number of lactation. The four groups of 4 cows each were randomly allocated to the four treatment combinations, namely; the MNG (age,10 wk; height, 1.3 M) supplemented daily with the SFBC or the PLBC, and the ONG (age, 15 wk; height, 2.0 M) supplemented with either the SFBC or the PLBC. The chemical composition of these feeds is presented in Table 1.

The NG was managed as recommended (MoLD, 1991) and the required amounts were estimated from intake of DM by a 450 kg cow (MAFF, 1984) and yields at respective stages of maturity (Muia et al, 1999). The field with MNG was subdivided into 70 equal plots and that with ONG into 105 equal plots. To ensure that same quality of NG was fed, clearing cuts were planned and executed sequentially starting on the plots with grass to be fed first and ending on plots with grass to be fed last (Kariuki, 1998). Clearing cuts on the plots with NG to be fed last were therefore done 70 days after the first clearing cut for the MNG while for the ONG, last clearing cut was done 105 days later.

The PL, collected from a deep litter system where layers were kept for 12 months was sun-dried for 3 days, sieved and stored in bags. The PLBC was compounded using 360, 400, 230 and 10 g kg^{-1} DM of maize germ, PL, sunflower meal (SFM) and mineral premix, respectively while the SFBC was compounded using 630, 360 and 10 g kg^{-1} DM of maize germ, SFM and the mineral premix, respectively. The chemical composition of SFM was 931.3, 954.8, 240.8, 314.0 g kg^{-1} DM and 10.7 MJ kg^{-1} DM while PL contained 900.2, 772.0, 164.8, 439.4 g kg^{-1} DM and 9.6 MJ kg^{-1} M of DM, OM, CP, NDF contents and estimated ME, respectively. Maize germ contained 920.2, 990.3, 90.8 and 283.7 g kg^{-1} DM of DM, OM, CP and NDF contents, respectively. Mineral premix contained 270.0, 185.1, 110.0, 30.0, 5.0, 1.6, 4.0, 4.0, 5.0, 0.2, 0.015, 0.002 g kg^{-1} DM and 1.68:1 ratio of Nacl, Ca, P, Mg, Fe, Cu, Mn, S,

Zn, Co, Se, Mo, and Ca:P ratio, respectively. The concentrates were formulated to be iso-nitrogenous (24 g N kg^{-1} DM) and with a calorific value of 17.0 to 19.0 MJ kg^{-1} DM. The grass was chopped using an electric chaff-cutter to a mean particle length of 2.5 cm to avoid selection of the more nutritious leaves and clean water was available all the time. Feeding was done twice (08.00 and 17.00 h) daily at *ad libitum* level of intake (120 % of previous days determined intake) and the SFBC or PLBC were offered at a daily rate of 3.65 kg DM in equal amounts during milking (06.00 and 15.00 h).

The cows were fed the diets for a 14-day adaptation, a 14-day covariance, and an 84-day experiment period. The feeds offered and refusals were recorded for each cow daily. Representative samples of feeds offered and refusals by each cow were dried at 70 ° C for 24 h, bulked on a weekly basis and stored in tightly closed containers awaiting laboratory analyses. Representative samples of the concentrates were also taken weekly. Feed intake was estimated as the difference of feed offered and that refused per week. Live-weight changes were monitored fortnightly and milk samples taken twice weekly were stored at –20 ° C pending laboratory analyses.

Experiment 2

Forty eight cows from the same herd (live-weight 436.0 ± 36.3 kg) were selected based on live-weight, milk yield and body condition. The cows were in their early- to mid-lactation (mean 99.3 ± 35.9 days). Prior to the experiment, the animals were grazed on mixed pastures as described in experiment 1. The cows were blocked into two groups based on number of lactation; 16 cows in first lactation and 32 cows with 2 to 5 lactation. Each group was subdivided based on live-weight and days in milk into 4 similar groups of 4 cows for the first

lactation and 8 cows for those in later lactation. The treatments were MNG only diet (T0) or MNG supplemented daily with 0.91 (T1), 3.65 (T2) or 6.35 (T3) kg DM of the PLBC. The treatments were randomly allocated to the 4 sub-groups within each group. The management of the grass and other protocols were as in Experiment 1.

Estimation of energy content and total protein digested in the intestines

Gross energy (GE) was determined by a bomb calorimeter (adiabatic; Gallencamp, England). The digestible OM (DOM, g kg^{-1} DM) and metabolisable energy (ME, MJ kg^{-1} DM) of NG were estimated using the equations, DOM = 677.99 – (12.57*Age of NG in weeks) (Muia et al., 2000 a). ME = DOM/1000*18.5*0.81 (AAC, 1990). The OM digestibility (OMD) and ME content of the concentrates were estimated using the equations, OMD (g kg^{-1}) = 919 – (0.355 *NDF) + (0.387*ADF) – (2.17*ADL) – (0.39*EE) (Jarrige, 1989). Where, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent lignin, and EE = crude fat all in g kg^{-1} DM. DOMD (g kg^{-1} DM) = (0.92*OMD) - 12 (MAFF, 1984). ME (MJ kg^{-1} DM) = DOMD*0.015 (MAFF, 1984). The total protein digested in the intestines for NG and the concentrates were estimated in a separate study by Muia et al. (2000 b).

Gross margin calculations

The cows were assumed to be under a zero-grazing system of production. The costs of milk production were estimated using the assumptions that:- y = 0.013 + (0.361*x) (Muia et al., 1999) Where, y = DM yield (ton^{-1} ha^{-1}) and x = NG age in weeks. The carrying capacity (CC) was calculated using the equation; CC = DM yield (kg ha^{-1} day^{-1})/ANDMI, where, ANDMI = napier DM intake with an allowance of 25 % feed left-over. Labor requirement was

1 worker per every 2 cows at monthly earnings of Ksh. 3000.00 and Ksh. 5000.00 for the rural and urban worker, respectively. The number of cuts for the MNG and the ONG were 5.2 and 3.5 per year, respectively. Fertilizer N:P:K (20:10:10) was applied at a rate of 500 kg ha^{-1} yr^{-1} and the cost per kg was Ksh. 26.00. The fertilizer CAN (26 % N) was applied at a rate 50 kg per cut and the cost was Ksh. 20.00 per kg. The veterinary costs of Ksh. 500 cow $^{-1}$ month $^{-1}$ included curative drugs, vaccinations, acaricide, pye grease, mastrite and bactergents (Waithaka and Nijssen, 1992).

The cost of the SFBC was Ksh. 18.00 per kg while those of the PLBC were Ksh. 12.40 and 14.40 for the rural and peri-urban areas, respectively. Majority of dairy farmers also practice commercial poultry production and supplement their animals with PL as a source of protein. Although there is yet no formal marketing, those farmers with more animals or with less PL purchase extra requirements from their neighbors. The current average price per kg of milk of Ksh. 15.00 and 25.00 were used for the rural and peri-urban areas, respectively. The milk yield, feed intake, and level of supplementation were as in Experiments 1 and 2. The milk yield not corrected for butter fat content was used in calculations. The miscellaneous costs were estimated as 5 % of the total costs and the currency exchange rate was Ksh. 75.00 per U.S. dollar ($).

Laboratory analyses

Feed samples were dried at 105 ° C for 24 h to determine DM and ashed at 500 ° C for 6 h to determine ash content. The EE content was determined using the soxhlet extraction in a diethyl ether after HCl hydrolysis and the CP content was determined using the micro-Kjeldahl procedure (AOAC, 1990). The NDF, ADF and ADL were determined according to Van Soest and Robertson (1985). Milk samples were analyzed for butter fat content (BF) using the

Gerber method and the CP and solid-not-fat (SNF) contents were analyzed using the methods of Pearson (1976).

Statistical analyses

In Experiment 1, analysis of variance to determine effect of treatments on study parameters (nutrient intake, live-weight changes, and milk yields and composition) was done according to a randomized complete block design in a 2 x 2 factorial (i.e. age of NG and supplements) arrangement. The statistical model was $Y_{ijkl} = \mu + A_i + S_j + AS_{ij} + B_k + C_l + e_{ijkl}$ where Y, dependent variable; μ, overall mean; A, age of napier effect; S, supplement effect; AS, interaction of A and S effect; B, block effect (stage of lactation); C, covariant effect and e, the error-term. Pre-planned contrasts on the study parameters were MNG vs ONG, SFBC vs PLBC and early- vs mid-lactation. In Experiment 2, the effect of supplementation of the MNG with graded levels of the PLBC on the same study parameters were determined in a randomized complete block design. The statistical model was $Y_{ijk} = \mu + T_i + B_j + C_k + e_{ijk}$ where T, treatment effect and B, block effect (number of lactations) while the other abbreviations were as described in Experiment 1. The responses (linear, quadratic or cubic) of study parameters with increase in level of supplementation were also investigated. The statistical analyses and separation of means were done using the general linear model procedure in SAS program (1988).

Results

Nutritive value

The chemical composition, and estimated energy and total protein digested in small intestines (TPDI) are presented in Table 1. The nutritive values of MNG or PLBC in Experiments 1 and 2 were similar. The contents of CP, ME and the TPDI in ONG were lower than in MNG by 37, 12 and 38 %, respectively while the content of ADL in MNG was 25 % lower than in ONG. Although the energy and protein contents of the PLBC were similar to values of the SFBC, amount of TPDI was 16 % lower. However, the ADL content was 23 % lower in SFBC than PLBC.

Intake of nutrients

The intakes of nutrients are presented in Tables 2 (Experiment 1) and 3 (Experiment 2). The daily DM intake of NG (NDMI), and total intakes of DM (TDMI) and CP (TCPI) were lower by 7, 7 and 29 %, respectively ($P < 0.001$) for cows fed the ONG than those fed the MNG diets. In contrast, total intake of OM (TOMI) was 1.3 % higher for cows fed the ONG than the cows fed the MNG diets. The TOMI and the TCPI were 1.5 and 0.7 % higher, respectively for cows supplemented with the SFBC than those supplemented using the PLBC ($P < 0.001$). The intake of nutrients were higher for the cows in mid- than those in early-lactation ($P < 0.001$). Interaction of napier age with supplement was recorded for TDMI, TOMI and TCPI ($P < 0.001$). In Experiment 2, intake of nutrients increased linearly with level of supplementation ($P < 0.001$). The mean of NDMI for the supplemented MNG diets was 15 % lower than the MNG only diet ($P < 0.001$) while the TDMI, TOMI and the TCPI were lower

Table 1 The mean (±SD) chemical composition and estimated metabolisable energy content of napier grass and concentrates used in experiments 1 and 2

	Experiment 1								Experiment 2			
	MNG		ONG		SFBC		PLBC		MNG		PLBC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Observations (n)	12		12		12		12		12		12	
Dry matter (g kg^{-1})	183.1	13.2	237.8	15.2	907.9	6.9	911.4	5.6	179.2	9.9	914.6	10.8
Chemical composition (g kg^{-1} DM):												
Organic matter	786.9	17.2	876.5	13.2	936.9	7.5	907.9	14.7	790.0	22.0	906.8	9.9
Crude protein	84.1	14.0	53.0	8.4	152.6	8.2	150.0	13.2	85.3	9.0	150.0	7.3
Neutral detergent fibre	544.5	20.6	630.3	19.7	234.4	20.2	249.7	21.3	540.0	20.1	250.7	20.8
Acid detergent fibre	308.8	30.8	358.2	20.4	115.5	12.4	143.9	22.1	307.3	13.7	145.1	20.6
Acid detergent lignin	39.1	7.9	51.9	6.5	37.4	4.6	48.8	10.2	39.9	7.4	47.2	7.7
Crude fat	35.3	5.1	27.1	5.6	64.3	8.3	20.1	4.5	34.6	4.9	22.4	6.1
Energy content (MJ kg^{-1} DM):												
Gross energy (GE)	16.1	1.7	16.8	1.5	19.2	1.6	17.8	1.8	15.8	2.0	17.4	1.9
Estimated ME	8.3	-	7.3	-	10.5	-	10.5	-	8.3	-	10.5	-
Estimated TPDI (g kg^{-1} DM)	79.1	-	49.0	-	114.5	-	95.7	-	117.6	-	121.3	-

MNG, napier at medium maturity (age, 10 wk; height, 1.3 m); ONG napier at old maturity (age,15 wk; height, 2.0 m); SFBC, sunflower meal based concentrate; PLBC, poultry litter based concentrate; SD, standard deviation; ME, metabolisable energy; TPDI, total protein digested in the intestines.

Table 2 Feed intake, live-weight change, and milk yields and composition in Friesian cows fed napier grass at medium or old maturity and supplemented with either sunflower or poultry litter based concentrate (Experiment 1)

	MNG		ONG					Contrasts		
	SFBC	PLBC	SFBC	PLBC	N	SED	NA*SUP	MNG vs ONG	SFBC vs PLBC	EL vs ML
Live-weight (kg)	435.4[a]	438.2[a]	441.0[a]	440.8[a]	8	21.10	NS	NS	NS	NS
LWC (kg cow^{-1} day^{-1})	0.05[a]	0.05[a]	-0.03[b]	-0.02[b]	8	0.01	NS	***	NS	***
Feed intake:										
NDMI (kg cow^{-1} day^{-1})	12.2[a]	12.2[a]	11.2[b]	11.1[b]	96	0.10	NS	***	NS	***
TDMI (kg cow^{-1} day^{-1})	15.8[a]	15.7[a]	14.9[b]	14.8[b]	96	0.10	NS	***	NS	***
TDMI (g kg^{-1} W$^{0.75}$)	166.2[a]	166.0[a]	156.1[b]	154.2[b]	96	1.32	***	***	NS	***
TOMI (g kg^{-1} W$^{0.75}$)	136.5[b]	135.3[b]	139.1[a]	136.3[b]	96	1.10	***	***	***	***
TCPI (g kg^{-1} W$^{0.75}$)	16.6[a]	16.5[a]	12.1[b]	11.9[c]	96	0.10	***	***	***	***
Milk yield parameters:										
Milk (kg cow^{-1} day^{-1})	11.7[a]	11.4[a]	6.0[b]	5.9[b]	96	0.13	NS	***	NS	***
4% FCM (kg cow^{-1} day^{-1})	11.2[a]	10.7[b]	5.8[c]	5.6[c]	96	0.14	NS	***	***	***
BF (g kg^{-1} milk)	37.3[b]	36.0[c]	38.1[a]	36.2[c]	96	0.04	NS	NS	***	***
CP (g kg^{-1} milk)	27.4[b]	28.7[a]	27.6[b]	27.4[b]	96	0.05	*	NS	NS	NS
SNF (g kg^{-1} milk)	77.2[c]	78.3[bc]	82.4[a]	80.9[ab]	96	0.13	NS	***	NS	NS

N, number of observations; SED, standard error of difference between means; MNG, napier at medium maturity (age, 10 wk; height, 1.3 m); ONG, napier at old maturity (age, 15 wk; height, 2.0 m); SFBC (SF), sunflower meal based concentrate; PLBC (PL), poultry litter based concentrate; LWC, live-weight change; NDMI, napier dry matter intake; TDMI, total dry matter intake; TOMI, total organic matter intake; CP, crude protein; TCPI, total CP intake; FCM, 4 % fat corrected milk; BF, butter fat; SNF, solid-not-fat; different superscripts, [a], [b], and [c] within a row indicate significance ($P < 0.05$); ***, indicate significance at $P < 0.001$; NS, indicate no significance at $P > 0.05$; EL, early-lactation; ML, mid-lactation; NA, age of napier grass; SUP, supplement.

Table 3 Feed intake, live-weight change, and milk yields and composition in dairy cows fed napier grass at medium maturity (MNG) supplemented with graded levels of poultry litter based concentrate (Experiment 2)

	Treatments						Contrasts	Relationship (P < 0.05)
	T0	T1	T2	T3	N	SED	Heifers vs Cows	Supplementation
Supplement (% TDMI)	0	6	22	38	-	-	-	-
Live-weight (kg)	433.8^{a}	435.8^{a}	436.3^{a}	436.8^{a}	12	9.67	***	-
LWC (g cow^{-1} day^{-1})	-0.02^{d}	0.04^{c}	0.06^{b}	0.08^{a}	12	0.01	***	linear
Feed intake:								
NDMI (kg cow^{-1} day^{-1})	13.6^{a}	13.2^{b}	11.5^{c}	10.0^{d}	144	0.07	***	Linear
TDMI (kg cow^{-1} day^{-1})	13.6^{d}	14.2^{c}	15.2^{b}	16.4^{a}	144	0.07	***	Linear
TDMI (g kg^{-1} W $^{0.75}$)	142.8^{d}	148.5^{c}	159.5^{b}	170.9^{a}	144	0.84	NS	Linear
TOMI (g kg^{-1} W $^{0.75}$)	112.8^{d}	118.4^{c}	130.5^{b}	142.8^{a}	144	0.67	*	Linear
TCPI (g kg^{-1} W $^{0.75}$)	12.2^{d}	13.3^{c}	16.1^{b}	18.9^{a}	144	0.08	**	Linear
SR (kg N kg^{-1} C)	0^{c}	0.38^{b}	0.56^{a}	0.56^{a}	144	0.07	NS	Linear
Milk yield parameters:								
Milk yield (kg cow^{-1} day^{-1})	7.8^{d}	8.9^{c}	10.9^{b}	13.1^{a}	144	0.11	***	Linear
4% FCM (kg cow^{-1} day^{-1})	7.7^{d}	8.6^{c}	10.6^{b}	12.8^{a}	144	0.11	***	Linear
BF (g kg^{-1} milk)	39.9^{a}	37.9^{c}	38.0^{c}	38.5^{b}	144	0.22	***	Quadratic
CP (g kg^{-1} milk)	30.7^{a}	29.9^{b}	29.7^{b}	29.1^{c}	144	0.34	NS	Linear
SNF (g kg^{-1} milk)	86.5^{a}	77.9^{c}	81.2^{b}	79.3^{bc}	144	1.02	***	Cubic

N, number of observations; SED, standard error of difference between means; PLBC, poultry litter based concentrate; LWC, live-weight change; NDMI, napier dry matter intake; TDMI, total dry matter intake; TOMI, total organic matter intake; TCPI, total CP intake; SR, substitution rate; % FCM, 4 % fat-corrected milk yield; BF, butter fat; CP, crude protein; SNF, solid-not-fat; MNG only diet (T0); MNG supplemented with 0.91 (T1), 3.65 (T2) and 6.35 (T3) kg DM cow^{-1} day^{-1} of PLBC; different superscripts, $^{a, b}$, ^{c} and ^{d} within a row indicate significance (P < 0.05); ***, indicate significance at P <0.001; NS, indicate no significance at P > 0.05.

Table 4. The estimated cost of milk production from data in Experiments 1 and 2.

Parameters		Experiment 1				Experiment 2			
		MNG + SFBC	MNG + PLBC	ONG + SFBC	ONG + PLBC	T0	T1	T2	T3
Napier grass:									
DMR (kg cow^{-1} day^{-1})		15.25	15.25	14.00	13.88	17.00	16.50	14.38	12.50
CC (cow ha^{-1})		3.39	3.39	3.69	3.72	3.04	3.14	3.60	4.14
Milk (kg/ha^{-1})		39.66	38.65	22.14	21.95	23.71	27.95	39.24	54.23
Production costs (Ksh kg^{-1} milk):									
Fertilizer		1.27	1.30	2.04	2.05	2.09	1.78	1.35	0.93
Veterinary		1.42	1.46	2.78	2.82	2.14	1.87	1.53	1.27
Labor	-rural	4.29	4.40	8.36	8.50	6.41	5.63	4.59	3.89
	-urban	7.14	7.33	13.93	14.16	10.68	9.39	7.65	6.38
Concentrates	-rural	5.61	3.97	10.95	7.67	0.0	1.27	4.15	6.01
	-urban	5.61	4.61	10.95	8.91	0.0	1.47	4.82	6.98
Miscellaneous	-rural	0.63	0.56	1.21	1.05	0.53	0.53	0.58	0.61
	-urban	0.77	0.74	1.49	1.40	0.73	0.73	0.77	0.78
Total cost	-rural	13.22	11.69	25.34	22.09	11.17	11.08	12.20	12.71
	-urban	16.21	15.44	31.19	29.34	15.66	13.49	16.12	16.34
Profit/loss (Ksh. kg^{-1} milk)									
	- rural	1.78	3.31	-10.34	-7.09	3.83	3.92	2.80	2.29
	- urban	8.79	9.56	- 6.19	-4.34	9.34	11.51	8.88	8.66

MNG, napier at medium maturity (age, 10 wk; height, 1.3 m); ONG, napier at old maturity (age, 15 wk; height, 2.0 m); SFBC, sunflower based concentrate; PLBC, poultry litter based concentrate; T0, MNG only diet (T1), and MNG supplemented with 0.91 (T1), 3.65 (T2), and 6.35 (T3) kg DM of PLBC cow^{-1} day^{-1}; DMR, dry matter requirements; CC, carrying capacity.

by 11, 14 and 24 %, respectively ($P < 0.001$) for the MNG only diet than the mean of the supplemented MNG. The rate of substitution of MNG by the PLBC increased linearly with level of supplementation ($P < 0.05$). Although absolute intake of nutrient were higher ($P < 0.05$) for the cows than the heifers, the values expressed per metabolic weight were similar ($P > 0.05$).

Milk yield and live-weight changes

The milk yield and composition, and live-weight changes are presented in Tables 2 (Experiment 1) and 3 (Experiment 2). In Experiment 1, the milk yield and milk yield corrected for 4 % butter fat (FCM) were 48 % lower for the ONG than for the MN diets ($P < 0.001$). The maturity of NG did not affect the BF and CP contents of milk ($P > 0.05$). However, the SNF content was about 5 % lower for the MNG than for the ONG diets ($P < 0.001$). The milk yield and contents of CP and SNF were unaffected by type of supplement ($P > 0.05$). However, the yield of FCM and content of BF were lower by about 3.5, and 4 %, respectively ($P < 0.001$) for the PLBC diets than for the SFBC diets. There were slight live-weight gains on animals fed the MNG diets and slight live-weight loss on those fed the ONG diets. However, the type of concentrate supplementation did not affect live-weight changes of the animals. The FCM yields and BF content were higher for the cows in early- than those in mid-lactation ($P < 0.05$). However, the SNF and CP contents were unaffected by stage of lactation ($P > 0.05$). Although the cows in early-lactation lost weight, those in mid-lactation gained weight. The interaction of age of napier with supplementation was recorded only for CP content of milk ($P < 0.05$).

In Experiment 2, milk yield increased linearly with level of supplementation ($P < 0.05$). However, increasing the level of supplementation had a quadratic effect on BF content and a cubic effect on the SNF content ($P < 0.05$). The milk yield and the yield of the FCM were

about 28 % lower for the MNG only diet than for the mean of the supplemented MNG diets ($P < 0.001$). The contents of BF, CP, and SNF were lower by 4.5, 3.6 and 8 % respectively ($P < 0.001$) for the mean of the supplemented MNG diets than for the MNG only diet. The cows fed MNG only diet lost weight while live-weight gains increased linearly with level of supplementation ($P < 0.05$). The milk yield and SNF content were higher while the BF content was lower for the cows than the heifers ($P < 0.001$). The CP content of milk was unaffected by parity ($P > 0.05$) but the heifers gained more weight than the cows ($P < 0.001$).

Estimated profit margins

Table 4 shows the estimated milk production costs and profit margins. The cost of the PLBC was lower than that of SFBC by 30 and 40 % for the rural and peri-urban areas, respectively. In Experiment 1, feeding the ONG supplemented with either the SFBC or the PLBC at a daily rate of 3.65 kg per cow resulted in loss of revenue for both rural and the peri-urban areas. The profit was 46 % and 8 % lower when the MNG was supplemented with the SFBC than with PLBC in the rural and peri-urban areas, respectively.

In Experiment 2, the highest profits in both the rural and urban areas were achieved when cows were supplemented with the PLBC at a daily rate of 0.91 kg of DM cow $^{-1}$. The mean profit for the supplemented NG was about 22 % lower than that for the MNG only diet in the rural areas but the profit from the supplemented MNG was 4 % higher than from the MNG only diet in urban areas. Although labor consisted of about 40 % and 50 % of the total cost in the rural and urban areas, respectively it was not possible to separate costs of various activities. In practice, a worker perform several daily routine activities such as harvesting, transporting and chopping NG or other forages and feeding to the animals, milking and transporting milk to the market, cleaning stables, weeding and returning slurry (manure and urine) to the fields.

Discussion

The chemical composition of the MNG and the ONG in our study was consistent with report by Snijders et al. (1992), Kariuki, (1998) and Muia et al. (1999). However, chemical composition values in our study were higher than in other reports (Wouters, 1987; Muinga et al., 1995) probably because of differences in soil fertility, growth period, and management practices and in some cases, the weather. The low intake of nutrients for the ONG than the MNG diets (Table 2) could be ascribed to the high fibre content, low N and low digestibility as forages mature (Van Soest, 1982; Minson, 1990). The higher rumen degradation of young compared to old NG (Kariuki, 1998; Muia et al., 2000 b) result in a shorter feed residence period in the rumen, and thus an increased intake. The higher intake of nutrients in cows fed the SFBC than the PLBC diets was a reflection of the higher contents of OM and CP (Table 1). Also, the differences in feed intake could be due to deficiencies or imbalances, rate and extent of degradation and passage rate of particulate matter from the rumen (Wilson and Kennedy, 1996). In contrast, the inclusion of PL to replace other conventional protein sources in concentrates did not affect intake or digestibility of the basal diet in other studies (Kayongo and Irungu, 1986).

The intake of nutrients in the current study were higher than in other reports (Muinga et al, 1993; Muinga et al, 1995) and higher than intake estimates of between 12 and 13 kg DM based on live-weight of the cows (MAFF, 1984). The higher intake than expected may partly be attributed to measurement errors. However, the feed intake values in the current study were comparable to values when dairy cows fed NG were supplemented with cotton seed cake based concentrate (Anindo and Potter, 1986). A similar decrease in NDMI as in our study (Table 3) was reported when concentrates (Anindo and Potter, 1986; Muinga et al., 1993) or legumes (Muinga et al., 1995) were used as supplements. In contrast, NDMI increased when dairy

cows were supplemented with copra cake (Muinga et al., 1993). Since the substitution rates were less than 1.0, increasing the amount of concentrate increased the TDMI even though the NDMI was declining. At similar levels of concentrate supplementation, the substitution rates of 0.39 reported by Anindo and Potter (1986) were lower than values in our study. This may be because of the differences in the quality of the basal diet, the supplement, level of supplementation and animal related factors (Grainger, 1990).

The milk yield and yield of FCM were higher on the MNG than the ONG diets mainly because of the higher quality (Table 1), and TCPI (Table 2). As a consequence, cows fed the ONG diets lost more weight than those fed the MNG diets. In addition to variations in voluntary intake, nutrient imbalances, variations in energy density and the efficiency of utilization of digestible or metabolisable energy may contribute to variations in milk yield (Minson, 1990; Clark et al., 1992). Forages with high fibre supply less protein in the small intestines due to low rumen microbial production, a low extent and availability of rumen by-pass protein, and a low apparent protein digestibility than less fibrous forages (Van Bruchem et al., 1989). The MNG diets with less fibre than the ONG diets were expected to support more propionate and less acetate fermentation hence a low content of BF (Sutton et al., 1987). The CP content in milk was unaffected by starch or fibre content of diets (Sutton et al., 1987) in agreement with our results (Table 2). However, for unknown reasons, the content of SNF was higher on the ONG than the MNG.

Since milk yields were unaffected, the higher yields of FCM for the SFBC than for the PLBC was because of the higher BF content (Table 2). The lower BF content for the PLBC diets than for the SFBC diets was because of the reduction in forage degradation due to a possible high passage rate out of the rumen. High levels of minerals in PLBC and the small particle size due to rapid degradation might accelerate the passage of digesta out of the rumen (Silanikove and Tiomkin, 1992). At similar levels of intake, milk yields (not corrected for

butter-fat) by ewes (Muwalla et al., 1995) and by dairy cows (Odhuba, 1989) were not significantly different when forages other than NG were supplemented with either PL or conventional protein based concentrates in agreement with our results. Milk yields were higher while yields of the FCM were comparable for dairy heifers supplemented with either cotton seed cake or PL based concentrates (Kayongo and Irungu, 1986). In contrast to our results, the BF content in milk was unaffected by supplementation with either PL or sunflower meal based concentrate (Odhuba, 1989).

The high intake of nutrients by cows on the supplemented MNG than the MNG only diet was probably the reason for the observed higher milk yields and weight gains (Table 3). The reported low milk yield and greater weight losses in cows fed MNG only diet than those fed MNG supplemented with concentrates (Anindo and Potter, 1986; Muinga et al., 1993) or legumes (Muinga et al., 1995) were consistent with our results. Since the BF content was lower, the higher yield of FCM for the supplemented MNG than the MNG only diet was mainly because of the higher yield of milk. In agreement with our study, low BF content in milk was reported when cows were fed on supplemented than non-supplemented forages (Rendel, 1990; Stockdale et al., 1990). The supplemented MNG had higher content of rumen fermentable OM and CP hence less acetate and more propionate than the MNG only diet (Muia et al., 2000 c). Diets high in starch and with less fibre are associated with lower BF content than those with less starch and high fibre content (Sutton et al., 1987). In contrast to our results, CP content in milk was unaffected by fibre content or starch (Sutton et al., 1987).

Use of PLBC was associated with higher profits than the SFBC because of the relatively inexpensive PL. At the prevailing market prices, supplementing cows on the ONG with either PLBC or the SFBC will result in loss of revenue because of the high costs of NG production. In actual practice instead of using the expensive fertilizers, farmers apply manure to NG and for this reason, feeding of the ONG during the dry seasons may be profitable. Also,

since milk prices are usually more favorable during the dry than the wet seasons, supplementing the ONG may be profitable. At the current milk prices, feeding MNG only diet or when supplemented with about 1 kg DM of the PLBC is more profitable than at high levels of supplementation. The decline in profit with level of supplementation beyond 1 kg of PLBC is a reflection of the lower milk yield as NG is substituted by the supplement. However, the high profits in the peri-urban areas can allow the use of high levels of either the SFBC or the PLBC supplementation. For high milk yielding cows, the SFBC will however be preferred because it contains a higher amount of by-pass protein digested in the intestines than the PLBC (Muia et al., 2000 b).

The harmful pathogens in PL can completely be eradicated by ensiling (Patil, et al, 1993; Kaur, et al, 1997). The alternative and inexpensive sun-drying method was also reported to reduce the pathogen risk in PL to levels not harmful to livestock (Kayongo and Irungu, 1986; Muwalla et al., 1995; Jordan et al., 1997; McCann and Martin, 1997). The use of antibiotic (e.g. ionophores) contaminated PL may be associated with cardiac failure leading to death when fed to ruminants (Bastianello et al., 1995). However, growth promoters are not commonly used for poultry production in developing countries. A severe liver damage resulting in mortality rates of between 10 and 20 % in beef cattle supplemented at more than 10 kg DM of PL was reported (Silanikove and Tiomkin, 1992). They associated the toxicity of the PL to the absorption of excess NH_3-N from the gut and a low metabolisable energy intake by the animals. It appears therefore that a concentrate constituted using sun-dried PL and a readily degradable energy source in the rumen would therefore pose no pathogenic or toxicity problem to animals. Further, PL contains high levels of macro- and micro-elements (Ben-Ghedalia et al., 1996), and its use as a protein source may reduce the costs of mineral supplementation to dairy cows.

Conclusions

The ONG was less nutritive than the MNG diets and as a result, it was not profitable to produce milk at the prevailing market prices of milk and cost of inputs. Since the nutritive value was higher, milk yields were higher in cows supplemented with the SFBC than those supplemented with the PLBC. However, milk production costs were lower in cows supplemented with the PLBC than those supplemented with the SFBC by 46 % and 8 % in the rural and peri-urban areas, respectively. We concluded that since PL is readily available and inexpensive, a PLBC should be used as an alternative concentrate to reduce costs of supplementation and improve small-holder dairy production on NG diets.

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References

AAC, 1990. Feeding standards for Australian livestock. Australian Agricultural Council. Ruminant sub-committee CSIRO. East Melbourne, Australia.

AOAC, 1990. Official method of analysis. Association of Official Analytical Chemists. Washington, DC.

Anindo, D.O. and Potter, H. L., 1986. Milk production from napier grass (*Pennisetum purpureum*) in zero-grazing feeding systems. East African Agriculture and Forestry Journal, 52: 106-111.

ARC, 1984. The nutrient requirements of ruminant livestock (Suppl. No. 1). Agricultural Research Council. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

Bastianello, S. S., Fourie, N., Prozesky, L., Nel, P.W. and Kellerman, T.S., 1995. Cardiomyopathy of ruminant induced by the litter of poultry fed on rations containing the ionophore antibiotic maduramicin. 11. Micropathology and Histopathology. Pathology Section, Ondersterpoort Veterinary Institute, Private bag X5, Ondersterpoort, south Africa. Ondersterpoort Journal of Veterinary Research, 62: 5-18.

Ben-Ghedalia, D., Miron, J. and Yosef, E., 1996. Apparent digestibility of minerals by lactating cows from a total mixed ration supplemented with poultry litter. Journal of Dairy Science, 79: 454-458.

Clark, J.H., Klusmeyer, T.H. and Cameroon, M.R., 1992. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. Symposium: Nitrogen metabolism and Amino Acid Nutrition in Dairy Cattle. Journal of Dairy Science, 75: 2304-2323.

Grainger, C., 1990. Effect of stage of lactation and feeding level on milk yield response by stall fed dairy cows to change in pasture intake. Australian Journal of Experimental Agriculture, 30: 495-501.

Jaetzold, R. and Schmidt, H., 1983. Farm Management Information. Handbook of Kenya, vol. 11 a. Ministry of Agriculture, Nairobi, Kenya.

Jarrige, R., 1989. Ruminant nutrition: recommended allowance and feed tables, INRA, John Libbey, London.

Jordan, D. J., Klopfenstein, T.J. and Klemesrud, M.J., 1997. Dried poultry waste as a degradable protein source in forage diets. Journal of Animal Science, 75: 94 (abstract).

Kariuki, J.N., 1998. The potential of improving napier grass under small-holder dairy farmer's condition in Kenya. PhD thesis, Wageningen Agricultural University, The Netherlands.

Kayongo, S. B. and Irungu, K.R.G., 1986. Evaluation of broiler waste in formulation of concentrate for lactating Friesian heifers grazing irrigated pastures. East African Agriculture and Forestry Journal, 52: 9 - 15.

Kaur, B., Wadhwa, M., Singh, N. Bakshi, M.P.S. and Gupta, R.P., 1997. Processing and evaluation of poultry droppings as livestock feed. Indian Journal of Animal Science, 67: 716-719.

MAFF, 1984. Energy allowances and feeding systems for ruminants. Ministry of Agriculture Fisheries and Food, Department of Agriculture and Fisheries for Scotland, Department of Agriculture for Northern Ireland. Reference book 433. Her Majesty's Stationary Office, London.

McCann, M. A. and Martin, S.A., 1997. Use of poultry litter as beef cattle feed: presence of pathogens and nutrient content. Journal of Animal Science, 75:2 (Abstract)

Minson, D. J. (Ed.), 1990. Forage in ruminant nutrition. Academic Press, Inc. San Diego. U.S.A.

MoLD, 1991. Zero-grazing: A handbook on technical aspects. Ministry of Livestock Development (MoLD), Nairobi, Kenya, pp. 75.

Muia, J.M.K., Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 1999. Optimal stage of maturity for feeding napier grass (*Pennisetum purpureum*) to dairy cows in Kenya. Tropical Grasslands, 33: 182-190.

Muia, J.M.K., Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 2000 a. Prediction of yield and digestibility of napier grass (*Pennisetum purpureum*) from maturity, leaf: stem ratio and laboratory analyses. Tropical Science, (in press).

Muia, J.M.K, Tamminga, S., Mbugua, P.N. and Kariuki, J.N., 2000 b. Rumen degradation and estimation of microbial protein yield and intestinal digestion of napier grass (*Pennisetum purpureum*) and various concentrates. Animal Feed Science and Technology (submitted).

Muinga, R. W. Thorpe, W. and Topps, J. H., 1993. Lactational performance of Jersey cows given napier grass (*Pennisetum purpureum*) with and without protein concentrates in the semi-humid tropics. Tropical Animal Health and Production, 25: 118-128.

Muinga, R.W., Thorpe, W. and Topps, J.H., 1995. The effects of supplementation of *Leucaena leucocephala* and maize bran on voluntary intake, digestibility, live-weight change and milk yield of Bos Indicus X Bos Taurus dairy cows and rumen fermentation in steers offered *Pennisetum purpureum ad-libitum* in the semi-humid tropics. Animal Science, 60: 13-23.

Muwalla, M.M., Abo-Shehada, M. N., Tawfeek, F., Abuirmelleh, N.M. and Hill, H., 1995. Use of dried poultry litter in the diets of pregnant and lactating Awassi ewes. Tropical Animal Health and Production, 27: 106 -112.

Mwangi, D. M., 1995. Diagnostic survey in livestock feeds, feeding and management practices in central Kenya. In: Fungoh P.O, Mbadi G.C.O. and Ondatto H. (Eds.), Proceedings of the 4th Kenya Agricultural Research Institute Scientific Conference, 1994, Nairobi, Kenya, pp. 293-305.

Patil, A. R., Goetsch, A. L., Galloway, D. L. Sr. and Forster, L. A. Jr., 1993. Intake and digestion by Holstein steer calves consuming grass hay supplemented with broiler litter. Animal Feed Science and Technology, 44: 251-263.

Pearson, D., 1976. The chemical analysis of foods. 7th Edition. Churchhill Livingstone, Longman, Edinburgh, U.K.

Odhuba, E.K., 1989. Towards efficient utilization of poultry waste by ruminants In: Said, A. N. and Dzowela, B.H. (Eds.), Overcoming Constraints to the Efficient Utilization of Agricultural By-products as Animal Feeds. Proceeding of the Fourth annual Workshop held at the Institute of Animal Research, Mankon Station, Bameda, Cameroon, 20-27 October 1987, ARNAB, Addis Ababa Ethiopia, pp. 114-132.

Rendel, P.F., 1990. Supplemental concentrates with four levels of crude protein for grazing dairy cows. Journal of Agriculture of the University of Puerto Rico, 74: 281-292.

SAS, 1988. User's guide, release 6.03 Edition. Statistical Analysis System Institute (SAS/STAT). Carry, N.C.

Silanikove, N. and Tiomkin, D., 1992. Toxicity induced by poultry litter consumption : effect on measurements reflecting liver function in beef cows. Animal Production, 54: 203-209.

Snijders, P.J.M., Kariuki, J.N., Orodho, A. B., Kiura, J.N. and Mogaka, L. M., 1992. Effect of nitrogen fertilization and cutting stage on yield and quality of napier grass (Pennisetum purpureum). Kenya Agricultural Research Institute, NDDP, NAHRC, Naivasha, Kenya, pp. 46.

Stockdale, C.R., Currie, R. and Trigg, T.E., 1990. Effects of pasture and supplement quality on the response of lactating dairy cows to high energy supplements. Australian Journal of Experimental Agriculture, 30: 43-50.

Sutton, J. D., Bines, J. A., Morant, S.V., Napper, D. J. and Given, D. I., 1987. A comparison of starchy and fibrous concentrates for milk production, hay utilization and energy intake by Friesian cows. Journal of Agricultural Science (Camb.), 109: 375-386.

Van Bruchem, J., Bongers L.J.G.M., Lammers-Wienhoven, S. C. W.,Van Bagma, G. A. and Van Andrichem, P.W.M., 1989. Apparent and true digestibility of protein and amino acids in the small intestines of sheep as related to duodenal passage of protein and non-protein dry matter. Livestock Production Science, 23: 317-327.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B books, Corvallis, Oregon, USA.

Van Soest, P.J. and Robertson, J.B., 1985. Analysis of forage and fibrous foods. AS 613 Manual, Department of Animal Science, Cornell University, Ithaca.

Waithaka, M. M. and Nijssen, J.M.A., 1992. Production costs of milk under zero-grazing conditions. A report, National Animal Husbandry Research Centre, Naivasha, Kenya, 19 p.

Wilson, J. R. and Kennedy, P.M., 1996. Plants and animal constraints to voluntary intake associated with fibre characteristics and particle breakdown and passage in ruminants. Australian Journal of Agricultural Research, 47: 199-225.

Wouters, A. P., 1987. Dry matter yield and quality of napier grass on farm level from 1983-1986. Ministry of Livestock Development, NDDP/RO9/143, Nairobi, Kenya, 39 pp.

Chapter 9

General Discussion

General Discussion

Introduction

In Kenya, high population pressure has resulted to small landholding (2-3 ha) in the medium and high rainfall areas and the priority in these areas is to put more land under crop production for human consumption. Little land is therefore available for fodder production and as a consequence, dairy cattle are often underfed especially during the dry season when only poor quality forages and crop residues are available. Napier grass (*Pennisetum purpureum*) is a major feed resource for smallholder dairy production systems mainly because of its high dry matter (DM) yields. The official recommendation (MoLD, 1991) is to feed napier grass (NG) to dairy cows at a height from 60 to 100 cm (age, 6-10 wk) when crude protein (CP) content is optimal (80-120 g kg^{-1} DM) for moderate milk production (ARC, 1984). The estimated carrying capacity of the grass at this stage of maturity is about 3.8 cows ha^{-1} (Snijders, 1989). However, rainfall amount has a great influence on yields and quality of NG (Anindo and Potter, 1994) and the current recommended stage of maturity may thus be inappropriate for regions with different amounts of precipitation.

Crude protein content is not closely related to performance of ruminants and *in vitro* digestibility which is commonly used to estimate nutritive value of NG is less accurate than *in vivo* digestibility (McDonald et al., 1988). In addition, for efficient utilization, dairy cattle rations should be formulated using the new protein evaluation systems (rumen degradation and intestinal protein digestion) which have been adopted to replace the use of CP content and digestible CP (Jarnge, 1989; Tamminga et al., 1994). There is therefore need for more data on

rumen fermentation patterns, rumen degradation and intestinal protein digestion of NG and locally available supplements in particular concentrates and protein ingredients.

For high milk production in dairy cows fed NG, supplementation is necessary. However, the locally purchased concentrates are too expensive for smallholders and the quantities of the high-protein forages are not sufficient for livestock supplementation (Mwangi, 1995). Furthermore, there is need to look for alternative, readily available and relatively inexpensive concentrates (e.g. poultry litter based concentrates) to improve smallholder dairy production at economic optimal levels of supplementation. The possibilities of developing models for the prediction of yield and nutritive value of NG and its potential for milk production should be explored to minimise costs of experimentation.

Literature review on yield and nutritive value of napier grass and its potential for milk production in dairy cows

Most of the information on chemical composition, yields, *in vitro* digestibility, rumen degradation, intestinal digestion, rumen fermentation patterns, and milk production on NG-based diets were reviewed in Chapter 2. The limitations related to poor utilization and hence the low productivity when smallholder dairy cows, are fed NG, were identified. Chapters 3 to 8 are therefore research interventions to seek for solutions to constraints identified in Chapter 2. It was evident from Chapter 2 that there was more information on agronomy, yields, chemical composition and *in vitro* digestibility of NG than on *in vivo* digestibility, rumen degradation, intestinal digestion, rumen fermentation and milk production in dairy cows.

Information on CP content, *in vitro* OM digestibility, and DM yields derived from several experiments indicated that the official recommendation (MoLD, 1991) for feeding NG to

dairy cows from 60 to 100 cm (age, 6-10 wk) and the calculated carrying capacity of about 3.8 cows ha^{-1} (Snijders, 1989) were still valid as a general guideline. However, since yield and nutritive value of NG are influenced by amount of rainfall among other factors (Anindo and Potter, 1994), more specific recommendations should be developed for the high and medium rainfall areas in Kenya. The use of CP content was found not to be closely related to animal performance because of its inability to assess the amounts of protein degraded in the rumen, by-passing the rumen and digested in the intestines. Also, use of CP content does not indicate its relationship with energy content (Tamminga, 1982; Nocek, 1988; Oldham, 1988). We therefore suggested that methods closely associated with animal performance such as protein: energy (nutrient) ratio and amount of digestible nutrients should be used to determine optimal stage of maturity for feeding the grass to dairy cows.

From literature review it was evident that there was more information on rumen degradation of fodder trees and legumes (high-protein forages), and NG at young to medium maturity. However, data on rumen degradation of OM and CP of NG at advanced stages of maturity as would be fed in the dry seasons, concentrates and protein ingredients and their intestinal digestion were scarce. The reviewed data indicated that rumen degradation of NG, oil seed meals and the legumes tended to decrease with increase in the rate of passage (Kp) through the rumen. Relatively high proportions of NG and legumes could escape rumen fermentation than the oil seed meals. Only NG attained the range from 25 to 30 g N kg^{-1} fermentable carbohydrate (FCHO) required for efficient rumen microbial protein (RMP) synthesis (Tamminga et al., 1994; Chenost and Kayouli, 1997). The legumes (40-45 g N kg^{-1} FCHO) and oil seed meals (155-175 g N kg^{-1} FCHO) were inefficiently utilised because relatively high proportion of CP was fermented in the rumen. Total protein digested in the small intestines (TPDI) was lower for the NG than the legumes and oil seed meals mainly because of the low OM and CP contents and low degradation. It was suggested that young NG with more than 100

g CP kg^{-1} DM should be supplemented with an energy source (*e.g.* molasses) which is readily degradable in the rumen to optimise RMP synthesis. However, NG with less than this optimal level of CP will require N and probably energy source which is readily degradable in the rumen for optimal RMP yield. An oil seed meal could serve as a good supplement to poor quality NG. Urea could also provide the required ammonia nitrogen (NH_3-N) concentration in the rumen but molasses should also be added for efficient utilisation of the released NH_3-N.

Data on rumen fermentation patterns indicated that more information was available on NG supplemented with high-protein forages but data on NG supplemented with concentrates was scarce. Rumen pH when NG was supplemented with the high-protein forages was within the range from 6.3 to 7.0 considered optimal for RMP synthesis (Ørskov and Ryle, 1990; Chenost and Kayouli, 1997). In contrast, NH_3-N concentrations were higher than requirements of 50 mg l^{-1} for maximum RMP yield (Satter and Slyter, 1974) and within the range of 100 to 200 mg l^{-1} required for optimal digestion and/or feed intake (Preston and Leng, 1987). The volatile fatty acid (VFA) concentrations in the rumen increased with level of supplementation with the high-protein forages. The percentage acetate (65-74 %), propionate (15-20 %), and butyrate (8-16 %) were within the normal ranges (Thomas and Rook, 1981) and the acetate: propionate ratio remained above the required ratio of 4:1 below which milk butter fat content is depressed (Russell et al., 1992).

There was more information on utilisation of NG in dairy cows supplemented with concentrates than legumes. A lower DM intake (DMI) was achieved with *Leucaena* than concentrate supplementation possibly due to differences in quality of diets offered and/or animal breed differences. The legumes are more bulky than concentrates (Topps, 1995) and due to rumen fill limitations (Van Straalen and Tamminga, 1990), the legumes are expected to have a higher substitution rate for NG than the concentrates. The NG only diets supported daily milk yields of about 6.8 kg cow^{-1} while daily milk yields of 9.2 and 7.2 kg cow^{-1} were obtained when

NG was supplemented with concentrate and *Leucaena*, respectively. The low yields of *Leucaena* supplemented group was possibly due to the observed low intake of nutrients and minimal mobilisation of body reserves as compared to the concentrate supplemented group. Milk yields from NG-based diets were lower than what is expected from a similar CP content (ARC, 1984) and the genetic potential of the dairy cows possibly due to deficiencies in essential amino acids for milk synthesis (Satter, 1986) or nutrient imbalances (Leng, 1993).

The identified areas of further research were:-

- To replace the CP content with parameters more closely associated with animal performance such as digestible nutrients and nutrient ratio (CP kg^{-1} DOM) methods for use in determination of optimal stage of maturity for feeding napier grass to dairy cows.
- To have specific recommendations for optimal maturity at which NG should be fed to dairy cows in the high and medium rainfall areas in Kenya.
- To obtain more information on rumen fermentation patterns on NG-based diets, and rumen degradation of OM and CP and intestinal protein digestion of NG at medium and advanced stage of maturity and locally available concentrates and protein ingredients.
- To obtain more information on feed intake and milk production in dairy cows, and the technical and economic optimal levels of supplementation of NG with alternative and inexpensive concentrates.
- To look for possibilities of minimising the costs of experimentation by developing models for prediction of yield and nutritive value of NG and its milk production potential from the generated data in this study and other relevant sources.

The optimal stage of maturity to harvest napier grass

A summary of the changes in nutritive value, yields and estimated milk production as napier grass matures under high and low watering regimes is presented in Table 1. The quality of NG was classified based on the optimal nutrient ratio method into high (210-270 g CP kg^{-1} digestible OM (DOM), medium (200-194 g CP kg^{-1} DOM), and low (90-180 g CP kg^{-1} DOM) quality (Table 1). The nutrient ratio method was preferred to the other methods in Chapter 4 because it takes into account the interactions of energy with protein which, have a major influence on animal performance (Tamminga, 1982; Nocek, 1988; Oldham, 1988). The carrying capacities were calculated from DM yields in Chapter 4 assuming intake of DM by a 450 kg cow of 14, 13, and 12 for the high, medium and low quality napier, respectively. The OM contents were obtained from Chapter 4 and the neutral detergent fibre (NDF) and acid detergent lignin (ADL) contents and OM and NDF digestibility and estimated metabolisable energy (ME) content were obtained from Chapter 3. Milk yields were estimated assuming requirements for maintenance (450 kg live-weight cow) of 48 MJ ME and 341 g CP and for yield of 1 kg of milk of 5.25 MJ ME and 90 g CP (McDonald et al., 1988; NRC, 1988).

In determining the stage of maturity to harvest NG, the objective is to maximise the intake of nutrients by ruminants from the grass on sustainable basis. This can be achieved by obtaining the optimum yield and nutritive value of NG. The official recommendation (MoLD, 1991) to harvest NG at 60 to 100 cm (age, 6-10 wk) was based on optimal CP content (80-120 g CP kg^{-1} DM) for daily milk production of about 8 to 12 kg cow^{-1} (ARC, 1984). The mean carrying capacity at these stages of maturity was estimated to be about 3.8 cows ha^{-1} (Snijders, 1989). However, use of CP content has shortcomings in that rumen degradation and intestinal protein digestion are not known. These parameters have an important influence on utilization and subsequent performance of animal (Ørskov, 1982; ARC, 1984). Also, the above referred to

Table 1. The changes in nutritive value, yields and estimated milk production as napier grass mature under two watering regimes.

Parameters	High-watering regime (1200mm yr^{-1})			Low-watering regime (800 mm yr^{-1})		
	HQN	MQN	LQN	HQN	MQN	LQN
Age (wk)	3 - 8	9 - 10	11 - 15	3 - 6	7 - 8	9 - 15
Height (cm)	60 - 120	130 - 140	150 - 200	30 - 50	55 - 60	70 - 110
CP (g kg^{-1} DM)	150 - 110	100 - 90	85 - 55	135 - 110	100 - 95	90 - 45
NDF (g kg^{-1} DM)	510 - 580	600 - 610	620 - 690	550 - 590	600 - 610	620 - 650
ADL (g kg^{-1} DM)	30 - 35	37 - 38	39 - 44	34 - 35	36 - 37	38 - 39
In vivo OMD (g kg^{-1} OM)	700 - 630	610 - 600	580 - 520	720 - 680	670 - 660	645 - 570
In vivo NDFD (g kg^{-1} DM)	670 - 600	580 - 570	560 - 500	650 - 620	610 - 600	580 - 520
ME (MJ kg^{-1} DM)	9.5 - 8.4	8.2 - 8.0	7.8 - 7.0	9.4 - 8.9	8.7 - 8.5	8.3 - 7.3
DM yield (tonnes ha^{-1})	2.7 - 8.0	9.1- 10.2	11.2 -15.5	1.0 - 2.2	2.3 - 2.9	3.2 - 5.4
Yield DOM (tonnes ha^{-1})	1.6 - 3.9	4.30 -4.8	5.2 - 7.0	0.7 - 1.2	1.3 - 1.5	1.7 - 2.6
Yield DCP (tonnes ha^{-1})	0.3 - 0.5	0.52 -0.52	0.5 - 0.4	0.1 - 0.16	0.2 - 0.2	0.17 - 0.1
CC (cows ha^{-1})	9.2 - 10.2	11.1-11.2	12.1- 12.3	3.4 - 3.7	3.6 - 4.0	4.2 - 4.3
NR (g CP kg^{-1} DOM)	270 - 215	200 - 194	180 - 130	250 - 210	200 - 186	170 - 99
Milk ME (kg cow^{-1} day^{-1})	16.2 - 13.3	11.2 - 10.7	8.7 - 6.9	15.9 - 14.6	12.4 - 11.9	9.8 - 7.5
Milk CP (kg cow^{-1} day^{-1})	19.5 - 13.3	10.7 - 9.2	7.5 - 3.5	17.2 - 13.3	10.7 - 9.9	8.2 - 2.2

HQN, high quality napier grass; MQN, medium quality napier grass; LQN, low quality napier grass: NR, nutrient ratio; DOM, digestible organic matter; DCP, digestible crude protein; ME, metabolisable energy; NDF, neutral detergent fibre; ADL, acid detergent lignin, DM, dry matter; CP crude protein; CC, carrying capacity; NDFD, NDF digestibility; OMD, organic matter digestibility.

recommendation does not take into account the influence of amount of rainfall on yields (hence carrying capacity) and nutritive values of the fodder (Anindo and Potter, 1994). The time to harvest NG could also depend on the type of the animal to which the fodder is to be fed and the degree of utilisation (Goldson, 1977; Boonman, 1991).

The use of *in vivo* OM digestibility described in Chapter 3 indicated that NG should be fed for milk production from 3 to 11 weeks when OM digestibility was above the level of 600 g kg^{-1} DM required for moderate milk production by dairy cows (ARC, 1984). However, use of digestibility does not partition quantity of nutrient supply for microbial growth in the rumen and the amount digested in the lower gut. As a consequence, it is difficult to assess the required levels of supplementation for optimal RMP synthesis and performance by ruminants using digestibility data. The *in vivo* OM digestibility of NG was negatively affected as it matured although the ADL content was below the critical level of 60 g kg^{-1} DM (Van Soest, 1982). This was an indication that the variations in anatomical structure and fibre chemistry were likely to be closely related to digestibility of NG than the content of ADL (Jung and Allen, 1995; Wilson and Hatfield, 1997). The main reason why sheep were used to determine digestibility although the results were to be used for dairy cows was to minimise expenses. However, digestibility values obtained using sheep were similar to values obtained using cows by Aerts et al. (1984). For DM digestibility above 550 g kg^{-1} DM, the difference between cows and sheep tend to be minimal and can safely be ignored (Heaney, 1979). Therefore, the digestibility values obtained in the current study ranging from 3 to 10 weeks of grass growth could be used reliably for cows.

At the optimal stage of maturity using the nutrient ratio method in chapter 4 (Table 1), the yield of digestible CP were maximum while those of digestible OM were optimal. At the high quality, the grass could not support daily milk yields above 16 kg cow^{-1} due to ME deficiency while the CP content limited daily yields to about 2 - 8 kg cow^{-1} at the low quality stages. However, the energy and CP contents were balanced at the medium quality stages and

yield of about 9-10 kg cow^{-1} could be obtained from NG only diet. Although the estimated daily milk yields were higher at young stages of maturity, harvesting NG at these stages may not be practical because of reduced persistency, high costs of fertilization and labour costs among other factors. Theoretically, the high quality NG could supported high milk yields due to the high contents of CP and ME. In practice, high milk yields may not be achieved since N in young forage is inefficiently utilized because of the higher degradation in the rumen than energy (ARC, 1984; Valk et al., 1990; Van Vuuren et al., 1991; Poppi and McLennan, 1995).

At low quality, milk yield may be overestimated using the CP content because of the bound N within the indigestible vascular bundle (Van Soest, 1982). Also, as the cell wall content increases with maturity of forage, the endogenous loss of N is expected to increase (Van Bruchem, et al., 1991) hence all the N will not be available to the rumen microbes and the ruminant. Furthermore, not all the CP content in most tropical forages is true protein hence the use of CP content (N x 6.25) in feed tables may overestimate the true protein value of the forage (Reeves et al., 1996). The limitation of the nutrient ratio method is that the requirements for rumen microbes may not be the same as that of the host animal. Also, the method does not indicate the rumen degradation and intestinal protein digestion characteristics and the amino acid profiles of the CP content.

The temperature, soil fertility, and availability of water are associated with maturation process of plants and will affect yield and nutritive value of forage (Van Soest, 1982; Snijders et al., 1992; Anindo and Potter, 1994). The stages of maturity for feeding NG to dairy cows in the high and medium rainfall areas in Kenya were not different based on CP content (Chapter 4) or *in vivo* OM digestibility (Chapter 3). However, based on the nutrient ratio method (Chapter 4), the grass should be harvested earlier (age, 7-8 wk; height, 55-60 cm) and later (age, 9-10 wk; height, 130-140 cm) in the medium and high rainfall areas of Kenya, respectively. At similar stages of maturity, the DM yields and carrying capacity were about 3 times higher for the high

than the low watered NG. At the low watering regime, the DM yield (19 tonnes ha^{-1} $year^{-1}$) and carrying capacity (3.7 cows ha^{-1}) were comparable to the official recommendations in Kenya. However, the optimal maturity for feeding NG during the dry seasons needs further attention.

It was evident from Chapter 3 and 4 that NG could maintain its quality for a long period (3-11 wk) and as a result it could be used as a dry season feed. However, to improve production, ruminant fed NG at advanced maturity should be supplemented. Its yields of DM are higher than yields of most tropical grasses hence its popularity among smallholder dairy farmers in Kenya. The nutritive value is comparable to that of other Kenyan grasses such as *Pennisetum cladestinum* (Abate and Abate, 1991) and non-traditional forages (Kevelenge, 1992). Although the amount of rainfall affect yield and nutritive value of NG, the influence of soil fertility on these factors in relation to optimal maturity for feeding the grass to dairy cows needs further attention.

Supplementation to improve nutritive value of napier grass

In Chapter 3, *in vivo* digestibility of NG in sheep was improved by minimal supplementation with soyabean meal. There was no difference in digestibility of the supplemented and non-supplemented NG at the age of about 3 to 4 weeks when CP content was above 120 g kg^{-1} DM. However, from the age of 5 or 6 weeks the digestibility of the supplemented NG was significantly higher than that of the non-supplemented grass probably because of supply of essential nutrients by soyabean meal which were limiting rumen microbial activity and growth when the grass was fed alone. This improvement in digestibility through supplementation was greater at advanced stages of maturity when non-supplemented grass was likely to be more deficient in essential nutrients for optimal rumen fermentation. Normally CP

content of about 60-70 g kg^{-1} DM is the minimum required by rumen microbes to break down ingested feed (ARC, 1984). However, NG with a CP content as high as 120-g kg^{-1} DM could not supply adequate nutrients for optimal rumen digestion probably because of energy deficiency.

This observation in Chapter 3 was consistent with other reports that CP content from 90 to 120 g kg^{-1} DM in NG was inefficiently utilised in the rumen (Van Eys et al., 1986; Njwe and Chiffon, 1991: Mgheni et al, 1996). As was indicated earlier, most tropical forages have high non-protein N indicating that the true protein is low and that the CP concentration (N x 6.25) tend to overestimate the true value protein to ruminants (Reeves et al, 1996). At high CP content, shortage of energy or other essential nutrients such as sulphur and phosphorous could have also limited digestibility of NG and supply of the deficient nutrients through supplementation were expected to enhance its digestibility. After supplementation, the OM digestibility of 600 g kg^{-1} DM required for daily milk yields of about 10 kg cow^{-1} (ARC, 1984) was realised at 3 to 14 weeks of growth up from the 3 to 11 weeks for the non-supplemented grass.

Rumen degradation results in Chapter 6 indicated that NG was deficient in rumen fermentable CP (FCP) and could not support the required range of 25 to 30 g kg^{-1} of fermentable carbohydrate (CHO) considered optimal for rumen microbial protein (RMP) synthesis (Tamminga et al., 1994). The old NG (ONG) was more deficient in rumen FCP and had a lower total protein digested in intestines (TPDI) than the medium maturity NG (MNG). Protein ingredients supported higher RMP synthesis and TPDI than concentrates. Among the protein ingredients, the poultry litter (PL) supported lowest while soyabean meal (SBM) supported the highest RMP synthesis and TPDI. Also, the PL based concentrate (PLBC) supported lower RMP synthesis and TPDI value than the other concentrates.

It was generally evident from data in Chapter 6 that, lower RMP synthesis were found in feeds containing CP content values lower than 100 g kg^{-1} DM such as the MNG and the ONG.

This was because these diets had insufficient FCP to match the available rumen fermentable CHO for rumen microbes as was suggested by Minson (1990). In this chapter, the CP and OM contents were positively related while the detergent fibres and degree of lignification were negatively related to solubility of CP and OM in the rumen. Data from this Chapter indicated that although differences in RMP yields may be minimal, differences in TPDI may be greater because of variations among feeds in amount of by-pass protein digested in the lower gut.

It was concluded in Chapter 6 that supplementing animals fed NG diets with SBM, sunflower seed meal (SFM) and cotton seed cake (CSC) would support high performance while moderate levels of production would be obtained by supplementing with SFM based concentrate or the locally available commercial concentrate. However, supplementing animals fed NG diets with PL or PL based concentrate would result in low production. To sustain same level of production, animals fed MNG should be offered supplemented containing about 30 g TPDI kg-1 DM less than animals fed ONG (e.g. SFM or SBM, CSC or SBM, PL or CSC, and PL or SFM, respectively). It should however be noted that these differences in nutritive value among the protein ingredients and concentrates may not be apparent in terms of animal production.

When the degradation in the rumen is higher as on MNG vs ONG, SFBC vs PLBC and supplemented MNG vs MNG only diets (Chapter 6), intake is elevated (Chapter 7) because of the shorter feed residence period in the rumen (Ørskov, 1982). The rumen pH for all the diets was optimal for RMP synthesis and cellulose digestion. The more fibrous diets were positively related to high pH because of the relatively more time spent eating and ruminating hence more salivation and buffering capacity (Feng et al, 1993). The PL in the PLBC was the reason for the higher NH_3-N concentration and the higher pH as compared to the SFBC. Increasing the level of the PLBC decreased cellulose digestion hence the low rumen pH. Alternatively, the high intake of nutrient and their degradation in the rumen decreased the pH when the PLBC was increased.

The feeds with higher rumen degradation in Chapter 6 resulted in higher RMP yields, higher intake of nutrient hence higher concentration of VFA in Chapter 7. The lower acetate (A): propionate (P) ratio is expected due to the higher FOM on the MNG vs ONG diets and the supplemented MNG vs MNG only diets. The higher rates of degradation (kd) and passage form the rumen (Kp) for the PLBC resulted in lower degradation of NG hence the higher proportion of propionate and low A: P ration than the SFBC. In Chapter 7, the low concentration of NH_3-N on the MNG and the ONG only diets could not support optimal RMP synthesis in agreement with the rumen degradation results in Chapter 6. The NH_3-N concentration for most of the diets was below 100-g l^{-1} (Preston and Leng, 1987) required for optimal digestion and feed intake. However, feed intake and concentration in the rumen of VFA indicated that supplementation provided optimal environment for digestion. The higher concentration of NH_3-N in the rumen on the MNG than the ONG may be due to the higher CP content (Minson, 1990) and the higher rumen degradation (Chapter 6). Alternatively, the high pH on ONG could have enhanced absorption of NH_3-N reducing its concentration in the rumen. The higher rate of degradation of PL in the PLBC diet resulted in the observed higher concentration of NH_3-N in the rumen than for the SFBC diet as was the case with non-protein N in other reports (Baldwin and Allison, 1983; Van Houtert, 1993). The higher concentration of NH_3-N with increasing level of PLBC supplementation was due to the higher total CP intake than for the MNG only diet. The NH_3-N concentration was lower than in other studies with NG-based diets (Muinga et al., 1995; Kariuki, 1998) probably because the concentration in the rumen is a function of production, absorption, utilization, rumen pH and rumen outflow rate as suggested by Feng et al. (1993) and Van Houtert (1993). Data from Chapter 7 indicated that for improved digestion and feed intake animals fed MNG should be supplemented with PLBC while SFBC should be used on animals fed ONG.

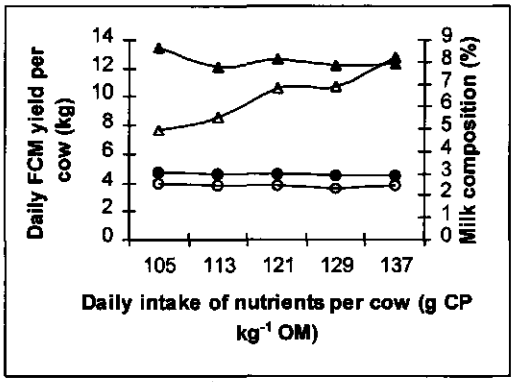
Supplementation to improve milk production in dairy cows

In Chapter 8, intake of nutrients was higher for the MNG than the ONG diets because of the higher degradation in the rumen (Chapter 6). Also, intake of nutrients for SFBC was higher than PLBC in contrast with a report by Kayongo and Irungu (1986). The substitution rate when NG was supplemented with the PLBC ranged from 0 to 0.56 implying that increasing the amount of the concentrate increased total DMI even though napier DMI was declining.

The cows fed MNG diet produced more milk and gained weight because of high intake of degradable nutrients in the rumen as compared to the cows fed ONG diet. Since milk yields were unaffected, the higher yields of fat corrected milk (FCM) on the SFBC vs the PLBC was because of the higher butter fat (BF) content. The lower BF content for the PLBC was probably due to the higher rate of degradation in the rumen than the SFBC diet (Chapter 6). Increasing level of PLBC was responsible for the observed higher milk yield and weight gain in cows fed supplemented MNG than those fed non-supplemented MNG. The MNG supported daily milk yield of about 7-8 kg per cow due to inadequate intake of energy and protein in agreement with results in Chapter 2 and the official recommendations (MoLD, 1991). The low BF content for supplemented NG was probably because of higher Kp value resulting in less degradation in the rumen of the forage hence a lower A: P ratio than for the MNG only diet in consistence with reports on other forages (Robinson et al, 1987).

Feeding the ONG during the dry season was shown to be unprofitable at the prevailing market prices. However, when considering that milk prices are higher during the dry seasons than during the wet seasons and that smallholder usually apply manure on NG instead of expensive fertilizers, milk production may be profitably when cows are fed ONG. Labour was the most expensive input accounting for about 40 % and 50 % of the total costs in the rural and

(a)



(b)

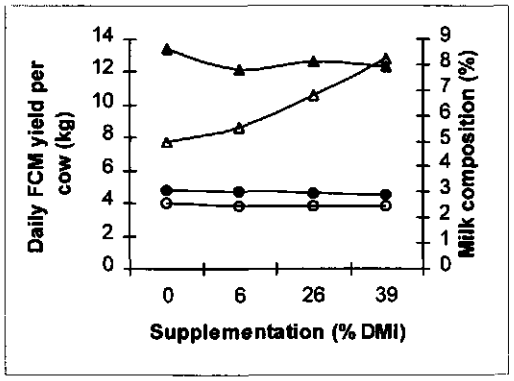
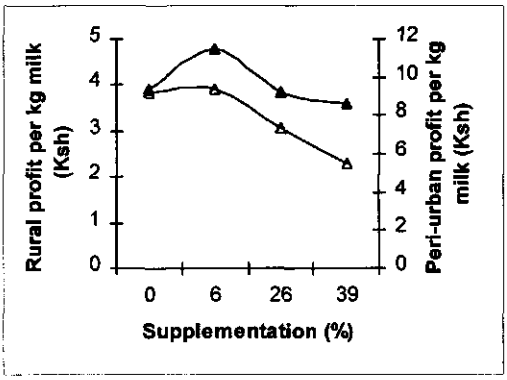


Figure 1. The butter-fat corrected milk (FCM) yield (Δ), butter fat (●), crude protein (O), and solid not fat (▲) in relation to (a) intake of nutrient, and (b) level of supplementation as a percentage of total DM intake (DMI).

(a)



(b)

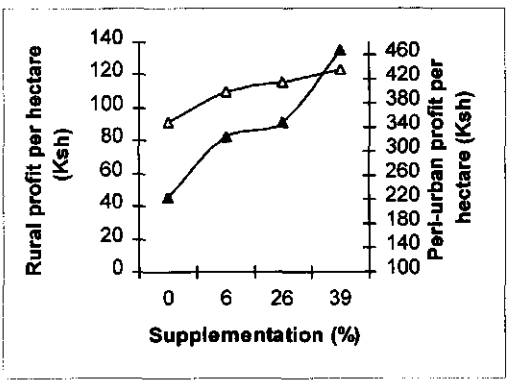


Figure 2. The profit margins of milk production in relation level of supplementation (% of DMI) when expressed (a) per kg of milk, and (b) per hectare in the rural (Δ)and peri-urban (▲) areas.

peri-urban areas, respectively. The profits were 46 % and 8 % lower when cows fed MNG were supplemented with SFBC than PLBC in the rural and peri-urban areas, respectively.

The technical optimal level of supplementing the MNG with the PLBC was not achieved since milk yields increased linearly with level of supplementation (r^2 = 0.99; rsd = 0.28; P < 0.01) and nutrient intake (r^2 = 0.95; rsd = 0.51; P < 0.01) as indicated in Figure 1 a and b. Although CP in milk decreased linearly, the relationship of milk BF and SNF with nutrient intake and level of supplementation was not linear. The economic optimal level of supplementation when expressed as profit per kg milk was achieved at 6 % level of supplementation in the rural (r^2 = 0.95; rsd = 0.21; P < 0.05) and peri-urban (r^2 = 0.50; rsd = 1.54; P > 0.05) areas (Figure 2 a). When expressed per hectare, profits increased linearly with level of supplementation for the rural (r^2 = 0.81; rsd = 7.29; P > 0.05) and peri-urban (r^2 = 0.87; rsd = 44.64; P > 0.05) areas (Figure 2 b). However, in addition to voluntary intake, other factors such as nutrient imbalances, the variations in energy density and the efficiency of utilization of digestible or metabolisable energy may contribute to variations in milk yield (Robinson et al., 1987; Minson, 1990; Clark et al., 1992).

Prediction of yields and nutritive value of napier grass and its potential for milk production.

For sound farm planning, knowledge of yields and nutritive value of napier grass and its milk yield potential when fed to dairy cows is vital. The yields of the grass is related to stocking rates while the nutritive value and milk production potential will assist in making correct budgets and supplementation schedules for a profitable dairy enterprise. However, for prediction

equations to be of any meaningful use, they have to be accurate and reliable under different situations.

The equations developed to predict yields and nutritive value of NG under high (1200 mm $year^{-1}$) and low (800 mm $year^{-1}$) watering regimes accounted for more variations in these dependent variables under those specific conditions (Chapters 3 and 4). However, when data from the two watering regimes was pooled, the regression equations accounted for less variation in these dependent variables than for the specific watering regimes (Chapter 5). For example the DM yields (y, *tonnes* ha^{-1}) were predicted from age (x, wk) of the grass using the equations; $y = -0.54 + 1.07$ x ($r^2 = 0.99$, rsd = 0.22; $P < 0.001$; n = 13), and $y = 0.01 + 0.36$ x ($r^2 = 0.99$; rsd = 0.11; $P < 0.001$; n = 13) for the high and the low watering regimes, respectively. The prediction equation for the pooled data from the two watering regimes was; $y = -0.26 + 0.72$ x ($r^2 = 0.41$; rsd = 3.33; $P < 0.001$; n = 26). The use of age alone accounted for less variation in DM yields ($r^2 < 0.40$; rsd = 11.65; $P < 0.05$; n = 25) for data derived from different regions and at different seasons and years (Chapter 2). However, when age (x, wk) and DM content (x1, g kg^{-1} DM) of the grass were used, the regression equation accounted for more variation in DM yields (y, tonnes ha^{-1} $year^{-1}$); $y = -10.45 + 2.61$ x + 0.08 x1; ($r^2 = 0.92$; rsd = 0.05; $P < 0.001$; n = 25).

The DM yield could be accurately predicted using age or height at different years because of similar management, water supply and fertilizer application on-station and because of the same reasons, prediction of DM yields was, therefore, less accurate on-farm (Chapter 5). The use of age or height to predict yield of NG would be a more practical method for adoption by the dairy farmers due to ease of application. In most cases, age of NG would be unknown, hence height would be more suitable for prediction of yield of the grass. Prediction of DM yield using stage of maturity of NG was less accurate on-farm ($r^2 = 0.50$; rsd = 0.80; $P < 0.01$; n = 14). But for advisory purposes, the simplicity, ease of application and less expense when using age or height to estimate DM yield of NG may outweigh the relatively high standard errors. However,

the use of age or height for general prediction of DM yield of NG may be complicated by differences in amount of rainfall (Chapter 5) and soil fertility (Wouters, 1987) and under such conditions more specific prediction equations may be more appropriate.

In Chapter 5, *in vivo* OM digestibility (y, g kg^{-1} DM) was predicted from age (x, wk) of NG using the equations; $y = 745.51 - 15.08 x$ ($r^2 = 0.91$; rsd = 19.47; $P < 0.001$; $n = 13$), and $y = 756.38 - 12.41 x$ ($r^2 = 0.92$; rsd = 14.62; $P < 0.001$; $n = 13$) for the high and low watering regimes, respectively. The prediction equation of the pooled data from the two watering regimes was; $y = 677.99 - 12.57 x$ ($r^2 = 0.82$; rsd = 23.25; $P< 0.001$; $n = 26$). The use of age accounted for less variations *in vitro* OM digestibility ($r^2 < 0.32$; rsd = 54.73; $P < 0.05$; $n = 25$) in Chapter 2 because the equations were derived from data obtained under different conditions, seasons and years. The *in vitro* OM digestibility of NG was accurately predicted by using either a multiple regression equation involving contents of ADF and ADL ($r^2 = 0.86$; rsd = 23.56; $P < 0.001$; $n = 11$) or equations derived from contents of ADL ($r^2 = 0.85$; rsd = 25.14; $P < 0.001$; $n = 11$) and CP ($r^2 = 0.71$; rsd = 27.85; $P < 0.001$; $n = 30$) as single independent variables. In Chapter 2, the CP content (x, g kg^{-1} DM) accounted for more variations in *in vitro* OM digestibility (y, g kg^{-1} DM) of NG ($y = 548.54 + 1.16 x$; $r^2 = 0.88$; rsd = 20.57; $P < 0.05$; $n = 25$) under different management, growth conditions, seasons and years.

Since CP content and digestibility decline while the cell wall content increases as forages mature (Van Soest, 1982; Cherney et al., 1993), there is a negative relationship between digestibility and detergent fibres and degree of lignification (Wilson et al., 1991; Reeves et al., 1996; Wilson and Hatfield., 1997) as we observed (Chapter 5). The CP content is positively related to digestibility through its influence on microbial protein synthesis and rumen degradation (Matejovsky et al, 1995). Also, these chemical parameters may be related to digestibility due to their influence on amount of energy and the association with maturity of the grass. However, variations in both the anatomical structure and fibre chemistry in various feeds

and forages mean that similar numerical values of fibre component (e.g. ADL) do not represent similar levels of digestibility of the cell wall (Jung and Allen, 1995). In addition, there are indications that the fibre fractions may not be suitable for prediction of digestibility for all forage samples except those of primary growth (Givens et al, 1993). The relationship of cell wall fractions with digestibility is also influenced by season and year of harvest (Givens et al., 1993). As a consequence, these chemical parameters should be used with caution when predicting digestibility of NG since they are likely to be influenced by amount and nature of cell wall in addition to environmental factors. For practical purposes, chemical parameters, which are less expensive to determine, and do not require sophisticated equipment are likely to get farmers support regardless of their accuracy in prediction of nutritive value of NG.

The *in vitro* OM digestibility accounted for more variation (r^2 = 0.82; rsd = 22.28; P < 0.001; n = 26) in *in vivo* OM digestibility as well as the multiple regression equations (r^2 = 0.85 - 0.91; rsd = 16.70 - 21.60; P < 0.001; n = 26) and height (r^2 = 0.83; rsd = 21.92; P < 0.001; n = 26). The *in vitro* OM digestibility is closely related to *in vivo* OM digestibility than chemical composition and other plant related parameters because it tends to eliminate most of the animal related variations (McDonald et al, 1988) as was observed in Chapter 5. However, the use of *in vitro* OM digestibility to predict *in vivo* OM digestibility has limitations which include variations in values obtained both within and between batch runs (Ayres, 1991). There is also the need to have fistulated animals close to the laboratory. Therefore, the difficulties involved in standardisation of the method and the expenses associated with routine analyses, limit application of this procedure for testing farmer samples. Inclusion of standard samples of known *in vivo* digestibility and as similar as possible to the forage being tested will ensure accurate calculations of *in vivo* digestibility of the forage being tested. This method may be useful in research since it is applicable to a wide range of forages.

The decrease in amount of variations in the dependent variables accounted for by the independent variables when data was pooled was expected because of the more variability of the variables considered. Multiple regression equations accounted for more variations in DM yield and *in vitro* and *in vivo* OM digestibility than equations derived from single independent variables (Chapter 5). However, the equations derived from single independent variable predicted these dependent variables more accurately on-station than the multiple regression equations which implied that the accuracy of prediction equations may be influenced by other non-plant related factors not included in the equations as was suggested by Golding et al, (1976).

The regression equations we developed should be used for prediction of DM yields and OM digestibility of NG under similar conditions and at similar range of maturity. Since the results were obtained over a short period (13 weeks) and at a specific location (Naivasha), there is need to collect data for a longer period and to cover different seasons, years and regions of the country for the prediction equations to be more accurate. The inaccuracy of prediction equations when developed from few independent variables was evident in Chapter 2. The equations accounted for more variation in dependent variables in Chapter 2, but either overestimated or underestimate CP and DM yields in Chapters 4 and 5, OM digestibility in Chapters 3, 4, and 5, rumen degradation in Chapter 6, rumen fermentation patterns in Chapter 7, and milk production in Chapter 8. The implication to this is that these regression equations could only be accurate when plant and animal related factors were similar as in Chapter 2. This then provides further evidence that a regression equation may account for more variations in a dependent variable under a particular condition but may be an inaccurate predictor for the same dependent variable under different situations.

Table 2 Regression equations for prediction of rumen fermentation patterns in steers and milk production parameters in dairy cows from intake of nutrients of napier grass-based diets

Rumen fermentation parameters (n = 5)				Milk production parameters (n = 5)			
Equation	R^2	RSD	Sign.	Equation	R^2	RSD	Sign.
$y1 = -22.84 + 77.27\ x$	0.94	6.94	0.01	$Y1 = 1.47 + 6.15\ x$	0.95	0.51	0.01
$y2 = 66.18 + 33.25\ x$	0.84	5.28	0.05	$Y2 = 6.45 - 3.69\ x + 1.23\ x^2$	0.71	0.11	NS
$y3 = 6.88 - 0.39\ x$	0.13	0.37	NS	$Y3 = 3.27 - 0.22\ x$	0.82	0.04	0.05
$y4 = 67.98 + 1.22\ x$	0.19	0.91	NS	$Y4 = 13.41 - 7.20\ x + 2.32\ x^2$	0.64	0.30	NS
$y5 = 17.42 + 1.32\ x$	0.72	0.30	NS	$Y1 = -10.48 + 1.76\ x_1$	0.95	0.51	0.01
$y6 = 3.95 - 0.21\ x$	0.40	0.09	NS	$Y2 = 18.26 - 2.42\ x + 0.10\ x_1^2$	0.71	0.11	NS
$y1 = -141.40 + 19.38\ x_1$	0.73	15.19	NS	$Y3 = 3.70 - 0.63\ x_1$	0.82	0.04	0.05
$y2 = 7.57 + 8.99\ x_1$	0.75	5.99	NS	$Y4 = 36.16 - 4.63\ x_1 + 0.19\ x_1^2$	0.64	0.30	NS
$y3 = 8.78 - 0.21\ x_1$	0.46	0.29	NS	$Y1 = -8.52 + 0.15\ x_2$	0.95	0.51	0.01
$y4 = 62.68 + 0.59\ x_1$	0.57	0.67	NS	$Y2 = 15.69 - 0.19\ x_2 + 0.001\ x_2^2$	0.71	0.11	NS
$y5 = 15.26 + 0.34\ x_1$	0.60	0.36	NS	$Y3 = 3.61 - 0.01\ x_2$	0.82	0.04	0.05
$y6 = 4.11 - 0.04\ x_1$	0.17	0.11	NS	$Y4 = 31.24 - 0.37\ x_2 + 0.001\ x_2^2$	0.64	0.30	NS
$y1 = -148.40 + 1.93\ x_2$	0.94	6.94	0.01				
$y2 = 12.15 + 0.83\ x_2$	0.84	5.28	0.05				
$y3 = 7.52 - 0.01\ x_2$	0.13	0.37	NS				
$y4 = 65.99 + 0.03\ x_2$	0.72	0.30	NS				
$y5 = 15.27 + 0.03\ x_2$	0.72	0.30	NS				
$y6 = 4.28 - 0.01\ x_2$	0.40	0.09	NS				

y1, ammonia N; y2, total volatile fatty acids; y3, pH, y4, acetate, y5, propionate, y6, butyrate; Y1, fat corrected milk yield; Y2, butterfat %; Y3, crude protein %; Y4, solid not fat %; x, total CP intake; x_1, total OM intake; x_2, total CP intake: total OM intake ration (g TCP Kg^{-1} TOMI); NS not significant at $P > 0.05$.

The increase in the total CPI and the CPI: OMI ratio had a significant and linear influence on the concentrations of NH_3-N and VFA in the rumen but the other rumen fermentation parameters were unaffected (Table 2). This was an indication that there was a faster rate of increase in the CPI (80 %) than increase in the OMI (27 %) hence higher amounts of FCP than FOM from 0 to 40 % level of supplementation with the PLBC. The increase in the CPI, OMI and the CPI: OMI ratio had a significant and linear influence on the FCM and CP in milk. However, the relationship of feed intake with milk BF and SNF was not linear. The increase in the FCM was mainly due to the increase in milk yield since the BF content in milk tended to decline. Although some of the equations in Table 2 could account for more variations in the dependent variables, their use to predict these variables would not be expected to be accurate since the equations were developed from limited data and also due to the complexity of these dependent parameters.

Practical implication and conclusions

The nutritive value and DM yield of napier grass are influenced by my factors among which amount of water supply was shown to be important from this study. The optimal stages of maturity at which NG should be fed to dairy cows were therefore indicated to occur earlier in the medium than in the high rainfall areas. There is great potential for improvement of feed intake and digestion of NG through supplementation with concentrates constituted using poultry litter. From this study, the regression equations developed on-station could accurately predict DM yield and digestibility of NG at different period on-station. However, although it may be difficult to predict digestibility of NG on-farm, the possibility to predict DM yields from its age and height does exist. The regression equations obtained using limited data could account for more

variations in rumen fermentation and milk production parameters but these equations may not be accurate predictors of this dependent variable under different conditions.

The supplementation of NG at medium maturity with a poultry litter-based concentrate could reduce costs of milk production under smallholder dairy production systems. However, if feeding of the ONG has to be profitable, the cost of forage production has to be reduced by using more manure and less of fertilizers. If cost of forage production is reduced, feeding of ONG is likely to be profitable during the dry seasons when milk prices are expected to be higher than during the wet seasons. The profit differences between the rural and peri-urban areas could be narrowed if rural farmers are able to market milk in the urban areas. This could be possible with improved infrastructure and marketing channels.

It was concluded that use of NG only diet or when supplemented with about 1 kg DM of PLBC was more profitable than at higher levels of supplementation. For efficient utilisation of nutrients, NG only diet should therefore be fed to dairy cows at optimal stage of maturity. However, due to inherent variations in soil fertility and amount of rainfall from one area to the other, the optimal stage of maturity should be specific for regions with different climates. For supplementation to be profitable, the unit cost of the supplement has to be lower than unit price of milk and of good quality to support high milk yields per unit increase of the supplement.

Areas of further research

- The optimal stage at which NG should be fed to dairy cows should be determined using rumen degradation and intestinal protein digestion of CP and its supply of individual and total amino acids to be absorbed in the small intestines.

- The utilisation of NG during the dry seasons when feeds of poor quality and not in adequate amounts needs further attention.
- There is need to develop the critical levels of CP and ME in the locally available feedstuffs in relation to maintenance and production requirements by ruminants.
- More information on rumen fermentation patterns and optimal levels of milk production in dairy cows when fed better quality NG-based diets than in this study is required.
- More data need to be generated from representative regions of the country, seasons, and years for more accurate prediction of DM yield and nutritive value of NG and its potential for milk production.

References

Abate, A and Abate A.N., 1991. Wet season nutrient supply to lactating grade animals managed under different production systems. East African Agriculture and Forestry Journal, 57: 33-39.

Ayres, J.F., 1991. Sources of error with *in vitro* digestibility assay of pasture feeds. Grass and Forage Science, 46: 89 - 97.

ARC, 1984. The nutrient requirements of ruminant livestock (Suppl. No. 1). Agricultural Research Council. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

Aerts, J.V., De Boever, J. L., Cottyn, B.G., De Brabander, D.L., and Buysse, F. X., 1984. Comparative digestibility of feedstuffs by sheep and cows. Animal Feed Science and Technology, 12: 47-56.

Anindo, D. O. and Potter, H. L., 1994. Variation in productivity and nutritive value of napier grass at Muguga, Kenya. East Africa Agriculture and Forestry Journal, 59: 117-185.

Baldwin, R.L. and Allison, M.J., 1983. Rumen metabolism. Journal of Animal Science, 57: 461-477.

Chenost, M. and Kayouli, C., 1997. Roughage utilization in warm climates. Animal Production and Health Paper No. 135, FAO, Rome.

Cherney, D. J. R., Cherney, J. H. and Lucey, R. F., 1993. *In vitro* digestion kinetics and quality of perennial grasses as influenced by forage maturity. Journal of Dairy Science, 76: 790 - 797.

Clark, J.H., Klusmeyer, T.H. and Cameroon, M.R., 1992. Microbial protein synthesis and flow of nitrogen fractions to the duodenum of dairy cows. Symposium: Nitrogen metabolism and Amino Acid Nutrition in Dairy Cattle. Journal of Dairy Science, 75: 2304 - 2323.

Feng, P. Hoover, W.H., Miller, T.K. and Blauwie, R., 1993. Interaction of fibre and non structural carbohydrates on lactation and ruminal function. Journal of Dairy Science, 76: 1324-1333.

Givens, D. I., Moss, A. R., and Adamson, A. H., 1993. Influence of growth stage and season on the energy value of the herbage. 1. change in metabolisable energy content. Grass and Forage Science., 48: 166 - 174.

Golding, E.J., Moore, J.E., Franke, D.E., and Ruelke, O.C., 1976. Formulation of hay grass diets for ruminants. 1. Evaluation of multiple regression equations for predicting of bermuda grass hay quality from laboratory analysis. Journal of Animal Science 42: 710-716.

Goldson, J.R., 1977. Napier grass in east Africa. A review. Technical report No.24. Pasture Research Project. National Agricultural Research Station, Kitale, Kenya. 126 pp.

Heaney, D. P., 1979. Sheep as a pilot animal. In: Pigden, W.J., C.C. Balch and Michael Graham (Eds). Standardization of Analytical Methodology For Feeds. Proceeding of a workshop, 12th - 14th March, Ottawa, Canada. pp. 44 - 48

Jarrige, R., 1989. Ruminant nutrition: recommended allowance and feed tables, INRA, John Libbey, London.

Jung, H.G. and Allen, S., 1995. Characteristics of plant cell - wall affecting intake and digestibility of forage by ruminants. Journal of Animal Science, 73: 2774 - 2790.

Kariuki, J.N., 1998. The potential of improving napier grass under smallholder dairy farmer's condition in Kenya. PhD thesis, Wageningen Agricultural University, The Netherlands.

Kayongo, S.B. and Irungu, K.R.G., 1986. Evaluation of broiler waste in formulation of concentrate for lactating Friesian heifers grazing irrigated pastures. East African Agriculture and Forestry Journal, 52: 9 - 15.

Kevelenge, J.E.E., 1992. Nutrient intake, *in vivo* digestibility and performance of wether sheep fed on non-traditional fodder in Kenya. East African Agriculture and Forestry Journal, 58: 65-72.

Leng, R. A., 1993. Quantitative ruminant nutrition - a green science. Australian Journal of Agricultural Research 44:363-380.

Matejovsky, K. M. and Sanson, D. W., 1995. Intake and digestion of low -, medium - and high -quality grass hays by lambs receiving increasing levels of corn supplementation. Journal of Animal Science. 73: 2156 - 2163.

Mcdonald, P., Edwards, R. A. and Greenhalgh, J. F. D., 1988. Animal nutrition. 4th Edition, London, New York.

Mgheni, D. M., Hvelplund, T. and Weisbjerg, M.R., 1996. Rumen degradability of dry matter and protein in tropical grasses and legume forages and their protein value expressed in the AAT-PBV protein evaluation system. In: Ndikumana, J. and P. Deleeuw (Eds) Sustainable Feed Production and Utilization for Smallholder Livestock Enterprises in Sub-sahara Africa. Proceeding of the 2nd African feed Resource Network (AFRNET) Workshop, 6^{th}-10^{th} December, 1993, Harare, Zimbabwe. pp 77-84.

Minson ,D.J. (Ed.), 1990. Forage in ruminant nutrition. Academic press, Inc. San Diego.

MoLD, 1991. Zero-grazing: A handbook on technical (compiled by A. P. Wouters, October, 1986). Ministry of Livestock Development, NDDP, Nairobi, Kenya.

Muinga, R.W., Thorpe, W. and Topps, J.H., 1995. The effects of supplementation of *Leucaena leucocephala* and maize bran on voluntary intake, digestibility, live-weight change and milk yield of Bos Indicus X Bos Taurus dairy cows and rumen fermentation in steers offered *Pennisetum purpureum* ad-libitum in the semi-humid tropics. Animal Science, 60: 13-23.

Mwangi, D.M., 1995. Diagnostic survey in livestock feeds, feeding and management practices in central Kenya. In: Fungoh P.O, Mbadi G.C.O. and Ondatto H. (Eds.), Proceeding of 4th Kenya Agricultural Research Institute Scientific Conference, 1994, Nairobi, Kenya. pp. 293-305.

Njwe, R. M. and Chiffon, M. K., 1991. Performance of Dwarf sheep fed Elephant grass (*Pennisetum purpureum*) and concentrate supplements containing rubber seed as substitute for cotton seed cake. World review of Animal Production, 16: 43 - 45.

Ørskov, E.R., 1982. Protein nutrition in ruminants. Academic press, London.

Ørskov, E.R., and Ryle, M., 1990. Energy nutrition in ruminants. Elsevier Science publishers, London, U.K.

Poppi, D.P. and Maclennan, S.R., 1995. Protein and energy utilization by ruminants at pasture. Journal of Animal Science 73: 278-290.

Preston, T.R. and Leng, R.A., 1987. Matching ruminant production systems with available resources in the tropics and sub-tropics. Penambul Books, Armidale, Australia. 245 pp.

Reeves, M., Fulkerson, W.J. and Kellaway, R.C., 1996. Forage quality of Kikuyu grass (*Pennisetum clandestinum*): the effect of time of defoliation and nitrogen fertilizer application and in comparison with perennial ryegrass *(Lolium perenne)*. Australian Journal of Agricultural Research, 47: 1349-1359.

Robinson, P.H., Tamminga, S and Van Vuuren, A.M., 1987. Influence of declining level of feed intake and varying the proportion of starch in the concentrate on milk production and whole trait digestibility in dairy cows. Livestock Production Science, 17: 19-35.

Russell, J.B., O'Connor, J.D., Fox, D.G., Van Soest, P.J. and Sniffen, C.J., 1992. A net carbohydrate and protein system for evaluating cattle diets. 1. Ruminal fermentation. Journal Animal Science, 70: 3551 - 3561.

Satter, L.D., 1986. Protein supply from undegraded dietary protein. Symposium: protein and fibre digestion, passage and utilisation in lactating cows. Journal of Dairy Science, 69: 2734-2749.

Satter, L.D. and Slyter, L.L., 1974. Effect of ammonia concentration on rumen microbial protein production *in vitro*. British Journal of Nutrition, 32: 199-208.

Snijders, P.J.M., Kariuki, J.N., Orodho, A.B., Kiura, J.N. and Mogaka, L.M., 1992. Effect of nitrogen fertilization and cutting stage on yield and quality of napier grass (*Pennisetum purpureum*). Kenya Agricultural Research Institute, NDDP, NAHRC, Naivasha, Kenya. 46 pp.

Tamminga, S., Van Straalen, W.M., Subnel, A.P.J., Meijer, R.G.M., Steg, A., Wever, C.J.G. and Blok, M.C., 1994. The Dutch protein evaluation system: the DVE/OEB system. Livestock Production Science, 40:139-155.

Thomas, P.C. and Rook, J.A.F., 1981. Manipulation of rumen fermentation. In: Haresign, W. and D.J.A, Cole (Eds), Recent Development in Ruminant Nutrition. Butterworth, London. pp 157-183.

Topps, J. H., 1995. Forage legumes as protein supplements to poor quality diets in the semi-arid tropics. In: Wallace, R.J. and Lahlou-Kassi, A. (Eds.), Rumen Ecology Research Planning. Proceedings of a Workshop, International Livestock Research Institute, Nairobi, Kenya, pp. 183-190.

Valk, H., Poelhuis, K. and Wentink, H.J., 1990. Effect of fibres and starchy carbohydrate in concentrate as supplements in herbage based diet for high yielding dairy cows. Netherlands Journal of Agricultural Science, 38: 475-486.

Van Bruchem, J., Oosting S.J., Bongers L.J.G.M., Lammers-Wienhoven, S.C.W. and Gurses C., 1991. Treatment of wheat straw with ammonia: the effect of energy and protein supplements on intestinal available amino acids in sheep. In: Ibrahim, N.M.N., de Jong, R., Van Bruchem, J. and Purnamo, A. (Eds,), Livestock and Feed Development in the Tropics. Proceedings of an International Seminar, Brawijaya University, Malang, Indonesia. pp. 98-105.

Van Eys, J.E., Mathius, I.W., Pongsapan, P. and Johnson, W.L., 1986. Foliage of the tree legumes *Gliricidia, Leucaena* and *Sesbania* as supplements to napier grass diets for growing goats. Journal of Agricultural Science, Cambridge, 107: 227-233.

Van Houtert, M.F.J., 1993. The production and metabolism of volatile fatty acids by ruminants fed roughage: A review. Animal Feed Science and Technology, 43:189-225.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B books, Corvallis, Oregon, USA.

Van Straalen, W.M. and Tamminga, S., 1990. Protein degradation of ruminant diets. In: Wiseman J. and Cole D.J.A. (Eds.), Feedstuff Evaluation. Butterworth, London. pp 55-72.

Van Vuuren, A.M., Tamminga, S. and Ketelaar, R.S., 1991. *In sacco* degradation of organic matter and crude protein of fresh grass (Lolium perenne) in the rumen of grazing dairy cows. Journal of Agricultural Science (Camb.), 116: 429-436.

Wouters, A.P., 1987. Dry matter yield and quality of napier grass on farm level from 1983-1986. Ministry of Livestock Development, NDDP/RO9/143, Nairobi, Kenya, 39 pp.

Wilson, J.R., Deinum, B. and Engels, F.M., 1991. Temperature effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. Netherlands Journal of Agricultural Science, 39: 31-48.

Wilson, J.R. and Hatfield, R.D., 1997. Structural and chemical changes of cell-wall types during stem development: consequences for fibre degradation by rumen microflora. Australian Journal of Research, 48: 165-180.

Summary

Summary

In Kenya, the high human population in the high agricultural potential areas has resulted into landholdings of 2-3 hectares and thus the free grazing systems have been replaced by confinement of dairy cattle under zero-grazing production systems. Napier grass (NG) is among the major feed resources for these systems of dairy production mainly because of its high dry matter (DM) yields. The official recommendation is to feed napier grass to dairy cows at a height of 60-100 cm (age 6-10 wk) when the carrying capacity is about 3.8 cows per hectare. However, at farm level, the average milk yields of about 5-7 kg on a NG-only diet and 8-10 kg for supplemented NG are below the genetic potential of dairy cows. The low performance could be attributed to inadequate and low quality of the NG offered to animals.

The DM yields and nutritive value of NG are influenced by various factors among which the amount of rainfall plays a major role. The recommendation referred to earlier is based on crude protein (CP) content of the grass which is not closely related to ruminant performance. Therefore, there was a need to develop specific recommendations for areas with different precipitation using better methods for evaluating the nutritive value of NG.

The low milk yields at farm level could also be related to low levels of supplementation because the available concentrates are too expensive for the smallholder farmer. Also, fodder trees and legumes are potential dairy cattle supplements but due to poor establishment and persistency, the quantities at farm level are inadequate for livestock production. As a consequence, farmers are feeding home-compounded concentrates using poultry litter (PL) as the source of protein. Information of how to improve nutritive value of NG using these home-compounded concentrates and their contribution to milk production in dairy cows was therefore

required. In addition, farmers needed to know the optimal levels of supplementation at the prevailing market prices and cost of inputs.

Chapter 1 is a brief introduction of Kenya's agricultural sector, livestock sub-sector, dairy cattle industry and constraints, and the role NG plays in the nutrition of dairy cattle by smallholders. A review paper covering the current knowledge on the nutritive value of NG and its potential for milk production was presented in Chapter 2. From this review it was noted that information on DM yield, agronomy, chemical composition and *in vitro* digestibility of NG was available but data on rumen fermentation, rumen degradation and intestinal protein digestion, and performance by ruminants on NG-based diets were scarce. Data on the DM yield and nutritive value of NG indicated that the current recommendation at which the grass is offered to dairy cows was still valid as a general guideline. However, there was need for more specific recommendations for the high and medium rainfall areas in Kenya. It was recommended that the current use of CP content and digestible CP as a measure of nutritive value should be replaced by the modern protein evaluation methods. It was noted that NG-based diets supported rumen pH and ammonia N concentrations suitable for maximum rumen microbial protein (RMP) synthesis and feed intake. The RMP synthesis were 25, 44, and 168 g N kg^{-1} fermentable carbohydrate (FCHO) while the total protein digested in the intestines (TPDI) were 70, 90, and 80 g kg^{-1} DM for NG, legumes, and oil seed meals respectively. The NG-only diet (60-70 g CP kg^{-1} DM) supported a mean daily milk yield of 6.8 kg cow^{-1} which was accompanied by live-weight loss (- 0.44 kg $cow^{-1}day^{-1}$). The concentrate supplemented cows produced more milk (9.5 vs 6.6 kg $cow^{-1}day^{-1}$) but lost more weight (- 0.48 vs - 0.37 kg $cow^{-1}day^{-1}$) than the *Leucaena* supplemented cows. There potential existed for prediction of DM yield, nutritive value and milk yield in dairy cows.

In Chapter 3, an experiment was conducted in a completely randomised design to investigate the effect of moisture supply, age at harvesting and supplementation with soyabean meal on *in*

vivo digestibility of NG. The digestibility was determined weekly from 3 to 15 weeks of growth of NG under two watering regimes to simulate annual precipitation in the medium (800 mm) and high (1200 mm) rainfall areas of Kenya. The watering regime, maturity and supplementation all affected digestibility of the grass ($P < 0.05$). The mean organic matter digestibility (OMD) was 640 g kg^{-1} and 630 g kg^{-1} and crude protein digestibility (CPD) was 620 and 630 g kg^{-1} for the high- and low-watered grass, respectively. The mean OMD were 650 and 610 g kg^{-1} whilst CPD were 670 and 590 g kg^{-1} for the supplemented and non-supplemented grass, respectively. The difference between the digestibility of the supplemented and non-supplemented NG increased as it matured. Nutrient deficiencies significantly limited digestibility from the age of 5 and 6 weeks of growth for the low- and high-watered grass, respectively. It was concluded that NG should be fed as a sole diet to lactating dairy cows at 3-11 weeks and 3-10 weeks in the medium and high rainfall areas of Kenya, respectively when digestibility does not limit production.

The optimal maturity for feeding NG to dairy cows was determined using CP content, yields of digestible organic matter (OM) and CP, and CP: digestible OM ratio parameters in Chapter 4. The yields of NG from the 3rd to the 15th week of growth were determined for two watering regimes (1200 vs 800 mm) using a split-plot design and the digestibility as in Chapter 3. The optimal ages obtained using these methods were within the 6-10 weeks but the heights were different from the 60-100 cm ranges that are recommended for feeding the grass to dairy cows in Kenya. Further, the recommended maturity was different and more specific for each watering regime. The nutrient ratio method was preferred since it considered the interrelationship between protein and energy concentrations. This method indicated that napier grass should be fed to dairy cows at 50-60 cm (7-8 wk) and 130-140 cm (9-10 wk) in the medium and high rainfall areas in Kenya, respectively.

In Chapter 5, the data on the DM yield and *in vivo* and *in vitro* digestibility of NG from Chapters 3 and 4 were pooled and assessed by linear and quadratic regressions. The accuracy of

developed regression equations was tested using existing on-station and on-farm data. Multiple regression equations accounted for more variations in DM yield, *in vitro* OMD and *in vivo* digestible organic matter than equations derived from single independent variables. However, the regression equations derived from single independent variables were more accurate predictors of DM yield and *in vitro* OMD than the multiple regression equations. Prediction of DM yield was more accurate than that of *in vitro* OMD. The DM yield could be accurately estimated using age or height ($r^2 > 0.85$; rsd < 1.60; $P < 0.001$) whereas *in vitro* organic matter digestibility (OMD) was predicted better from cell-wall fractions and CP content ($r^2 > 0.50$; rsd < 41.20; $P < 0.001$) on-station. However, prediction of DM yield on-farm was less accurate ($r^2 = 0.50$; rsd = 0.77; $P < 0.01$) and possible only for the high rainfall districts.

In Chapter 6, a study was conducted in a randomized complete block arrangement using 4 steers to compare rumen degradation and estimated rumen microbial protein yield and intestinal protein digestion values of poultry litter (PL), sunflower seed meal (SFM), soyabean meal (SBM) and cotton seed cake (CSC) in Trial 1, and PL based concentrate, SFM based concentrate, and a locally available commercial concentrate, and napier grass (*Pennisetum purpureum*) at the recommended medium (MNG) and most (ONG) mature stages in Trial 2. The data were used to suggest appropriate supplements for animals fed MNG or ONG diets. Optimal efficiency of rumen microbial protein (RMP) synthesis were obtained in concentrates (26-27 g N kg^{-1} fermentable OM (FOM)) but the protein ingredients had higher (37-88 g N kg^{-1} FOM) and napier grass lower (10-19 g N kg^{-1} FOM) values. Estimated RMP yields (44 vs 52 g kg^{-1} DM) and total protein digested in intestines (TPDI) (49 vs 79 g kg^{-1} DM) were lower for ONG than MNG ($P < 0.05$). Among the protein ingredients, estimated yields of RMP (58 vs 87 g kg^{-1} DM) and TPDI (89 vs 219 g kg^{-1} DM) were lowest on PL vs SBM ($P < 0.05$). Comparison of concentrates showed that the PL based concentrate had the lowest while the commercial concentrate had the highest estimated yields of RMP (75 vs 84 g kg^{-1} DM) and

TPDI (96 vs 118 g kg^{-1} DM) ($P < 0.05$). Supplementing animals with SBM, SFM or CSC would support high performance while moderate levels of production would be obtained from SFM based concentrate or the local commercial concentrate. However, supplementing animals with PL or PL based concentrate would result in low levels of production. To sustain same levels of production, animals fed ONG should be offered supplements containing about 30 g kg-1 DM more TPDI (e.g. SBM vs SFM; SBM vs CSC; CSC vs PL; SFM vs PL) than animals fed MNG.

Nutrient intake and rumen fermentation patterns were determined when four fistulated Friesian steers (4 x 4 Latin square) fed medium (MNG) or old (ONG) maturity napier grass *(Pennisetum purpureum)* were supplemented with equal amounts of sunflower seed meal (SFBC) or poultry litter (PLBC) based concentrates (Trial 1), or when the steers fed MNG were supplemented with graded levels of the PLBC (Trial 2). The results are presented in chapter 7. The data was used to suggest suitable supplement for MNG or ONG. In Trial 1, intake of crude protein (CPI) (15.3 vs 11.1 g kg^{-1} $W^{0.75}$, $P < 0.001$) and organic matter (OMI) (127.1 vs 124.7 g kg^{-1} $W^{0.75}$, $P < 0.05$) were higher on MNG vs ONG diets. The CPI and OMI were 3 % higher on SFBC vs PLBC diets ($P < 0.01$). The MNG had higher concentrations of rumen ammonia (NH_3-N) (101.0 vs 51.2 mg l^{-1}) while pH (6.7 vs 7.1) and acetate (A) to propionate (P) ratio (3.7 vs 3.9) were lower than values for the ONG diets ($P < 0.001$). The rumen concentration of NH_3-N (70.9 vs 81.3 mg l^{-1}) and pH (6.82 vs 7.0) were lower while the A:P ratio (3.8 vs 3.7) was higher for the SFBC than the PLBC diets ($P < 0.05$). In Trial 2, the CPI (15.1 vs 10.6 g kg^{-1} $W^{0.75}$) and OMI (186.2 vs 100.7 g kg^{-1} $W^{0.75}$) of the supplemented MNG were higher than for the MNG only diet ($P < 0.001$). The rumen pH (6.7 vs 6.1) and A:P ratio (3.8 vs 3,6) were higher while concentration of NH_3-N (56.6 vs 87.5 mg l^{-1}) was lower for the MNG only diet than for the supplemented MNG ($P < 0.001$). To improve feed intake and digestion, animals fed MNG should be supplemented with PLBC while the SFBC should be used on animals fed ONG.

Two experiments were conducted in Chapter 8 in a randomised complete block arrangement using Friesian cows fed diets similar to those fed to steers for each Trial in Chapter 7. The objectives were to determine feed intake, live-weight changes, milk yield and economics of milk production. In Experiment 1, the intakes of organic matter (OMI) was lower (135.9 vs 137.7 g kg $^{W\ 0.75}$) while intake of crude protein (CPI) was greater (16.6 vs 12.0 g kg W $^{0.75}$) for MNG than ONG diets ($P < 0.001$). The OMI (137.0 vs 135.0 g kg W $^{0.75}$) and CPI (14.3 vs 14.2 g kg W $^{0.75}$) were higher for SFBC than PLBC diets ($P < 0.05$). The fat-corrected milk yield (FCM) was higher (11.0 vs 5.7 kg cow^{-1} day^{-1}) on MNG vs ONG diets ($P < 0.001$). In Experiment 2, the OMI (112.8 vs 130.6 g kg W $^{0.75}$) and the CPI (12.2 vs 16.1 g kg W $^{0.75}$) were lower for MNG-only diet than the mean of the supplemented MNG ($P < 0.001$). The MNG-only diet supported lower yields of FCM (7.7 vs 10.7 kg cow^{-1} day^{-1}) than the mean of the supplemented MNG ($P < 0.001$). Although cows fed supplemented MNG diets gained weight, those fed supplemented ONG diet or MNG-only diet lost weight. Feeding of the supplemented ONG resulted in loss of revenue while supplementing with the PLBC had higher profits than the SFBC. We concluded that use of the PLBC would lower costs and improve milk production in dairy cows fed NG-based diets.

In Chapter 9, the main findings in this study were discussed and the practical implications considered in relation to milk production under smallholder farmer's condition. It was noted that the nutritive value of NG could be improved though harvesting at optimal stages of maturity and through supplementation. The technical optimal level of supplementation was not achieved in this study possibly due to the low quality or nutrient imbalances of the diets used. However, the economic optimum level of supplementation when profits were expressed per kg of milk were achieved by supplemented at 6 % of the total DM intake in the rural and peri-urban areas. In contrast, when profits were expressed per hectare, the economic optimum levels were not achieved since profit increased with levels of supplementation. The regression equations

developed from data in this study could account for more variations in DM yield and nutritive value of NG, and milk yield in dairy cows on NG-based diets. However it was noted that more data was needed for accurate prediction of these dependent variables under different conditions.

Samenvatting

Samenvatting

In Kenya, is als gevolg van de hoge bevolkingsdichtheid in de landbouwgebieden met hoge potentie, de bedrijfsgrootte afgenomen tot 2-3 ha en is bovendien het systeem van vrije begrazing vervangen door het op stal houden van melkkoeien in een 'zero grazing' systeem. Voor deze systemen van melkveehouderij is napier gras (NG) één van de belangrijkste bronnen van voer, vooral als gevolg van de hoge opbrengsten aan droge stof (DS) die het kan leveren. Het gangbare advies is om aan melkkoeien met een matige melkproductie NG te voeren bij een lengte van 60-100 cm (6-10 weken), wat een veebezetting van ongeveer 3,8 koeien ha^{-1} mogelijk maakt. Echter, de gemiddelde melkproducties op bedrijfsniveau zijn slechts ongeveer 5-7 kg per dag op een rantsoen van alleen NG en 8-10 kg als wordt bijgevoerd. Dit is beneden de erfelijke aanleg van de aanwezige melkkoeien. Deze lage productie moet vooral worden toegeschreven aan de lage kwaliteit van het NG waarmee de dieren worden gevoerd.

De opbrengsten aan DS en de voederwaarde van NG zijn sterk afhankelijk van een aantal factoren, waaronder de hoeveelheid neerslag één van de belangrijkste is. Het bovengenoemde advies houdt met deze factoren geen rekening. Het is bovendien nog gebaseerd op het gehalte aan ruw eiwit (RE) in het gras wat geen goede maat is voor de door herkauwes te behalen productie. Er was dus een noodzaak om aanbevelingen te ontwikkelen die specifiek waren voor gebieden met verschillen in de hoeveelheid neerslag en ze bovendien te baseren op betere methoden van voederwaardeschatting voor NG.

De lage melkprducties op bedrijfsniveau zijn ook het gevolg van de lage niveaus van bijvoedering, als gevolg van voor de kleine boeren te hoge krachtvoerprijzen. Vlinderbloemige en andere struiken zijn potentieel goede bronnen van bijvoeding voor melkvee. Echter, het aanleggen en onderhouden ervan geeft zoveel problemen dat ze niet geschikt zijn om op grote schaal als bijvoedering voor het vee te gebruiken. Mede als gevolg hiervan zijn boeren eigengemaakte krachtvoeders gaan ontwikkelen, waarin pluimveemest (PM) als eiwitbron wordt gebruikt. Er zijn daarom gegevens nodig over hoe de voedrwaarde van NG verbeterd kan

worden wanneer deze zelfbereide krachtvoeders worden gebruikt en ook welke bijdrage deze krachtvoeders kunnen leveren aan het verbeteren van de melkproductie. Ook moeten de boeren weten wat optimale niveaus van bijvoedering zijn bij de gangbare markprijzen en kosten van andere inputs.

In hoofdstuk 1 wordt in een korte inleiding het belang weergegeven van de landbouw in Kenya in het algemeen en daarbinnen dat van de veehouderij en melkveehouderij. Beperkingen worden aangegeven en de rol die NG speelt in de voeding van melkvee bij de kleine boeren wordt besproken. In hoofdstuk 2 wordt een overzicht gegeven van de bestaande kennis over de voederwaarde van NG en de potentiële waarde die het heeft voor melkproductie. Een belangrijke conclusie van dit overzicht is dat er wel informatie beschikbaar is over agronomische aspecten, zoals de opbrengst aan DS, de chemische samenstelling en de *in vitro* verteerbaarheid van NG. Echter, gegevens over afbraak en fermentatie in de pens, alsmede over de productiviteit van herkauwers die met op NG gebaseerde rantsoenen gevoerd worden, blijken erg schaars. De verzamelde gegevens over de DS opbrengst en voederwaarde van aan melkvee gevoerde NG wezen uit dat de gangbare adviezen als een algemene richtlijn wel bruikbaar zijn. Echter, ook werd geconcludeerd dat er in Kenya voor de gebieden met hoge en die met lage hoeveelheden neerslag aparte richtlijnen nodig zijn. Ook wordt aanbevolen het gebruik van RE en verteerbaar RE (vre) als maat voor de voederwaarde van NG te vervangen door een modern systeem voor eiwitwaardering.

Gegevens in de literatuur geven aan dat op NG gebaseerde rantsoenen in de pens een pH en een gehalte aan ammoniak-N (NH_3-N) kunnen handhaven die voldoende zijn voor een maximale microbiële groei en activiteit en ook voldoende voor een optimale vertering en voeropname. Voor NG, vlinderbloemige struiken en residuën van oliezaden werden potentieel maximaal in de pens te synthetiseren hoeveelheden microbiëel eiwit (MEP) afgeleid van respectievelijk 25, 44 en 168 g N kg^{-1} werkelijk in de pens gefermenteerde organische stof (TFOS). De totale hoeveelheid eiwit die uit vertering in de darm beschikbaar kwam (DVE) werd respectievelijk vastgesteld op 70, 90 en 80 g kg^{-1} DS. Op rantsoenen van alleen NG (60-70 g

RE kg^{-1} DS) kon een dagelijkse melkproductie gerealiseerd worden van 6,8 kg koe^{-1} wat echter wel gepaard ging met gewichtsverlies (-0,44 kg koe^{-1} dag^{-1}). Als aan zulke rantsoenen krachtvoer werd toegevoegd steeg de melkproductie (9,5 vs. 6,6 kg koe^{-1} dag^{-1}), maar was het gewichtsverlies hoger (-0.48 vs. -0,37 kg koe^{-1} dag^{-1}) dan wanneer de rantsoenen werden gesupplementeerd met *Leucaena*. De mogelijkheden om opbrengst, voederwaarde en melkproductie te voorspellen bij het voeren van op NG gebaseerde rantsoenen werd behoorlijk hoog ingeschat.

In hoofdstuk 3 wordt verslag gedaan van een volledig gewarde blokkenproef waarin de invloed van de toevoer van vocht, de ouderdom bij oogsten en het bijvoeren van sojaschroot (SS) op de *in vivo* verteerbaarheid van NG in hamels is onderzocht. In dit onderzoek werd de verteerbaarheid van wekelijks geoogste partijen NG bepaald tijdens de groeiperiode van 3 tot 15 weken onder 2 regimes van beregening. Dit werd gedaan om de jaarlijkse neerslag in de gematigde (800 mm) en hoge (1200 mm) neerslag gebieden in Kenya na te bootsen. Regime van beregening, groeistadium en bijvoedering hadden alle een significante ($P<0.05$) invloed op de verteerbaarheid. Voor de hoog en laag beregende NG waren de verteerbaarheden van de organische stof (OS) respectievelijk 640 en 630 g kg^{-1} en die van RE 620 en 630 g kg^{-1}. Voor wel of niet met een eiwitbron bijgevoerde rantsoenen waren de OS verteerbaarheden respectievelijk 650 en 610 en die van RE 670 en 590 g kg^{-1}. Het verschil in OS verteerbaarheid tussen het met SS gesupplementeerde en niet gesupplementeerde gras nam toe met het ouder worden van het gras. Het RE gehalte werd een significant beperkende factor voor de OS verteerbaarheid vanaf de 5^e en 6^e groeiweek voor respectievelijk het laag en hoog beregende gras. Geconcludeerd werd dat, wanneer als voorwaarde geldt dat de OS verteerbaarheid geen beperkende factor mag zijn voor productie, een puur NG rantsoen aan melkkoeien gevoerd kan worden wanneer het in de hoge en lage neerslag gebieden in Kenya geoogst wordt in groeistadia van tussen respectievelijk 3-11 weken en 3-10 weken.

Het optimale groeistadium waarin NG aan melkkoeien gevoerd kan worden werd in hoofdstuk 4 bepaald op basis van de parameters RE gehalte, opbrengst aan verteerbare OS

(VOS) en RE en de RE:VOS verhouding. De opbrengsten van NG tussen de 3e en 15e groeiweek werden met een split-plot proefopzet berekend voor de beide beregenings regimes (1200 en 800 mm). Verteerbaarheden werden berekend zoals weergegeven in hoofdstuk 3. De voor voeding aan melkvee optimale leeftijden waren op basis van deze methoden 6-10 weken, maar de hierbij horende gewashoogtes waren lager dan de 60-100 cm die momenteel in Kenya worden aanbevolen. Verder verschilde de aanbevolen ouderdom voor de beide regimes van beregenen. Omdat het rekening houdt met de interactie tussen eiwit en energie wordt aan de RE:VOS verhouding als kwaliteitsparameter de voorkeur gegeven. Op basis van dit kwaliteitscriterium viel af te leiden dat in de matige en hoge neerslag gebieden van Kenya NG geoogst en aan melkvee gevoerd zou moeten worden bij respectievelijk 50-60 cm (7-8 weken) en 130-140 cm (9-10 weken).

In hoofdstuk 5 zijn de in hoofdstuk 3 verkregen gegevens over DS opbrengst en *in vivo* en *in vitro* verteerbaarheid van NG gepoold en geanalyseerd met behulp van lineaire en kwadratische regressies. De nauwkeurigheid van de gevonden regressieformules werd getest met 'on-station' en 'on-farm' verzamelde gegevens. Multiple regressievergelijkingen verklaarden meer variatie in de DS opbrengst, de *in vitro* VOS en de *in vivo* VOS dan vergelijkingen die waren verkregen op basis van enkelvoudige onafhankelijke variabelen. Echter enkelvoudige regressievergelijkingen gaven een nauwkeuriger voorspelling van DS opbrengst en *in vitro* VOS dan multiple regressie. De voorspelling van DS was nauwkeuriger dan die van *in vitro* VOS. De DS opbrengst kon behoorlijk nauwkeurig ($R^2 > 0,85$, rsd < 1,60, $P < 0,001$) worden geschat op basis van ouderdom en gewashoogte, terwijl de *in vitro* VOS beter werd voorspeld ($R^2 > 0,50$, rsd < 41,20, $P < 0,001$) uit "on-station" bepaalde gehaltes aan celwandfracties en RE. De voorspelnauwkeurigheid van de DS opbrengst "on-farm" liet te wensen over ($R^2 = 0,50$, rsd = 0,77, $P < 0,01$) en was alleen bruikbaar voor de gebieden met een hoge neerslag.

In hoofdstuk 6 worden de resultaten gerapporteerd van een tweetal, volgens een geward blokkenschema opgezette proeven, waarin met behulp van nylon zakjes incubaties in 4 ossen de afbraak van OS en RE in de pens werd bepaald. Uit de verkregen resultaten werden

vervolgens opbrengsten aan MEP en DVE geschat. In de eerste proef werd de pensafbraak van PM en van gangbare eiwitrijke voedermiddelen zonnebloemzaadschroot (ZBZS), sojaschroot (SS) en katoenzaadschilfers (KZS) bepaald. In de tweede proef werd de afbraak bepaald van een mengvoer waarin PM was opgenomen, een mengvoer met ZBZS en een commerciëel mengvoer, alsmede die van NG van middelmatig oud (10 weken, MNG) en een oud (15 weken, ONG) groeistadium. Deze gegevens werden vervolgens gebruikt voor het ontwikkelen van aanbevelingen voor geschikte toevoegingen aan het rantsoen van dieren die met MNG en ONG werden gevoerd. Optimaal geachte efficiënties van de synthese van MEP werden berekend voor krachtvoeders (26-27 g N kg^{-1} fermenteerbare OS, FOS), maar de waarden voor eiwitrijke grondstoffen waren hoger (37-88 g N kg^{-1} FOS) en voor NG lager (10-19 g N kg^{-1} FOS). De geschatte opbrengsten per kg opgenomen DS waren voor MEP (44 vs 52 g kg^{-1}) en voor DVE (49 vs 79 g kg^{-1}) significant ($P < 0,05$) lager voor ONG dan voor MNG. Binnen de eiwitrijke voedermiddelen waren MEP (58 vs 87 g kg^{-1}) en DVE (89 vs 219 g kg^{-1}) lager ($P < 0,05$) in PM dan in SS. Een vergelijking van de verschillende krachtvoeders liet zien dat die met PM de laagste en het commerciële mengvoer de hoogste MEP (75 vs 84 g kg^{-1}) en DVE (96 vs 118 g kg^{-1}) hadden ($P < 0,05$). Het aan koeien verstrekken van enkelvoudig SS, ZBZS of KZS zou hoge producties kunnen geven, terwijl krachtvoer met daarin ZBZS of het commerciële mengvoer kon resulteren in middelmatige producties. Pluimveemest of mengvoer met PM als bestanddeel zou slechts lage producties kunnen geven. Om eenzelfde productieniveau te bereiken, zou aan het rantsoen van dieren die ONG krijgen, krachtvoer moeten worden verstrekt met daarin 36% meer DVE dan aan dieren die met MNG worden gevoerd

De opname aan nutriënten en de pensfermentatiepatronen werden middels een proefopzet volgens een 4x4 Latijns vierkant gemeten in 4 ossen die ad lib met respectievelijk ONG en MNG gevoerd werden, met daaraan toegevoegd gelijke hoeveelheden krachtvoer met PM dan wel ZBZS als ingrediënt. Dezelfde metingen werden gedaan bij dieren gevoerd met MNG waaraan oplopende hoeveelheden krachtvoer met daarin PM werd toegevoegd. Van de resultaten wordt in hoofdstuk 7 verslag gedaan. De uitkomsten werden gebruikt om

aanbevelingen te doen over geschikte krachtvoeders naast MNG en ONG. In de eerste proef waren de opname aan RE (15,3 vs 11.1 g kg^{-1} $LW^{0.75}$; $P < 0.001$) en OS (127,1 vs 124.7 g kg^{-1} $LW^{0.75}$; $P < 0.05$) hoger op het rantsoen met MNG dan op dat met ONG. De RE en OS opnames waren 3% hoger met ZBZS dan met PM als ingrediënt. In de pens van met MNG gevoerde dieren waren de concentraties aan NH_3-N hoger (101,0 vs. 51,2 mg L^{-1}), terwijl de pH (6,7 vs. 7,1) en de verhouding (3,7 vs 3,9) tussen azijnzuur en propionzuur (HAc/HPr) lager was dan bij met ONG gevoerde dieren ($P < 0,001$). Rantsoenen die ZBZS bevatten gaven in vergelijking met die welke PM bevatten lagere gehaltes aan NH_3-N (70,9 vs 81,3 mg L^{-1}) en een lagere pH (6,82 vs 7,0) en een hogere HAc/HPr (3,8 vs 3,7) verhouding ($P < 0,05$),

In proef 2 waren de opnames aan RE (10,6 vs 15,1 g kg^{-1} $LW^{0.75}$) en OS (100,7 vs 182,6 g kg^{-1} $LW^{0.75}$) hoger voor de rantsoenen met krachtvoer dan die van puur MNG ($P < 0,001$). Pens pH (6,7 vs. 6,1) en HAc/HPr verhouding (3,8 vs 3,6) waren hoger, terwijl de concentratie aan NH_3-N (56,6 vs 87,5 mg L^{-1}) lager was voor het pure MNG rantsoen dan voor de gesupplementeerde rantsoenen ($P < 0,001$). Om de voeropname en de vertering te verbeteren, zouden dieren die met MNG worden gevoerd, krachtvoer supplementen met daarin PM moeten krijgen, terwijl dieren die ONG krijgen krachtvoer met daarin ZBZS nodig hebben.

Hoofdstuk 8 geeft de resultaten van twee volgens een geward blokkenschema uitgevoerde proeven, waarin zwartbonte melkgevende koeien werden gevoerd met rantsoenen die vergelijkbaar waren met die uit hoofdstuk 7. Bepaald werden de voeropname, de veranderingen in lichaamsgewicht, de melkproductie en de productiekosten. In proef 1 waren de opnames aan OS (IOS) lager (135,9 vs 137,7 g kg^{-1} $W^{0.75}$) en die van RE (IRE) hoger (16,6 vs 12.0.g kg^{-1} $W^{0.75}$) voor de rantsoenen op basis van MNG vergeleken met die op basis van ONG ($P<0.001$). De IOS (137,0 vs 135,0 g kg^{-1} $W^{0.75}$) en IRE waren hoger (14,3 vs 14,2 g kg^{-1} $W^{0.75}$) op rantsoenen met ZBZS dan op die met PM ($P < 0,05$). De voor vetgehalte gecorrigeerde melkproductie (FCM) was hoger (11.0 vs 5.7 kg koe^{-1} dag^{-1}) bij het voeren van rantsoenen op basis van MNG dan die op basis van ONG ($P < 0,001$). In proef 2 waren IOS (112,8 vs 139,6 g kg^{-1} $W^{0.75}$) en IRE (12,2 vs 16,1 g kg^{-1} $W^{0.75}$) lager voor het rantsoen van pure MNG dan het

gemiddelde van rantsoenen met een krachtvoer supplement (P < 0,001). Rantsoenen op basis van alleen NG resulteerden ook in een lagere productie van FCM (7.7 vs 10.7 kg koe^{-1} dag^{-1}) in vergelijking met gesupplementeerde rantsoenen (P<0.001). De met MNG gevoerde dieren namen in gewicht toe, maar de dieren die met alleen ONG of MNG werden gevoerd vielen af.

Het aanvullen van een rantsoen op basis van oud NG met krachtvoer deed de winst dalen. Het aanvullen van op NG gebaseerde rantsoenen met krachtvoer met daarin PM gaf een hogere winst dan een aanvulling door krachtvoer met ZBZS. Geconcludeerd werd bij koeien die gevoerd worden op basis van NG, dat het gebruik van krachtvoer met daarin PM een positieve invloed heeft op de melkproductie en de prodcutiekosten verlaagt.

In hoofdstuk 9 worden de belangrijkste resulten van dit onderzoek besproken. Daarbij wordt speciaal aandacht geschonken aan de praktische gevolgen voor de productie van melk onder de productieomstandigheden van kleine boeren in Kenya. De voederwaarde van MG kan worden verbeterd door het te oogsten bij een optimaal groeistadium en het geven van een aanvulling met krachtvoer. Het technisch optimum voor aanvullingen van op NG gebaseerde rantsoenen met krachtvoer werd in dit onderzoek niet bereikt, wat mogelijk werd veroorzaakt doordat de gevoerde rantsoenen een te lage kwaliteit hadden of niet voldoende gebalanceerd waren. Echter een economisch optimum kon wel worden vastgesteld, namelijk bij het voeren van rantsoenen op basis van alleen NG in de 'rurale' gebieden of bij het aanvullen van op NG gebaseerde rantsoenen met 6% krachtvoer dat PM bevat in de 'peri-urbane' gebieden. Wanneer het werd berekend dan wel uitgedrukt per ha, werd het economisch optimum niet gehaald omdat de winst bleef toenemen met de onderzochte niveaus van krachtvoer aanvulling. Hoewel de ontwikkelde regressieformules een behoorlijk deel van de variatie in DS opbrengst en voederwaarde van NG en melkproductie op basis van NG konden verklaren, zijn er voor het met voldoende nauwkeurigheid voorspellen van deze afhankelijke variabelen onder veschillende omstandigdheden meer gegevens nodig.

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John Muasya Kilumba Muia was born on December 23, 1956 in Machakos, Kenya. From 1965 to 1971 he attended Matungulu Primary School and later joined Kinyui High School from 1972 to 1975. He studied at the University of Nairobi from 1977 to 1981 where he obtained a Bachelor of Science degree in Agriculture.

He was employed as a research officer by the Ministry of Agriculture in 1981 and posted to the National Animal Husbandry Research Station at Naivasha. From 1981 to 1982 he worked with Small Ruminant Collaborative Research Support Programme and from 1983 to 1984 with the National Sahiwal Breeding Programme. In 1985/86, he took a post-graduate course at the Centre for Tropical Veterinary Medicine, University of Edinburgh in Scotland and graduated with a Masters degree in Animal Production and Health. In 1987, he worked with Pig Research and Management section and in 1988 he joined the Dairy Cattle Research Section.

In 1989, he joined the Kenya Agricultural Research Institute. In 1993, under the Dutch funded National Dairy Cattle and Poultry Research Project, he attended a course in the Netherlands and developed a PhD research proposal. In 1996, he was registered for a split-PhD programme at Wageningen University and thereafter compiled a PhD thesis entitled "Use of napier grass to improve smallholder milk production in Kenya." His research work has appeared in international scientific journals, local conferences, workshops, seminars, annual reports and farmer's booklets.