R6775 - Evaluation and Improvement of Feeding Strategies for Optimising Feed Intake in Crop/Livestock Systems.

Volume 2 – Appendices

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

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List of Appendices

Appendix 1

Report on a Participatory Rapid Appraisal of Feed Resource Availability and Utilisation on Dairy Farms in Kiambu District, Kenya

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Introduction

Smallholder dairying in Kenya accounts for around 80*per cent* of domestic milk supply. In the high potential areas of the country, such as Central Province, participation in dairying is widespread. A recent survey of households in Kiambu District revealed that 80 *per cent* of farming households operated a dairy enterprise in conjunction with food (maize) and cash cropping (tea, coffee) on farms with land areas less than one ha (MoALDM / KARI / ILRI, 1995).

Dairying with exotic breeds of cattle (Friesian, Ayrshire) is a recent innovation on many smallholdings in the district. It may be traced back to the mid-1950's when the colonial administration granted land tenure rights to smallholders in "non-scheduled areas" and created credit schemes for the purchase of grade animals and developed dairy support services. However, the ownership of European breeds did not become widespread until after Independence in 1963 when large tracts of farmland were transferred to smallholders.

Smallholder milk production systems were initially based upon paddock grazing with pastures planted to Kikuyu grass (*Pennisetum clandestinum*) or Rhodes grass (*Chloris gayana*). Traditional inter-generation subdivision of land amongst family members together with the rapidly increasing population densities in high potential areas (3.34 *per cent* per year) now severely constrains opportunities for the grazing of animals. Large proportions of land in high potential areas are now occupied by intensive and continuous cropping. Grazing land is now almost non-existent and, with the associated risks of crop damage, exposure to ticks and livestock thefts, has made grazing almost a redundant production method. The majority of dairy producers in Central Province now rely upon stall-feeding as a means of producing milk from permanently confined animals.

The work described in this appendix represents the project's initial diagnostic study of current feeding practices and farmers' perception of them in the Kiambu dairy system. The findings are derived from a short-term particpatory rapid appraisal (PRA) and were used in the design of the subsequent longitudinal study (described in Appendix 2) which collected detailed information on types and quantities of feed offered over the course of a year. The PRA was based on a series of single-farmer interviews to investigate how smallholder farms now use the limited, and still diminishing, feed resources available to them to support milk production. In addition, the study sought to describe the feeding strategies that had been adopted by farmers with the specific aim of promoting more efficient use of feed resources that, in many cases, are of low quality.

The PRA effectively followed up on an extensive cross-sectional characterisation survey of households in Kiambu District conducted in a collaborative campaign by staff from the Ministry of Agriculture and Livestock Development (MoALDM), the Kenya Agricultural Research Institute (KARI) and the International Livestock Research Institute (ILRI). This study, described by Staal *et al*. (1998), sought to characterise the smallholder dairy production system in Kiambu District by taking a "dairy shed" approach by attempting to profile the industry; from production through marketing to consumption. The study also strongly complimented recent farmer-surveys conducted by MoALDM/KARI/ILRI which looked at feed resource management, use of maize stover as feed (Methu, 1998) and the adoption of planted fodders. It was anticipated that basing the diagnostics for the current project on this type of structured analysis would allow subsequent studies to be conducted with farmers clustered in clearly defined resource endowment categories and thereby assist targeting of interventions to identifiable recommendation domains.

Study Site

Climate and soils.

Kiambu District, adjoining Nairobi to the immediate Northwest, covers an area of 1448 km^2 and features a wide range of agro-ecological zones. The major changes in these occur as altitude increases from around 1200 to 2550 metres above sea level along a Southeast - Northwest axis. At the highest altitudes tea is the major crop gown with coffee appearing in mid altitudes to finally give way to cropping systems where maize predominates. The growing of horticultural crops such as bean, potatoes (*Solanum* and *Ipomea*), kales and cabbages occur in most zones as complimentary crops.

Rainfall is bimodal. The main rains occur from April through to July and the short rains during October / November. Yearly average rainfall is between 800 and 1200 mm with 60 *per cent* occurring during the main rains. However, rainfall patterns over the past 30 years have been highly variable. Nitisols are the predominant soil type. These are deep and exhibit high capacity for phosphorus fixation. Cropping intensity and high rainfall contribute to a rapid depletion of plant nutrients in the rhizosphere, particularly nitrogen.

Administrative

Kiambu District is divided into five Divisions; Kiambaa, Lari, Limuru, Githunguri and Kikuyu. Each of the divisions is divided into locations and within these, sub-locations. Population density varies amongst sub-locations but, on average, the recent census suggested a high, average population density for Kiambu of around 480 per km^2. In many sub-locations this can exceed 600 however.

Farming systems

Smallholder farming systems in Kiambu are mixed, with dairy production as a compliment to tea, coffee and food crop growing in all agro-ecological zones. The intensive rearing of pigs and poultry also occur but tend to be concentrated within particular Locations. Goats and sheep are also kept but are generally fed by supervised grazing on public land.

Marketing of agricultural products.

Marketing and production of coffee and tea are controlled by parastatal organisations. Whilst these agencies provide farmers with credit for inputs such as fertiliser and herbicides, they also represent the only outlet for products. In contrast, the deregulation of the dairy industry in 1994 now permits farmers to sell surplus milk to other customers besides the Kenya Co-operative Creameries. Since 1994 private dairy co-operatives have emerged and have now been joined by farmer's informal self-help groups. These co-ops and self-help groups provide marketing facilities in the main but increasingly some of the larger ones are supplying input and advisory services for feed, veterinary and artificial insemination. It is now, no longer illegal to sell milk privately direct to consumers and this informal mode of transaction has become widely practised. Many farmers also grow vegetables that are sold in Nairobi by traders who collect from the farm gate for onward transmission to wholesalers in capital.

The MoALDM / KARI / ILRI Characterisation Survey

Methodology

Table 1: *Themic grouping of variables from the characterisation survey variables for factor analysis.*

Theme	*Survey variables*
1 - Level of intensification	Milk per acre Concentrate purchased per tropical livestock unit (TLU) Fodder purchased per TLU Napier purchased per TLU Land owned per TLU
2 - Level of household resources	% of female headed households Off-farm income category Total household income level Total land ownership Total number of dependents in household
3 - Level of market access	Distance to Nairobi Access to co-operative AI Price received per kg milk co-operative membership use of the informal market for milk sales

A survey of 365 randomly sampled households (one *per cent* of all households in Kiambu District) was conducted in July / August 1996 in an effort to characterise dairy producers (Staal *et al*., 1998). Of the surveyed households, 340 were agricultural and 263 of these operated a dairy enterprise. Availability of on-farm resources, farm productivity, access to purchased agricultural inputs and services, market access and sources of household income were key parameters in this survey. The purpose of the survey was to develop a rapid and robust methodology for use by NARES (National Agricultural Research and Extension Services) for the assessment of opportunities and constraints within the smallholder market-oriented dairy sector.

The survey was carried out by staff from MoALDM, KARI and ILRI in 24 Sublocations in Kiambu District. Households were systematically selected along two randomly drawn transect lines between landmarks in each sublocation. The number of households selected was proportional to the population density of each Sublocation.

The survey was conducted in the three main agro-ecological zones: tea / dairy (103 households), coffee / dairy (137 households) and the food crop / dairy (125 households) zones.

Summary of data analysis of characterisation survey

Principal components analysis identified 27 survey variables which explained the majority of the variation observed amongst households. Fifteen of these variables were combined in three themic groups of five to describe farmers in terms of their 1) level of intensification, 2) level of household resources and 3) level of market access. These three themes are presented in Table 1 along with their constituent variables.

Subjecting variables in the three themic groups to rotated factor analysis gave rise to five significant factors (vectors) against which a cluster analysis was carried out using a data set of 230 dairy farmers. This reduced number of dairy farmers (originally 263) occurred because of incomplete data sets for 33 farms.

Results of analysis of the characterisation survey

The cluster analysis revealed five distinct clusters of farmers. Clusters 1 and 2 (18 and 32 *per cent* of the particpants in the survey respectively) were chosen as containing the target farmers for this present study since they were judged as representing the most resource poor farmers. Farms in Clusters 1 and 2 occupied the smallest total land area (1.42 and 1.97 acres respectively compared with an overall mean of 2.97) and were placed in a low mean household income category (2 and 2.54 respectively compared with figures of more than 3 for clusters 3-5). The main parameters distinguishing Cluster 1 farmers from those in Cluster 2 appeared to be a higher milk yield per day (5.57 kg compared with 4.76 kg) and higher milk yields per acre (9.64 kg compared with 5.25 kg). In addition, more cluster 1 farmers were co-operative members (61 compared with 22 per cent) and fewer sold milk through the informal market (47 compared with 92 *per cent*). The apparently higher productivity observed on farms in Cluster 1 was attributed to greater purchased inputs of concentrate feeds (5,793 cf 3,713 KSh / TLU / year) and fodder (2,407 cf 942 KSh / TLU / year). Similar acreages were planted with Napier grass (0.28 and 0.31 acres/TLU) in both clusters.

Materials and Methods

Selection of farmers for the PRA visits

In selecting particpants for the PRA study, only farmers from Clusters 1 and 2 were considered. It was hypothesised that, given similar physical resource endowments, the greater tendency to purchase feeds amongst Cluster 1 farmers indicated a more informed attitude towards feeds and feeding. For example, Cluster 1 farmers may have possessed a greater awareness of fodder quality and its relationship to cost or, due to their more liberal use of concentrated feeds be attuned to the concept of feeding concentrates for milk production.

Together with extension staff, farmers were selected so that, over a period of two weeks, interviews could be held with 5 male and 5 female headed households, 5 coffee and 5 food crop based farms and 5 farmers in each of Clusters 1 and 2. Participating farmers were selected at random, although logistical considerations such as local availability of front line extension staff was considered. Of the original selection, two farmers were replaced and an additional 2 farmers were interviewed so that 7 male headed households were interviewed. Six farms were located in each of the two farming systems. Five were in Cluster 1 and six were in Cluster 2, with one additional farm, the poorest farmer, included who had not been participated in the original characterisation survey.

PRA implementation

A checklist was designed so that the PRA could address the following specific objectives;

1 To explore in greater detail farmer feeding strategies and determine whether there are feeding practices which intentionally or unintentionally manipulate intake.

2 To identify potentially researchable issues that can be developed under the feeding strategies project.

3 To consider the hypothesis developed in the characterisation survey that ‘The main factor resulting in the apparently higher efficiency of resource utilisation by Cluster 1 farmers was off-farm purchase of forages and other feeds’.

4 If this is correct, to consider what factors influence farmers’ decisions on feed purchase.

5 To determine what parameters should be considered in the longitudinal monitoring.

6 To evaluate methodology for short PRA visits to be carried out during the course of the project.

Each interview was carried out over a period of 2-3 hours by a team of 8-10 people. The team consisted of a core of three members from MoALDM extension services (including the front-line staff responsible for interviewing that farmer in the characterisation survey), one from KARI (principal interviewer), two from ILRI and two from NRI (a social scientist and a nutritionist), attending on each day. Other staff from MoALDM, KARI and ILRI attended on different days. Interviews were conducted, in Kikuyu, by two KARI staff members. Non-Kikuyu speaking members of the team were able to follow the procedure by reading notes prepared by two rapporteurs and through occasional translations by the interviewer. Use of the checklist ensured that similar subject areas were covered in each interview. However, the interview was semi-structured so that other members of the team were able to pursue alternative lines of questioning when appropriate. The intention was not to collect detailed quantitative data. A seasonal calendar of availability of different feeds using matrix scoring was attempted for each farmer. This proved slightly problematic at the start, but developed more effectively during the course of the interviews.

Results

The results of the survey are discussed using the main headings from the checklist. A preliminary evaluation of the methodology is also given and finally, a note on some of the problems observed in the questionnaire.

Methodology

The technique of a series of single-farmer ‘PRAs’ conducted with farmers identified as resource-poor from the characterisation study worked well. As the team, and especially the main interviewer, got more accustomed to the approach, it was found that more time became available for more in-depth probing of particular subjects without trying farmers’ patience.

Most of the questions to be answered could be approached through semi-structured interviewing. The sole visualisation attempted was a calendar of availability of different feeds using matrix scoring which proved slightly problematic. When farmers were asked to rank ‘availability’ across months, it proved difficult to differentiate between availability and use. For example, resources such as tree leaves and banana pseudostems, which were used in times of severe shortage were considered as available all the time they were not being used, with availability decreasing in the months of usage. It was also difficult to consider ‘availability’ of fodders such as napier grass, that may be managed for short- or long-term ends. Furthermore, a confounding effect of off-farm purchase of napier grass and maize stover as well as other forages was noted. This meant that, in effect, it was easier to talk about feed use. The question of whether matrices should be read across (representing the use of an individual feed across months) or down (the relative contribution of different feeds in a given month) also required some consideration. The pragmatic solution, which proved less cumbersome than it may at first appear, was to score the relative importance of fodder within each month, but the use of each concentrate feed, which was more uniform, across months.

Errors in characterisation survey questionnaire

It was clear that most of the characteriation study questionnaires relating to the farmers interviewed during the PRA contained some errors. In some cases this could be attributed to mis-interpretation. For example, the land available to a particular household was sometimes confused with that belonging to a single family but split between a number of brothers heading separate households. Often quantities of milk produced did not tally with milk sales, the latter exceeding the former. Records of off-farm income may have been difficult to obtain and in some cases did not appear to take account of income from lump-sum redundancy payments, from members of the family working off-farm or from other activities such as ownership of a small kiosk. In some cases farmers talked of considerable purchases of napier grass and other fodder resources, such as cut grass, which were not recorded during the characterisation study. In one case a farmer stated that he bought 12 sacks of concentrate / year, buying either maize germ or dairy meal depending on finances at the time of purchase. In the questionnaire, this was recorded as 12 sacks of each. Whilst these errors appeared significant when considering an individual farm it was judged nevertheless that the large number of respondents in the charaterisation survey would mean that the outcome of the cluster analysis would not have been seriously affected by them.

Livestock Production Objectives

Many farmers quoted the primary objective of livestock production as being provision of milk for the family, with income from milk sales and manure as secondary benefits. Profit from the sale of bull-calves was not really mentioned, although prices current during the study were around 10,000 - 15,000 KSh.

Most of the farmers appeared to sell milk to individual customers rather than to the co-operative. It appeared that in some cases selling to the co-operative was not practical since it required milking at midday in order to supply milk at a prescribed time. A number of farmers did milk at midday and the reason for this appeared to be a wish to satisfy the co-operative. Although one farmer milked at 01.30 - 02.00 h, most milked later in the morning, which meant that the time between milkings deviated significantly from the 12 hours generally considered optimal, although this may represent a concept imported from the industrialised systems where milk yields are high.

Labour bottlenecks

Questions regarding labour use and availability received varying amounts of attention during the interviews. Periods of high labour demand included the major and minor coffee picking seasons (April and Nov - Dec); the maize harvest; land preparation; weeding and fodder collection in drought periods when sometimes more than twice as much time was required to collect the same amount of cut grass. Although some farmers said that the livestock suffered in busy periods, particularly during the coffee harvest, other farmers paid external labour to assist and one even stated that animals took priority and it was the crops that suffered. The maize harvest combined fodder collection with harvesting and therefore did not have a negative effect on fodder collection.

For the poorest farmer, labour seemed to be a major constraint. This woman worked as a labourer earning 60 KSh / day on six days of the week. This left her with one remaining day to walk the 10km to tend her rented plot. Tasks relating to her livestock were carried out at the beginning and end of the day. This farmer stated that she was aware that chopping stover shorter than she currently did (i.e. into lengths of around one foot) would increase intake. However, she did not have time to do this as chopping one 'load' of stover (the amount that she could carry on her back) into 1ft lengths would have taken her one hour.

Although tasks were shared between men and women, the interviews generally revealed that women took far more responsibility for livestock-related tasks.

Management of Napier Grass

Manure was commonly used on napier grass unless it was grown at some distance from where the animals were kept in which case transportation became a problem. Fragmentation of holdings was found to be common in the area and represents a significant constraint on crop-livestock integration. In some cases fertiliser was applied, particularly where coffee was produced, but farmers tended to split the fertiliser provided by the coffee co-operatives between the cash crop and the Napier grass. Farmers stated that ideally, napier grass should be cut when the plant is approximately 4 foot (*circa* 1.3m) tall. However, the grass was often cut when it was low as 1 foot in height, in times of feed scarcity. Availability of alternative fodder resources appeared to be the main factor influencing frequency of cutting. When poor quality feeds such as dry maize stover and banana pseudostems were used, many farmers fed small amounts of napier or cut grass too. In some cases this was judged to promote intake of the poorer feed and in some instances to provide at least a small amount of a feed that would contribute to milk production. Most farmers stated that they avoided cutting napier during the coldest month of July, when regrowth was particularly poor.

Management of maize

Green maize thinnings were considered to be a source of fodder by all farmers and to be of as good quality as napier grass. Multiple seeds, 3 - 4 seeds per hill were planted and plants were thinned at around 1-2 months before harvesting. One farmer planted closer together, while the poorest farmer did not plant extra seed, but thinned weak looking plants. If the short rains failed then sometimes the whole crop would be salvaged as fodder. A number of farmers intercropped maize with napier grass, two during the establishment phase of the grass only, one in grass planted at a wider spacing with a view to harvesting the grain and one in normally spaced napier grass purely as an additional fodder source.

Maize provided two other sources of fodder, green maize stover collected when green maize was harvested and dry maize stover collected following harvest of the maize grain. Residues were collected and stored on-farm for short periods, either on racks or upright in stooks or against hedges to avoid termite damage. Storage was only for short periods and the stover generally lasted for a maximum of 2 months.

Other crop residues and on-farm feeds

There were a range of other residues used frequently or occasionally such as sweet potato vines, bean haulms, kale leaves and potato peel, but none of these were of major importance. Kitchen waste was commonly used but, again, was in very limited supply. Banana pseudostems were used by all farmers interviewed and in some cases appeared to be the principal source of fodder during a large part of the year. This feed was paricularly important when alternative sources were limited, either due to limited land, drought, distance of the source from the homestead or a lack of cash for purchasing feed. Most farmers recognised the limited value of pseudostems, which they said consisted mainly of water (pseudo stems have a DM content of only around 100-150 g/kg) and attempted to add small amounts of other green material or bran. In a survey, also conducted in Kiambu district, Methu (1998) found that the practice of offering small quantities of green material was considered necessary when feeding dry maize stover by 55 *per cent* of farmers.

Other sources of fodder included grass found around the farm, at the sides of the fields around the homestead and along the coffee bench terraces. Often this was preferred to roadside grass that was considered to be a source of ticks. In some areas competition for this grass was found to be intense. However, farmers spent a lot of time collecting the grass and time spent on this activity increased drastically in the dry season when some farmers spent in excess of 4 hours collecting grass. Only one farmer grazed her animal, although the grazing land to which she had access was becoming increasingly scarce, with land being partitioned between siblings who were taking over the land for alternative purposes. On one farm, riverside grass was cut and considered to be much "cleaner" than that found on the roadside. During the months of fodder scarcity leaves from fruit trees, such as the Loquat and avocado, were offered to livestock. Weeds collected during weeding and land preparation were another common fodder source.

Purchase of fodder

All of the farmers interviewed purchased fodder to supplement on-farm production. Instances of purchasing napier grass, green and dry maize stover, roadside grass and sweet potato vines were cited. Two informants purchased vegetable waste from nearby markets at certain times of year. Prices were extremely variable and appeared to depend considerably on season. When fodder was scarce, prices increased as much as four times compared to prices in the season of plenty. Methods of purchase also varied. Some farmers purchased 15 metre lines of napier grass, while others purchased plots of up to 0.25 acres at one time. One farmer appeared to rely almost entirely on external purchases of fodder, since only a very small amount of Napier grass was grown on his farm. This farmer purchased three cuts of napier grass from a 0.125 acre plot owned by a neighbouring farmer at 1500 KSh per cut. She was allowed to cut the grass as she needed and had purchased three cuts during the year of the study, always ensuring that the height of the plant was around four feet. No reduction in price was offered if the grass was cut at a lower height. This same farmer stated that rental of an equivalent amount of land was 700 KSh / year. In contrast, another farmer was required to cut all the napier grass from a plot in one go. Transport to the farm by pick-up truck was included in the price. This farmer experienced storage problems with some of the grass lost to termite attack and drying out.

Exchanges of fodder for manure occurred, although most farmers said they were unusual. They were generally conducted on the basis of both commodities being converted to notional cash equivalents. The poorest farmer, a widow, exchanged one wheelbarrow of manure for two woman-loads of maize stover that she had cut herself near to her compound. This woman sold maize stover grown on a rented plot 10km away and used the money to purchase napier grass. Transactions involving exchanges of fodder and milk were even rarer, although sometimes fodder was accepted when no cash was available to pay for milk. In one case, a factory watchman allowed one farmer an unofficial cut of grass in exchange for milk.

One farmer mentioned commercial fodder sellers, although they avoided purchasing from these people since they were convinced the fodder was stolen. They themselves had problems with theft of napier grass and the only time that they purchased it was following theft of their own.

Other purchased feeds

Concentrated feeds used included dairy meal (although this was infrequent due to its high cost of around 600 KSh. per 70 kg bag), maize germ, wheat pollard and maize bran (farmer-ranked in this order for quality). Poultry litter was also used but always in combination with maize bran or maize germ as farmers claimed that animals would not eat it when fed alone. Relative proportions of the mixture varied from equal amounts (the most common pattern) to approximately 5 :1 poultry litter : bran.

Farmers appeared to consider bran as a gut-filler and often increased the amount fed in times of scarcity, particularly when the main constituent of the diet was banana pseudostem. It was often stated that bran was good for the animal's health but that dairy meal, and to a lesser extent maize germ were good for producing milk. The poorest farmer said that she thought that concentrates were good for general health but not milk production and that napier and cut grass were the best feeds for producing milk.

The cost of concentrate was lower in local shops than in the co-operatives, but farmers with access often preferred to purchase from the co-ops in order to take advantage of the credit facility. Only the poorest farmer bought no concentrate whatsoever and she used kitchen waste in place of concentrate to occupy the animal when milking. Most tended to use maize germ in preference to the more expensive dairy meal.

Use of concentrate was quite difficult to ascertain, although our understanding improved as the interviewers and other members of the team became more skilled. Maize germ, or a mixture of poultry litter and bran was often used in place of expensive dairy meal and fed, most commonly, to milking cows at the time of milking. The amount given varied between farmers but in all cases a flat rate was fed throughout lactation. Between drying-off and parturition, a period that appeared to vary between 1 - 3 months, no concentrate was fed and one farmer suggested that this would help to avoid calving problems.

Selling fodder

Only one farmer interviewed sold fodder. This was maize stover produced by the poorest farmer on a plot that was too far away to be able to carry it back to the homestead. Those selling fodder tended to fall into three categories: those with no animals who sell crop residues, those with large holdings producing surplus material and farmers with no animals but growing napier grass specifically for sale.

Processing

Both green and dry maize stover were chopped (as was napier grass) when harvested at a height of approximately one metre. Chopping was carried out to increase intake of the stemmy parts of the forage and to avoid wastage of forage which animals had a tendency to pull into the pen and trample when left for long periods. Methu (1998) found that 92 *per cent* of farmers in Kiambu chopped maize stover and that all farmers used it for feed and none for direct incorporation into the soil. The length of chop appeared to vary largely according to the person chopping. Most farmers considered the dryness of the stover a problem and soaked the chopped material overnight to soften it. Mineral salt was added to make it more palatable and in one case, molasses which had been found to be more effective than salt. It was noteworthy that this farmer also fed poultry litter, but not at the same time as the molasses, which may have benefited utilisation of both feeds. One farmer, who did not soak, fed the stover very early in the morning when the dew had softened it. This farmer also attempted to 'trick' the animal into consuming rejected parts of the stover by returning them to the trough once fresh material had been added. Most farmers said there were always some parts that the animal would not eat and one stated that, in the season of plenty, they did feed until there was some left over. One farmer deliberately wilted green stover, claiming that this practice improved intake.

Quantity

Although there were rarely significant amounts of material left in the trough before the first morning feed, there were parts of the dry stover and the napier grass stems that were not consumed. These were mixed with the manure to make compost. Other material included in the compost was mainly fodder pulled into the pen that was then trampled on and subsequently rejected by the animal. Although at least one farmer stated that when fodder availability was high there were some refusals, excess feeding did not generally appear to be intentional and was mainly a function of availability.

Frequency of feeding

Most farmers appeared to offer fodder more than once per day. A number of reasons were given. Some farmers stated that if all the fodder was put in the trough at the same time, feed would be pulled into the pen and wasted. Most farmers thought that if they did not feed more than once this would disrupt milking and some that if fodder was not offered in the afternoon, before evening milking, milk yields would decrease. Some farmers also fed frequently to avoid hungry cows being noisy, particularly overnight, or even to avoid them damaging the stall and escaping. One farmer stated that his animals needed time to rest and digest the material after the morning and midday feeds. Frequency of feeding changed during times of scarcity, in most cases by dropping the midday feed. However, one farmer actually increased feeding frequency when feed was scarce from two to three separate feeds.

Whether mixtures of fodder were divided into equal portions, or fed separately tended to depend on how the feed was collected. Sometimes cut grass would be collected and offered in the morning and then stovers or weeds gathered during the day would be offered at midday or in the evening when the farmers returned to the homestead. Only one farmer appeared to make a conscious effort to offer fodders separately, giving small amounts of napier grass before feeding stover, principally to avoid wastage of stover as the animal searched for the green material.

Mixing fodders

Mixtures of fodders appeared to be offered mainly in times of feed scarcity. Different fodders were used as they became available and the farmer collected what she or he could. Some farmers felt that mixing fodders was 'good' for the animal as it prevented them from getting bored. However, this appeared to be based largely on personal feelings. Other farmers felt that mixing allowed the animals to make their own choice of feeds and what was eaten at what time. Most farmers recognised that dry maize stover and banana pseudo-stems were very poor feeds and attempted to add some green fodder such as napier or other cut grass, preferring to offer small amounts of this together with the stover rather than a larger amount in fewer feeds. The rationale offered was either that the animals needed some green material for milk production or that it encouraged consumption of the dry material, or indeed both.

Day-to-day variation appeared to be dictated principally by availability of feeds. Extreme variations occurred from time-to-time. For example, one farmer purchased a large amount of sweet potato vine which was fed as the principal fodder for a period of one to two weeks. Other feeds such as green maize stover and weeds would be fed as collected. It might be expected that, under these circumstances, variations in feed offers would be considerable.

Feed allocation

Most farmers did not differentially allocate fodder to animals of different productive state or capacity, although some separated young, weaned animals and one farmer tethered the lactating animal outside the stall in order to offer additional forage. Another farmer favoured young animals when feeding sweet potato vines. However, milking animals did receive preferential treatment in terms of the concentrate that was fed during milking. Most farmers offered some form of concentrate, either maize germ, or a mixture of poultry litter and maize germ or bran. Some farmers mixed in small amounts of fodder with the concentrate, although this practice appeared to be undertaken mainly in order that when milking took longer the animal had feed in front of it throughout, thus avoiding behavioural problems. The one farmer who did not feed concentrate offered kitchen waste during milking.

Ranking of fodders

It was often difficult to separate rankings which combined quality (in terms of potential to produce milk) and quantity. Although sweet potato vine was often given a low ranking, this appeared to be on the basis of the small quantities in which it was available. Napier grass, cut grass and maize stover were all cited as the preferred fodder, but farmers who were asked which fodder would produce the most milk if equal amounts were fed cited sweet potato. Stover and banana pseudo stems were considered the poorest fodder.

Perception of manure

Most farmers did not consider that manure varied in quality depending on the feeds used. Exceptions included two farmers who felt that grass gave better manure than the stover. This perception appeared to be mainly related to the dryness of the material and the particle size. Two farmers spoke of manure produced in pastoralist systems, but of these, one considered the material better, although it was not clear why and the other worse because it was drier and land required further applications of manure after a shorter time.

On all but one farm, manure was pulled to one side of the pen and kept in a heap for 1 - 3 months. Reasons given for this practice were to dry it making it easier to spread and offering the stover and other feed refusals a chance to rot. One farmer had composted the manure in a covered pit. A stick was inserted into the compost and regularly withdrawn. Mould attached to the stick was considered an indication of excessive temperature and water was applied to cool the pit.

Aspirations: including perceptions of cattle breeds

Most farmers, when asked what information they required or how they planned to increase milk production mentioned improved breeds of animals. Some were asked what the implications were of feed shortages for these animals. One farmer said that she would make more effort to find more feed whilst another said they would then keep one animal instead of two, which would be easier to feed and keep alive on income from vegetable crops when the cow was dry.

Researchable Issues

In industrialised production systems, farmers aim to feed their animals so they are able to fulfil their genetic potential. Optimal rations are devised, which provide the nutrients they estimate their animals require to achieve given levels of production. A wide range of purchased feeds as well as those produced on-farm are available and least cost rations are estimated which maximise profit margins. In smallholder farming systems such as that considered here, this possibility does not exist. Information collected in the PRA described here, combined with earlier results confirm that available feed resources are often not adequate to satisfy even very low levels of production. The actual quantity of feed may vary between neighbours and depend on a variety of factors, including total land area available, numbers of household members that must be provided for (which may determine the area required for food crops) and levels of income from both on and off farm activities, which will determine the levels of off-farm purchases that can be considered. However, it may be accepted that in a changing market economy, the potential to purchase feeds may increase or decrease depending on circumstances.

One option to increase productivity would be to develop novel ways of increasing available resources. Strategies which offer the potential of increased fodder availability include planting fodder trees, inter-cropping with forage legumes, establishing new varieties of crop or improving management practices to increase yields. There has been a considerable body of work evaluating new plant species, determining optimum supplementation regimes and crop management practices. Already the extension services are able to give some advice on use of legumes such as *Desmodium, Calliandra,* etc. Furthermore, these issues are currently being considered at a number of KARI centres, including Muguga and Kitale under the NARP II project and DfID funded projects at Embu. Further supplementation studies using novel feeds, or agronomic studies to increase production are not amongst the objectives of the current project.

Another well established constraint to production is the poor quality of available feeds. This is particularly the case in dry seasons where the principal feed available is often maize stover, with poor digestibility and low protein content. The results of the survey showed that farmers recognised that animals had a problem in consuming dry stover. Even when the quantity of stover was limited, farmers were anxious to ensure that animals consumed all the material that was offered. A number of strategies were used to maximise intake under these circumstances, including chopping and soaking, offering stover at times when dew increased moisture and mixing with more palatable ingredients. Studies in the NARP II project based at KARI centres in Kitale and Muguga have addressed this issue, with studies to evaluate methods of soaking as well as methods to improve stover quality through urine/urea treatment.

It was clear from the PRA results that farmers employ various strategies aimed at making what they consider to be best use of their feeds and many of these strategies had the effect of altering the animals natural pattern of intake. Feeds were often offered mixed together, allowing animals to choose the order of consumption, while sometimes feeds were offered separately so there was no opportunity to select. Decisions on how to mix different feeds appeared to be based on considerations such as feed wastage if feeds of different quality were mixed; an animals preference for a variety of feeds to avoid losing interest in a single feed; and the benefits to milk production of adding small amounts of better quality forages or other feeds when the main available feeds were of poor quality. Rather than offering all of the feed at one time, available feed was divided into portions to be fed at various times during the day. Sometimes the offer patterns reflected patterns of collection of feed, while conscious efforts were also made to avoid behavioural problems, or to enforce times of resting from eating. Other factors affecting decisions included practical considerations of available labour and timing of other activities such as milking.

These findings influenced the decision that experimental work conducted by the project (see Appendices 3 and 4) should focus on manipulation of a given quantity of feed to maximise the efficiency of nutrient utilisation. This included a consideration of whether the benefits of a given strategy are similar between levels of feeding, or whether different strategies are appropriate dependant on quantity and quality of the feed. Some of the relevant issues highlighted by the PRA are considered below.

Within a day - Frequency and timing of feeding

All the farmers in the study fed at least twice and often more than twice. Feeding frequency is known to alter efficiency of digestibility, although most experimental work has been carried out at high levels of feeding. In the smallholder systems in the study, frequent feeding often appeared to be a strategy to spread the intake of small amounts of feed over the day and avoid behavioural problems with hungry animals. If small amounts of feed were fed alone, the normal intake control mecahnisms operating would result in an animal eating all the feed in a short period of time, leaving the rumen empty for the remainder of the day. This might be expected to have a detrimental effect on the micro-organisms that would be ameliorated by enforcing the animal to spread intake over the day. Increasing the number of times feed was offered as available feed decreased, a strategy employed by one of the farmers interviewed in the PRA may have a beneficial effect. One area of future study might consider frequency of feeding of small quantities of feed and the effect of altering frequency of feeding on intake patterns, digestibility and efficiency of feed utilisation and the interactions with level of feeding.

Timing of feeding in relation to milking may also be important. Farmers in the survey often milked at intervals of less than 12 hours in response to the collection times of the Co-operative or of other milk purchasers. If milk is collected in the early afternoon milking is carried out at midday and although one farmer milked at around 0200am, others did not. A number of farmers in the survey said that the evening feed was important for milk production the following day.

Within a day - Mixing forages and other feeds

Other manipulations within a day related to whether feeds were fed separately or mixed and if separately, the sequence of feeding the different types of feed. Mixing feeds may provide a better balance of nutrient intake, although some farmers saw disadvantages in that animals spilt the less palatable feeds, which were subsequently wasted, while searching for more favoured forage types. A study designed to address this issue might consider the implications of mixing feeds, should they be mixed together, allowing the animal to select for themselves the sequence of feeding or should they be offered individually in an imposed sequence.

Within a day - Supplementation

Consideration of the optimum supplementation regimes when intake is manipulated in the ways mentioned above might also be important. Again the actual quantity of supplement, be it tree fodder, herbaceous legume, agro-industrial by-product or concentrate will be determined by external constraints which are not within the scope of the present project. However, given that changing markets are likely to change incentives for purchase of external inputs, it should be considered whether the strategies suggested are appropriate for high (but still below maximum potential) as well as low levels of feeding.

Between day - Alternating fodder type offered from day to day

Some farmers intentionally mixed different fodder types to avoid the animal becoming ‘bored’, while others mix fodders when feeds are limited and they are forced to collect what they can from a variety of sources. Bran (but not concentrates considered to be of better quality) is also fed mixed with fodder, the amount being increased in times of scarcity. The mixture offered may depend largely on other farming activities. Weeds will be included when the fields are being weeded, green maize stover will be fed as the green maize cobs are harvested, cut grass might be collected on the way to or from the fields when there are activities there, purchased fodders may be used when finances permit. The implications on utilisation of the feeds when feed offered changes from day to day were examined in the on-station studies that are presented in Appendices 3 and 4.

Between day - Seasonal manipulation of a given amount of concentrate

Another clear trend observed was that farmers did not match concentrate feeding to level of production. Cows were given a flat rate of concentrate throughout lactation, which was normally cut to zero during the drying off period. Levels of concentrate were low and apparently dictated by financial constraints. The extension service make pragmatic suggestions for concentrate feeding, that farmers gradually increase the quantity of concentrates offered until no response in milk yield is observed. However, for those farmers in the survey levels of feeding were too low to follow such suggestions.

It may be that the concentrate would be more efficiently used (in terms of digestibility and milk production) in combination with larger amounts of better quality fodder (i.e. in times of high availability) than when the fodder source consisted mainly of poor quality stovers or banana pseudostems and give increased milk production over a whole year. This would have important implications for constancy of milk supply. It may well be, given that milk production for the family was the main objective of the farmers interviewed, that farmers will prefer a more constant milk supply than increased overall milk production. These factors would have to be taken into consideration. It should also be taken into consideration that concentrates were principally fed during milking to encourage milk let down and to calm the animal. It is unlikely that the recommendation not to feed any concentrate at all at certain times of the year would be well accepted.

Appendix 2

Factors Affecting the Dynamics of Feed Resource Utilisation in a Small-scale Dairy System in Central Kenya.

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Introduction

Feed shortages have been identified widely as a major constraint to improved productivity of livestock kept under smallholder conditions in developing countries. It has also been recognised that the nature and severity of these shortages may be affected by a range of factors that operate in different farming systems (e.g. ILCA, 1987). Despite this widespread perception, there have been few attempts to identify the principal sources of variation in the supply and utilisation of feed resources *at the farm level* and then to quantify their effects. Without information at this level of detail, effective planning of research and targeting of extension recommendations for assisting smallholder farmers to optimise supplies of nutrients to their animals must be compromised.

Although detailed monitoring of a constraint cannot be assumed to automatically reveal causes and possible solutions (Roeleveld, 1996), well-targeted monitoring can generate data which have the potential to be used not only at the diagnostic stage, but also to pre-test proposed interventions. In many cases researchers seek to identify trends and recommendations are not normally set at household level, but at the level of farming system or agro-ecological zone. However, it is clear that variation amongst neighbouring farmers is high, despite common climatic conditions and soil types. In a detailed study carried out in Nepal, Thorne *et al*. (1998) showed considerable among farm variability in terms of amounts and type of feed offered, even after accounting for systematic sources of variation such as location, ethnicity and season.

Recent longitudinal surveys in Kenya have included that of Mason *et al*. (1997). This showed large differences in the type and amount of feed offered amongst seasons. Other workers have also demonstrated high variability even within seasons (e.g. Abate *et al*. 1990; Solano *et al*., 1998). Early PRA work with the small scale dairy farmers targeted by this study highlighted considerable variation in feeding strategies employed by them (Romney *et al*., 1998) and a subsequent longitudinal study showed that contribution of the two main sources of fodder offered to cattle, varied greatly in terms of percentage contribution to total fodder DM; Napier varying from 30-85% and maize stover from 10-40%.

The study described here was designed to provide a more detailed analysis of feeding practices and their consequences on small-scale dairy farms in central Kenya and to use this information in a systematic analysis of the potential for alleviating feed related constraints in the study system.

Materials and Methods

Study Site

The study was located in Kiambu district, central Kenya. The district covers an area of 1448km^2 to the north-west of Nairobi. It is, therefore, essentially peri-urban in nature and marketing opportunities and arrangements for crop and livestock products, including milk from smallholder dairy production, tend to reflect this.

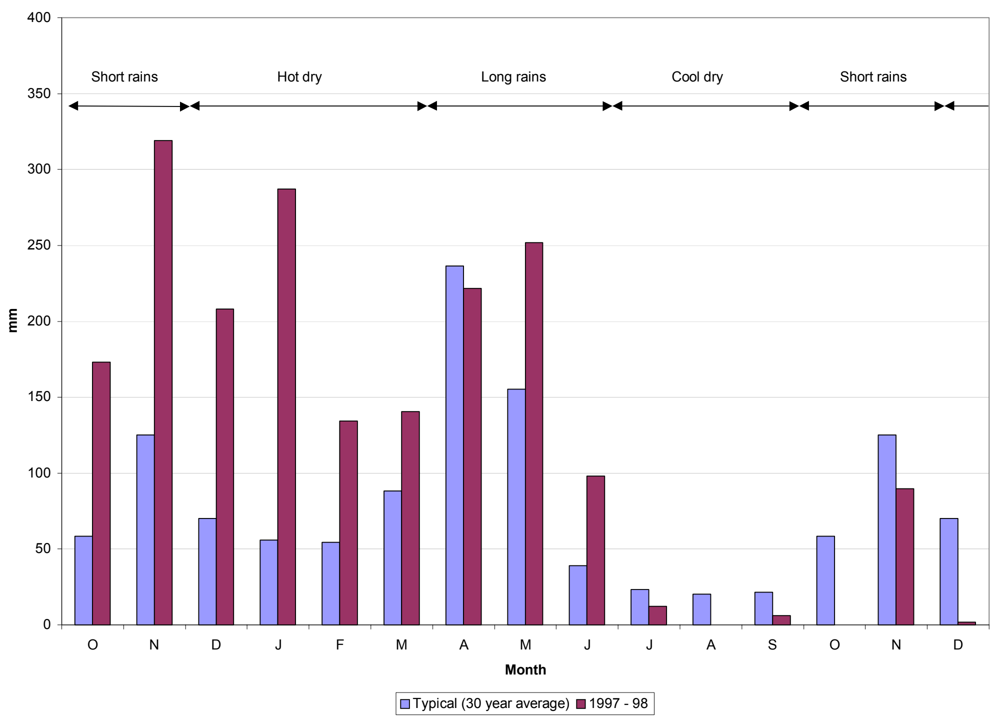
Thirty-year averages derived from climate recording indicate a mean annual precipitation of 800 – 1200mm distributed bi-modally into long rains (LR; April – July; 60 *per cent* of annual precipitation) and short rains (SR; October – November; 40 *per cent* of annual precipitation). The intervening periods are classified as cool, dry (CD; July – September) and hot, dry (HD; December – March) seasons.

Farmer Selection and Characteristics

Twenty one farmers from Kiambu district were selected by reference to an earlier characterisation study reported by Staal *et al*. (1998). Three major factors, based on identifiable characteristics of the farms and farmers participating in the study, were identified for the analysis of both recorded and derived variables.

- *Land-use classification*. Thirteen of the 21 farmers were located in a Coffee – Dairy zone (corresponding broadly to the agro-ecological zones (AEZs) UH1 and LH1 identified by Jaetzold and Schmidt, 1983). The remaining eight farmers were operating a system based predominantly on Horticulture - Dairy production (UH2, UM3, LH2 – 5; Jaetzold and Schmidt, 1983).
- *Labour class*. The assignment of farmers was based on observations of the sources of labour for milking and fodder collection and feeding, recorded during the course of the study. In practice, this became a two-way classification of households using their own labour *versus* households that were reliant upon hired labour.
- *Season*. The typical seasonal progression of LR – CD – SR – HD has been somewhat disrupted in recent years. The study was conducted between October 1997 and December 1998 and this period was no exception. During the study there was, notably, a relatively high rainfall during both SR (1997) and HD (1998) although levels of precipitation during the subsequent LR were fairly typical (Figure 1). SR (1998) was late arriving and overall rainfall during this period was low

Figure 1: *Rainfall over the study period (October 1997 – December 1998) compared with typical rainfall patterns (30 year average) for Kiambu, Kenya.*



On-farm Recording

Data collection was based around a series of monitoring visits to participating farms by a team of enumerators who were also members of the local extension service. Each farm received a monitoring visit at intervals of approximately 14 days. Visits started at approximately 06.00h (hours), timed, in most cases, to coincide with the first feeding events of the day, and were terminated after the final feeding event, usually at around 17.00h. On some monitoring visits to some farms, milking and feeding took place before 06.00h (between 02.00h and 04.00h). In these instances, recording was based on farmer-recall. During the course of each visit, a complete record was made of feeding patterns for the day, of changes in the structure of the livestock holding since the previous visit and of the bodyweights and productive outputs of individual animals.

Changes in herd structure were recorded throughout the study. These included sales and purchases, births and deaths. Estimates of cow bodyweights (BWs) were made from heart girth measurements using the following equation derived for crossbred cattle of a similarly variable genotype in Northern Tanzania (Msangi, Dijkman and Thorne, unpublished data).

$$BW = (0.1416 \times HG - 5.0564)^2$$

Where BW = bodyweight (kg) and HG = heart girth (cm)

Body condition scores were also assessed at each monitoring visit based using a simple scale of one (very thin) to five (very fat).

The use of feeds on participating farms was recorded for all the individual feeding events that took place during each monitoring visit. The quantities of individual feeds (prior to any mixing) that were offered to each animal (or group of animals fed together) were measured using a suspended 50kg spring balance. Estimates of the dry matter (DM), crude protein (CP) and metabolisable energy (ME) contents of the feeds observed in use during the course of the study were derived from book values.

Statistical Analyses

All statistical analyses were conducted using the standard directives and library procedures provided by Genstat 5, release 3.2 (NAG, 1995). Categorical effects (for example, the distribution of labour use amongst different types of labour source) were evaluated using χ^2 tests for independent samples. The effects of the main factors and their interactions on the values of the measured and derived variables in the data set were evaluated using a variance components analysis executed with REML. This allowed the effects of unbalanced factors to be evaluated within a multi-factorial framework, and variances within and amongst farms to be compared.

Results

Farm Characteristics

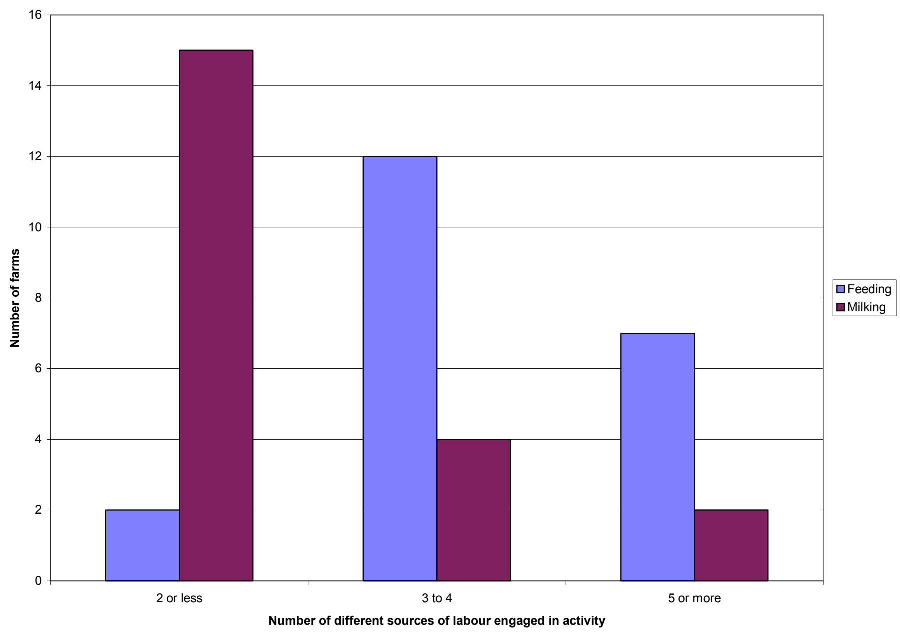
Sources of Labour for Feeding and Milking

Three farmers in the horticulture zone and two in the coffee zone were found to be reliant, predominantly (more than 80 *per cent* of feeding events) on hired labour for feeding. On these five farms, hired labour also carried out most of the milkings observed. In addition, on two farms in the coffee zone, hired labour was used for 27 and 58 *per cent* of the feeding events recorded. However, these farms used virtually no hired labour for milking. On all other farms, the use of hired labour was minimal (less than 10 *per cent* of feeding events). Therefore, for the purposes of more detailed analysis of labour use, the farms were categorised into three “labour classes” (hired, household and intermediate), in terms of the sources of labour used on them.

There was no evidence of systematic differences in source of labour between the two different land-use zones ($\gamma^2 = 2.28$; $P = 0.320$). However, on individual farms, labour for feeding was generally supplied by a wider range of different people than labour for milking ($\gamma^2 = 16.72$; $P < 0.001$; Figure 2).

The number of different individuals contributing to the labour force for feeding was similar on farms in each labour class. However, on farms in the hired labour class, a much higher percentage of the feeding appeared to be carried out by one individual (hired = 86.9 *per cent*, household = 57.6 *per cent*, intermediate = 56.7 *per cent*; $P < 0.001$; $SE_D = 3.9$ *per cent*) who was, almost invariably, employed on a long-term basis. In the household and intermediate labour classes, the main feeder was generally found to be the household head or their spouse with periodic support from other adults or youths over the age of 15. The use of child labour (under 5 years of age) for feeding was generally uncommon.

Figure 2: *Diversity in the sources of labour for different dairy related activities (feeding and milking).*



Only two farmers fell into the intermediate labour class. As these were both located in the coffee zone, they were excluded from the more detailed analysis of livestock productivity and feed resource utilisation that follows in order to avoid confounding. Therefore, the analysis reported here includes 19 farmers.

Herd Sizes

There was evidence of a systematic difference in herd sizes amongst the study strata. Participating farmers using hired labour in the coffee zone kept substantially larger herds than those in other categories (mean total herd weight of 1884kg compared with a mean of 842kg over the other three categories; $P < 0.001$, $SE_D = 141kg$). However, as only two of the study farmers fell into this category, it is not possible to infer whether larger herd size was characteristic of this type of farmer. Herd sizes were quite variable in general with a coefficient of variation in excess of 55 *per cent*.

Livestock Performance Indicators

Bodyweight and Condition Changes

There was no evidence of systematic differences in BW changes. Over the 15 month study period and over all farms, a mean weight gain of 144g animal^{-1} day^{-1} was observed.

Mean BW gains in animals gaining weight were higher in animals on farms using hired labour in the coffee zone (1276g animal^{-1} day^{-1} *vs* 891g animal^{-1} day^{-1} in other animals; $P = 0.007$, $SE_D = 111g$ animal^{-1} day^{-1}). However, animals that were losing weight generally did so more rapidly on farms that hired labour than on farms using household labour (-1101g animal^{-1} day^{-1} *vs* -868g animal^{-1} day^{-1}; P = 0.014, SE_D = 112g animal^{-1} day^{-1}).

Mean body condition scores were influenced by season (P < 0.001, SE_D = 0.1). The highest condition scores of 2.7 were observed during the cool dry season of 1998 following a build up of condition over the preceding HD and LR seasons.

Milk Production

Overall mean milk yields recorded were 6.1 litres day^{-1}. Milk production was higher from animals in the coffee zone (6.7 litres day^{-1}) than from animals in the horticulture zone (5.5litres day^{-1} ; P = 0.036, SE_D = 0.6litres day^{-1}).

Feed Utilisation

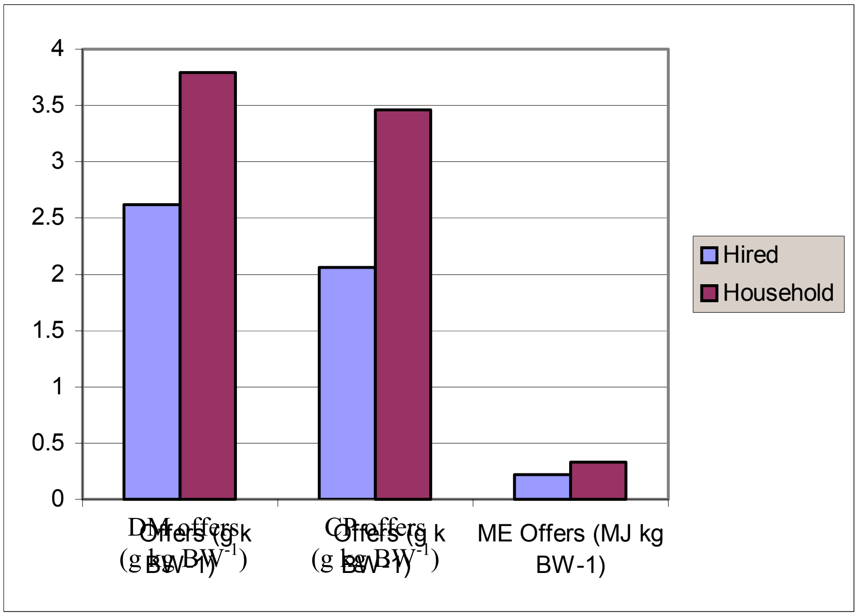
Offer Rates to Animals

The principal source of variation in mean daily offer rates of DM was found to be the type of labour used for feeding on the participating farms. Farms employing hired labour generally fed at lower offer rates (2.6 *per cent* of BW) than farms that were reliant, principally, on household labour (3.7 *per cent* of BW; P < 0.001, SE_D = 0.3 *per cent* of BW). Across farms of all types, DM offer rates to lactating cows (3.0 *per cent* of BW) exceeded those to non-lactating cows (2.4 *per cent* of BW; P = 0.004, SE_D = 0.2 *per cent* of BW). It is also noteworthy that no significant seasonal patterns were observed in DM offer rates.

Estimates of CP and ME offer rates based on book values showed a similar effect of labour source with higher offer rates of both protein (P < 0.001) and energy (P < 0.001) recorded on farms using household labour for feeding (Figure 3).

Figure 3: *Effects of labour source on the quantity (dry matter - DM) and quality (crude protein – CP and metabolisable energy - ME) of feed offered to dairy cattle on farms participating in the study.*

ME offers
(MJ kg BW^{-1})



Milk Production Efficiency

The milk production efficiency (M_{PE}) of the feed offered was calculated for individual observations of DM offer rates (DMO; kg day^{-1}) and daily milk yields (MY; litres day^{-1}) as:

$$M_{PE} = MY / DMO$$

Thus, M_{PE} represents the quantity of milk (in litres) that will be produced by one kilogramme of feed DM. As such it can be regarded as a relative indicator of the quality of the diet actually consumed by the animals, a variable that could not be measured directly in the current study.

M_{PE} values were higher, overall, on farms in the coffee zone than in the horticulture zone (P = 0.003). However this appeared to be due mainly to much lower M_{PE}s observed on the farms that used household labour in the horticulture zone (0.26 l kg^{-1} *vs* 0.34 – 0.36 l kg^{-1} in the other three categories; P = 0.17, SE_D = 0.03). There was also evidence of seasonal influences on M_{PE} values. These exhibited a marked dip from a fairly constant value of around 0.34 l kg^{-1} – 0.35 to 0.29 l kg^{-1} during the final, short rainy season of the study (P = 0.38, SE_D = 0.03 l kg^{-1})

Feed Management

Composition of collected feeds

Table 1 inventories the feeds collected by participating farmers during the course of the study. Most of the feeds observed amongst feed collections could be classed as either grasses, crop residues or concentrates with only limited observations (in terms of both frequency and proportion of the diet) of the use of other, miscellaneous feeds.

Pronounced seasonal effects were observed in patterns of feed utilisation (Figure 4). The use of grass was observed least frequently during CD (1998) and the SR that followed it (P = 0.002). Interestingly, frequency of grass use was relatively high during the abnormally wet HD of 1998. The frequency of crop residue use was also influenced markedly by season (P = 0.009). Crop residue use tended to mirror grass use with the most extensive use of one being made when the other was used less. There was no evidence of a seasonal effect on the occurrence of concentrate feeding with a year-round mean of concentrate in use on 77 *per cent* of the monitoring visits.

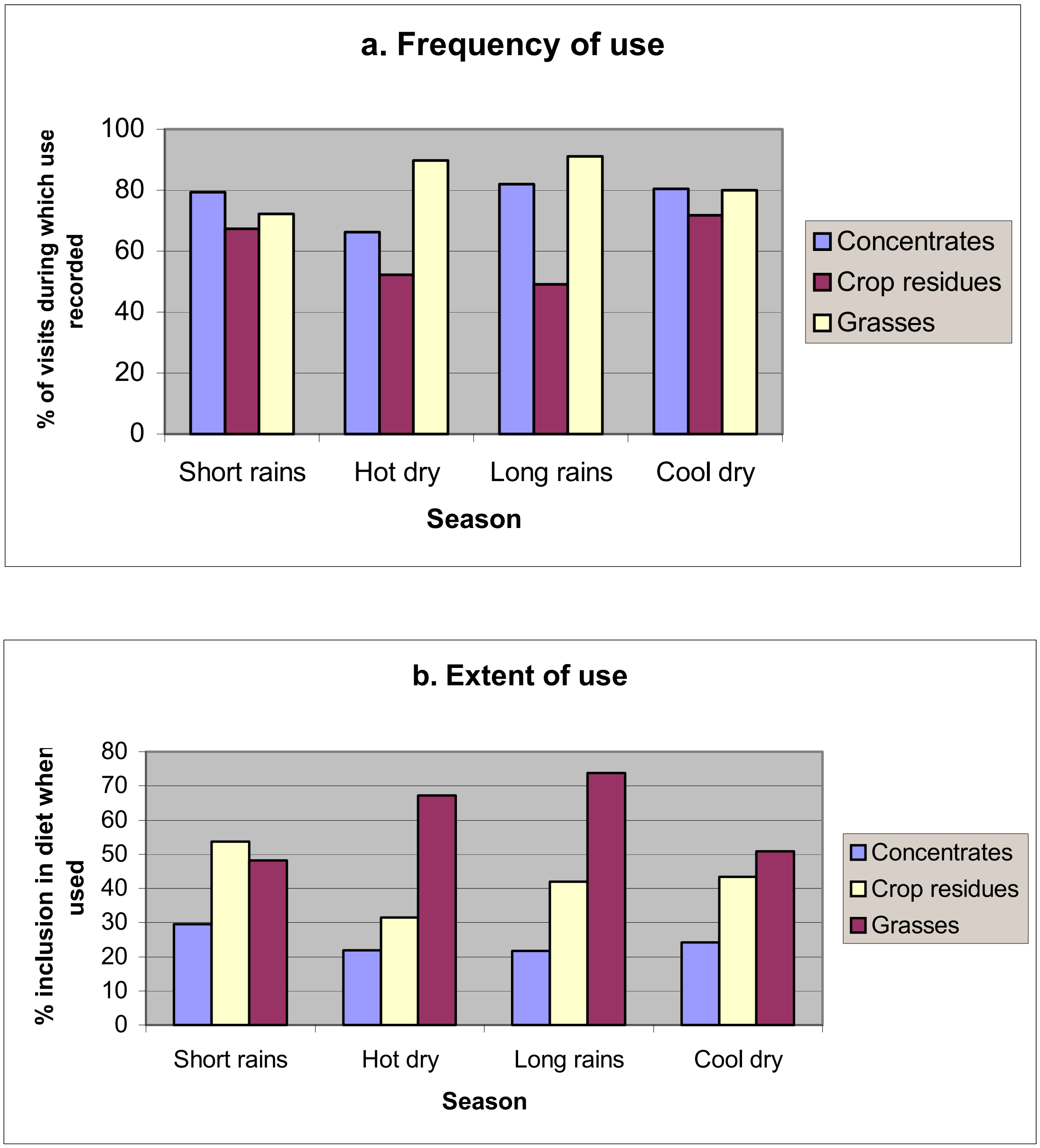
Grasses were used at lower DM inclusion rates as well as less frequently in CD (1998) and SR (1998; $P < 0.001$). As with the frequency data, crop residue inclusion levels tended to mirror the pattern for grasses with the greatest reliance placed on crop residues when grasses were apparently in shortest supply ($P = 0.003$). There were no seasonal patterns observed in levels of concentrate inclusion. However, higher rates of concentrate inclusion were observed on farms hiring labour (30 *per cent* of DM fed) than on farms using labour from the household (19 *per cent* of DM fed; $P = 0.005$, $SE_D = 3.5$ *per cent* of DM fed).

In addition to the seasonal effects observed, grasses were fed more often on farms using household labour (90 *per cent* of visits) than on farms hiring labour (77 *per cent* of visits; $P = 0.003$, $SE_D = 0.04$ *per cent* of visits). Crop residues tended to be used more frequently on farms in the coffee zone (67 *per cent* of visits) than in the horticulture zone (53 *per cent* of visits; $P = 0.015$, $SE_D = 6$ *per cent* of visits).

Table 1: *Inventory of feeds and their types recorded in use on participating farms during the course of the study.*

Grasses	*Concentrates*
Couch grass (*Cynodon dactylon*)	Bone meal
Cut grass	Calf pellets
Napier grass (*Pennisetum purpureum*)	Commercial dairy meal
Napier grass (>6 ft)	Cottonseed cake
Napier grass (1 ft)	Fish meal
Napier grass (2 ft)	Maize bran
Napier grass (3 ft)	Maize germ
Napier grass (4 ft)	Pig finisher
Napier grass (5 ft)	Poultry litter
Napier grass (6 ft)	Wheat bran
Rhodes grass (*Chloris gayana*)	
Star grass (*Cynodon nlemfuensis*)	
Crop residues	*Miscellaneous*
Banana leaves	Bean leaves
Banana pseudostem	Colostrum
Banana thinnings	Kitchen waste
Courgette leaves	Maclick super (commercial supplement)
Maize (green thinnings)	Milk
Maize stover (dry)	Mineral salt
Maize stover (green at harvest)	Minerals
Maize stover (soaked overnight)	Sweet potato vines
Maize stover (soaked overnight/salt)	Water
Maize waste	Leaves of *Calliandra calothyrsus*
Sugar cane tops	Kales
Wheat straw	Vegetables
	Weeds

Figure 4: *Effects of season on the extent and use of grasses, crop residues and concentrates by participating farmers.*



Overfeeding Index

Overfeeding – i.e. offering more feed than a particular animal might reasonably be expected to eat is a common practise on small-scale dairy farms. To examine the distribution of this practise, an "overfeeding index" was calculated as:

OFI = (ADMO / PDMI) – 1

Where ADMO = actual dry matter offered (kg day^{-1}) and

PDMI = potential dry matter intake (kg day^{-1}; calculated as *per cent* of BW)

A value of OFI of greater than zero represents overfeeding of the animal.

A degree of apparent overfeeding was observed on 75 *per cent* of the visits made to participating farms with some evidence that this occurred less frequently during LR (1998; 50.3 versus 83.8 *per cent* of visits; P = 0.026, SE_D = 13.6 *per cent* of visits). The extent of overfeeding - when it occurred - was influenced by the type of labour used on the farm (P = 0.008, SE_D = 8 *per cent* of predicted voluntary intake). Animals on farms using household labour appeared to be overfed to a greater extent (53 *per cent* of predicted voluntary intake) than those on farms that hired labour (31 *per cent* of predicted voluntary intake).

Frequency of Feeding

On average, lactating animals were fed more often during the day (*circa* 5 times day^{-1}) than non-lactating animals (*circa* 3 times day^{-1}; P < 0.001, SE_D = 0.1 times day^{-1}).This difference appeared to be more pronounced on farms using hired labour (P < 0.048, SE_D = 0.2 times day^{-1}). Animals on farms in the horticulture zone also tended to be fed slightly more often (4.2 times day^{-1}) than those on farms in the coffee zone (3.8times day^{-1}; P = 0.001, SE_D = 0.1 times day^{-1}).

Timing of Feeding

In order to examine the distribution of feeding during the course of the day, percentages of the total dry matter fed during each of three periods was calculated. These were early (before 10.00), daytime (between 10.00 and 16.00) and late (after 16.00).

On farms in the coffee zone, feeding was concentrated in the morning period with an average of more that 56 *per cent* of DM fed before 10.00 compared with only 45 *per cent* of DM fed before this time on farms in the coffee zone (P = 0.004, SE_D = 3.8 *per cent* of DM fed). This was accompanied by lower levels of feeding during the daytime on farms in the coffee zone (40 vs 32 *per cent* of DM fed; P < 0.001, SE_D = 3.7 *per cent* of DM fed). Farms in both zones fed similar proportions of the total daily DM during the later part of the day (after 16.00). However, farms that were reliant on household labour appeared to make greater use of the evening period for feeding (20 *per cent* of DM fed; P = 0.05, SE_D = 4 *per cent* of DM fed) than farms hiring labour (12 *per cent* of DM fed).

Sources of Feed Collected

Most of the feed used by participating farmers during the course of the study could be identified as having originated from the farm itself (on-farm), by collection from outside the farm's boundaries (off-farm) or as purchased feed (purchased). A clear seasonal pattern was observed in the use of on-farm feeds (P = 0.014, SE_D = 8 *per cent* of the feeds collected) with these making up between 64 *per cent* of the feeds collected during CD (1998) and 84 *per cent* during LR (1998).

Farms in the household labour class used off-farm feeds (excluding purchased feeds) more often (on 31 *per cent* of visits) than farms using hired labour (6 *per cent* of visits; P = 0.002, SE_D = 8 *per cent* of visits) although no differences amongst farms in percentage inclusion levels (mean = 47 *per cent*) of off-farm feeds were observed when these were collected. Most notably, there appeared to be no use at all of off-farm feeds on farms using household labour during rainy seasons. When used, levels of inclusion of purchased feed were reasonably constant across all farms at around 27 *per cent* of the dietary dry matter.

Discussion

Characteristics of Feed Management on the Study Farms

The notion that it is possible to characterise farm households in such a way that the targeting of technical innovations in livestock production – or indeed other agricultural enterprises – is made more effective, is an appealing one. The study described here was designed to describe sources of variation in feed resource utilisation and production parameters in a market-oriented, smallholder dairy system in central Kenya. An important objective was to discover whether relatively simple indicators could be derived from this type of analysis that would allow the constraints and opportunities open to particular "types" of farmer to be predicted effectively.

Agricultural research and development activities in Kenya have been informed for some time by the land-use based classification of Jaetzold and Schmidt (1983). However, the AEZs derived from this classification focus largely on cropping activities and thus do not place adequate emphasis on the importance of livestock, particularly dairy production (Staal *et al*., 1998), at some locations. By including AEZ as a major factor in the analysis, the current study goes some way in establishing the utility of crop-based classifications (of which there are many), for characterising among-farm variation in livestock management practices and options.

A key feature of the study farms appeared to be their differentiation in terms of labour availability and use. The principal source of labour (hired vs household) appeared to affect a wide range of the observed parameters relating to feed availability (in terms of both quantity and source), feed management and, as a result, levels of production. In this instance, labour source appeared to represent the key, differentiating factor amongst the farms studied.

It seems likely that reasons for hiring labour vary. In the present study, of the farms relying mainly on hired labour, all had family members bringing in income to the farm, whereas, on farms that were more reliant on household labour, more than 50 per cent of the households had no family members with off-farm income. Access to off-farm income may be associated with increased wealth. Indeed, an earlier characterisation study conducted upon a superset of the farmers participating in the one reported here, off-farm income was found to be strongly related to wealth (Staal *et al*., 1998). Accordingly, we might expect that farms hiring labour would invest less in terms of management and feeding – a contention that is consistent with the lower feed offer rates observed on farms hiring labour in the current study. There are a number of possible reasons for these differences in feed management practices between the two groups:

- the contribution of the dairy enterprise to family income is lower than on farms where all income is generated on-farm;
- more family members working off-farm means that fewer family members are available to collect feeds and work with the animals;
- household labour has a greater stake in the animals being fed and are, therefore, more conscientious in gathering feed;
- a greater reliance on concentrate feeding on farms hiring labour (facilitated by access to off-farm income) allows production to be maintained at lower feed offer rates.

There was also some evidence that feeding of limited resources on farms hiring labour may have been targeted more effectively on animals that were perceived as being more productive. During periods when animals were growing, liveweight gains were more rapid on these farms. However, animals that were losing weight also did so more rapidly that on farms that used household labour. Furthermore, there was an indication (although not statistically significant at P = 0.100) that the targeting of concentrate feeds on lactating animals was more intensive on farms that hired labour.

Seasonality in Feed Resource Utilisation

The impacts of seasonally varying environmental factors on the use of feed resources by farmers has been appreciated for a considerable time (e.g. Thorne *et al*., 1998). The imposition of seasonal variation in feeding strategies leads to considerable variation in the potential productivity of livestock and may, thereby, have considerable implications for the viability of the farm household that is dependent on the outputs of its livestock.

Seasonal variation in the use of feed resources and the production parameters measured was a key feature of the study reported here. The results highlight a number of interesting and important aspects of seasonally mediated feed resource utilisation and its impacts on animal productivity. All of the study strata were found to represent significant sources of variation in the study variables. Despite the unusual distribution of rainfall over the study period, seasonal impacts on livestock productivity were observed. These were generally manifest in weight and condition score changes, rather than reduced, or increased milk production, perhaps because of the relatively low mean milk yields (6.7 l day^{-1})

observed. The linkages between these seasonal variations could be clearly attributed to variations in feeding practices, generally with a lag of several weeks. Periods of low rainfall were generally associated with a subsequent switch from grass-based diets to crop residue-based diets and a greater reliance upon feeds sourced from off the farm. However, offer rates of dry matter appeared unaffected by these seasonal changes in diet composition. These findings would suggest that, in a era of increasingly variable and atypical climatic patterns, there is a need to evaluate resource availability against actual seasonal patterns, rather than generalised ones.

Implications of the Study's Findings for the Identification of Indicators to Aid Intervention Targeting

There are many factors that will affect a farmer's use and management of feeds. Two of these are highlighted here in order to illustrate how diversity in feed availability is likely to affect intervention targeting:

- It might be considered that there are three main sources of feed: on-farm; purchased off-farm; and gathered off-farm from communal lands, such as roadsides and forests. The reliance a farmer places on each resource will depend, not only on the quantity available on their own land, but their potential to take advantage of the off-farm sources will depend on the availability of labour and / or cash. Those farms using hired labour appeared to be more cash-dependant and this may reflect the fact that a greater proportion of the family worked off-farm, presumably resulting in greater cash flow but reduced availability of family-labour for on-farm tasks. These farms used more concentrate than those relying on household labour – but had generally lower offer rates (although diet quality may have been higher because of the higher concentrate inclusion rates, which might account for the lack of production differences between the labour classes).
- The agro-ecological zone in which they were located also appeared to affect the the way in which animals were fed in terms of timing. In the coffee zone, feeding was concentrated in the morning period. It seems likely that this observation reflects differences in milking patterns. Of the 13 farmers studied in the coffee zone, 10 milked their animals between 2.00 - 3.30 am, whereas in the horticulture zone no farmer milked before 5.00 am. Since most farmers will offer some feeds during milking, it is likely that this resulted in the observation of most feeding taking place in the morning.

These findings highlight the limitations of technical innovations based on static feeding trials alone. These are unlikely to reflect the complex background of feed availability and management against which they are likely to be applied. As a result rates of adoption are likely to be low and limited to farmers whose actual circumstances happen to reflect the assumptions on which their development was based.

Appendix 3

The Effect of Alternate Feeding of Two Forages Differing in Nutritive Value on Intake, In Vivo *Digestibility and Liveweight Change of Growing Dairy Cattle*

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Introduction

In temperate, developed countries, farmers carefully control feed offered to their animals, particularly dairy animals, so there are no sudden changes in type or quantity of feed offered and any changes are related to production of the animal rather than feed supply. However, in tropical, developing countries inadequate supply of good feed throughout the year is a major constraint to ruminant production where both the livestock and human populations are high. This is so because the high population increases pressure on land for crop production for human consumption and reduces land for grazing and fodder production. In addition it has resulted in smallholder dairy production systems becoming closely integrated with cropping, for example in India (Payne, 1990), Tanzania (Msanga *et al*., 1998), Indonesia (Trisunuwati *et al*., 1991) and Kenya (Peeler and Omore, 1997). In Kenya, approximately 80 per cent of the dairy animals are kept by smallholder farms in the high and medium potential areas (Peeler and Omore, 1997). In the high potential areas, the dairy animals are stall fed mainly napier grass (*Pennisetum purpureum)* planted by the farmers (Karanja, 1981). In Kiambu and Muranga districts of the Central Kenya highlands the inadequate supply of napier grass due to small land size allocated to it (NDDP, 1989) and inhibited growth by lack of rain during dry season (Staal *et al*., 1998) lead to opportunistic use of feeds available in small amounts such as crop residues, banana leaves and pseudo stems (Owango *et al*., 1998), weeds and maize thinnings (Staal *et al*., 1998) and purchased fodder which include napier grass from non-dairy farmers, cut grass from public areas, grass and legume hays, barley and wheat straw from rift valley region of Kenya (Staal *et al*.,1998; Owango *et al*., 1998).

The microbes take time to adapt to feeds of different chemical composition (Church, 1979; Lyle *et al*., 1981; Rowe and Aitchison, 1986; Goodson *et al*., 1988; Leedle *et al*., 1995). Therefore, it might be expected that when the animals are abruptly and frequently changed to different forages the microbes have no time to adapt and therefore poor nutrient utilisation results.

Few experiments have been carried out where feeding is not consistent over days. Hunt *et al*. (1989) fed steers on moderate quality hay (CP 66 g kg^{-1} DM) and supplemented with the same amount of high protein feed in the form of cotton seed cake (CSC) at intervals of 12, 24 or 48 h and observed no differences in dry matter intake (DMI) and daily weight gains. Coleman and Wyatt (1982) fed steers on range hay plus a fixed amount of cotton seed cake at a rate of 0.4, 0.9 or 1.8 every day, alternate or every fourth day and observed no difference in DMI or DM digestibility. Collins and Pritchard (1992) fed sheep *ad libitum* on poor forage maize stover and supplemented with same amount of maize gluten meal (MGM) daily at 8.9 *per cent* of the diet (dry matter) DM, or on alternate days at 17.8 *per cent* of the diet DM and observed no difference in DMI and nitrogen (N) and DM digestiility. However there are no reports of trials examining the efffect of abrupt and frequent change in forage type on *in vivo* digetibility and live-weight change. Consequently the objective of this experiment was to study the way in which a fixed amount of forage offered to cattle influenced live-weight gain and *in vivo* digestibility.

Objective

This experiment, and its partner described in Appendix 4, were designed to explore the biological implications of some of the findings of the PRA study (see Appendix 1, page 14 in prticular). Its specific objective was to study the effect of offering a fixed amount of napier grass and barley straw, either mixed together, or alternated between days, on feed intake, *in vivo* digestibility and live-weight change. It was hypothesised that abrupt and frequent changes in feeding given amounts of good and poor quality forages would reduce *in vivo* digestibility and growth rate of growing dairy cattle compared to offering the same quantity of the two forages (over a period of 40 days) in equal proportions daily.

Materials and methods

Animals and housing

Thirty-six growing Friesian or Ayrshire crossbred cattle, with a mean age of 13 months and mean weight of 186 (s.d 53) kg, were allocated to four experimental groups of nine animals each. Because of the wide range in live-weight, groups were balanced for live weight by blocking. The animals were individually housed in concrete-floored pens of 8 m x 4 m that were cleaned daily. Each pen had a feed trough measuring 0.9 m x 1.3 m.

Feeds

Two feeds that are known to be different in nutritive value were chosen. Barley straw and napier grass (*Pennisetum purpueum*) were used to represent poor and good quality forage respectively. The napier grass regrowth was harvested from a 4 hectare plot within the National Agricultural Research Centre station, Muguga, to which 50 kg calcium ammonium nitrate per ha (hectare) was applied 90 days before the start of the trial. Napier grass was cut daily when at 1.0 m height at the beginning of the experiment, but in the last 10 days of the trial it had grown to an approximate height of 1.5 m. It was chopped by hand to a length of around 10-15 cm before feeding. A single batch of barley straw (*Hordeum* sp.) was bought to last the whole experimental period in order to minimise the impacts of the variation that might occur amongst batches. The straw was fed long and not chopped or processed. All the animals had water and mineral lick (19.95 g Ca, 11.76 g P, 10.26 g Na, 0.16 g Cu per kg) available at all times.

Dietary treatments and feeding

The experiment consisted of four dietary treatments: 50:50 mixture of napier grass and barley straw fed every day (1), napier grass and barley straw alternated daily (2), napier grass and barley straw alternated every 5 days (3) and napier grass and barley straw alternated every 10 days (4). Mean, *ad libitum* intakes observed in a 15 days pre-trial period were 1.4 and 2.4 *per cent* of live weight for barley straw and napier grass, respectively. During the main experimental period of 40 days the animals were offered (based on an estimate for each, individual animal) 90 *per cent* of the mean *ad libitum* intake observed in the pre-trial period on a live weight basis. Initial live weights were used so that intake would be restricted, reflecting the practical situation on farm in the project area where animals are rarely fed *ad libitum*. All animals received forages in two equal portions at 08.30 h and 16.00 h. Animals on the mixed feed received 45 *per cent* of the mean *ad libitum* intake of each forage, with napier grass offered in the morning and barley straw in the afternoon. At 20 and 40 days into the experiment, all the animals had received the two forages in the same amounts, on a live weight basis, although in different sequences.

Experimental design

Treatments were randomly allocated to the groups of animals giving a randomised complete block design (Snedecor and Cochran, 1982). The animals on Treatments 2, 3 and 4 were divided into two groups and allocated at random such that five animals started with barley straw and four with napier grass. This was to remove any bias arising as a result of changes in nutritive value of napier grass expected as the season progressed.

Measurements

Dry matter, organic matter and nitrogen intake. Although offer rates were restricted some refusals occured and actual intake was recorded. Napier grass and barley straw offered to each animal was weighed daily and any feed refusal was removed and weighed daily before fresh forage was offered during the pre-trial and experimental periods. Proportion of leaf and stem in the offered napier grass was determined daily and refused leaf and stem were weighed separately for individual animals. Daily dry matter (DM) of each fraction was determined at 105°C for 48 h for both offered and refused material for sub- samples of leaf and stem bulked from all animals. Sub-samples of offered and refused leaf and stem dried at 65°C for 48 h were bulked for each 5-day period for determination of nitrogen, total ash, neutral detergent fiber (NDF) and acid detergent fiber (ADF).

Faecal production and apparent digestibility. Apparent digestibility of the diets was determined by total collection of faeces. Faeces produced from each animal were collected from the floor immediately after voiding, by an animal attendant who was present all the time. From day 11 individual animal faeces, weighed every morning at 8.00 h, was mixed well and representative samples dried at 65°C for 48 h to constant weight for estimation of daily DM production and a composite sample taken every 5 days for chemical analyses. Samples were then ground in a Wiley hammer mill through a 1 mm screen and stored for chemical analyses. Digestibility of dry matter, organic matter and crude protein was calculated for the last 20 days and for 5 day periods during the last 30 days.

Live weight measurements. The animals were weighed before the morning feed on three consecutive days before the start of the experimental period and on three consecutive days before the end of the trial. The mean values of each of the three days were taken as the start and final live weights and used to estimate live-weight change.

Chemical analyses. DM of the samples was determined by drying samples at 105°C for 48 h, total ash by ashing at 555^0 C for 4 h and crude protein (CP) by Tecator Kjeltec auto 1030 Analyser. Neutral detergent fibre (NDF) and Acid detergent fibre (ADF) were determined by the $ANKOM^{200}$ Fiber Analyzer and # F57 filter bags (Komarek *et al*. 1996). The metabolisable energy (ME) of food eaten and for barley straw and napier grass and passage of feed residue from the rumen were estimated by the method of AFRC (1993).

Statistical analyses

Daily intakes of DM, organic matter (OM) and nitrogen, live-weight change estimated over the whole 40 days experimental period and intake and digestibility estimated over the last 20 days were analysed using one way analysis of variance (ANOVA) procedures of Genstat Lawes agricultural Trust (NAG, 1995). The means were compared by t-test (least significant difference).

The first and second 5 days following a change in forage type were compared for the parameters above using a randomised block ANOVA procedure, with the animals as blocks. Each feed was analysed separately and the means were compared by t-test (least significant difference).

The DM intake, faecal DM production and DM digestibility for napier grass and barley straw during the last second and third 10 day periods were re-analysed in a split plot design to look at the daily patterns of change. The analysis was carried out only on the second and third 10 days periods because of the increase in DM for napier grass in the last 10 days. Sources of variation in the statistical model that were tested against the residual mean square included, animal, period and feed in the main plot and day and day by feed interaction in the sub-plot. The sum of squares for day and day by feed interaction effects were further separated using orthogonal polynomials into linear, quadratic and cubic relationships to describe the response pattern on the parameters as the animals adapted to the feed. The F test was used to test for significant effects of the parameters measured.

Results

Composition of feeds

The chemical composition of the offered feeds is presented in Table 1. There was a gradual decrease in the crude protein content of napier grass as the trial progressed, while the DM increased with time. The change in CP and DM were a reflection of the maturity of napier grass which occurs in the growing season. The experiment started in the middle of the long rains and ended at the beginning of the short dry season. As expected the CP of barley straw did not show much change, since a single batch was purchased to last the whole experiment. The average CP of napier grass and barley straw was 99 and 24 g kg^{-1} DM, respectively. The ME values of napier grass and barley straw were estimated as 8.0 and 7.5 MJ kg^{-1} DM, respectively based on the prediction equations of AFRC (1993).

Intake, faecal production, apparent digestibility and live-weight change

Intake and live-weight change in the last 40 days and intake, faecal production and digestibility in the last 20 days are shown in Table 2. During the last 20 and 40 days all the animals had received the two forages in the same amounts, on a live weight basis, although in different sequences. No significant ($p>0.05$) differences were observed in any of the parameters measured over 20 or 40 days, except live-weight change, where animals on 5 days alternate feeding lost significantly ($p<0.05$) more weight. The animals fed napier grass and barley straw in a mixture of 50:50, or at 1 day, 5 and 10 days had a metabolisable energy (ME) requirements for maintenance of 27.3, 27.3, 27.6 and 28.3 MJ day^{-1}, respectively.

Table 1: *Chemical composition of the feeds (g kg^{-1} DM unless otherwise stated).*

	Napier					Straw				
Days	ODM (g DM kg^{-1})	CP	OM	ADF	NDF	ODM (g DM kg^{-1})	CP	OM	ADF	NDF
1-5	163	115	824	488	679	854	25	918	479	840
6-10	158	114	818	464	659	842	23	919	465	845
11-15	170	110	839	469	690	861	25	920	459	822
16-20	163	91	836	477	693	848	24	918	524	851
21-25	172	102	836	441	663	872	29	921	477	794
26-30	186	87	840	446	668	900	23	921	526	792
31-35	204	86	823	499	726	894	25	919	544	788
36-40	218	87	844	483	671	894	19	926	496	826
Mean	179	99	832	471	681	871	24	920	559	820
Sd $\pm$	21.4	12.7	9.7	2.0	2.2	22.9	2.7	2.7	3.1	2.5

ODM = Oven dry matter; CP = Crude protein; OM = Organic matter; ADF = Acid detergent fibre; NDF = Neutral detergent fibre

Table 2: *Intake (g kg^{-1} W$^{0.75}$ day^{-1}), apparent digestibility and live-weight change of growing dairy cattle when fed napier grass and barley straw in a mixture of 50:50, 1 day or 5 and 10 days change over.*

	Mixture (50:50)	1 day	5 day	10 day	Sed	Significance
Parameters					Feed	Feed
Data estimated over final 40 days						
Intake						
Dry matter	61.1	60.5	58.2	60.2	2.72	ns
Organic matter	51.1	50.6	48.7	50.4	2.26	ns
Nitrogen intake	0.74	0.73	0.72	0.72	0.003	ns
Live-weight change, g day^{-1}	+8.2	+ 26.1	- 125.0	-8.3	52.61	*
Data estimated over final 20 days						
Intake						
Dry matter	65.7	65.4	62.9	63.6	2.68	ns
Organic matter	54.9	54.7	52.9	53.2	2.33	ns
Nitrogen	0.74	0.74	0.71	0.72	0.028	ns
Faeces						
Dry matter, kg day^{-1}	1.3	1.3	1.3	1.3	0.17	ns
Organic matter, kg day^{-1}	1.0	1.0	1.0	1.1	0.14	ns
Nitrogen, g day^{-1}	16.8	17.0	16.6	17.4	2.10	ns
Digestibility, %						
Dry matter	55.9	60.3	59.2	58.8	1.03	ns
Organic matter	61.9	61.9	60.9	60.7	0.92	ns
Nitrogen	60.3	59.8	58.8	58.7	0.15	ns

Sed = standard error of difference of two means ns = non-significant ($p>0.05$); *$p<0.05$.

Intake, faecal production and apparent digestibility for napier grass and barley straw in the first or second 5 day period after change over during 10 days alternate feeding

Intake, faecal production and digestibility during the first or second 5 days period after change over from barley straw or napier grass are shown in Table 3. There were no significant differences in intake except that animals on napier grass ate significantly ($p<0.001$) more N and DM during the second 5 days compared to the first 5 days, which may reflect a consistent decrease in intake on the second day following a change over.

Faecal DM ($p<0.05$) and N production ($p<0.05$) were significantly higher during the second 5 days compared to the first 5 days following a change to napier grass.

The reverse trend was observed for barley straw, and significant differences ($p<0.001$) were observed for both faecal dry matter and N production ($p<0.001$). The DM and OM digestibility for napier grass and barley straw were higher during the second 5 days compared to the first 5 days, although the differences were only significant for barley straw DM digestibility ($p<0.001$). Napier grass N digestibility was higher ($p<0.001$) the first 5 days compared to the second 5 days. The animals ate 1.3 and 0.6 times ME for maintenance when fed napier grass and barley straw during the second 5 days, respectively.

Pattern of change

Intake, faecal production and in vivo digestibility when napier grass and barley straw were fed in a mixture of 50:50, 1 day or 5 and 10 days change over

Only change in DM intake, digestibility and faecal production were determined on a daily basis. Other chemical constituents of the feed and faeces could not be analysed daily because of the high cost of chemicals and inadequate laboratory facilities. The patterns of change in these parameters are presented in Figures 1, 2 and 3, respectively. The intake of napier grass was consistently higher than barley straw, a pattern which is clear in 1 day, 5 and 10 day intervals of feeding. The 1 day treatment also shows constant DMI of barley straw while DMI of napier grass increased reflecting the higher DM content in the last 10 days. Daily fresh napier grass offered were estimated assuming constant DM content. When animals were abruptly fed napier grass after barley straw, intake on the second day was consistently lower than the first day and then intake increased again (C and D in Figure 1).

Faecal production was relatively constant when animals were fed a mixed diet of napier and barley straw, with an increasing trend towards the end reflecting the increase in napier DM. Faecal DM was also relatively constant at 1 day interval of feeding, although the daily variation was relatively greater than in the mixed feeding. A gradual decrease and increase in faecal production for barley straw and napier grass, respectively, was observed in the first 5 days after a change in both 5 and 10 days treatments. The faecal DM was then relatively stable for barley straw but tended to decrease for napier grass in the second 5 days.

Table 3 *Intake, faecal production and apparent digestibility for napier grass and barley straw over 5 day periods during 10 day alternate feeding when the previous forage consumed was the same or different (kg DM day^{-1} except where stated). Values presented are means for each feed type, averaged across animals, periods and days (n = 9).*

	Napier				Straw			
Parameters	Different	Same	Sed	Significance	Different	Same	Sed	Significance
Intake								
Dry matter	4.1	4.5	0.03	***	2.1	2.2	0.06	ns
Organic matter	3.4	3.5	0.28	ns	1.9	2.0	0.67	ns
Nitrogen, g day^{-1}	63.9	67.7	0.78	***	9.0	8.7	0.16	ns
Faeces								
Dry matter	1.5	1.7	0.07	*	1.1	1.0	0.02	***
Organic matter	1.2	1.2	0.23	ns	0.9	0.9	0.07	ns
Nitrogen, g day^{-1}	17.8	20.4	0.91	*	12.4	10.4	0.21	***
Digestibility, %								
Dry matter	62.8	63.0	1.46	ns	45.3	52.5	1.19	***
Organic matter	64.7	65.8	3.26	ns	51.1	56.0	2.87	ns
Nitrogen	73.3	67.7	1.11	***	-40.3	37.6	2.87	ns

Sed = standard error of difference of two means   ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001.

Figure 1: *Dry matter intake for napier grass and barley straw fed in a mixture 50:50, 1 day 5 and 10 days change over. Over 40 days, equal quantities of forage, on a liveweight basis, were fed to animals on all treatments. The two separate symbols represent the average values for the five animals that started with barley straw and the four that started with napier grass.*

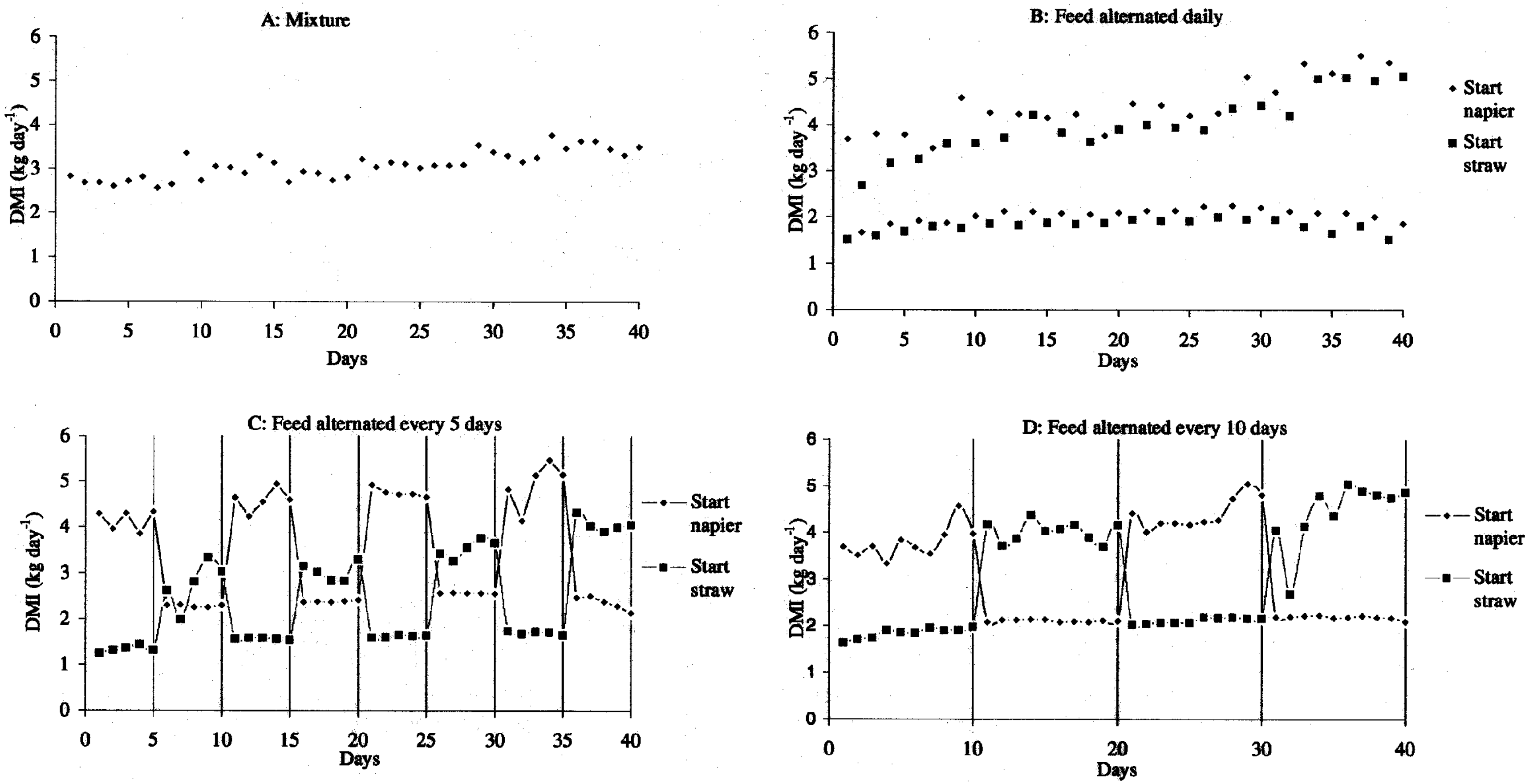


Figure 2: *Faecal dry matter production for napier grass and barley straw fed in a mixture 50:50, 1 day 5 and 10 days change over. Over 40 days, equal quantities of forage, on a liveweight basis, were fed to animals on all treatments. The two separate symbols represent the average values for the five animals that started with barley straw and the four that started with napier grass.*

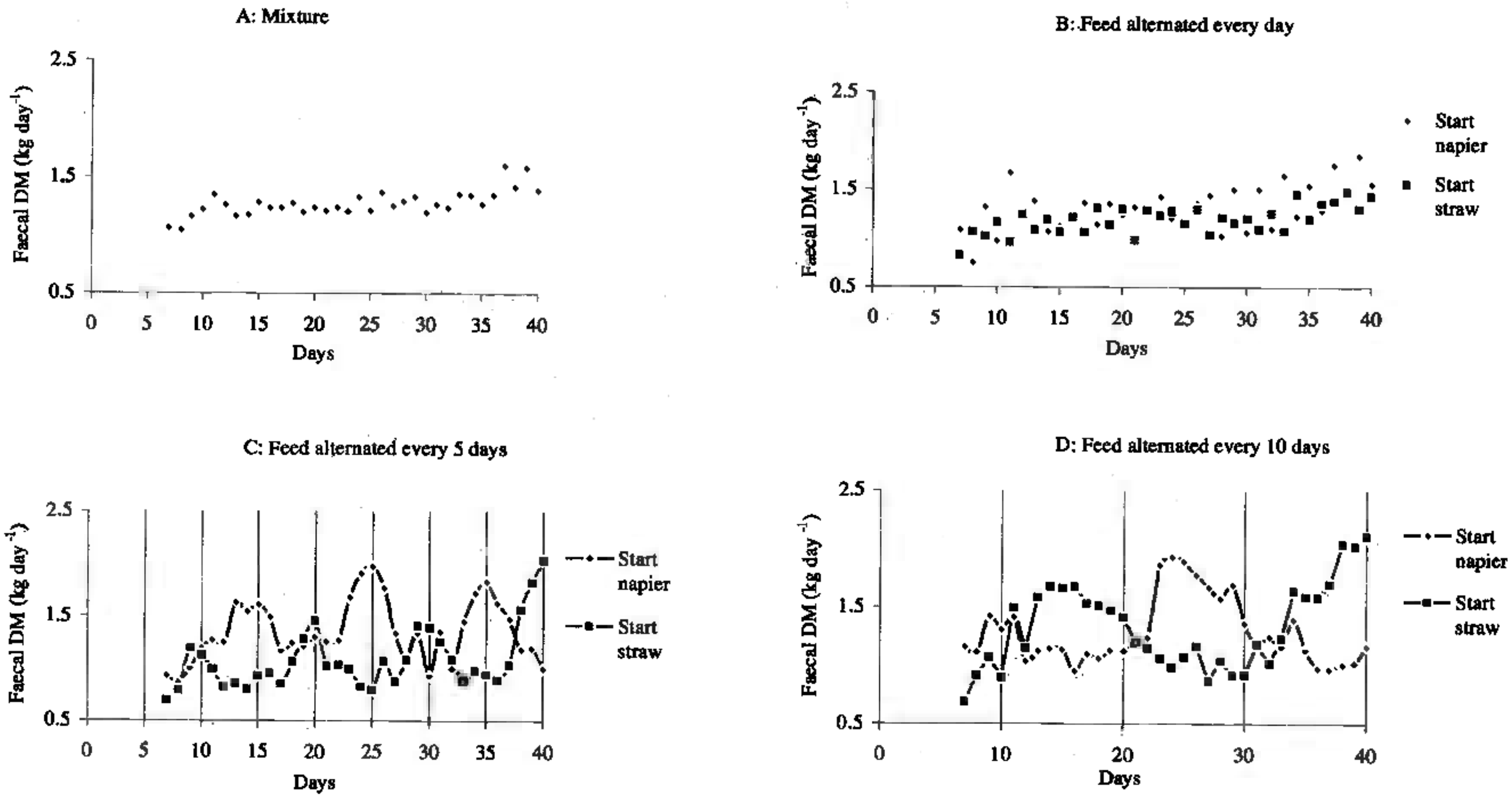
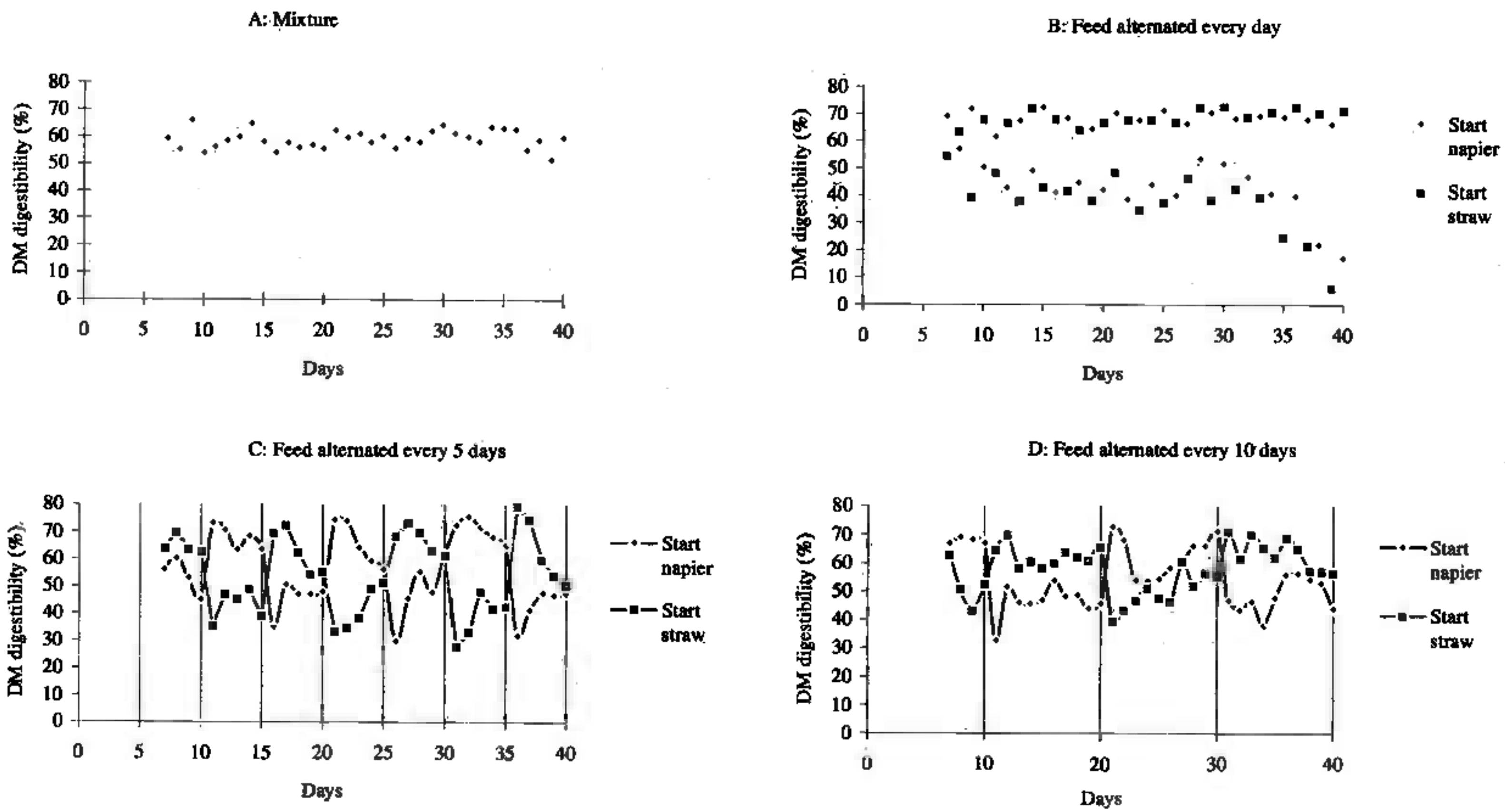


Figure 3: Dry matter digestibility for napier grass and barley straw fed in a mixture 50:50, 1 day 5 and 10 days change over. Over 40 days, equal quantities of forage, on a liveweight basis, were fed to animals on all treatments. The two separate symbols represent the average values for the five animals that started with barley straw and the four that started with napier grass.



The DMD (dry matter digestibility) showed less daily variation when the animals were fed napier grass and barley straw in a mixture. For the 1 day interval of feeding, intake sharply increased for napier grass and decreased for barley straw while the faecal DM remained relatively constant resulting in sharp increase and decrease in daily DMD. The decrease in DMD digestibility was relatively great in the last 10 days of the experiment because of the increase in napier grass DM. Abrupt reduction in DMI but relatively high FDM on the first day for barley straw resulted in low DMD which gradually increased as FDM decreased in the first 5 days after a change in both 5 and 10 days treatment. For napier grass, abrupt increase in DMI on the first day but relatively low faecal DM resulted in high DMD which gradually decreased as FDM increased in the first 5 days after a change in both 5 and 10 days treatment. The DMD was relatively stable for barley straw but tended to increase for napier grass in the second 5 days, although this pattern of increase was not so marked in the last 10 days because of the increase in napier grass DM.

Pattern of change in dry matter intake, faecal production and digestibility for 10 days change over

Figure 4 shows the mean pattern in DMI, faecal DM production and DM digestibility estimated between 11-30 days, while Table 4 shows the results of the statistical analysis. There was a significant day by feed interaction in all the parameters indicating different patterns for the two forages.

The DM intake decreased on the second day and then increased slightly for napier grass, while it was stable for barley straw, reflecting a difference in the slopes for the two feeds ($p<0.05$). Following an initial decrease in FDM production for napier grass on Day 2 compared to Day 1, it increased to a maximum on Day 4 then it gradually declined from Day 5 to Day 10. In contrast, for barley straw, it decreased on Day 2 and was fairly stable reflecting differences in quadratic curvatures ($p<0.001$). As a result napier grass DMD sharply declined from Day 2 to 3 followed by a gradual increase, whereas for barley straw it decreased on Day 1 and then gradually increased to a maximum at Day 7 and remained fairly stable, exhibiting quadratic curvatures ($p<0.001$).

Discussion

Intake and digestibility

The lack of significant differences in total intake when the animals were fed fixed amounts of napier grass and barley straw in mixture of 50:50 or abruptly changed from napier grass to barley straw at 1, 5 or 10 day intervals over 20 or 40 days (Table 2) was not surprising since intake was restricted. However, despite this there seemed to be a consistent decrease in DMI for napier grass on the second day, with the animals on the 5 and 10 day intervals of feeding refusing on average 10.6 % of the offered feed compared to 4.7 % on the first day. The high intake of napier grass DM intake on the first day might be explained by the relatively low palatability of the previous barley straw consumed. Van Soest (1982) reported that forages with relatively low NDF, such as napier grass, are more palatable than those with high NDF, such as barley straw. Another reason might be that when the animals were abruptly changed to napier grass they showed high motivation to consume it on the first day in order to satisfy their satiety, since their intake had been restricted by feeding barley straw. Baumont (1996) reported that one of the feeding behaviours in ruminants is to learn from immediate previous experience to prefer a feed that would be eaten faster and that would allow them to reach satiety level more rapidly. One possible explanation for the decrease in intake on the second day could be physical gut fill caused by the presence of the high quantity of napier material consumed the previous day which was still mixed with the coarse barley straw (Figure 5). Leek (1986) reported that coarse forages exert increased distension to the reticulo-rumen stimulating the distension epithelial receptors in the reticulo-rumen which signal termination of the meal in that day.

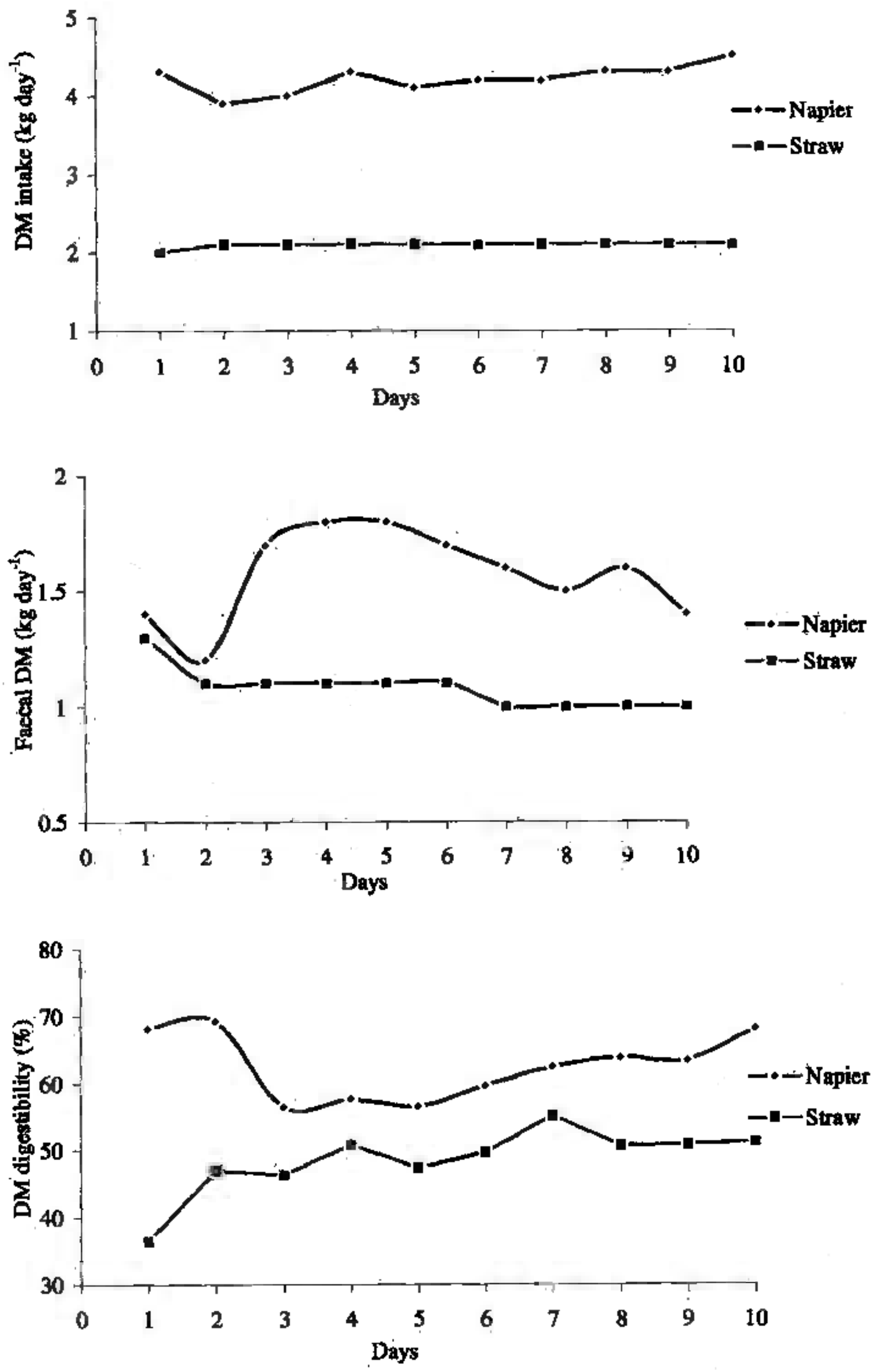
Table 4: *Main effect mean intake, faecal production and apparent digestibility (kg DM day^{-1} except where stated) by animals consuming napier grass or barley straw following an abrupt change in feed type at 10 days change over. Values presented are means for each feed type averaged across animals and periods for the last second and third periods of 10 days (n = 9).*

	Main effect mean		Sed			Significance								
									Polynomials					
									Day			Day x Feed		
	Napier	Straw												
Parameters			Feed	Day	Day x Feed	Feed	Day	Day x Feed	L	Q	C	L	Q	C
Intake														
Dry matter	4.2	2.1	0.18	0.06	0.20	***	***	***	***	ns	ns	*	*	ns
Faeces														
Dry matter	1.56	1.07	0.06	0.07	0.11	***	***	***	ns	***	ns	**	***	ns
Digestibility, %														
Dry matter	62.5	48.3	1.76	2.46	3.74	***	**	***	**	ns	ns	**	***	ns

Sed = standard error of difference of two means   ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

L = linear; Q = quadratic; C = cubic

Figure 4: *Dry matter intake, faecal production and apparent digestibility for napier grass and barley straw at 10 day intervals.*

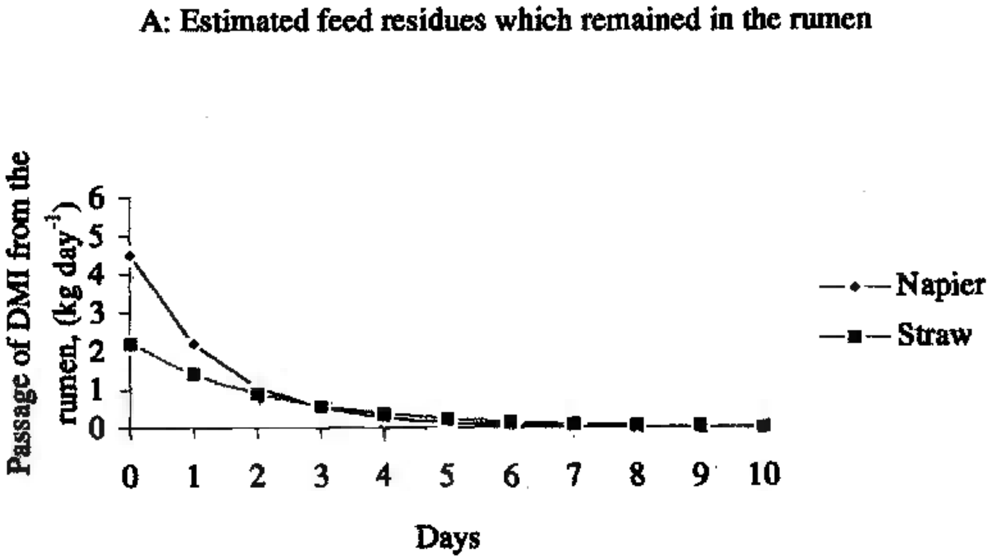


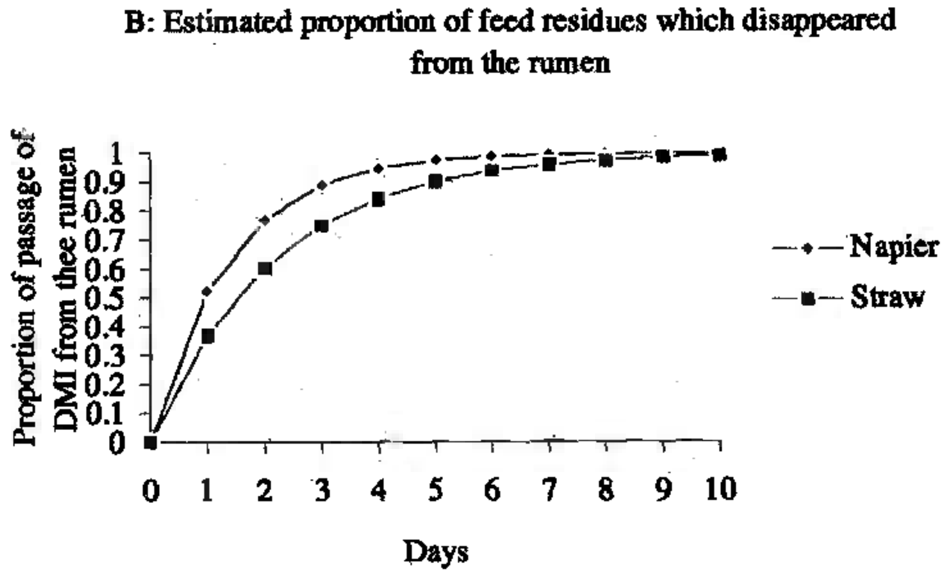
The high significant DMI for napier grass on the second 5 days compared to the first 5 days (Table 3 and Figure 1) may reflect the decrease in napier grass intake on the second day and indicate adaptation to the feed in the second 5 days, although it may be confounded by the increase in napier grass DM in the last 5 days (Figure 1 B). Re-analysing the data, excluding the last 10 days indicated, that there were no significant differences in DMI for napier grass for the first 5 days compared to the second 5 days. Napier grass DMI in the second 5 day period was comparable to that reported by Abou-Ashour *et al*. (1984). The level of DMI of 2.2 kg day^{-1} for barley straw in the second 5 days was comparable to that of 2.7 kg day^{-1} observed when growing cattle (144 kg live weight) were fed untreated barley straw (Ternouth *et al*., 1996). The higher intake in their study might be because animals were fed *ad libitum* while in the present study intake was restricted at 90 % of observed *ad libitum* intake. The relatively low level of intake of barley straw is consistent with earlier observations in ruminants fed on diets containing crop residues like barley straw (Devendra, 1988; Minson *et al*., 1993).

Faecal production was low for napier grass while it was high for barley straw in the first 5 days compared to the second five days when the animals were relatively well adapted to the feeds (Table 3 and Figure 2). The low faecal production for napier grass during the first 5 days was probably due to the low faecal production from the previous barley straw consumed. Low faecal DM production has been observed in ruminants when low protein and high fibrous feed which support only low intake are fed. Manyuchi *et al*. (1996), observed low faecal DM production when sheep were fed low protein veld hay (CP 28.8 g kg^{-1} DM; ADF 516 g kg^{-1} DM) compared to napier grass (CP 135 g kg^{-1} DM; ADF 331, g kg^{-1} DM).

As long ago as the previous century Kellner (1898), cited by Nicholson *et al*. (1956)*,* reported that a period of at least five days should be allowed for ruminants so that residues from the previous feed would be voided. This is supported by Figure 5 presenting, for an average days intake of each forage, the amount of residue remaining in the rumen and the proportion removed 1-10 days later. Five days after a feed more than 98 % and 90 % of napier grass or barley straw feed residue respectively would be expected to have left the rumen. If the change in faecal production for animals consuming napier grass reflected only the change in proportion of residues from the straw fed previously, faecal production from napier grass in the second 5 days would have continued to increase or flatten out. However, it decreased suggesting an improvement in digestibility as the animals were relatively adapted to the feed (Figures 3 and 4). This was seen in the pattern of DM digestibility where a gradual decrease and increase following the change to napier grass was observed as the animals adapted, while the tendency for barley straw was an increase. Lloyd *et al*. (1956) observed that when sheep were abruptly changed from pasture to low quality field cured hay (CP 72 g kg^{-1} DM) the DM and crude fibre digestibility calculated over 10 day running averages for 60 days decreased for the first 5 days, increased slightly, then decreased up to 10 days, after which there was a tendency for rhythmic fluctuations. The same authors concluded that there was no precision gained in practice by determining the digestibility beyond 10 days. The improvement in DMD, OMD for napier grass the second 5 days compared to the first 5 days may be that the animals were relatively well adapted to the feeds. Although the differences were not significant it should be noted that the first 5 days value was probably over estimated because of the low faecal residue from the previous barley straw consumed influencing faecal residues in the first 5 days. The DMD for barley straw was significantly higher the second 5 days compared to the first 5 days, but it may still be confounded by the voiding of the feed residue as a result of the expected lower passage rate compared to napier grass (Figure 5). The DM digestibility for napier grass of 63.0 % in the second 5 days was comparable to that of 63.7 % (Veereswara *et al*., 1993) in sheep fed napier grass (CP 71 g kg^{-1} DM; NDF 708 g kg^{-1} DM). The DM digestibility of barley straw during the second 5 days was 52.5 % which was comparable to 50.0 % in cattle fed untreated barley straw (Silva *et al*., 1989).

Figure 5: *Estimated amount of average days DM intake feed residues which remained and proportion that disappeared 1 – 10 days later from the rumen for napier grass and barley straw. (Assumed passage rates of 0.030 and 0.019 h-1 for napier grass and barley straw respectively).*





In the present experiment total tract apparent digestibility and intake over the last 20 days, when the animals had a chance to consume the same amount of napier grass and barley straw on live weight basis albeit in different sequences, was not significantly different between the treatments. Although there is no literature on similar work to the present study, there is some research where concentrate has been alternated between days. Coleman and Wyatt (1982) fed steers on range hay plus a high protein feed in the form of cotton seed cake at a rate of 0.4, 0.9 or 1.8 every day, alternate or every fourth day and observed no differences in DMI or DM digestibility.

Although rumen microbial supply and ammonia-nitrogen were not measured, it may be expected that napier grass may have provided nitrogen limiting in barley straw when the two forages were fed in mixture, at 1 day or during the first few days following a change to barley straw. This may be expected to result in improved rumen ammonia-nitrogen for microbial growth and increased fibre degradation of barley straw and digestibility of the total feed, but no significant differences were observed. Recently, Manyuchi *et al*. (1996) reported increase in digestibility of low quality forage (veld hay, CP 28 g kg^{-1} DM) supplemented with good quality forage (napier grass, CP 135 g kg^{-1} DM) attributed to improvement in the nitrogen level of the diet.

Live-weight change

In this study, although live-weight measurements were made over a short duration of 40 days the animals on 5 day intervals of abrupt changes from napier grass or barley straw lost significantly more weight compared to other treatments. Although there is no information on live-weight changes in a study similar to the one in this thesis, fluctuating concentrate supply has influenced live weight of ruminants. Brandyberry *et al*. (1992) found that beef cows grazing on rangeland gained less weight when protein supplement, in the form of alfalfa (lucerne) hay, was fed at a rate of 2 kg daily compared to 4 kg every other day. However, Hunt *et al*. (1989) fed steers on moderate quality hay (CP 66 g kg^{-1} DM) and supplemented with high protein feed in the form of CSC at intervals of 12, 24 or 48 h and observed no differences in DMI and daily weight gains.

When ruminants are fed only forages, microbial protein is the main source of protein for growth (Balcells *et al*., 1993). It may be expected that animals on mixed feed and 1 day change over which did not lose weight had less fluctuation in nitrogen supply from napier grass and relatively more homogeneous microbial supply compared to the ones on the 5 and 10 day intervals which lost weight. Low microbial population has been reported when barley straw is fed to sheep (Silva and ∅rskov, 1988; Balcells *et al*., 1993). Therefore when the animals were changed to napier grass from barley straw it may be expected that the rumen micro-organisms had not relatively adapted in number by 5 days following the change to supply the animal with protein for utilisation. For the animals on the 10 day change over, the rumen micro-organisms may have relatively adapted in number during the second 5 days and supplied the animals with more protein, which may explain why they lost less weight than the 5 day change over. Leedle *et al*. (1995), reported that rumen micro-organisms had not adapted to utilise lactate within 5 days as indicated by the higher than normal levels of lactate when beef cattle were switched from grass hay to grain based diet, since the build up of sufficient number of the rumen micro-organisms fermenting lactate requires time (Rowe and Aitchison, 1986).

During the first 5 days following a change over the microbial mass may have been too low to utilise the extra rumen ammonia-nitrogen from napier grass, resulting in increased loss of ammonia-nitrogen in urine as urea. Chiou *et al*. (1995) reported that when excess ammonia-nitrogen in the rumen is beyond the capacity of the microbial mass to synthesise protein, the animal metabolises the excess amount of ruminal ammonia-nitrogen through the liver and discards most of it as urea in urine, reducing the utilisation of dietary protein. Although this observation is from high nitrogen diets for lactating cows the results may apply in situations where ruminants are abruptly changed from a forage with low nitrogen to one ofhigh nitrogen content before the rumen micro-organisms increase in number to utilise the extra nitrogen.

Conclusions

There were some indications of reduction in digestibility for napier grass immediately after the abrupt change from barley straw, then digestibility gradually increased. However, the overall 20 day digestibilities were not significantly different between treatments. Therefore, there is no conclusive evidence that abrupt and frequent changes in feeding given amounts of relatively good and poor quality forage feed would reduce *in vivo* digestibility.

There was a significant loss in weight when animals were fed fixed amount of napier grass and barley straw at 5 day intervals compared to feeding in a mixture of 50:50 or alternated abruptly at 1 day, or 10 day intervals. However, this loss in weight could not be explained by non-significant differences in intake and *in vivo* digestibility between treatments. Therefore further work is required to examine alternative mechanisms to explain the differences.

Further Work

Further research is required to examine the adaptation at the rumen level, such as ammonia-nitrogen concentration, volatile fatty acid production, microbial nitrogen supply and rumen degradation of the feeds, which would give an indication of changes in microbial population as the animals adapt to abrupt change in feeding napier grass and barley straw. These investigations might explain why the animals on 5 day interval of feeding napier grass and barley straw lost significantly more weight compared to the other treatments, since it could not be explained by the non-significant differences in intake and digestibility. Further studies on nitrogen balance and *in vivo* digestibility are necessary which would give an indication of nutrient utilisation at the whole animal level as the animals adapt to the feeds. These are not only to explain why animals on 5 day intervals of abrupt feeding of napier grass and barley straw lost more weight, but to provide information that could be used to develop recommendations for farmers in ruminant production systems where fluctuation in quality and quantity of feed types are common.

Appendix 4

The Effect of Alternate Feeding of Two Forages Differing in Nutritive Value on Rumen Degradation, Ammonia Nitrogen, Microbial Nitrogen Supply, pH, Volatile Fatty Acids, Nitrogen Balance and In Vivo *Digestibility*

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Introduction

The results of the earlier experiment on this topic ("Experiment 1" described in Appendix 3 of this report) showed that animals on a 5 day change over from barley straw to napier grass lost significantly ($p<0.05$) more weight compared with 10 day and 1 day change which could not be explained by differences in *in vivo* digestibility or intake. Frequent and abrupt changes from good to poor quality or poor to good quality forages may lead to low degradation of feed and low microbial nitrogen supply because the rumen micro-organisms which need to adapt gradually to a change in feed have not adapted to forages of different chemical composition. Thus when the animals are abruptly changed to napier grass from barley straw with less than 60 g kg^{-1} DM crude protein, the rumen ammonia-nitrogen may be below the minimum of 50 mg l^{-1} required for optimal microbial activity (FAO, 1986; Satter and Slyter, 1974). As a result, the rumen micro-organisms may be expected to adapt gradually in number to supply more microbial biomass for use by the animal. Therefore, animals changed to napier grass at 10 day intervals may have relatively low microbial supply in the first 5 days compared to the second 5 days and this may explain why the animals on the 5 day change over lost more weight in Experiment 1.

Although ruminants may eat the same amount of relatively good and poor quality feed over a fixed time, they may go through a fluctuating supply of energy and protein that may influence their nitrogen balance. Nelson *et al*. (1965) cited by Coleman and Wyatt (1982) found that N retention by lambs fed a fixed amount of cotton seed cake every 6 days was 45 *per cent* less compared to every day feeding.

Ruminants fed low nitrogen diets are able to adapt to low nitrogen intake by reducing nitrogen loss in urine when compared with animals fed high nitrogen diets (Leng *et al*. 1985, cited by Smith 1989). Recently Alawa, (1991) fed sheep for 30 days on untreated barley straw supplemented with low levels of soya bean to supply 14.4 g kg^{-1} DM of readily degradable protein and found that sheep adapted gradually with time. There was a non-uniform gradual reduction in urinary nitrogen loss but consistent faecal N losses and high nitrogen retention over time. He suggested that adaptation to nitrogen conservation might be involved in the process of nitrogen cycling. Increased, urinary N losses may have occurred during the first 5 days following a change to barley straw and may explain the significant lower live weights in the 5 day change over in Experiment 1.

These observations led to the hypothesis that there are gradual changes in the rumen environment as animals adapt to the intake of a given forage and that, during this adaptive phase rumen NH_3-N is not used efficiently and is lost in the urine resulting in lower microbial production than expected. Therefore, if animals continuously change from one forage of different quality to another, they frequently go through an adaptive phase, which may explain the low nutrient utilisation.

Huntington and Offer (1994) compared rumen pH, NH_3-N, volatile fatty acids and 24 h rumen degradation of hay in sheep fed grass hay or a mixed diet of grass hay, rolled barley and flaked maize. They observed daily variation in total volatile fatty acid concentration for both diets (coefficient of variation, 0.25). Acetate, propionate, butyrate, pH and NH_3-N varied from day to day for each diet, indicating that there is an inherent day to day variability in the rumen environment which should be distinguished from the effects of adaptation to diets.

This experiment was carried out in two stages. The objective of Stage 1 was to determine day to day variability in the rumen environment in animals adapted to the diet of napier grass and barley straw. The objective of Stage 2 was to determine changes over time during adaptation to the two feeds. In addition, Stage 2 considered additional parameters of nitrogen balance and *in vivo* digestibility as the animals adapt to napier grass after barley straw or vice versa at 10 day intervals which might explain why the animals on a 5 days change over lost more weight.

Materials and methods

Feeds

Napier grass and barley straw were used during both stages of the experiment. During Stage 1 it was cut when at a height of 1.5 m and was chopped by hand to a length of 10-15 cm before feeding. In Stage 2 the napier grass had grown to a height of 2.5 m and the lower stems were cut and discarded reducing the length for feeding to approximately 1.5 m in order to reduce feed selection and refusal which would reduce intake. During the first two days of Stage 2 animals were still seen to be leaving the remaining hard stems. Therefore, hand chopping to an approximate length of 2.5 cm was adopted in order to avoid selection

Animals

Six Friesian steers fitted with permanent rubber rumen cannulae were divided into two groups of three animals balanced for initial live weight in both Stages 1 and 2. The initial live weight of the animals were 270 $\pm$ 29 kg and 308 $\pm$31 kg in Stages 1 and 2, respectively.

Housing

During Stage 1 the animals were housed in large individual pens 8 m x 4 m, similar to those used in Experiment 1. In Stage 2 they were placed in individual metabolism stalls with separate collection of faeces and urine in faecal pans and urine jars.

Feeding

Stage 1

In Stage 1, the animals were fed napier grass and barley straw at 2.4 and 1.4 *per cent* of live weight on a dry matter basis, respectively. These levels provided 100 *per cent* of the *ad libitum* intake observed in Experiment 1. The animals were fed once in the morning at 8.30 h. A cross over design of two periods, each with a 14 day adaptation and 7 day collection period was used. All animals were provided with a mineral supplement in the form of blocks, which were available all the times.

Stage 2

Stage 2 had an initial 4 day period in which all the animals were offered both forages in a mixture of 50:50 in order to get used to both forages. Then they were switched to a regime in which the forage offered was altered every 10 days. Half the animals started with straw and half with napier grass in a simple cross over design of three periods of 10 days. Animals were fed 90 *per cent* of mean *ad libitum* intakes observed in Experiment 1, estimated as percentage live weight on a DM basis. The animals were fed once in the morning at 8.30 h. All the animals were supplemented with mineral blocks all the time. Water was available *ad libitum.* Measurements were taken after the first 10 days for two periods of 10 days.

Measurements

Intake. Napier grass and barley straw offered and refused by each animal were weighed daily during both Stages 1 and 2 for the calculation of intake. Representative samples of offered and refused napier grass were taken daily for DM analysis during the 7 day collection periods of Stage 1 and the two 10 day collection periods of Stage 2. The napier grass samples were separated into stem and leaf in Stage 1 only because in Stage 2 napier grass was chopped by a hand chopper to approximate length of 2.5 cm which could not be separated into leaf and stem. Sub-samples were dried in the oven at 105^{o}C for 48 h for DM determination and at 65^{o}C for 48 h for chemical analyses. Sub-samples of napier grass dried at 65^{o}C in Stage 2 and of offered barley straw were taken over 5 day periods for chemical analysis.

Representative samples of offered and refused barley straw for all the animals were bulked for 7 days in Stage 1 and over 5 day periods in Stage 2 and sub-samples dried in the oven at 105^{o}C and 65^{o}C as for napier grass. Offered and refused samples of both napier grass and barley straw dried at 65^{o}C were ground through a 1 mm screen before chemical analyses.

Rumen pH, ammonia and total volatile fatty acids. On Days 1, 3, 5, 7 and 1, 3, 5, 7, and 10 of the collection periods in Stage 1 and 2 respectively, two 40 ml rumen fluid samples were taken from each animal at 1 hour before and 2, 4, 6, 8, and 10 hours after feeding. Strained rumen liquor was collected by suction using a plastic tube attached to a metallic probe covered with six layers of fine nylon cloth inserted into the rumen cannulae. The pH of the samples was determined immediately using a portable pH meter with a combined electrode on one of the samples. The samples for NH_3-N analysis were acidified with a few drops of concentrated sulphuric acid (H_2SO_4) until the pH was below 3 and stored at -20^oC. The samples for volatile fatty acid analysis were immediately stored at -20^oC.

Urine collection. Daily total urine production from each animal was collected into separate urine jars twice a day at 8.30 h to 16.30 h and 16.30 h to 8.30 h during the experimental period. Sulphuric acid diluted to 10 per cent was added to urine jars before collecting the urine to reduce pH below 3 in order to preserve the nitrogen. Approximately 250 ml of the total urine produced in the morning and afternoon were taken as representative samples and divided into two equal portions, one for nitrogen and the other for purine determination. The samples were stored at -20^oC. At the end of the collection period the morning and evening samples for each animal for each day were mixed together. Daily samples were taken for nitrogen and purine analyses.

Rumen degradation of napier grass and barley straw. To determine DM disappearance of the napier grass and barley straw in Stages 1 and 2, three grammes (3 g) of dry (dried at 65^oC for 48 h) samples of napier and barley straw milled through a 3.3 mm screen in a Wiley mill were placed in nylon bags (140 x 75 mm with a pore size of 40 to 60 μm) obtained from the Rowett Research Institute. The same napier grass and barley straw samples were used in Stage 1 and 2. On Days 1, 3, 5 and 1, 3, 5, 7 and 10 of Stages 1 and 2, respectively, three bags of each forage were inserted, and one bag of each forage removed after 24, 48 and 72 hours. In addition on Days 2, 4 and 2, 4, 6, 8 and 9 of Stages 1 and 2, respectively, one bag of each forage was inserted and removed after 24 hours. The bags were hand washed under running tap water until the water coming out of the bags was clear. The samples were then oven dried at 65^oC for 48 h to determine dry matter disappearance.

Faecal production and digestibility (Stage 2 only). Total faeces produced from each animal were collected in a faecal pan and weighed each day in the morning at 8.30 h during Days 11-30. An animal attendant was available all the time to make sure that all faeces voided were collected into the faecal pan immediately. The faeces were mixed well and a sub-sample of approximately 10 per cent taken, divided into two parts, weighed into small foil dishes and dried at 65^oC to constant weight for 48 h. One of the daily samples was bulked over a 5 day period while the other was kept as a daily sample. Daily samples were stored for chemical analysis as well as a further sub-sample taken from material bulked over 5 days. The dried samples were ground through a 1 mm screen and placed in labelled bottles for chemical analyses.

Live-weight measurements. Live-weight measurements were as in Experiment 1 (See appendix 3, page 35).

Chemical analysis of feed offered, feed refused and faeces samples. Daily napier grass and 5 days bulked barley straw feed offered, refused and daily faecal samples were analysed according to the following procedures: total nitrogen by Kjeldahl digestion followed by steam distillation (Tecator); NDF And ADF (Ankom Technology Corporation, Fairport, USA); total ash by heating at 550^0C for 4 hours.

Rumen ammonia. The rumen liquor samples stored at -20^oC were thawed overnight and centrifuged at 3000 revolutions per minute (rpm) for 15 minutes. Then 5 ml of rumen liquor was diluted with 95 ml of distilled water and 10 ml of 26 *per cent* hot sodium tetraborate solution (approximately 260 g $Na_2B_4O_7.10H_2O\ l^{-1}$) was added to the tube which was placed immediately on the Tecator apparatus. Free ammonia was liberated from the solution by steam distillation. The distillate was collected in boric acid (2 per cent; pH 4.5) and ammonia determined by titration (0.01 N hydrochloric acid). Standards (5 ml aliquots of 2 mg NH_3-N ml^{-1} diluted to 100 ml) and distilled water blanks (100 ml) were analysed in the same way to allow for correction and calculation of sample concentration. Ammonia concentration in the sample (mg NH_3-N ml^{-1}) was calculated as (all units are in ml):

(sample titre - blank)/(standard titre - blank) x (10 / aliquot of rumen liquor)

Urine nitrogen. Urine (5 ml) was analysed for urinary nitrogen by Kjeldahl digestion followed by steam distillation as per Experiment 1.

Volatile fatty acids. The rumen liquor samples stored at -20^0C were thawed overnight and centrifuged at 3000 rpm for 15 minutes. The supernatant was collected and volatile fatty acids were quantified using a gas chromatography (model Star 3400, series 4400 Varian) equipped with a flame-ionisation detector (FID). The columns were glass coils (1.5 m x 4 mm in diameter) packed with appropriate stationary phase. Sample volumes ranging from 1 to 2 μl were injected with a 10 μl syringe. The carrier gas was nitrogen and the peak areas were measured by computing integrator. The volatile fatty acids were analysed by the method described by Goetsch and Galyean (1983).

Rumen degradation of napier grass and barley straw. Rumen dry matter disappearance (degradation) in all the napier grass and barley straw samples incubated for different times were calculated using the following equation:

$$b = (c1-c2)/c1 \times 100$$

where: b = Per centage of DM disappearance

c1 = Initial sample weight (on dry matter basis) (g)

c2 = Final sample weight remaining in the bag (on dry matter basis) (g)

Purine derivative. The urine was analysed for purine derivatives (PD) (allantoin and uric acid mmol^{-1}). The purine derivatives were analysed according to the method of Chen *et al*. (1990). This method measures xanthine and hypoxanthine together as uric acid after treatment of the urine sample with xanthine oxidase. From the daily excretion of PD, the corresponding amount of microbial purines (X, mmol day^{-1}) absorbed by the animal was estimated from the PD based on the equation described by Chen *et al*. (1990):

$$PD = 0.84X + 0.150W^{0.75} e^{-0.25x}$$

Where W = Body weight in (kg)

The supply of microbial nitrogen entering the small intestine was then calculated from X using factors proposed by Chen *et al*. (1992): digestibility of microbial purines 0.83 and purine-nitrogen: total microbial-nitrogen ratio of 0.116: 1.00. Thus microbial nitrogen supply (g day^{-1}) was calculated using the following equation:

$$\text{Microbial N supply} = \frac{X \times 70}{0.83 \times 0.116 \times 1000}$$

where: 70 is the nitrogen content (mg mmol^{-1}) of purine.

Estimation of metabolisable energy. The ME of food eaten, napier grass and barley straw and metabolisable energy requirements for maintenance when the animals were changed to napier grass or barley straw were estimated as in Experiment 1.

Estimation of passage of feed residue from the rumen. The amount and proportion of DMI for napier grass feed residue that would be expected to pass out from the rumen during the 10 day interval of feeding was estimated as in Experiment 1. The ME intake in multiples of ME requirements for the animals with mean live weight of 308 kg in Stage 2 were 1.3 for napier grass and 0.7 for barley straw. The passage rate for napier grass estimated from the equation used in Experiment 1 was 0.030 h^{-1}. A value of 0.019 h^{-1} was used for barley straw for reasons described in Experiment 1.

Estimation of microbial N supply expressed per unit of digestible organic matter intake (DOMI). The microbial N supply per unit of DOMI for napier grass and barley straw were estimated using the digestible organic matter intakes estimated from the organic matter digestibility for each feed observed in the second 5 days (see Table 10).

Statistical analysis

For both Stages 1 and 2, data for individual animals were first tested for constant correlation and variance (for example to test if data for Days 1 and 10 are equally as correlated as Days 1 and 5 or Days 3 and 5) using general Linear model (GLM) of SAS (1995). The correlation between the individual animal observations was found to be equally correlated, therefore, the data for both periods were analysed in a normal split plot design by analysis of variance (ANOVA) procedures of Genstat (NAG, 1995).

The statistical analyses for rumen liquor measurements, DM disappearance of two substrates meaned over each day for 24, 48 and 72 h of incubations, intake, faecal and urine production, digestibility, microbial N supply and nitrogen retention included animal, period and feed in the main plot terms and day and day by feed interaction in the sub-plot terms. For parameters in Stage 2, the sum of squares for day and day by feed interaction effects were further separated using orthogonal polynomials comparisons into linear, quadratic and cubic relationships. This was to allow description of the response trend of the parameters as the animals adapted to the feeds.

In order to examine the interaction between DM disappearance of substrate with forage consumed, data for each substrate incubated at 24, 48 and 72 h were meaned over all days and analysed with animal, period and feed as the main plot term but substrate and substrate by feed interaction in the sub-plot terms.

An F test was used to test for significant effects of the parameters above.

As well as analysing patterns of daily change, mean values for the first and second 5 days following a change in forage type were compared for intake, faecal and urine production, microbial N supply and nitrogen retention. The sources of variation in the statistical model that were tested against the residual mean squares included, animal, period and feed as the main plot terms and type and type by feed interaction in the sub-plot terms. The means were compared by the t-test (Least significant difference).

Results

Composition of feeds

The chemical composition of the feeds is presented in Table 1a and 1b. The mean DM content for napier grass in Stage 1 was lower compared to Stage 2 (206 versus 337 g DM kg^{-1}). Figure 1 indicates that there was a gradual increase in napier DM in the first 10 days followed by a decrease the next 5 days and an increase in the last 5 days of stage 2. The same Figure also shows that the CP for napier grass was uniform in the first 10 days then it increased the next 5 days followed by a decrease in the last 5 days to similar levels as for the first 10 days. The napier grass CP was higher in Stage 1 compared to Stage 2 (82 versus 64 g kg^{-1} DM). The DM and CP for barley straw were similar in both stages. The ME for napier grass and barley straw used in Stage 2, were 7.4 and 7.5 MJ kg^{-1} DM, respectively.

Rumen pH, ammonia-nitrogen and volatile fatty acids

Influence of feed type

Tables 2 and 3 present the main effect means for feed type on rumen pH, ammonia-nitrogen, volatile fatty acids in animals adapted (Stage 1) to napier grass and barley straw and following an abrupt change in forage type (Stage 2). Total VFA, acetate, propionate and butyrate concentrations were higher for napier grass compared to barley straw in both stages and all differences were significant ($p<0.05$), except butyrate which was not significant in Stage 2. Molar proportions of acetate, propionate and butyrate were not significantly different for napier grass compared to barley straw in either stage. The NH_3-N concentration was significantly ($p<0.001$) higher for napier grass compared to barley straw in both stages, but mean NH_3-N concentration was much higher for napier grass and lower for barley straw in Stage 1 compared to Stage 2. Rumen pH was slightly lower for napier grass in both stages but the differences were only significant ($p<0.01$) in Stage 2 although it approached significance ($p=0.06$) in Stage 1.

Influence of feed type and day on concentration of rumen pH, ammonia- nitrogen and volatile fatty acids

Daily mean values for rumen pH, NH_3-N, total VFA, acetate, propionate and butyrate concentrations and molar proportion of the individual acids are presented in Figures 2 and 3 for Stages 1 and 2, respectively. The results of the statistical analysis are presented in Tables 2 and 3.

In Stage 1 significant day effects were observed for all the rumen parameters except molar proportion of butyrate. Significant day by feed interaction was observed only for rumen NH_3-N, total VFA (TVFA), acetate and propionate concentration. The interaction appears to be due to differences in the degree of day variability and in differences in trends between the two diets. Concentrations of NH_3-N and VFA tended to increase then decrease for napier grass whereas NH_3-N was relatively stable and VFA followed a reverse trend for barley straw (Figure 2).

In Stage 2 significant interactions between day and feed were also observed for concentrations of NH_3-N, total VFA and acetate. The concentration of rumen NH_3-N was similar for both napier grass and barley straw on Day 1. The values then increased or decreased for napier grass and barley straw, respectively, subsequently remaining relatively stable reflecting linear ($p<0.001$) and quadratic ($p<0.01$) curvature components of the slopes. The responses for TVFA and acetate were similar to NH_3-N with significant quadratic responses ($p<0.05$) being observed. Rumen pH increased on Day 3 after the change to barley straw and remained relatively stable for napier grass.

Table 1a: *Chemical composition of feeds (g kg^{-1} DM unless otherwise stated) in Stage 1*

	Napier			Straw		
	Period 1	Period 2	mean	Period 1	Period 2	Mean
ODM (g DM kg^{-1})	215	197	206	822	866	844
CP	85	78	82	24	19	22
OM	859	857	858	906	914	910
ADF	468	461	465	539	518	529
NDF	679	686	682	771	760	766

ODM = Oven dry matter; CP = Crude protein; OM = Organic matter; ADF = Acid detergent fibre;

NDF = Neutral detergent fibre

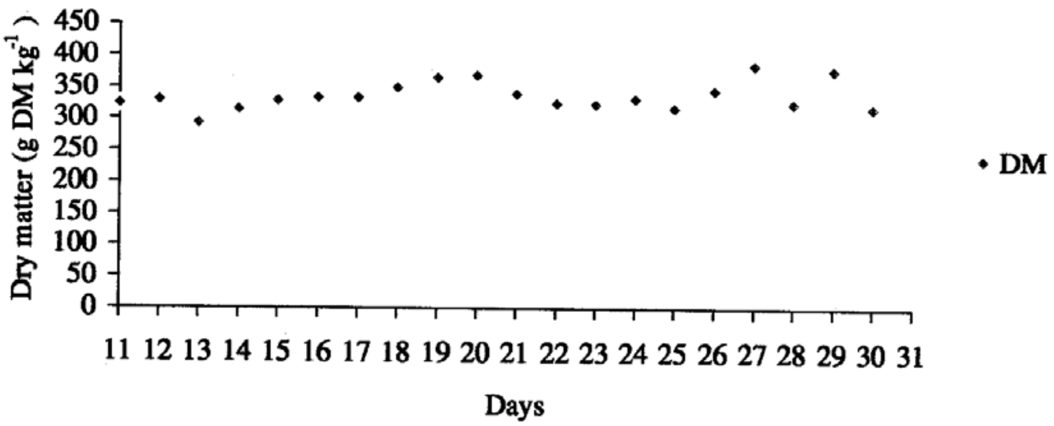
Table 1b: *Chemical composition of feeds (g kg^{-1} DM unless otherwise stated) in Stage 2*

	Napier					Straw				
	Period 1		Period 2			Period 1		Period 2		
Days	11-15	16-20	21-25	26-30	Mean	11-15	16-20	21-25	26-30	Mean
ODM (g DM kg-^{1})	318	351	328	350	337	839	848	824	801	828
CP	64	60	72	61	64	21	24	20	21	22
OM	878	869	869	874	873	905	913	916	914	912
ADF	432	502	494	488	479	558	628	649	672	627
NDF	696	686	684	690	689	764	735	749	726	743

ODM = Oven dry matter; CP = Crude protein; OM = Organic matter; ADF = Acid detergent fibre;

NDF = Neutral detergent fibre

Figure 1: *Changes in napier grass dry matter and crude protein content fed to the animals during day 11 – 30 of stage 2.*



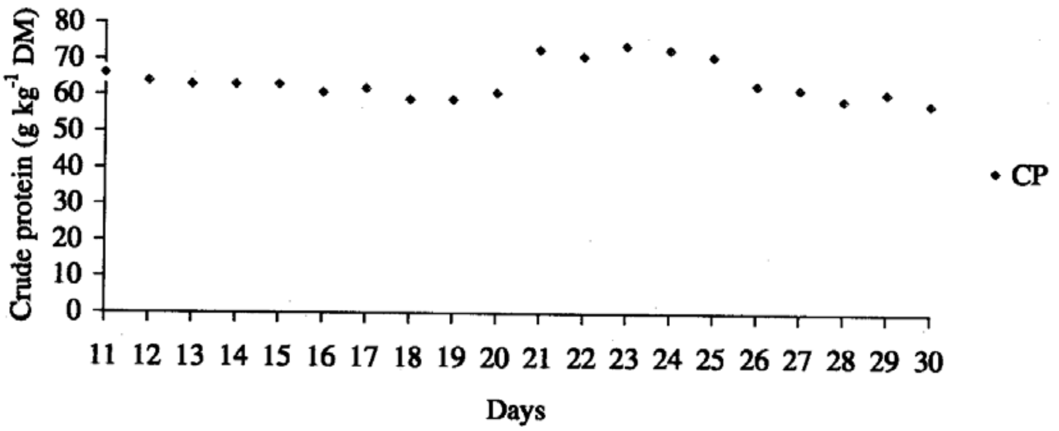


Table 2: *Main effect mean concentration of rumen ammonia-nitrogen, volatile fatty acids and pH in the rumen of adapted animals (Stage 1) consuming napier grass or barley straw. Values presented are means for each feed type, averaged across animals, periods and days (n = 6).*

	Main effect mean		Sed			Significance		
Parameters	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed
PH	6.7	6.8	0.02	0.03	0.04	$p<0.1$	*	ns
NH_3-N, mg l^{-1}	136.8	18.6	5.49	7.66	10.87	***	***	***
Total VFA, mM l^{-1}	109.3	80.7	4.00	3.04	5.46	**	**	***
Acetate, mM l^{-1}	76.8	58.6	3.47	2.25	4.43	**	*	*
Propionate, mM l^{-1}	19.3	114.2	0.55	0.83	1.15	**	***	*
Butyrate, mM l^{-1}	8.6	6.6	0.18	0.27	0.37	***	*	ns
Acetate, moles/100 moles	70.2	72.4	0.73	0.72	1.15	ns	*	ns
Propionate, moles/100 moles	17.6	17.5	0.41	0.52	0.76	ns	**	ns
Butyrate, moles/100 moles	7.9	8.3	0.21	0.17	0.30	ns	ns	ns

Sed = standard error of difference of two means ns = non-significant ($p>0.05$); *$p<0.05$; **$p<0.01$; ***$p<0.001$

VFA = total volatile fatty acids; NH_3-N= ammonia-nitrogen; mM l^{-1} = millimoles per litre; mg l^{-1} = milligrams per litre

Table 3: *Main effect mean concentration of ammonia-nitrogen, volatile fatty acids and pH in the rumen of animals consuming napier grass or barley straw following an abrupt change in feed type (Stage 2). Values presented are means for each feed type, averaged across animals, periods and days (n = 6).*

	Main effect mean		Sed			Significance								
									Polynomials					
									Day			Day x Feed		
Parameters	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed	L	Q	C	L	Q	C
PH	6.6	6.9	0.02	0.04	0.56	***	**	ns	**	*	ns	ns	p<0.1	ns
NH_3-N, mg l^{-1}	80.5	32.6	2.05	3.03	4.35	***	ns	***	ns	p<0.1	ns	***	***	*
Total VFA, mM l^{-1}	101.9	85.5	1.82	2.56	3.71	***	ns	**	**	ns	ns	ns	*	*
Acetate, mM l^{-1}	71.7	60.4	2.06	2.29	3.55	**	ns	*	p<0.1	ns	ns	ns	*	p<0.1
Propionate, mM l^{-1}	19.7	14.8	0.55	0.74	1.09	***	**	ns	***	ns	ns	ns	ns	ns
Butyrate, mM l^{-1}	11.1	7.2	2.33	3.56	5.07	ns	ns	ns	ns	ns	ns	ns	ns	ns
Acetate, moles/100 moles	70.3	70.6	1.32	1.42	2.22	ns	ns	ns	ns	ns	ns	ns	ns	ns
Propionate, moles/100 moles	19.4	17.5	0.69	0.72	1.15	ns	ns	ns	*	ns	ns	ns	ns	ns
Butyrate, moles/100 moles	11.0	8.4	2.41	3.59	5.14	ns	ns	ns	ns	ns	ns	ns	ns	ns

Sed = standard error of difference of two means ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

L = linear; Q = quadratic; C = cubic VFA = total volatile fatty acids; NH_3-N= ammonia-nitrogen; mM l^{-1} = millimoles per litre; mg l^{-1} = milligrams per litre

Figure 2: *Rumen pH, ammonia-nitrogen and total volatile fatty acids concentration in animals adapted (Stage 1) to napier grass and barley straw.*

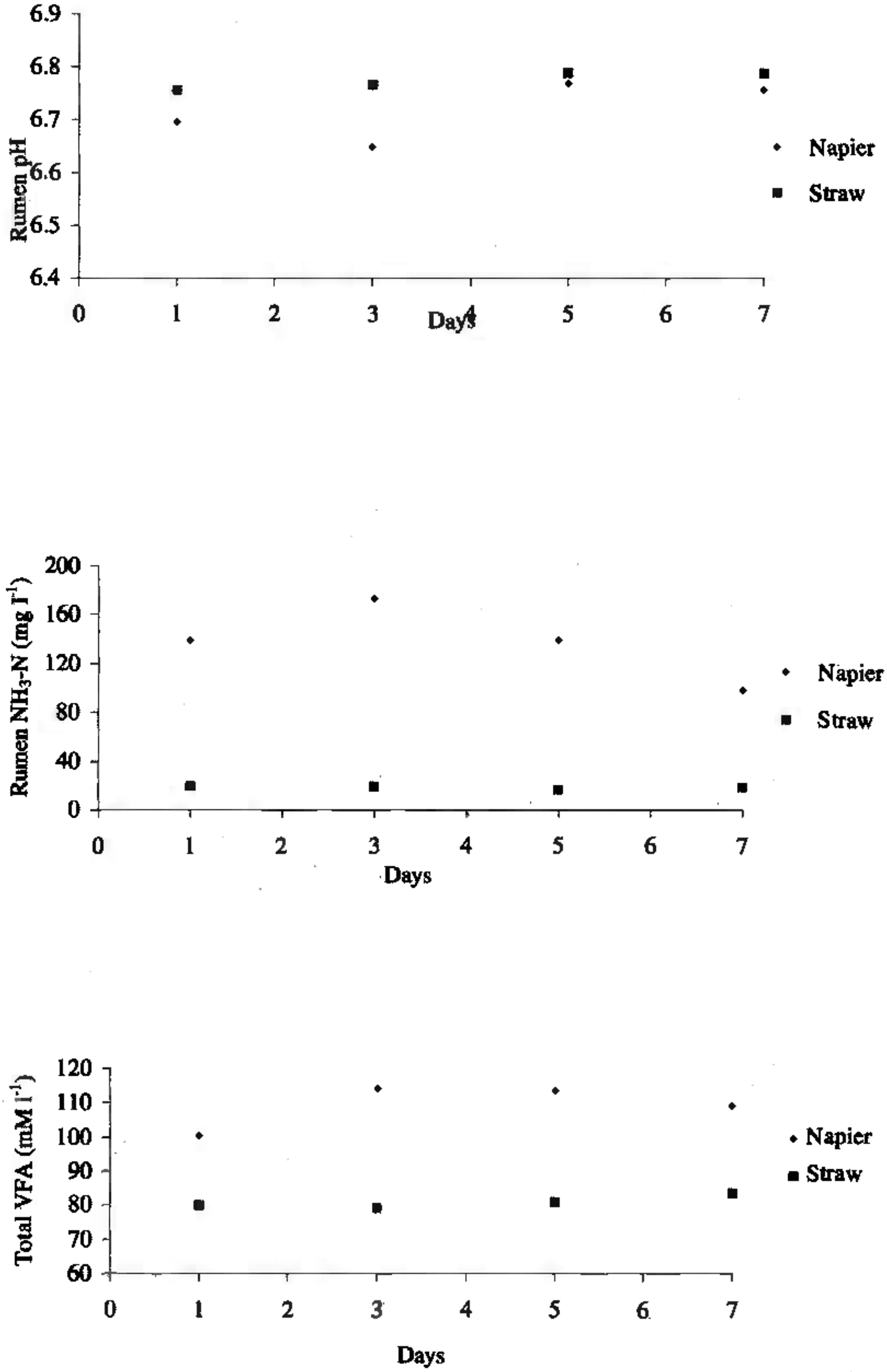
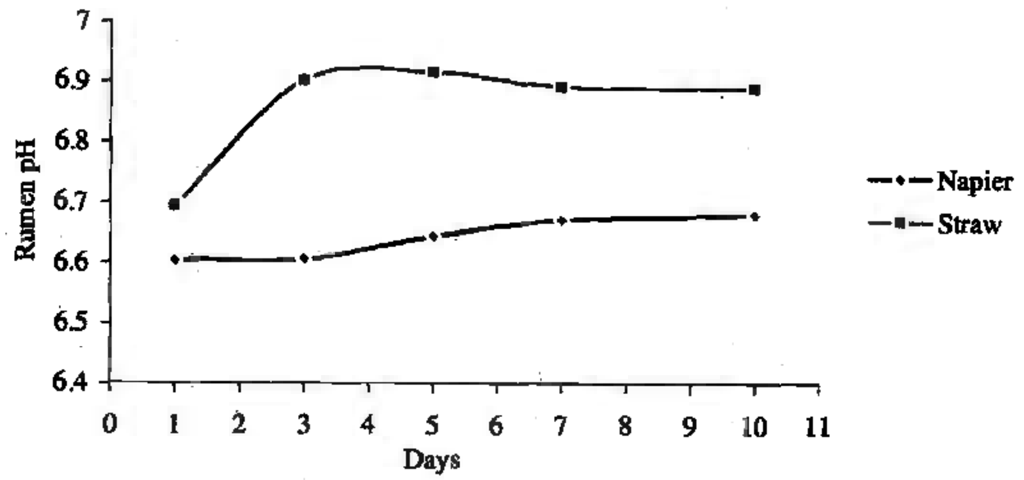
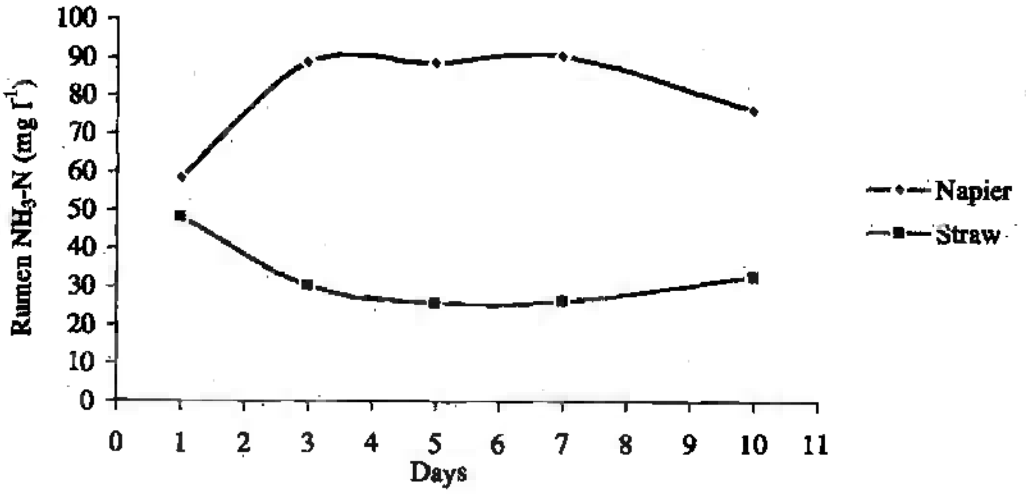
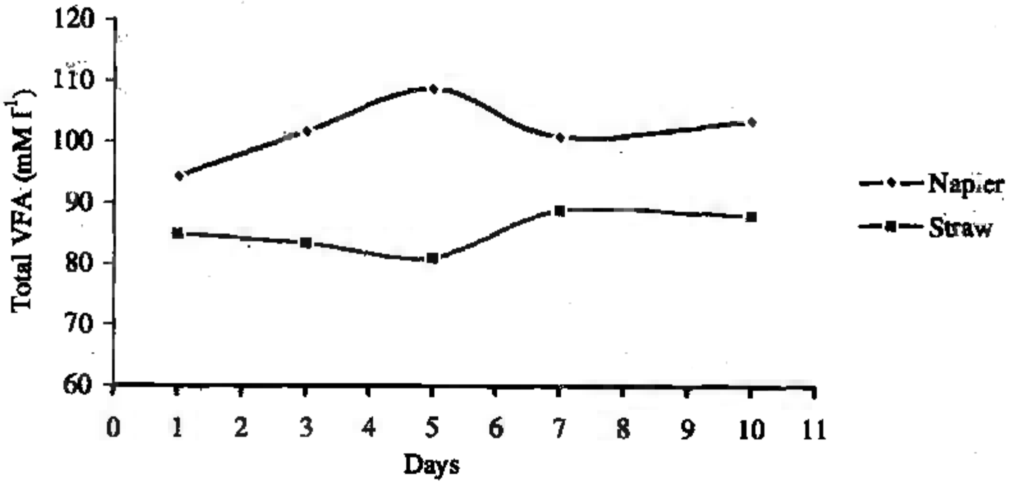


Figure 3: *Rumen pH, ammonia-nitrogen and total volatile fatty acids concentration for napier grass and barley straw following an abrupt change in feed type (Stage 2).*







Rumen dry matter disappearance for napier grass and barley straw substrates

Influence of feed type

DM disappearance for substrate napier was higher ($p<0.001$) than for barley straw at 24, 48 and 72 h and in animals fed both diets in both stages (Table 4 Stage 1; Table 5 Stage 2). Both substrates had higher DM ($p<0.001$) disappearance when incubated in the rumens of animals fed napier grass compared to barley straw at all hours of incubation in both stages, although the differences were not significant at 72 hours.

Influence of feed type and day on dry matter disappearance

Daily mean values for DM disappearance for the two substrates meaned over each day are presented in Figure 4 and 5 for Stages 1 and 2, respectively. The results of statistical analysis are in Table 6 and 7 for Stages 1 and 2, respectively. In both stages a significant day effect was observed at 24 and 72 h of incubation. Day by feed interaction was observed at 24 and 48 h of incubation in Stage 2 and no interaction was observed in Stage 1 where changes followed similar patterns for both feeds. In Stage 2 the DM disappearance at 24 h of incubation was relatively stable for napier grass, while for the barley straw diet DM disappearance decreased to Day 3, then tended to show smaller fluctuations, reflecting quadratic curvatures ($p<0.001$). At 48 h the DM disappearance was similar for both feeds on Day 1 after a change, then decreased or increased to relatively stable levels for animals consuming barley straw and napier grass, respectively, reflected by a significant interaction for the linear component ($p<0.05$). Changes at 72 h in DM disappearance were small and non-significant.

Table 4: *Dry matter disappearance (%) for napier grass and barley straw substrates at 24, 48 and 72 h in the rumen of adapted animals (Stage 1) consuming napier grass or barley straw. Values presented are means for each substrate averaged across animals, periods and days (n = 6).*

		Feed		Sed			Significance		
	Substrate	Napier	Straw	Feed	Substrate	Substrate x Feed	Feed	Substrate	Substrate x Feed
Hours									
24	Napier	38.8	30.9	0.52	0.39	0.66	***	***	ns
	Straw	33.1	25.7						
48	Napier	49.2	41.2	1.05	0.50	1.16	*	***	ns
	Straw	47.4	37.4						
72	Napier	58.2	47.4	0.97	0.35	1.03	ns	***	ns
	Straw	55.5	46.4						

Sed = standard error of difference of two means ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

Table 5: *Dry matter disappearance (%) for napier grass and barley straw substrates at 24, 48 and 72 h in the rumen of animals consuming napier grass or barley straw following an abrupt changed in feed type (Stage 2). Values presented are means for each substrate averaged across animals, periods and days (n = 6).*

		Feed		Sed			Significance		
	Substrate	Napier	Straw	Feed	Substrate	Substratex Feed	Feed	Substrate	Substratex Feed
Hours									
24	Napier	42.8	34.1	1.15	0.42	1.22	***	***	ns
	Straw	36.7	26.5						
48	Napier	52.7	42.7	1.13	0.59	1.28	*	***	ns
	Straw	50.2	39.5						
72	Napier	59.5	49.0	0.61	0.44	0.75	Ns	***	ns
	Straw	58.3	47.4						

Sed = standard error of difference of two means ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

Table 6: *Main effect mean dry matter disappearance (%) for napier grass and barley straw substrates (two substrates meaned over each day) at 24, 48 and 72 h in the rumen of adapted animals (Stage 1) consuming napier grass or barley straw. Values presented are of two substrates meaned over each day and are means for each feed type, averaged across animals, periods and days (n = 6).*

	Main effect mean		Sed			Significance		
Hours	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed
24	34.9	29.4	0.52	1.52	1.99	***	***	ns
48	45.2	42.4	1.05	1.06	1.62	*	ns	ns
72	53.3	50.6	0.97	1.07	1.57	*	***	ns

Sed = standard error of difference of two means ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

Table 7: *Main effect mean dry matter disappearance (%) for napier grass and barley straw substrates (two substrates meaned over each day) in animals consuming napier grass or barley straw following an abrupt change in feed type (Stage 2). Values presented are of two substrates meaned over each day and are means for each feed type, averaged across animals, periods and days (n=6).*

	Main effect mean		Sed			Significance								
									Polynomials					
									Day			Day x Feed		
Hour	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed	L	Q	C	L	Q	C
24	38.5	31.6	1.14	1.23	2.01	**	*	*	ns	*	ns	ns	***	ns
48	47.7	44.8	1.13	1.04	1.71	p<0.10	ns	**	ns	ns	ns	**	ns	ns
72	54.3	52.8	0.61	0.83	1.18	p<0.10	*	ns	*	ns	ns	ns	ns	ns

Sed = standard error of difference of two means   ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

L = linear; Q = quadratic; C = cubic

Figure 4: *Dry matter disappearance for napier grass and barley straw substrates (two substrates averaged by day) in the rumen of animals adapted (Stage 1) to napier grass and barley straw.*

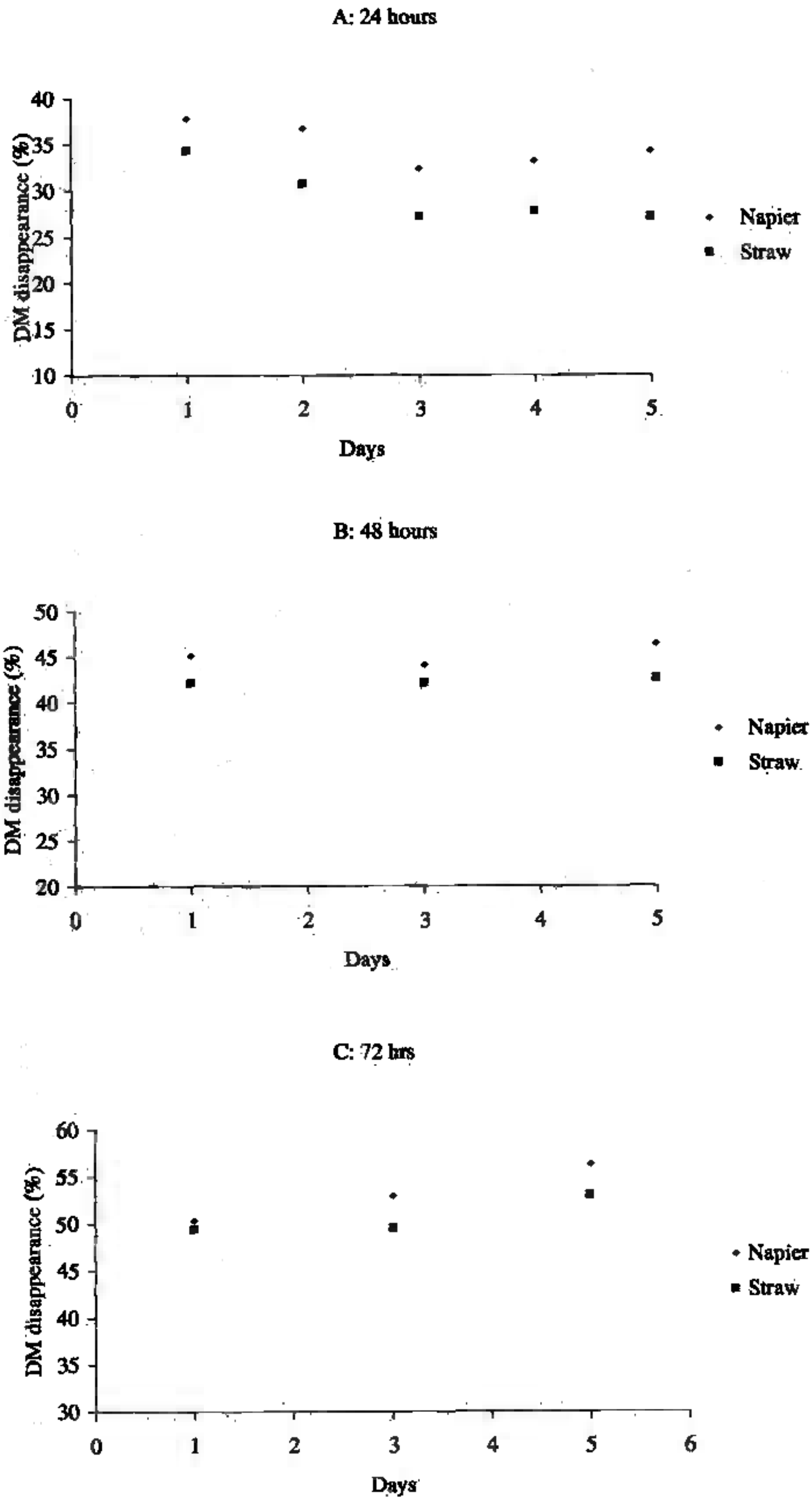
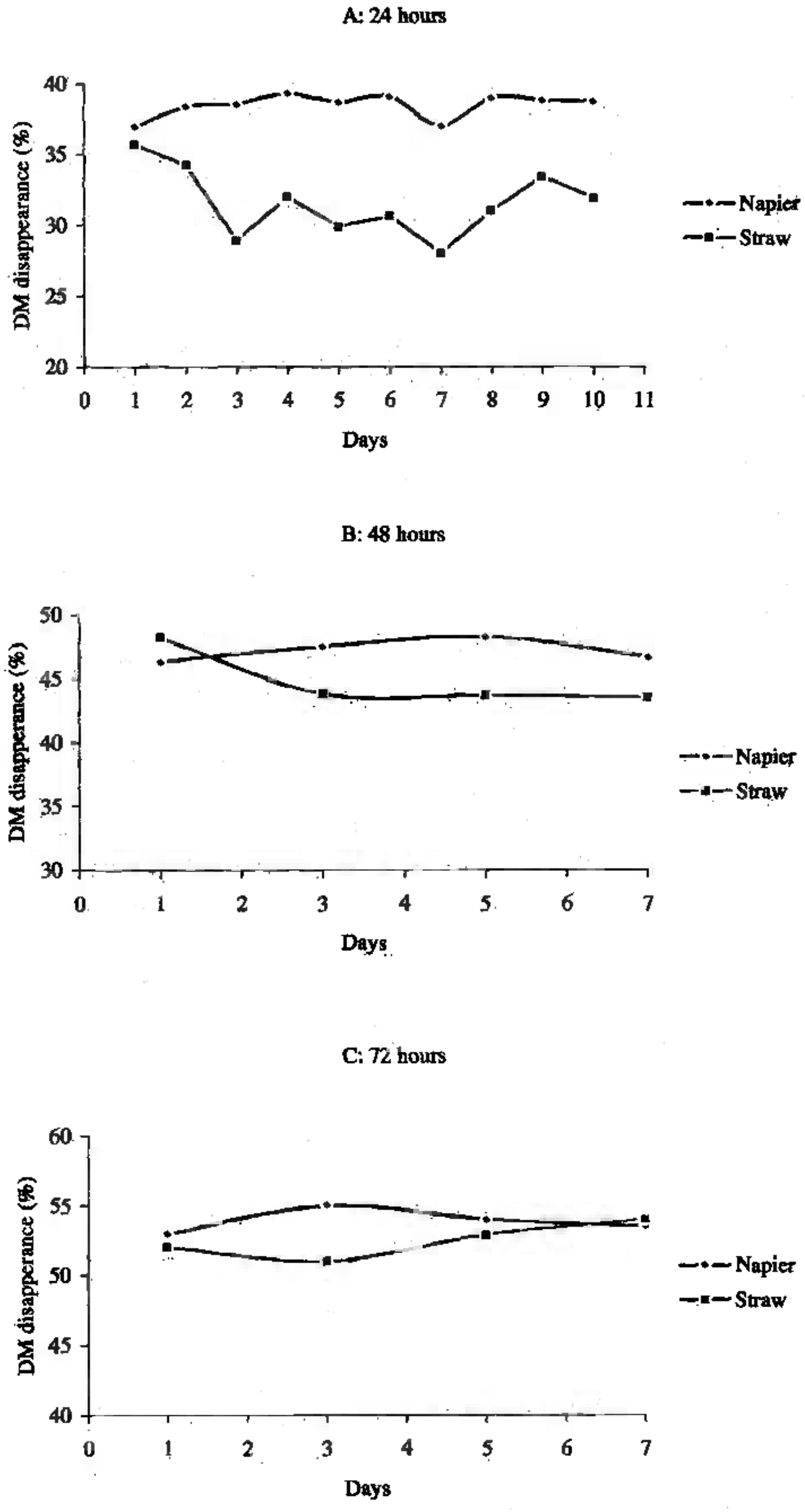


Figure 5: *Dry matter disappearance for napier grass and barley straw substrates (two substrates averaged by day) in the rumen of animals abruptly (Stage 2) changed to napier grass and barley straw.*



Intake, faecal and urine production, apparent digestibility and nitrogen retention.

Influence of feed type

Table 8 shows the main effect means for feed type as well as statistical analysis for dry matter intake (DMI), nitrogen intake (NI) in Stage 1. Table 9 shows DMI, NI, organic matter intake (OMI), digestible organic matter intake (DOMI), faecal dry matter (FDM), faecal organic matter (FOM), faecal nitrogen (FN) and urine nitrogen (UN) production, nitrogen retained (NR), nitrogen retained as per cent of nitrogen intake (NR/NI), dry matter digestibility (DMD) organic matter digestibility (OMD) and nitrogen digestibility (ND) in Stage 2. All parameter values were higher for napier grass compared to barley straw in both stages and the differences all significant at ($p<0.001$), except DM and OM digestibilities which were significant at ($p<0.01$).

Influence of day on intake, faecal and urine production, apparent digestibility and nitrogen retention

The actual daily values of changes in DMI and NI in Stage 1 are presented in Figure 6 .

The daily trends in DMI, NI, DOMI, FDM and FN production and UN production, NR, NR/NI, DMD, OMD and ND in Stage 2 are presented in Figures 7 to 9. The trend for OMI, FOM production and OMD are not presented graphically since the trend was similar to that for DM. The results of the statistical analysis are presented in Tables 8 and 9 for Stage 1 and 2 respectively. There was a significant day effect for all the parameters, except on FDM, FN and UN production. The day by feed interaction was significant for all the parameters.

In Stage 1 the DMI and therefore NI tended to increase and decrease for napier grass because of the day variability in DM and N content for napier grass (Figure 1) while they were relatively stable for barley straw.

In Stage 2 the DMI, NI and OMI were high on the first day after a change to napier grass, sharply decreased on Day 2 as observed for DMI in Experiment 1 (Figure 1 of Appendix 3) then gradually increased. The same parameters were relatively stable for barley straw as in Experiment 1, although slightly lower on the first day, reflecting both linear ($p<0.001$) and cubic curvatures ($p<0.01$).

Table 8 *Main effect mean intake by adapted animals (Stage 1) consuming napier grass or barley straw. Values presented are means for each feed type, averaged across animals, periods and days (n = 6).*

	Main effect mean		Sed			Significance		
Parameters	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed
Dry matter intake, kg day^{-1}	6.1	3.4	0.27	0.19	0.38	***	**	***
Nitrogen intake, g day^{-1}	79.1	12.5	3.8	2.29	4.84	***	***	***

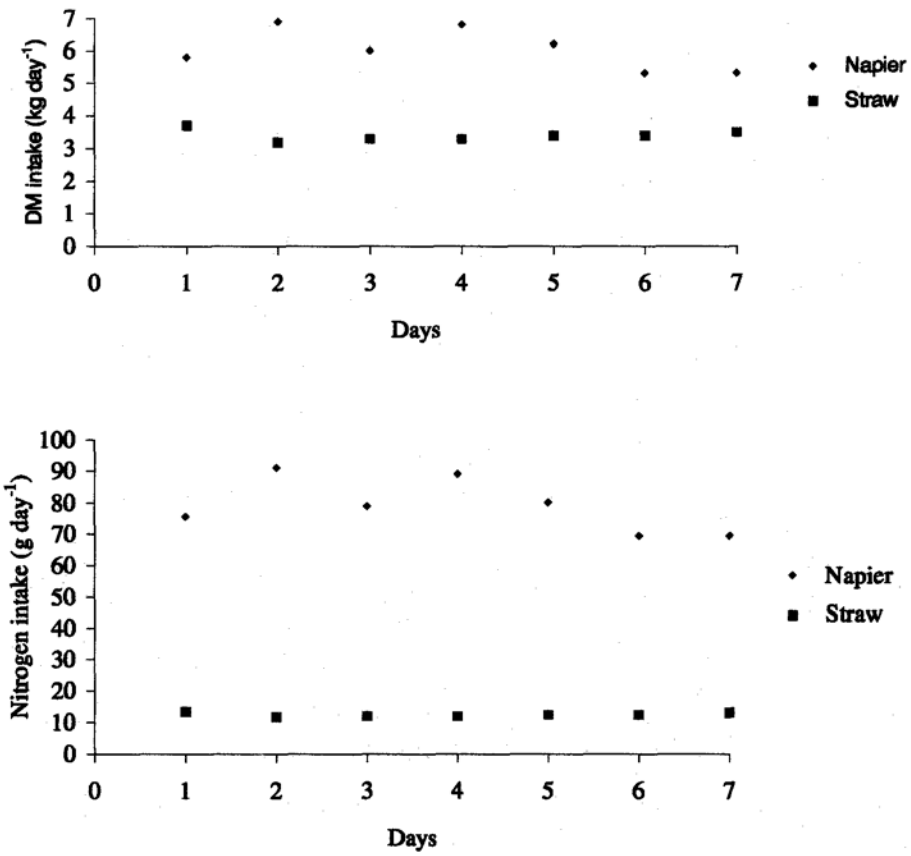
Sed = standard error of difference of two means   ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

Table 9: *Main effect mean intake, faecal and urine production, nitrogen retention and apparent digestibility by animals consuming napier grass or barley straw following an abrupt change in feed type (Stage 2). Values presented are means for each feed type, averaged across animals, periods and days (n = 6).*

	Main effect mean		Sed			Significance								
									Polynomials					
									Day			Day x Feed		
Parameters	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed	L	Q	C	L	Q	C
Dry matter														
Intake, kg day^{-1}	6.1	3.4	0.19	0.15	0.28	***	***	***	***	ns	**	***	ns	***
Faecal production, kg day^{-1}	2.9	1.8	0.07	0.11	0.16	***	ns	***	ns	ns	s	***	***	ns
Digestibility, %	53.3	45.5	1.15	3.04	4.24	**	***	***	***	***		***	***	***
Organic matter														
Intake, kg day^{-1}	5.3	3.1	0.17	0.13	0.25	***	***	***	***	ns	ns	***	ns	**
Digestible intake, kg day^{-1}	2.9	1.6	0.10	0.07	0.14	***	***	***	***	ns	ns	***	ns	ns
Faecal production, kg day^{-1}	2.3	1.5	0.07	0.09	0.14	***	ns	***	ns	ns	ns	***	***	ns
Digestibility, %	56.0	50.1	0.85	2.80	3.85	**	***	***	**	***	ns	***	***	**
Nitrogen														
Intake, g day^{-1}	62.3	11.7	2.32	1.37	2.96	***	*	***	ns	ns	ns	***	***	*
Faecal production, g day^{-1}	28.9	18.1	0.81	1.15	1.75	***	ns	***	ns	ns	ns	***	***	ns
Nitrogen digestibility, %	53.9	-59.2	4.16	7.62	11.04	***	***	***	***	***	ns	***	***	*
Urinary production, g day^{-1}	13.8	8.1	0.52	1.49	2.07	***	ns	***	***	ns	ns	***	***	ns
Nitrogen retention, g day^{-1}	20.6	-14.6	2.16	1.89	3.33	***	**	***	***	ns	ns	***	***	**
Nitrogen retained/nitrogen intake, %	32.1	-131.2	7.69	15.1	21.7	***	***	***	***	***	ns	***	***	p<0.1

Sed = standard error of difference of two means ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001 L = linear; Q = quadratic; C = cubic

Figure 6: *Dry matter and nitrogen intake for napier grass and barley straw in adapted animals.*

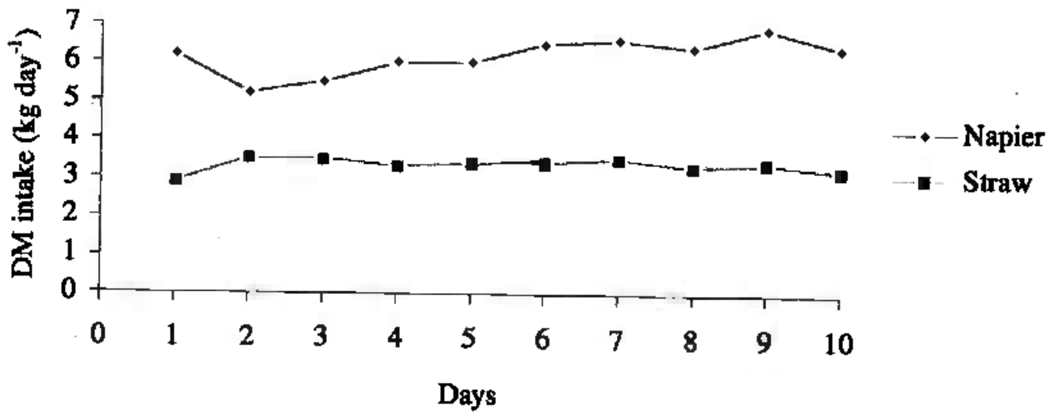


The FDM, FN and FOM values for napier grass were the same as for barley straw the first day after change over. The FDM, FOM and FN gradually increased to a maximum at Day 6 then FN gradually decreased for napier grass, while they gradually decreased and remained stable for barley straw, reflecting both linear ($p<0.001$) and quadratic curvature ($p<0.001$) components.

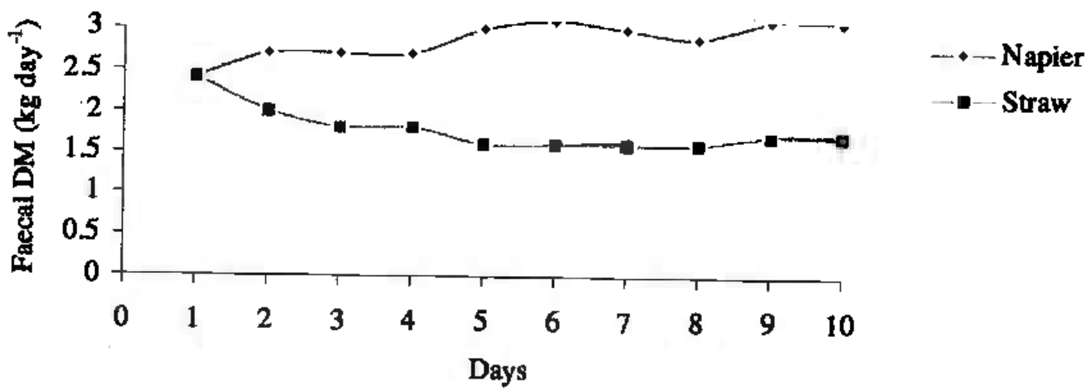
The DMD and OMD for napier grass after a change decreased sharply from Day 1 to Day 2, followed by a gradual decrease to Day 6 then became relatively stable. However, the ND for napier grass gradually decreased to Day 6 then increased. In contrast, the same parameters increased sharply from Day 1 to 2 for barley straw and increased more gradually to a maximum at Day 9, reflecting both linear ($p<0.001$) and cubic curvature components for feeds and day effect.

The UN production for napier grass was low the first day following a change from barley straw, gradually increased to Day 6, then gradually decreased, while it was high for barley straw, decreased and remained relatively stable reflecting linear ($p<0.001$) and quadratic component of the curvatures ($p<0.001$). The NR was positive and high for napier grass the first day, sharply decreased to a minimum at Day 6 then gradually increased. The reverse was observed for barley straw where the values were negative and were relatively stable after a gradual increase to a maximum on Day 6, exhibiting quadratic ($p<0.001$) and cubic ($p<0.01$) components of the curvatures. To determine the efficiency of nitrogen utilisation and to adjust for the influence of differences in N intake on NR, an estimate of nitrogen retained relative to the nitrogen intake (NR/NI) was estimated. The same trends were observed as for NR for both feeds.

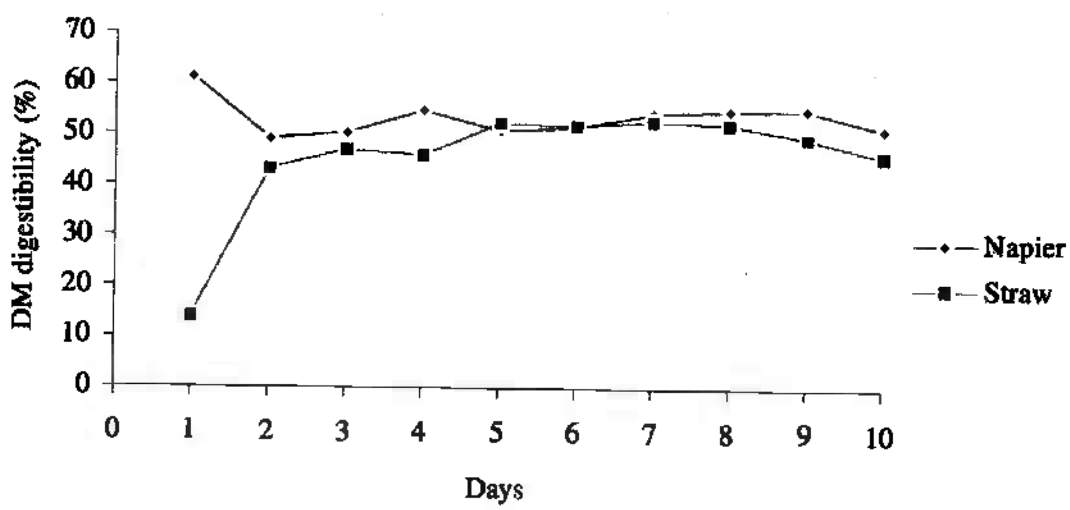
Figure 7: *Dry matter intake, faecal production and apparent digestibility for napier grass and barley straw following an abrupt change in feed type.*



DM intake (kg day^{-1})
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
Days
Napier
Straw

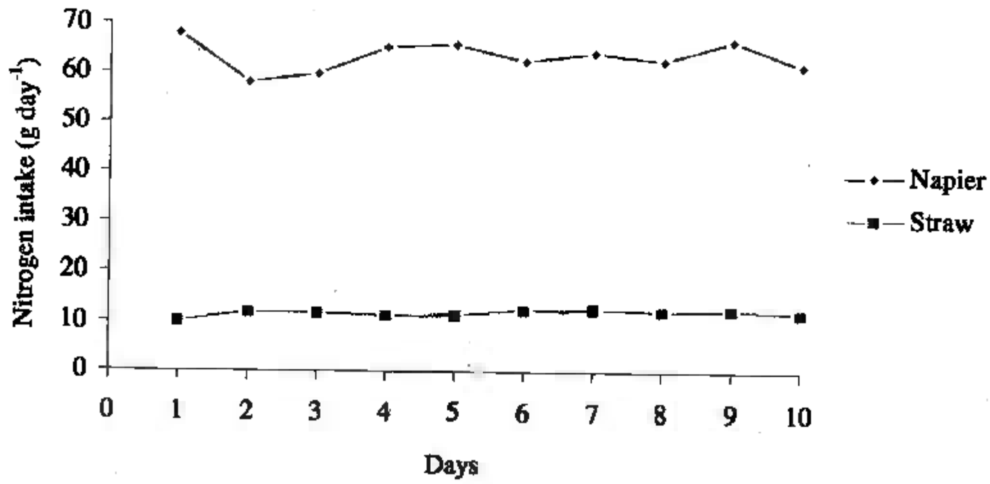


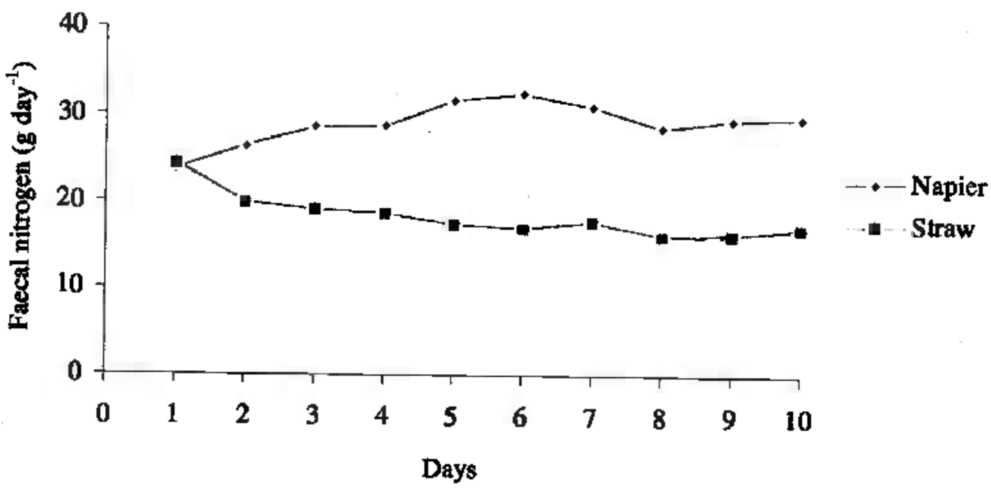
Faecal DM (kg day^{-1})
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
9
10
Days
Napier
Straw



DM digestibility (%)
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Days
Napier
Straw

Figure 8: *Nitrogen intake, faecal nitrogen and nitrogen digestibility for napier grass and barley straw following an abrupt change in feed type.*





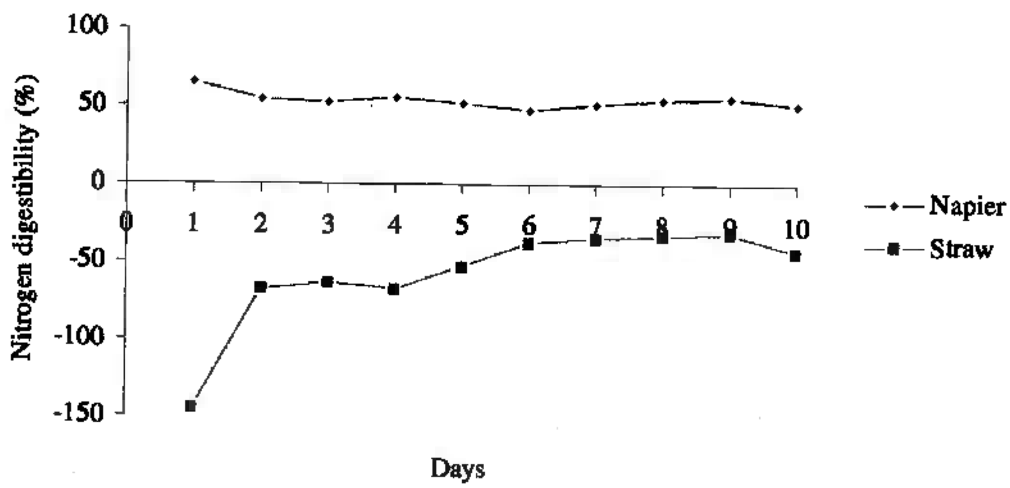
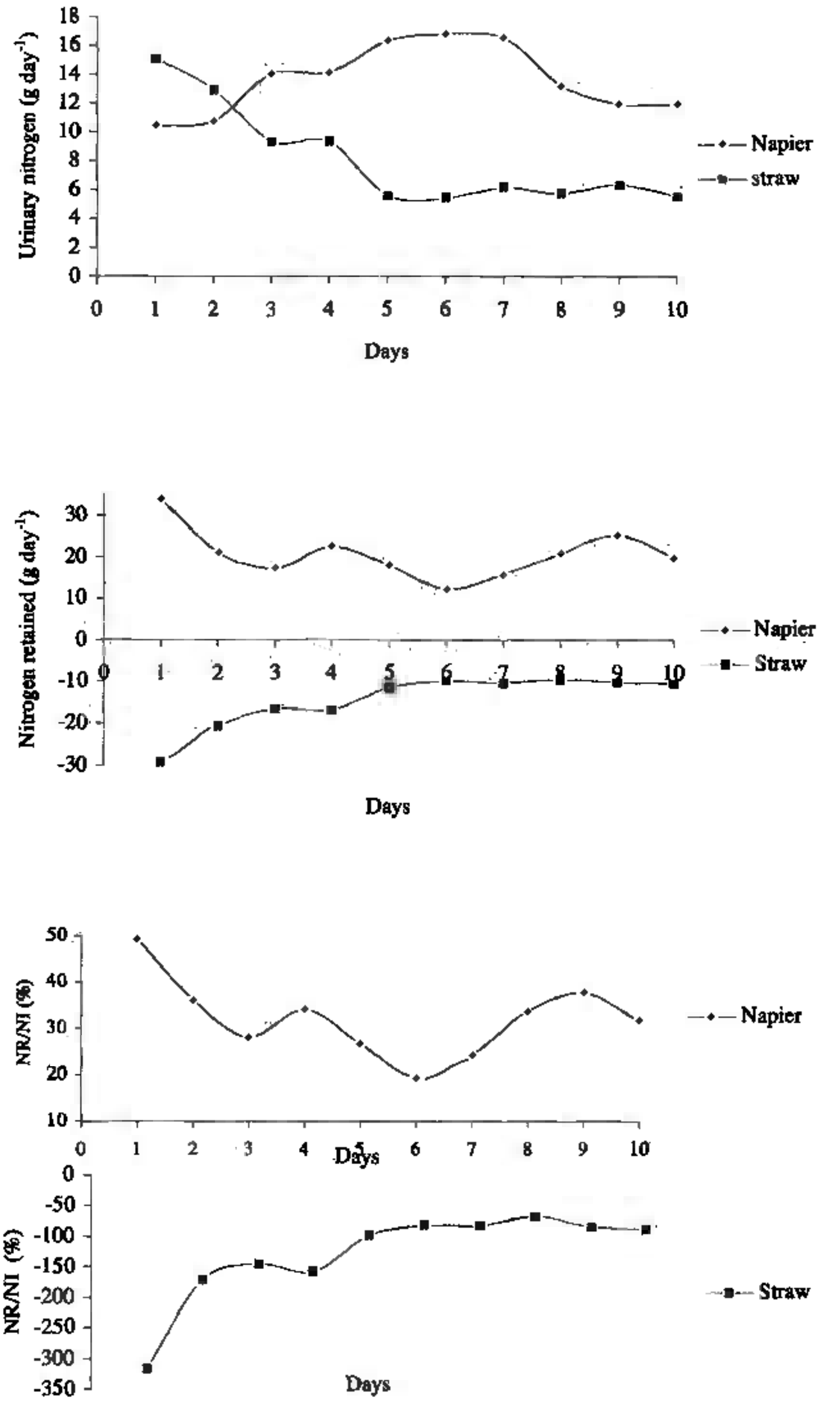


Figure 9: *Urinary nitrogen (UN), nitrogen retained (NR) and nitrogen retained / nitrogen intake (NR / NI) for napier grass and barley straw following an abrupt change in feed type*



Comparison of the first and second 5 day periods following a change in feed type

Mean intake, faecal and urine production, apparent digestibility and nitrogen retention observed in Stage 2 are presented in Table 10. There was a significant feed by type (first or second 5 days) interaction for all intake values except NI, the t-test showing no difference for barley straw but significantly ($p<0.05$) higher values in the second 5 days compared to the first 5 days for napier grass. The changes in napier grass intake appeared to be partly due to a sharp drop in intake on the second day after the change as observed in Experiment 1, followed by a gradual increase (Figure 7), although it may be confounded by the increase in napier grass DM content in the last 5 days of each 10 day measurement period (Figure 1). The animals ate 1.3 and 0.7 times ME requirements for maintenance in the second 5 days when fed napier grass and barley straw, respectively.

As in Experiment 1, faecal DM, OM and N production were significantly ($p<0.001$) higher during the second 5 days compared to the first 5 days for napier grass with the reverse trend being observed in animals consuming barley straw ($p<0.05$), as shown by t-test analysis.

The DM, OM and N digestibility for barley straw were significantly ($p<0.001$) higher the second 5 days compared to the first 5 days. The same parameters were not significantly ($p>0.05$) different for napier grass as in Experiment 1.

There was a significant feed by type (first or second 5 days) interactions for UN production, NR and NR/NI, t-test showing no significant differences for napier grass, but UN was significantly ($p<0.001$) lower and NR and NR/NI although negative were significantly ($p<0.001$) higher for barley straw in the second 5 days compared to the first 5 days.

Microbial nitrogen supply

Influence of feed type

Table 11 shows the main effect means for feed and statistical analysis for purine derivatives excreted, estimated purine derivatives absorbed, urine volume and calculated microbial N supply. All the parameters were higher for napier grass compared to barley straw ($p<0.001$) except microbial per unit of digestible organic matter intake.

Day to day changes in purine derivatives excreted, calculated purine derivatives absorbed, urine volume and microbial N supply as animals adapted to the feeds

The results of the statistical analysis of purine derivatives excreted, estimated purine derivatives absorbed, urine volume and microbial N supply are presented in Table 11. Although the only significant day effect was observed for urine volume ($p<0.01$), significant ($p<0.05$) day by feed interaction was observed for all the other parameters.

Table10: *Mean intake, faecal and urine production, nitrogen retention and apparent digestibility for napier grass or barley straw over 5 day periods when the feed consumed in the previous 5 days was the same or different (Stage 2) following an abrupt change in feed. Values presented are means for each feed, averaged across animals, periods and days (n = 6).*

	Napier		Straw		Sed			Significance		
	Different	Same	Different	Same	Feed	Type	Feed x Type	Feed	Type	Feed x Type
Parameters										
Dry matter										
Intake, kg day^{-1}	5.9	6.8	3.3	3.4	0.10	0.07	0.12	***	***	***
Faecal production, kg day^{-1}	2.7	3.2	1.9	1.7	0.06	0.07	0.09	***	ns	***
Digestibility, %	54.0	53.2	40.5	50.4	0.95	1.35	1.65	***	**	**
Organic matter										
Intake, kg day^{-1}	5.2	5.8	3.0	3.1	0.09	0.06	0.11	***	***	***
Digestible intake, kg day^{-1}	2.7	3.0	1.6	1.6	0.09	0.04	0.10	***	**	**
Faecal production, kg day^{-1}	2.2	2.6	1.6	1.4	0.05	0.07	0.08	***	p<0.1	**
Digestibility, %	57.2	55.1	46.6	53.6	0.75	1.38	1.57	***	ns	**
Nitrogen										
Intake, g day^{-1}	64.8	66.0	11.1	12.2	1.80	1.05	2.09	***	ns	ns
Faecal production, g day^{-1}	28.0	31.7	19.8	16.6	0.65	0.86	1.08	***	ns	***
Digestibility, %	56.4	52.0	-82.4	-36.0	3.96	3.40	5.22	***	***	***
Urinary production, g day^{-1}	13.9	15.3	10.4	5.8	0.90	0.90	1.27	**	ns	**
Nitrogen retention, g day^{-1}	22.9	18.9	-19.1	-10.2	2.03	0.53	2.10	***	***	***
Nitrogen retained/ nitrogen intake, %	35.1	28.3	-178.9	-83.6	7.92	5.82	9.82	***	***	***

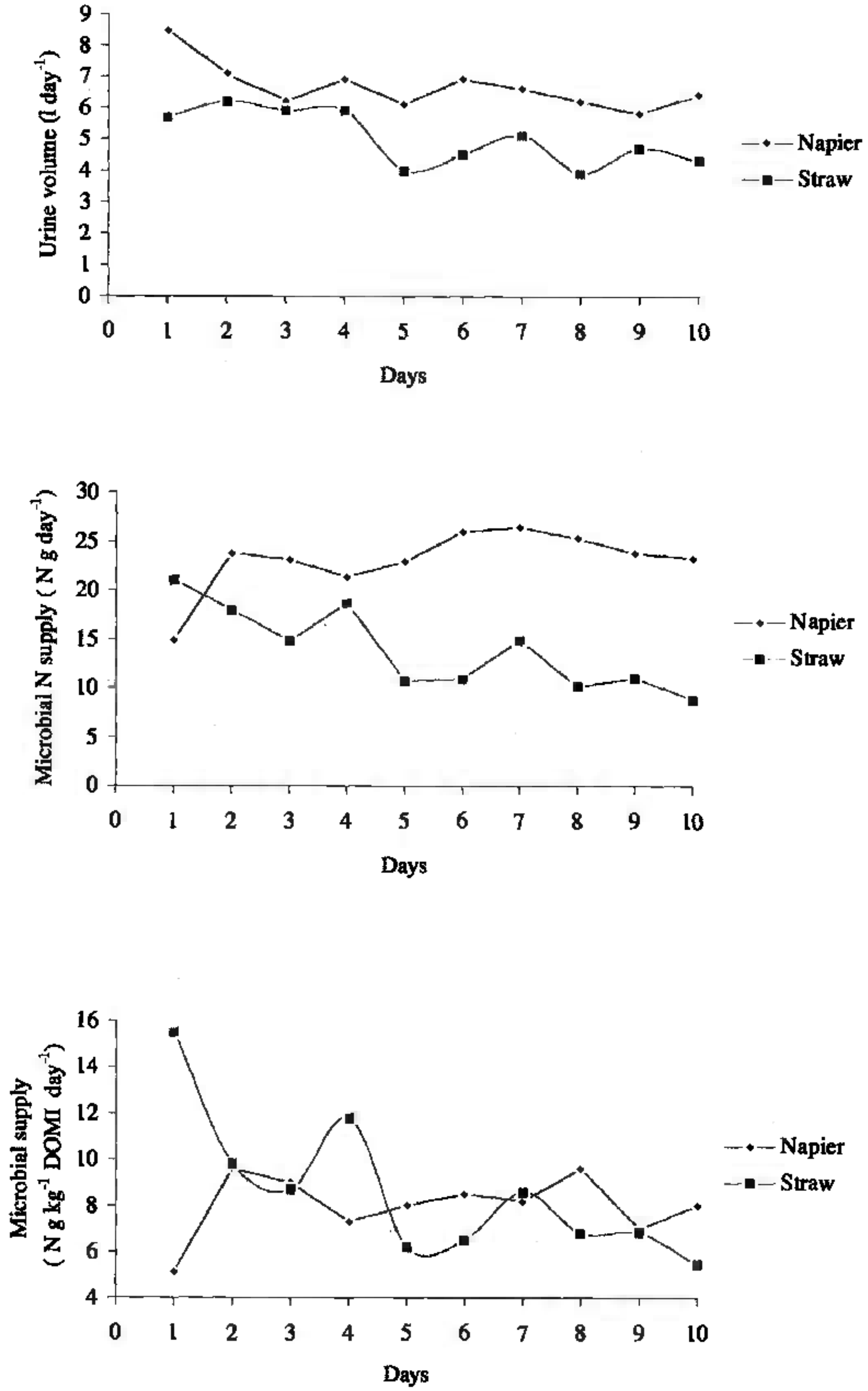
Sed = standard error of difference of two means; ns = non-significant; ns = (p>0.05); *p<0.05; **p<0.01; ***p<0.001

Table 11: *Main effect mean purine derivatives excretion, estimated purine derivatives absorbed, urine volume and microbial N supply by animals consuming napier grass or barley straw following an abrupt change in feed type (Stage 2). Values presented are means for each feed type, averaged across animals, periods and days (n = 6).*

	Main effect mean		Sed			Significance								
									Polynomial					
									Day			Day x Feed		
Parameters	Napier	Straw	Feed	Day	Day x Feed	Feed	Day	Day x Feed	L	Q	C	L	Q	C
Purine derivative excretion , mmol day^{-1}	37.1	27.1	0.60	3.38	4.58	***	ns	*	ns	ns	ns	***	*	ns
Estimated purine derivatives absorbed , mmol day^{-1}	31.1	19.1	0.68	4.03	5.44	***	ns	*	ns	ns	ns	***	*	ns
Urine volume, l day^{-1}	6.6	5.0	0.13	0.53	0.72	***	**	ns	***	*	ns	ns	ns	*
Calculated microbial N supply														
g N day^{-1}	22.6	13.9	0.49	2.93	3.96	***	ns	*	ns	ns	ns	***	*	ns
g N kg^{-1} DOMI day^{-1}	8.0	8.5	0.69	1.49	2.12	ns	ns	***	**	ns	ns	***	*	ns

Sed = standard error of difference of two means   ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001 L = linear;
Q = quadratic; C = cubic   DOMI = digestible organic matter intake

Figure 10: *Urine volume, calculated microbial protein supply for napier grass and barley straw following an abrupt change in feed type.*



The purine derivatives excreted, calculated purine derivatives absorbed and microbial N supply showed a similar trend and significance and only microbial N supply is presented graphically. Figure 10 shows the trend in microbial N supply and urine volume for the two feeds. The microbial N supply for animals consuming barley straw gradually declined throughout the 10 day period, while for those on napier grass, there was a sharp increase from Day 1 to 2, followed by a gradual increase to a maximum at Day 7. The interaction between diet and day indicated both linear ($p<0.001$) and quadratic ($p<0.05$) components. The urine volume declined to an apparent minimum after 5 days for napier and barley straw, respectively.

Comparison of the first and second 5 day periods following a change in feed type

The mean purine derivatives excreted, estimated purine derivatives absorbed, urine volume and calculated microbial N supply are presented in Table 12. Significant feed by type (first or second 5 days) interactions were observed for all parameters except urine volume and t-test showed that the purine derivatives excreted ($p<0.05$), estimated purine derivatives absorbed ($p<0.05$) and microbial N supply to the small intestine ($p<0.05$) were significantly higher for the second 5 days compared to the first 5 days following a change to napier grass. The same trend was observed for microbial N supply expressed per unit of digestible organic matter intake but was not significant. The reverse trend was observed for barley straw and significant for purine derivatives excreted, estimated purine derivatives absorbed and calculated microbial N supply ($p<0.001$). The urine production was similar for napier grass, but decreased significantly ($p<0.001$) for barley straw in the second 5 days compared to the first 5 days.

Discussion

Day to day change in rumen environment in adapted animals

Huntington and Offer (1994) fed sheep grass hay or a mixed diet of grass hay, rolled barley and flaked maize. They reported day-to-day variation in the rumen concentrations of pH, NH_3-N and total volatile fatty acids for both diets. Acetate, propionate and butyrate varied from day-to-day for each diet, indicating that there is an inherent day to day variability in the rumen environment which should be distinguished from the effects of adaptation to diets. Therefore, in this experiment Stage 1 was designed to determine the day to day variability in the rumen parameters in animals adapted to napier grass and barley straw, whereas Stage 2 was to determine changes over time during adaptation to the two feeds. Although day-to-day variations were observed in both stages, for example in rumen total VFA and NH_3-N concentrations for napier grass, it may reflect the pattern of intake and the variables were relatively stable for barley straw as the intake tended to be stable (Figure 2). In contrast the trends observed in Stage 2 for example in rumen total VFA and NH_3-N concentration for napier grass may not be explained by intake since they were observed for barley straw as well. However it should be noted that the rumen NH_3-N concentration for napier grass was higher in Stage 1 than 2, probably because of the higher crude protein content for napier grass.

Table 12: *Mean purine derivatives excreted, estimated purine derivatives absorbed, urine volume and microbial N supply for napier grass or barley straw over 5 day periods when the forage consumed in the previous 5 days was the same or different (Stage 2) following an abrupt change in feed. Values presented are means for each feed , averaged across animals, periods and days (n = 6).*

	Napier		Straw		Sed			Significance		
	Different	Same	Different	Same	Feed	Type	Feed x Type	Feed	Type	Feed x Type
Parameters										
Purine derivatives excreted, mmol day^{-1}	35.5	39.3	30.2	23.9	0.58	1.45	1.56	***	ns	**
Estimated purine derivatives absorbed , mmol day^{-1}	29.2	33.7	22.8	15.3	0.68	1.72	1.85	***	ns	**
Calculated microbial N supply										
g N day^{-1}	21.2	24.9	16.6	11.1	0.56	1.31	1.42	***	ns	**
g N kg^{-1} DOMI day^{-1}	7.8	8.3	10.4	6.6	0.69	0.58	0.90	ns	*	**
Urine volume, l day^{-1}	6.8	6.5	5.6	4.5	0.12	0.29	0.32	***	*	ns

Sed = standard error of difference of two means ns = non-significant (p>0.05); *p<0.05; **p<0.01; ***p<0.001

The rumen pH for barley straw was consistently high in Stage 1 while it tended to show rhythmic fluctuation for napier grass, probably because of the daily changes in intake and nitrogen content for napier grass. The lower pH for napier grass appear to be consistent with the greater total volatile fatty acid production. In Stage 2 the pH for barley straw and napier grass were similar on Day 1 and then increased to Day 3 for barley straw and remained stable while it was generally stable for napier grass. However, the pH in both stages was above 6.2 indicating that fibre degradation was not affected by the pH changes in this study. A pH of 6.2 is suggested as a critical level at which cellulolysis starts to be affected as a result of reduction in cellulolytic micro-organisms number (Mould *et al*., 1983).

The napier grass pH was 6.7 and 6.6 in Stages 1 and 2, respectively. Abdulrazak *et al.* (1996) reported a mean pH of 6.6 when cross bred steers were fed napier grass (CP 77 g kg^{-1} DM; NDF 706 g kg^{-1} DM). The pH was 6.8 and 6.9 in Stages 1 and 2, respectively, for barley straw and was similar to a pH of 6.8 reported for untreated barley straw (Silva and Ørskov, 1988).

Effect on rumen environment of abrupt change in feed type

Effect of abrupt change from napier grass to barley straw

The active digestion of the feed by the rumen micro-organisms, as indicated by the high microbial nitrogen supply and DM disappearance, may have resulted in higher rumen NH_3-N and total VFA concentrations for barley straw on Day 1 following a change from napier grass. The high efficiency of microbial nitrogen supply on Day 1 probably reflects the high dry matter disappearance and the high rumen total VFA and NH_3-N concentrations (Figures 3 and 10). Recycled nitrogen from the previous napier grass diet as urea in the rumen, although not measured in this trial, may have contributed to the higher NH_3-N levels observed on the first day. Norton *et al*. (1982) reported that endogenous urea, entering the rumen either via saliva or directly through the rumen wall, contributes more to the rumen NH_3-N pool in ruminants fed low nitrogen diets than those receiving normal or high amounts of nitrogen.

The reduction in dry matter disappearance to Day 3 (Figure 5) reflects the decrease in the nitrogen intake and may be in nitrogen recycled and a consequent reduction in rumen NH_3-N and microbial activity. This is evidenced by a gradual reduction in ammonia-nitrogen concentration below the minimum of 50 mg l^{-1} recommended for optimal microbial activity (FAO, 1986; Satter and Slyter, 1974), lower total VFA and microbial N supply as the animals adapted to the feed. Low microbial nitrogen supply has been reported when sheep were fed barley straw which supplied rumen NH_3-N below the recommended level (Balcells *et al*., 1993). The value of microbial nitrogen supply of 6.6 g kg^{-1} DOMI day^{-1} during the second 5 days for barley straw was low compared to that of 11.9 g kg^{-1} DOMI day^{-1} estimated by the total purine derivatives method in sheep which consumed 1.9 per cent their body weight of barley straw (Balcells *et al*., 1993). The high value in their study may be because of a higher crude protein content (CP 34 g kg^{-1} DM; NDF 769 g kg^{-1} DM) and high intake compared to the present study.

Effect of abrupt change from barley straw to napier grass

The low rumen total VFA and NH_3-N concentrations for napier grass on Day 1 may have resulted from the low degradation of the feed by a low population of the rumen micro-organisms as indicated by the low microbial N supply and DM disappearance (Figures 3, 5 and 10).

Church (1979) reported low rumen micro-organism numbers in the first 3-5 days following abrupt change to a high quality diet in the form of 1:1 mixture of alfalfa hay and concentrate in sheep previously fed rice straw. The same author reported that the rumen micro-organisms adapted to the feed and the number increased to that typical of the feed in 30-35 days. It may be expected that the increase in DM disappearance to a maximum on Day 4 and 5 at 24 and 48 h of incubation may reflect adaptation of the rumen micro-organisms to the feed and increases in the number of the micro-organisms for more degradation of the feed. This is evidenced by the gradual increase in total VFA, NH_3-N and microbial N supply.

The rumen NH_3-N concentration for napier grass of 80 mg^{-1} was lower than the value of 130 mg l^{-1} for napier grass (CP 77 g kg^{-1} DM; NDF 706 g kg^{-1} DM) fed to cross bred steers (Abdulrazak *et al*., 1996), this may be because of the low crude protein of the napier fed in stage 2 and the fact that animals were fully adapted to the feed. The total VFA concentration for napier grass of 101.9 mM l^{-1} was comparable to the values of 97.2 mM l^{-1} reported for napier grass (CP 64 g kg^{-1} DM; Muinga *et* *al*., 1995). The mean value of microbial nitrogen supply of 8.3 g kg^{-1} DOMI day^{-1} estimated for napier grass the second 5 days was low compared to the value of 14.7 g kg^{-1} DOMI day^{-1} estimated using the purine derivative method when crossbred steers were fed napier grass (Abdulrazak *et al*., 1996). The higher value in their study may reflect the higher CP content (CP 77 g kg^{-1} DM) of the napier grass fed.

Nitrogen balance

Effect of abrupt change from napier grass to barley straw

Nitrogen production in urine is low in ruminants fed low nitrogen diets, partly because of low concentration of plasma urea and partly due to a reduction in the ratio of urea excreted to that filtered in the glomerulus (Leng *et* al. 1985, cited by Smith 1989). Therefore a gradual decrease in urine production for barley straw fed immediately after napier grass may have been influenced by increased renal activity in regulating nitrogen loss in urine. Recently Alawa, (1991) fed sheep for 30 days on untreated barley straw supplemented with low levels of soya bean to supply 14.4 g kg^{-1} DM of readily degradable protein and found that sheep adapted gradually with time. There was a non-uniform gradual reduction in urinary nitrogen loss but consistent faecal N losses and high nitrogen retention over time. He suggested that adaptation to nitrogen conservation may be involved in the process of nitrogen cycling. The gradual decrease in urinary nitrogen excretion for barley straw over the first 5 days may be explained by high nitrogen supply from the previous napier grass which might have contributed towards the nitrogen recycled into the rumen through urea in saliva or directly into the rumen and converted into NH_3-N. Some of the NH_3-N may have been lost as urine nitrogen and not used in the rumen by the rumen micro-organisms might be because of insufficient fermentable carbohydrates from the low intake of barley straw as evidenced by the low volatile fatty acids production.

The urine nitrogen excretion was low and stable during the next 4 days for barley straw and this may have been because of little nitrogen to recycle and might be the animals were relatively adapted to conserve nitrogen. The NR value of -10.2 g day^{-1} for barley straw during the second 5 days was low compared to -5.5 g day^{-1} reported by Toppo *et al*. (1997) for wheat straw similar in composition (CP 33 g kg^{-1} DM; NDF 774; ADF 595) to the barley straw fed in this trial. The higher value may be because of the higher nitrogen intake by the crossbred cattle (300 kg, live weight) which were fed *ad libitum* while in this trial intake was restricted at 90 per cent *ad libitum*.

Effect of abrupt change from barley straw to napier grass

Chiou *et al*. (1995) reported that when excess ammonia-nitrogen in the rumen, is beyond the capacity of the microbial mass to synthesise protein the animal metabolises the excess amount of ruminal ammonia-nitrogen through the liver and discards most of it as urea in urine, reducing the utilisation of dietary protein. Although this information is from lactating dairy cows fed high nitrogen diets it may apply when the rumen micro-organisms have not increased in number following an abrupt change to napier grass. The gradual increase in urinary nitrogen production to a maximum on Day 6 for napier grass may be explained by the gradual increase in rumen micro-organisms and a consequent increase in degradation of the feed and release of more NH_3-N. The increased quantity of NH_3-N produced might not be utilised by the low population of the rumen micro-organisms and some could be lost as urine nitrogen. This may be explained by the low microbial N supply production following abrupt change to the feed and the increase in rumen NH_3-N levels to a maximum earlier at Day 3. There was a tendency for urine and faecal nitrogen production to reduce in the last 4 days. The rumen micro-organisms may have increased in number, as shown by the increase in microbial nitrogen supply, to a maximum on Day 7 and may be utilised the rumen NH_3-N better and degraded more feed such that less nitrogen escaped in urine and in faeces from the undegraded feed residue. As a result nitrogen retention showed a tendency to increase although it may have been confounded by nitrogen recycling which may have decreased urine production because of the decrease in napier grass nitrogen content and intake (Figure 8 and 9). However there was a tendency for efficiency of nitrogen utilisation to increase during this period.

Although no significant differences in nitrogen retention and efficiency of nitrogen utilisation were observed between the first 5 and the second 5 days for napier grass, these parameters appeared to gradually improve after the first 5 days. The improvement in nitrogen retention, and efficiency of nitrogen utilisation for napier grass suggest that the animals may have been well adapted to the feed and utilised it better. The nitrogen retention of 18.9 g day^{-1} for napier grass in the second five days was comparable to that reported for lactating dairy cows (384 kg, live weight) which ate 6.3 kg day^{-1} of napier grass (CP 64 g kg^{-1} DM, NDF 690 g kg^{-1} DM and ADF 476 g kg^{-1} DM; Muinga *et al*., 1995). The same authors reported a nitrogen retention of 2.0 g day^{-1} for napier grass but adding the 18.1 g day^{-1} in milk, the value was 20.1 g day^{-1}.

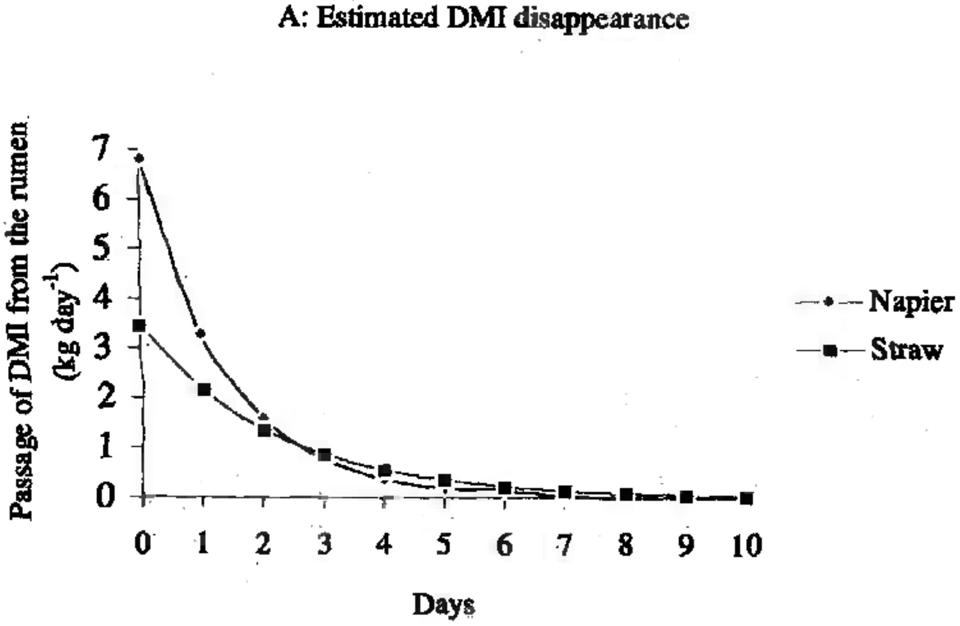
Intake and digestibility

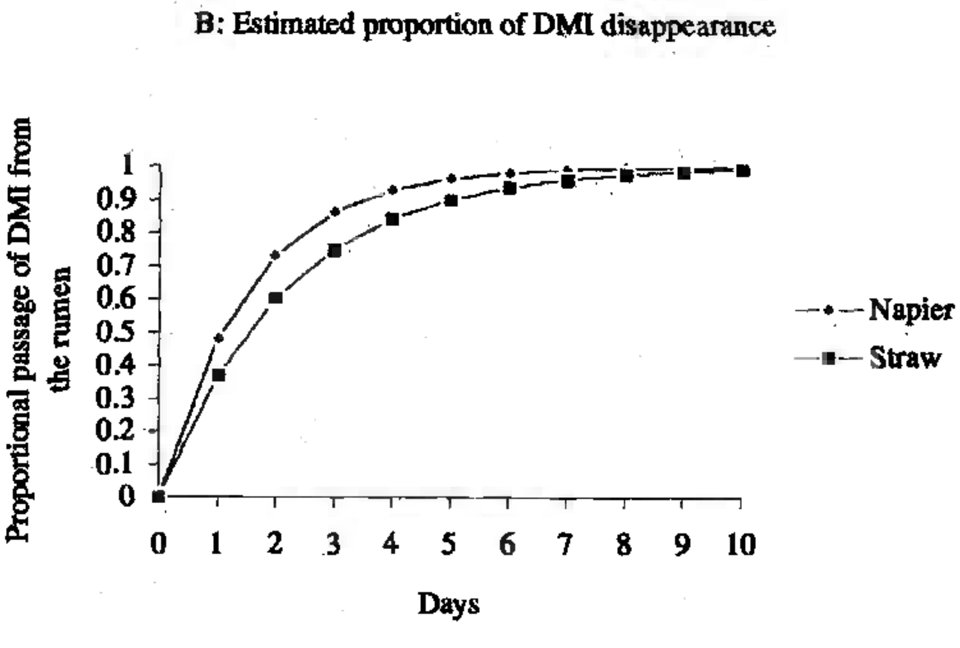
The napier grass intake decreased on the second day, with the animals refusing on average 14.5 % of the feed offered compared to 6.3 % on the first day. This decrease in intake is consistent with results reported in Experiment 1. The high intake for napier grass on the first day may be because of feed restriction and low palatability of previous barley straw consumed. Feed restriction has been reported to cause high motivation in sheep to eat hay and pelleted concentrate diet (Marsden and Wood-Gush, 1986 cited by Jeffrey *et al*., 1993). One factor that may have contributed to the decrease in intake is the rumen fill resulting from the relatively low DM disappearance for napier grass on Day 1 compared to other days. Forbes (1993) reported that the remaining indigestible fraction of a feed and the proportion of insoluble but digestible fraction of previous meals remaining at each time contribute bulk of digesta and may terminate eating when it reaches maximum rumen volume. Although the report is related to meals within a day it may also apply to meals between days.

The higher significant intake for napier grass in the second 5 days compared to the first 5 days may indicate adaptation to the feed. However it may reflect the low intakes on the second day (Table 10 and Figure 7) and may be further confounded by the increase in napier grass DM content in the last 5 days of both the first and the second 10 days (Figure 1). Napier grass DMI of 6.8 kg day^{-1} in the second 5 days, when calculated as kg 100^{-1} live weight, using mean live weight of 308 kg in trial 2, was 2.2 kg 100 kg^{-1} live weight. Anindo and Potter (1986) reported intake of 2.6 kg 100 kg^{-1} live weight in lactating dairy cows fed napier grass (CP 102 g kg^{-1} DM; ADF 429 g kg^{-1} DM) *ad libitum*. The higher intake in their study might be because their animals were fed *ad libitum* whereas in this study it was restricted at 90 per cent *ad libitum* intake and the napier grass had higher crude protein content than in this trial (Table 1b).

The trend of gradual increase and decrease in faecal production for napier grass and barley straw in the first 5 days may be explained by the passage of the previous feed residue from the rumen as in Experiment 1. Using estimated passage rates of 0.030 h^{-1} and 0.019 h^{-1} for napier grass and barley straw respectively it would be expected that five days after a feed more than 96 % of napier grass and 90 % of barley straw feed residue would have left the rumen (Figure 11). The absence of a decrease in faecal dry matter production in the second 5 days for napier grass as observed in Experiment 1 may be because of the decrease in crude protein and increase in dry matter content of napier grass and a consequent increase in DMI. However, the changes in faecal nitrogen production for napier grass seemed not to reflect only the change in proportion of residues from the previous barley straw consumed, since it tended to decrease (Figure 8) in the second five days. The decrease in faecal nitrogen production for napier grass reflects an observed improvement in digestibility which may have resulted from high degradation of the feed by the rumen micro-organisms and a decrease in nitrogen lost in the faeces. Arieli *et al*. (1991) fed heifers on wheat straw and in addition abruptly changed them to concentrate feed based on poultry litter from a concentrate diet isonitrogenous and isoenergetic to poultry litter but composed of cottonseed cake and soyabean meal.

Figure 11: *Estimated amount and proportion of the feed residues remaining 0 – 10 days following consumption of the average DMI observed in stage 2 for napier grass and barley straw (assumed passage rates of 0.030 and 0.019 h-1 for napier grass and barley straw respectively).*





They observed the DM digestibility for poultry litter to decrease for one week and gradually increase over the next 4 weeks as the animals adapted to the feeds. They attributed the decrease in digestibility to the decrease in degradation of the fibre component in the poultry litter diet in the first week. The DM digestibility for barley straw of 50.4 % in the second 5 days was comparable to the 52.5 % observed in Experiment 1. The DM digestibility for napier grass in the second 5 days was 53.2 %, and this was low compared to 63.0 % observed in Experiment 1. This might be because of low crude protein content of napier grass fed in trial 2. Anindo and Potter (1994) reported a decrease in DM digestibility for napier grass as crude protein content decreased.

Conclusions

The positive results obtained in dry matter disappearance for barley straw in the first day were explained by the high degradation of the feed by the enhanced rumen micro-organism population resulting from the improved rumen environment created by the previous napier grass fed. The gradual decrease in dry matter disappearance for barley straw may have been due to a subsequent decrease in this rumen micro-organism population. The dry matter disappearance for napier grass was low immediately after a change from barley straw and then gradually increased over the first 5 days which may be explained by the gradual adaptation and increase in the rumen-microganisms which degraded the feed better.

The gradual changes in nitrogen utilisation in the first 5 days for barley straw were probably influenced by the time taken for the previous feed residue from napier grass to be voided from the rumen which resulted in high faecal nitrogen production. High urine nitrogen production may have resulted from nitrogen recycled to the rumen from the previous napier grass fed. As a result of the high urine and faecal nitrogen production the nitrogen retention and efficiency of nitrogen utilisation was low and these values were stable after 5 days. The nitrogen retention and efficiency of nitrogen utilisation for napier grass appeared to be low immediately following a change from barley straw and gradually improved after 5 days. The improvement may have been due to increases in the micro-organisms which resulted in better degradation of the feed and reduced loss of nitrogen in faeces and urine.

There were indications of a reduction of nitrogen digestibility for napier grass immediately after a change from barley straw. The digestibility improved after the first 5 days which may have been due to improved degradation of the feed by the rumen micro-organisms and less loss of feed nitrogen in faeces.

Appendix 5

Field Experimentation to Examine Management Interventions for Improving the Supply of Fodder from the Maize Crop without Compromising Food Production

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Introduction

During a set of PRA studies, conducted with other funding to examine opportunities for increasing the effectiveness of using the maize crop for both food and feed, farmers expressed concern over the effects of increased maize planting density on grain yield. The field experiments described in this Appendix were designed to determine whether increasing seed rates could increase fodder supply from maize, without negatively affecting grain yield, under the management of farmers. The experiments were conducted during the short rains of 1998 and the long rains of 1999.

Materials and Methods

Experimental design

In the short wet rainfall season, six individual experiments were carried out on six farms (Table 1); three each in the Limuru and Githunguri divisions of Kiambu District. Each experiment had the same basic design. Two seed density treatments were combined factorially with two manure / fertiliser rates in a completely randomised block design with fourfold replication. The low seed rate (SR 1) x low manure / fertiliser rate (MR 1) reflected individual farmer practice. On each farm, the host farmer established this by demonstrating planting on the first plot. Spacing used between rows and holes and quantities applied were established and applied to the remaining plots for that treatment. Modified rates of seed (SR2) and manure (MR2) were agreed in discussions with farmers at planting. Treatment details and plot sizes are shown in Table 2. Seed rates were modified by increasing the number of seeds per hole, but at the same time altering the spacing. Manure / fertiliser rates were also adjusted on a per hole basis, so that although the change in quantity relative to the number of seeds per hole was constant, the per ha rates (Table 3) for MR1 and MR2 were different for SR1 and SR2.

The farmers made final decisions in planning of the treatments with regard to seeds per hole, spacing and manure levels and made all of the decisions concerning subsequent maize management such as time of weeding, thinning, removing of green cobs, leaf stripping and harvesting. Thus, each farm had to be treated as a separate experiment for analytical purposes.

In the long wet season, the short season trial design was repeated on four farms. However, specific parameters of the treatments were modified on all farms with regard to spacing and plant density, based on preliminary results and observation. On two farms, the trials were reduced to two treatments, with a single block for each treatment sub-divided into plots to provide a measure of variability. The treatments compared were:

SR1MR1: Farmer seed rate + farmer manure/fertiliser rate (control)

SR2MR1: High seed rate + farmer manure/fertiliser rate

Although this layout meant that statistical comparisons were less rigorous, the designs were chosen to enable farmers to easily distinguish between treatments and allow them to more easily base their crop management decisions such as thinning, on the appearance of the crop in the two treatments. In these trials, farmers thinned at will and collected data themselves, rather than making a decision to thin and arranging a date with researchers to allow them to collect data. It was expected that this methodology would give a better understanding of actual thinning patterns and why farmers thinned when they did.

Table 1: *Summary of characteristics of the six farms selected for the maize trials*.

Farm	Family size	Land size (ha)	Livestock production system	Grown cash crops	Cattle numbers	Area of Napier grass (ha)	Area of Maize (ha)
Upper midland zone							
Farm 1	10	1.9	Semi-zero grazing[1]	Cut flowers & pyrethrum	1 mature cow and 1 heifer.	0.3	0.8
Farm 2	14	0.7	Zero-grazing	-	4 mature cows	0.3	0.4
Farm 3	15	1.1	Zero-grazing	Vegetables (kale, cabbage and tomatoes)	2 mature cows and 1 heifer	0.3	0.4
Lower midland zone							
Farm 4	10	1.3	- [2]	250 and 1500 bushes of coffee & tea, respectively, on 0.6 ha	- [2]	0.1	0.5
Farm 5	6	2.2	Zero-grazing	2,500 bushes of coffee on 1.0 ha	1 mature cow and 1 heifer.	0.2	0.4
Farm 6	4	1.8	Semi-zero grazing	500 bushes of coffee on about 0.4 ha	1 heifer and 1 bull calf.	0.6	0.3

1 - A feeding system where animals are partially confined but sometimes graze, although pasture is usually not the main source of feed.

2 - This farmer did not own any animals but tricked his way into the experiments by borrowing a cow from a relative in order to meet the criteria.

Table 2: *A summary of maize management practices on different farms used in the short wet season.*

Farm	Experimental plot size [Length x Width] (m)	FARMER RATES (SR1 and MR1)				MODIFIED RATES (SR2 and MR2)			
		Seed rates (Seeds/ hole)	Fertiliser rates (Handfuls/ hole)	Manure rates (Handfuls/ hole)	Spacing [1,2] (cm)	Seed rates (Seeds/ hole)	Fertiliser rates (Handfuls/ hole)	Manure rates (Handfuls/ hole)	Spacing [1,2] (cm)
Upper midland zone									
Farm 1	4 x 6	3	0.18	1	100 X 67	5	0.29	2	100 X 67
Farm 2	4 x 6	3	0.22	0.5	100 X 56	6	0.40	1	100 X 67
Farm 3	4 x 6	3	0.22	1	50 X 46	6	0.40	2	50 X 67
Lower midland zone									
Farm 4	6 x 4	3	0.18	1	100 X 44	5.5	0.22	2	100 X 80
Farm 5	6 x 7	2*	1.00**	1**	100 X 58	4*	0.50**	2**	100 X 58
Farm 6	6 x 4	3.5	0.18	1	75 X 50	6	0.18	3	86 X 67

* - Seeds after every 30 cm in a furrow.
** - Handfuls per 30 cm.
1 - Spacing between holes within rows x between holes.
2 - Spacing estimated from number of holes / row and number of rows/plot
N/B One handful of fertiliser was, on average equivalent to 3.5 teaspoonfuls and a spoonful weighed an average of 30 g.
One handful of manure weighed an average of 103 g.

Table 3: *A summary of manure/fertiliser rate increases relative to plant density (kg/'000 seeds), seed rate ('000/ha) and the actual manure (t/ha) and fertiliser (kg/ha) application rates used on farms in the short wet season*.

Farm	Seed rate ('000 /ha)		Manure rates								Fertiliser rates							
			kg/'000 seeds				t/ha				kg/'000 seeds				kg/ha			
	SR1	SR2	SM MR1	SR1 MR2	SR2 MR1	SR2 MR2	SR1 MR1	SR1 MR2	SR2 MR1	SR2 MR2	SR1 MR1	SR1 MR2	SR2 MR1	SR2 MR2	SR1 MR1	SR1 MR2	SR2 MR1	SR2 MR2
Farm 1	45	75	33	67	20	40	1.5	3.0	1.5	3.0	6.4	10.0	3.8	6.0	286	450	286	450
Farm 2	55	90	17	33	10	20	0.9	1.8	0.9	1.8	7.8	14.0	3.9	7.0	428	770	350	630
Farm 3	130	180	33	67	24	48	4.3	8.7	4.3	8.7	7.8	14.0	3.9	7.0	1011	1820	700	1260
Farm 4	68	69	33	67	33	65	2.3	4.5	2.3	4.5	6.4	7.8	3.5	4.2	430	525	239	292
Farm 5	34	69	50	100	25	50	1.7	3.4	1.7	3.4	9.6	11.3	4.8	5.6	328	387	328	387
Farm 6	93	105	29	86	25	76	2.7	8.0	2.7	8.0	5.5	5.5	3.2	3.2	334	509	334	509

SR1MR1 - Farmer seed and fertiliser/manure rates
SR1MR2 - Farmer seed and modified fertiliser/manure rates
SR2MR1 - Modified seed and farmer fertiliser manure rates
SR2MR2 - Modified seed and manure/fertiliser rates

Experimental layout

In both seasons, the farmers selected and prepared the areas on which the experimental plots were established. The selection depended on the rotation plan of the farm and accessibility to the plot. The area allocated by the farmer for the experiment determined the size of the plots. Blocks were laid across the slope to take into account the effect of slope. Treatments were allocated randomly to the 4 plots within each block (Plate 1). Unrepresentative physical features, e.g. big shrubs falling in the middle of a plot, were avoided. Guard rows were included by marking out the outer row and holes at each end of each row. This left the actual net plot from which the main data were collected. A one-metre path separated plots. In the long wet season, four farms retained a 2 x 2 factorial arrangement while the other two farms used a simplified design employing replication of only two treatments. Guard rows were not included in simple plot designs to make it easier for farmers to collect data themselves. In the 2 x 2 factorial arrangement, plots were allocated to treatments ensuring that each treatment was not planted again on the same plot as in the short wet season.

Plate 1: *Experimental layout of plots on farm.*

Input rates and plant density

In the short wet season, all farmers applied di-ammonium phosphate (DAP) fertiliser and dry 'boma' manure from the range regions of rift valley province of Kenya. . Dry manure was used in the experiments because it was available in large quantities and was easier to transfer to farms and to apply in accurate amounts. All farmers chose to plant the maize variety H 513. The host farmers stated the usual number of handfuls per hole of manure/fertiliser applied to maize, which formed the rate for the control plots. The decisions of farmers on the higher rates depended on what they considered reasonable, given their own circumstances. Five farmers chose to double both fertiliser and manure rates, whilst farm 6 decided on a three-fold increase in manure while keeping fertiliser rates constant, since she felt it would be unlikely she could afford such an increase. In order to fully involve farmers, a decision was made not to carefully weigh manure/fertiliser and apply exact amounts per plot, but to allow farmers to apply inputs in their own way so that they were able to relate to the quantities used. Given that a number of farmers were involved in the planting and were likely to have different-sized handfuls, this meant that applications were not exact. However, it was felt that relative differences between treatments were constant. In order to estimate application rates on a per ha basis, a number of handfuls of manure and fertiliser were weighed to calculate average weights, which are shown as footnotes in Table 2.

In the long wet season, five farmers chose to plant the H 614 variety whilst the sixth farmer (Farm 5) planted H 625. The same types of fertiliser and manure applied in the short wet season were used again. Accurate amounts of manure/fertiliser were used on plots, following difficulty in estimating inputs in the short wet season trials. The farmers determined the rates applied to the control plots by placing the usual handfuls of manure or fertiliser in the same length of row outside the experimental plot. The total number of handfuls used were weighed and multiplied by the number of rows/furrows in each plot to determine the amount per row or plot. As in the first season, the increased rates of fertiliser and manure reflected amounts farmers felt they could feasibly manage to purchase or produce on farm. Treatment details are shown in Table 4. Later, the input rates were converted to rates per ha, which are summarised in Table 5.

Planting practices in the short wet season

Planting dates were agreed on between farmers and researchers before announcements were made to neighbours at local churches and at milk collection centres. Participants discussed the individual farmer practices and agreed or disagreed on issues they thought were not representative in the area. The participants proposals were adopted but, in most cases, the final decisions on spacing, manure/fertiliser rates, whether to intercrop with beans or not, and the arrangement of seeds in the hole, were made based on the host farmers practice. Other practices agreed on included the method of planting and sequence of input application. Four planting sequences and arrangements were suggested. However, after discussions amongst the participants, the idea of placing the seed followed by manure/fertiliser application and covering with soil was rejected because the seed would be buried too deeply in the soil.

The remaining three planting sequences and arrangements were used on each farm. A summary of different planting methods used on farms is shown in Table 6. The role of the researcher in this exercise was to facilitate exchange amongst participants on the planting practices. The host farmer demonstrated the usual planting method and any modifications were discussed and agreed upon by the participants to reflect a consensus. All farmers planted in stepwise fashion according to the agreed, modified method (Plate 2). Gaps where seed failed to germinate were filled 25 –35 days after planting.

Table 4: *A summary of farmer and modified maize management practices in the long wet season*.

Farm	Plot size [Length x Width] (m)	FARMER RATES				MODIFIED RATES			
		Seed rates (Seeds/hole)	Fertiliser rates (g/hole)	Manure[1] rates (g/hole)	Spacing [2,3] (cm)	Seed rates (Seeds/hole)	Fertiliser rates (g/hole)	Manure rates (g/hole)	Spacing [2,3] (cm)
Upper midland zone									
Farm 1 – (SD)	10 x 3.3	3	4.4	114	110 x 30	5.5	4.4	114	110 x 30
Farm 2	5 x 4.25	3	13.0	100	80 x 50	4.5	26.0	150	80 x 50
Farm 3	6 x 5	3	2.0	100	100 x 30	4.5	4.0	150	100 x 30
Lower midland zone									
Farm 4	6 x 6	3	4.5	91	70 x 60	4.5	9.1	136	70 x 60
Farm 5	6 x 6	3*	5.0*	100*	70 x 50**	4.5	10.0*	150*	70 x 50**
Farm 6 – (SD)	5.6 x 13	3	3.0	114	70 x 40	4.5	3.0	114	70 x 40

* - Seeds/fertiliser/manure rates after every 60 cm in a furrow.
** - Spacing between furrows.
SD - Simple design.
1 - Manure on DM basis
2 - Spacing between rows x holes.
3 - Estimated spacing from number of holes per row.

Table 5: *Summary of manure/fertiliser rates (t/ ha), and seed rate/plant populations ('000/ha) in the long wet season.*

Farm	***Manure rates***		***Fertiliser rates***		***Seed rates***		***Actual plant populations***		***% Increase in modified plots***		
	Farmer [1]	***Modified*** [2]	***Farmer*** [1]	***Modified*** [2]	***Farmer*** [1]	***Modified*** [2]	***Farmer*** [1]	***Modified*** [2]	***Manure***	***Fertiliser***	***Plant population***
Upper midland zone											
Farm 1 (SD)	*3.1*	*3.1*	*0.12*	*0.12*	*81*	*150*	*68*	*88*	*0*	*0*	*29*
Farm 2	*2.5*	*3.8*	*0.33*	*0.66*	*76*	*114*	*48*	*81*	*50*	*100*	*70*
Farm 3	*3.8*	*5.7*	*0.08*	*0.15*	*114*	*171*	*92*	*110*	*50*	*100*	*19*
Lower midland zone											
Farm 4	*2.3*	*3.4*	*0.11*	*0.23*	*75*	*112*	*55*	*63*	*50*	*100*	*13*
Farm 5	*2.8*	*4.1*	*0.14*	*0.28*	*82*	*124*	*64*	*88*	*50*	*100*	*37*
Farm 6 (SD)	*4.3*	*4.3*	*0.11*	*0.11*	*112*	*168*	*93*	*126*	*0*	*0*	*35*

SD - Simple design.

1 - MR1

2 - MR2

Plate 2: *Participatory planting on farm.*

All farmers, except farm 5 where furrows were used, dry-planted maize in lines using holes on both farmer practice and modified plots. Farms 2 and 4 intercropped maize and beans, whilst the rest of the farms planted maize alone. Farmers modified the size of holes or furrows, making them bigger with increasing plant density. In the intercropping systems, the geometry was modified in the low-density treatment by planting beans and maize in one hole whilst on high-density plots, beans were planted in the middle of the maize rows.

Table 6. *Summary of farmer practice and modified planting practices used on farms.*

Farms	Planting sites	Sizes of holes (cm)				Method of planting		Reasons for the change in planting method
		Farmer practice		Modified		Farmer practice	Modified	
		Width	depth	Width	depth			
1, 2 and 6	Holes	23-30	18-23	35-40	35-40	Manure/fertiliser were added in that order, then seed was dropped directly before the holes were covered with soil *.	[1] Manure/fertiliser was added before planting. [2]Seeds were buried in pairs around the hole using a machete. The hole was then covered by soil.	To avoid crowding of seeds, so that seedlings would have equal chances of utilising the nutrients.
3 and 4	Holes	30	13-15	38-40	18-20	Manure/fertiliser were added in that order. Maize seed was buried deeply on one side of the hole, with beans on the opposite side, and covered with soil.	[1] Mix fertiliser/manure/ soil before placing the seeds and covering with soil. [3]Same used for beans, except planted in between the two lines of maize.	To avoid 'burning of the seeds', particularly when the manure was wet and the rains delayed.
5	Furrows	30	18-28	30	18-23	Manure/fertiliser were broadcast in that order in the furrow. Seed was then dropped at each planting station before furrows were covered with soil. The seeds were scattered in twos.	[1] Mixed fertiliser/ manure/soil at the planting station where seed was dropped. The furrows were then covered with soil.	To reduce direct contact of seed with fertiliser/manure and avoid the scorching effect.

1 - Method used on high-manure plots (MR2) only.
2 - Method used on high-density plots (SR2) only.
3 - Method used on high-density plots (SR2) only.
* - Method used in short rainyseason only. In the long rainy season, manure /fertiliser was mixed with soil before placement of seed

Planting practices in the long wet season

The participants consisted of different groups of neighbours, but the farms and the planting approach were the same as the in short wet season. Farmers dry planted the maize crop early, in anticipation that the usual rains would come on time. The method of planting in the lower midland zone was the same as in the short wet season. However, in the upper midland zone, all farmers used holes and added manure/fertiliser, mixed with soil, before planting the seed and covering with more soil. Following preliminary results after the short wet season trials and discussions with participants, alternative ways of increasing the plant density, which might be expected to avoid competition between seedlings in the same hole, were explored with the farmers individually. Based on this:

a) One farmer, who used furrows, reduced the spacing used in the short wet season from 90 cm to 60 cm for all treatments, spreading out the seeds in the furrows.

b) The rest of the farmers preferred to continue to use holes however they decided they would thin more intensely on the high-density plots than the previous trial.

Gaps were not filled where germination failed because farmers noted that, in the short wet season, young seedlings were shaded out and it was not a common practice in the study areas.

A record of germination in each plot was kept in the long wet season. As soon as plants started to germinate, weekly counts were made over three weeks until a stable population was achieved. Thereafter, only the last count of plants on all farms was used to calculate germination percentages. The time (hours or days) taken for rain to fall after planting was recorded.

Data collection in the short wet season

The researcher carried out data collection with the assistance of the farmers and two Divisional Extension Officers, attached to the Ministry of Agriculture and Livestock Development (MALD) in Kiambu District. Since data were being collected on six farms, at least three persons were required to keep the appointments with farmers. When farmers were ready to thin their crops, they alerted the extension officer in advance during the weekly visits.

Weeds: Farmers on all farms weeded twice, each time taking 1 - 4 days, depending on labour availability. The assessment criteria for weeding included when the weeds started growing above the last two leaves of maize and if there was enough moisture in the soil. Farmers were left to weed as usual, except that they were asked to heap the weeds per plot together to allow for measurements to be taken. Weeds from each plot were weighed separately, disregarding guard rows. They were mixed well and a small amount taken from each plot to make a larger sample, from which two final samples were taken for further laboratory analysis after being mixed well again.

Thinning**:** The farmers decided which/ how many treatment plots they wanted to thin. The farmers themselves selected the plants to be thinned, whilst the researchers counted and weighed the plants. Values from the net plots were recorded separately from the guard rows. Total fresh weights of maize thinnings per plot were measured using an accurate balance. The number of plants harvested from the plots were counted at every thinning, and used to describe the thinning patterns on farms. This was achieved by subtracting the number of plants removed on each day of thinning from the previous plant populations in the plots, starting with the initial plant populations. Three to four maize plants were sampled from each plot and weighed to determine fresh weight. The whole plant samples were then fractionated in the laboratory into leaf (green and dry) and stem (sheath and tassels). Samples were transported in nylon gunny bags, to avoid loss of any plant material.

The same fraction was then combined across treatments and a single sub-sample taken for DM determination at 60^{o} C. The samples were milled through a 1-mm screen, bulked on a monthly basis and stored in airtight bottles to await chemical analysis.

Green maize stover: On farm 4, green stover was harvested as a result of harvesting green maize for sale. On the rest of the farms, all unproductive plants (also classified as green stover) were thinned from the crop at cobbing stage. This material was considered as thinnings and quantities produced are not presented separately in the results. However, it can be seen separately where quantities thinned at different stages following planting are presented. Total fresh weights of green stover, number of plants and sub-sampling at harvest of green maize were determined in the same way as for thinnings. The assessment criterion for harvesting green maize was that the crop had big cobs, which are necessary to fetch a good price. All the cobs were removed and graded into big, medium and small, which attract different prices. Very small cobs were used for home consumption. Cobs harvested from the same treatment group were combined and sub samples taken to represent each grade, for determination of grain yield and DM. Sub-samples of fresh green maize stover were taken from each treatment on-farm at harvesting time for green maize, and at the harvest of unproductive plants (also classified as green stover). Sampling and fractionation procedure was the same as for thinnings.

Dry maize stover following harvest: The farmers, researchers and extension officers participated in harvesting of maize. The fresh weight of dry stover and the number of dry stover plants in each plot were measured. The sampling and fractionation procedure for dry stover was the same as for thinnings and green maize stover.

Grain production: The fresh weight of maize on the cob in each treatment was measured. On all farms, participating farmers recognised the importance of measuring yield. However, farmers did not wish to shell maize to allow accurate estimation, since they normally store grain on the cob, which they say reduces pest attacks and preserves grain quality, allowing selection for seed in the following season, if necessary. Therefore, maize grain yield was estimated from the dry weight of maize on the cob by determining the cob: grain ratios from samples collected from each treatment. DM of cob and grain were estimated from single samples, bulked across plots and treatments, by drying to constant weight at 60 ^{o}C. The sample was shelled and the cob and grain separately dried again to constant weight at 60 ^{o}C, and the DM cob: grain ratio calculated. Cob size was determined by dividing the total dry weight of maize on the cob per treatment by the number of cobs.

Beans: Beans were harvested, weighed on haulms and allowed to dry for about a week. Extension officers arranged to be present on the day the beans were threshed. Dry beans on haulms were weighed before threshing. After threshing, beans and haulms were weighed separately and sub samples taken of each to estimate DM.

Leaf strippings: On farm 6, leaves below the cobs were all stripped off in the entire plot and fed to cattle at 107 days after planting. A sub-sample of leaf strippings was taken from all treatments for DM determination at 60 ^{0} C for 48 hours.

Remains after harvest: All the leaf matter that dropped during harvest was collected from the entire plot and weighed per treatment. The quantities are included in estimates of leaf matter from stover. Two samples were taken from combined material for DM determination. The leaf matter was available for animal feed.

Analytical methods: Dried samples by fraction (leaf + stem) from the same treatment on the same farm were bulked on a monthly basis. Composite samples of maize thinnings, green stover, dry stover, leaf strippings, weeds, bean haulms, remains after harvest, beans and maize grain, were analysed for DM, ash and CP according to the methods of the Association of Analytical Chemists (AOAC, 1984). Analyses were conducted to indicate how the composition changed with time.

Data collection in the long wet season

Two extension officers again assisted in data collection. On those farms where trials consisted of four treatments, data collection was the same as in the short wet season. Differences in data collection in the simple design trials were as follows:

For fresh fodder off-take from experimental plots, farmers thinned, weighed and recorded all the measurements on simple data-sheets. Extension officers/researchers made weekly or more frequent visits to collect completed data-sheets, to supply new ones, to take samples from the field for laboratory determinations, to check on the progress of farmers and to solve any problems encountered.

Differences in data collection for both types of trials were as follows:

Thinning patterns were determined in the same way as the short wet season, except that the initial plant population was considered to be the germinated plants.

Since farmers viewed thinning as all fodder harvested from planting to cobbing stage, and green stover was fodder harvested when green maize was obtained for food or sale, fodder was categorised into thinning, green stover and dry stover.

Stem and leaf fractions were sampled. The weight of stem included tassels, whilst leaf included sheath, ears, dry and green leaves. Representative samples of thinnings and green stover were taken from the field on days when the extension officers visited the farm to supply and collect filled questionaires.

The germination rates were determined per plot by taking weekly counts for three weeks continuously until a stable number of plants were achieved. The last count of plants on all farms was used to calculate germination percentages.

In addition to the feed analysis in the short wet season, neutral detergent fibre (NDF) and acid detergent fibre (ADF) levels were determined for weeds, bean haulms, cobs, maize thinnings, green and dry stover parts according to the methods described by Goering and Van Soest (1970). Only DM and CP were determined for beans and maize grain.

All farmers were supplied with thermometers to record temperatures twice a day in the morning and afternoon. Field technicians trained farmers on how to take recordings. Attempts to record rainfall were unsuccessful, owing to theft of rain gauges, and farmers forgetting to put them out during times of rain. As was the case in the short wet season, the time taken before fall of rain (hours or days) after planting was recorded.

Soil analyses

Duplicate soil samples were taken per farm by sampling across the whole experimental area before planting in the first short wet season. The first season post-harvest soil samples served as the pre-planting samples for the second season on four out of six farms, when the experiment was carried out on the same area of land. However, where the experiment was carried out on different areas of land, soil sampling was carried out before and after each growing season.

A simple random-sampling method was used to take soil samples. Two diagonal lines were marked across each of the corners of the plot to give four triangles per plot. Samples were then taken from the point where the diagonals intersected and at two points picked at random in each triangle of the plots. Sampling was conducted at depths of 0 – 20 cm and 20 – 40 cm. Samples from each of the sampling points at a given depth were bulked and the two samples taken to the laboratory for further sub-sampling and chemical analyses.

Two pre-planting samples collected from the whole area were mixed to form one composite sample, whilst two samples were collected in each plot at the end of the season. One sub-sample each was then taken for laboratory analyses. Soil samples were air-dried before analysis. Large soil clods were crushed in a mortar using a porcelain-capped pestle, to facilitate air-drying. Soil was dried in an oven for one week at 35 - 40^{o} C. Pulverisation was carried out before analyses for total N and organic carbon (C), whilst sieving was undertaken before analysis for micronutrients.

Analyses of total N, P and C contents were based on the Kjeldahl -oxidation procedures. For K, C and Mg, samples were prepared similarly and subjected to spectrophotometric measurements. The procedures are outlined in the working manual of Okalebo *et al.* (1993). Total ash was determined by igniting the sample slowly in a muffle to a final temperature of 550^{o} C. The loss in weight represents the moisture content and the organic matter content of the sample, whilst the residue represents the ash. The pH was determined by measurement of electro-conductivity, which determines the level of salinity.

Analysis of data

All data were summarised on spreadsheets using the computer package Microsoft Excel. Statistical analysis was carried out using analysis of variance (ANOVA) procedures of the Genstat statistical computer package. The 2 x 2 factorial design experiments were analysed using general ANOVA while the simple design experiments were analysed using one-way ANOVA (in randomised blocks).

Results

This chapter presents the results of experiments carried out on six farms. The results are discussed in two main sections representing the short and long wet seasons' results, respectively.

Short Wet Season

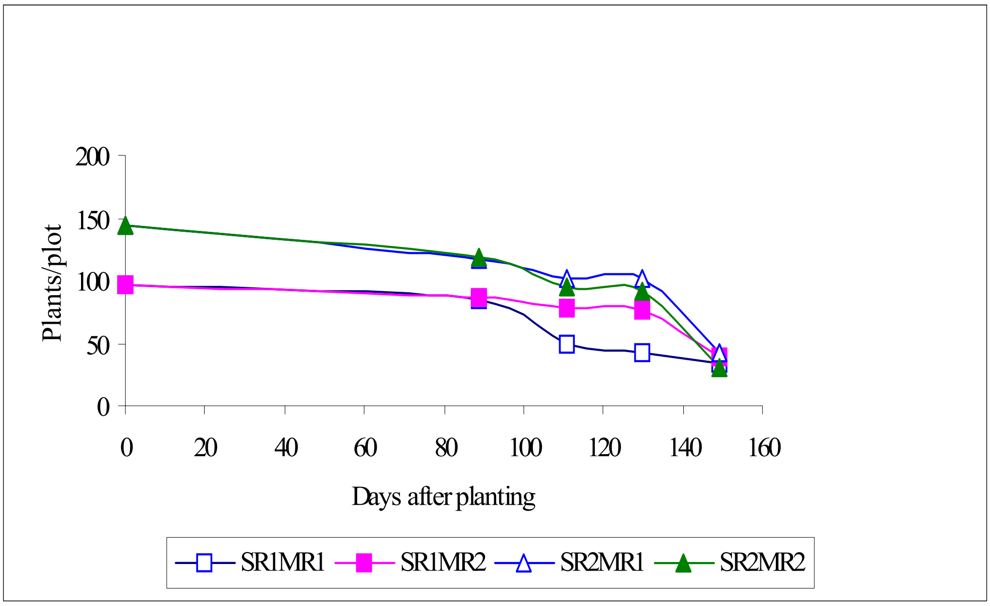
Due to insufficient rains in the upper midland zone, the crop did not mature to produce grain on three of the farms (1, 2 and 3). Farmers decided to salvage the entire maize crop as livestock feed. Farmer assessment criteria for abandoning the crop included dried tassels and non-formation of cobs on more than half of the plants. Results on the remaining three farms (4, 5 and 6) in the low midland zone where the crop matured to produce grain, are given in detail.

Thinning patterns on farms during the cropping season.

The distribution of thinning from planting to harvesting on farms 4, 5 and 6 in the lower midland zone, where the crop matured to produce grain, are shown in Figures 1, 2 and 3. Farmers thinned systematically across the field, without choosing particular treatments, to avoid the risk of missing plots. Although the intensity of thinning varied between treatments, it was apparent that some of them could not easily differentiate between treatments in the field by merely looking at the crop.

On all farms, farmers thinned between four and nine times in a period of up to 149 days (Figures 1 - 3). The decision to thin depended on two factors (a) the need for fodder regardless of the state of the crop and (b) the need to thin, where farmers considered that the population needed to be reduced in order to encourage healthy plant growth and avoid overcrowding.

Figure 1: *Thinning patterns on farm 4.*



SR1MR1 - Farmer seed and fertiliser/manure rates

SR1MR2 - Farmer seed and modified fertiliser/manure rates

SR2MR1 - Modified seed and farmer fertiliser manure rates

SR2MR2 - Modified seed and manure/fertiliser rates

Farm 5 which had had two adult cows and a calf thinned six times. However, the farmer was able to sell some of the thinning to neighbours, perhaps because the relatively larger size of farm (2.2 ha) offered the farmer other alternatives of fodder. Farm 6 thinned the highest number of times, and this may have been because it had only one plot planted to maize and one of Napier grass (0.3 ha), implying that the farm had a high dependency on the maize crop for fodder. A further indication of the high dependency on the maize crop was the fact that this farmer started thinning at 61 days after planting (DAP). Farm 5 had 0.6 ha of Napier grass and eight plots of maize.

Farm 4 which had no animals thinned the least number of times and sold all of the thinnings, making it likely that thinning was determined by crop needs and a need for cash. Farms 4 and 5 started thinning between 86 and 89 DAP. All farmers removed the highest number of plants between 104 and 130 DAP which corresponds to the cobbing stage (IITA, 1999). Thinning continued up to 130 DAP, which corresponds to the soft- and hard-dough stages. Farm 4 harvested green maize for sale around this stage and sold green stover for fodder.

Figure 2: *Thinning patterns on farm 5.*

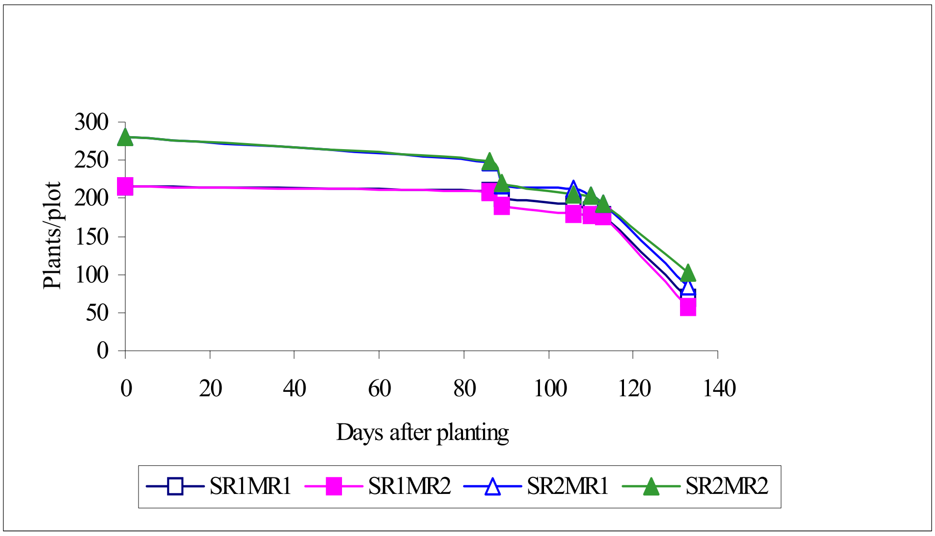
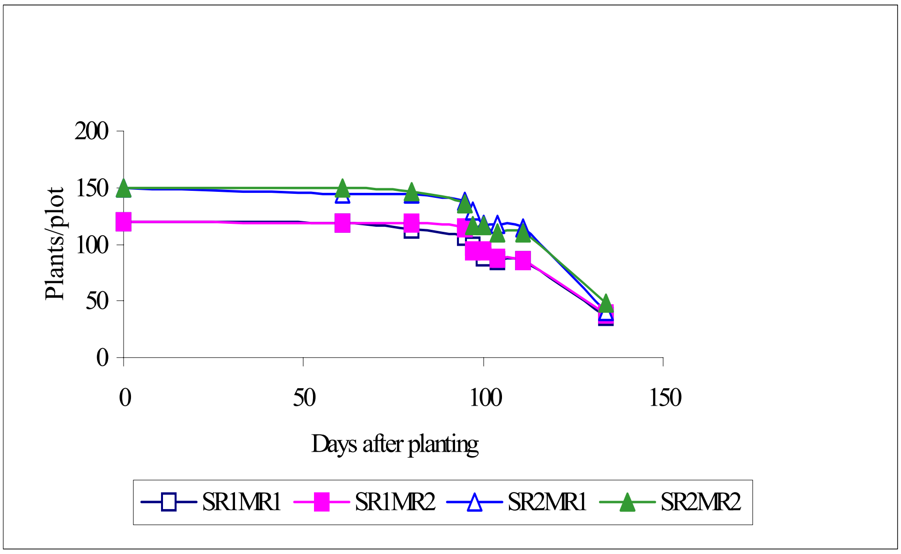


Figure 3: *Thinning patterns on farm 6.*



Farmers 4 and 6 thinned the high-density plots more heavily than SR1 plots. Thus, by the last thinning, differences in plant densities were small as shown by the convergence of the data in Figures 1 and 3. All farms showed a sharp drop in plant populations towards the end of thinning, because farmers explained that this was the time when they removed all barren plants and those with very tiny kernels, to give room for strong plants to complete grain filling. An average of 70% of the plant population was removed from the high-density plots. Of the 70 % thinned, up to a maximum of 31 % was removed by 119 DAP, whilst the remaining 40 % of thinnings was obtained between 120 and 150 DAP, which corresponds to the sharp fall in Figures 1 - 3. Table 7 shows the forage DM harvested at different stages of growth in the treatments on farms.

Maize fodder production

The main treatment effects on DM yields for all sources of forage from the maize plots including thinnings, dry stover, weeds and leaf stripping are summarised in Table 8. There was a significant ($p<0.05$) increase for thinnings on all farms except leaf on Farm 4 (Table 8). Manure/fertiliser rates showed no effects. Increasing seed rate increased the production of thinning ($p<0.05$) by up to 2.4 t DM/ha, representing increases of 17, 141 and 92 % for farms 4, 5 and 6 respectively (Table 9). No significant effects of manure/fertiliser rates were observed for thinnings, although there was a statistically significant interaction between seed and manure rate on farm 4. Dry stover production on farmers plots ranged from 4.7 to 5.4 t/ha. No significant effects of either seed rate or manure/fertiliser rate were observed on stover production, except for a positive response ($p<0.05$) of leaf DM yield on farms 4 and 5 to increased manure/fertiliser and seed rates, respectively. The total amounts of dry stover on modified plots showed very little response to fertiliser and there were no significant manure/fertiliser interactions. Leaf stripping was carried out on farm 6, and there was a significant ($p<0.05$) increase of between 11 – 74 % in leaf DM production relative to the control (Table 9).

Weed production on farms 4, 5 and 6 corresponded to 11 – 283 % increases relative to the control, although the increases were significant ($p<0.05$) only for farm 5. The weeds were available for cattle feeding after careful removal of those species thought to be poisonous. On the whole, the effects of increased seed rates were to increase the proportion of thinning on all farms (Figure 4). Leaf stripping was carried out on farm 6, where there was a significant increase of 74 % in leaf DM (Table 9) in response to increasing seed rate ($p<0.05$).

Table 7: *Mean dry matter production (DM t/ha) of maize forage in the treatments at different stages of growth.*

Days after planting	Farm 4				Farm 5				Farm 6			
	SR1 MR1	SR1 MR2	SR2 MR1	SR2 MR2	SR1 MR1	SR1 MR2	SR2 MR1	SR2 MR2	SR1 MR1	SR1 MR2	SR2 MR1	SR2 MR2
60 - 70	-	-	-	-	-	-	-	-	0.05	0.02	0.10	-
80 - 90	0.78	0.64	1.64	1.25	0.21	0.36	0.92	0.90	0.77	0.61	0.83	0.78
90 - 100	-	-	-	-	-	-	-	-	1.34	1.55	1.15	1.58
100 - 120	3.30	1.18	3.10	3.70	1.65	0.88	2.46	2.91	0.93	1.47	2.00	1.79
120 - 130	1.23	1.39	-	1.24	-	-	-	-	-	-	-	-
Total	**5.31**	**3.21**	**4.74**	**6.19**	**1.86**	**1.24**	**3.38**	**3.81**	**3.09**	**3.65**	**4.08**	**4.15**

SR1MR1 - Farmer seed rate and manure rate (control)
SR1MR2 - Farmer seed rate and modified manure rate
SR2MR1 - Modified seed rate and farmer manure rate
SR2MR2 - Modified seed rate and manure rate

Table 8: *Main treatment effects on mean DM fodder production (t/ha) of fodder resources in the short wet season.*

Farm	Parameter	Seed rates		Manure rates		Sed		Significance		
		1	2	1	2	main effect	interaction	seed	manure	seed x manure
Farm 4	Thinnings:					DM (t/ha)				
	Leaf	1.18	1.71	1.65	1.23	0.27	0.37	n.s.	n.s.	n.s.
	Stem	2.41	3.61	3.22	2.79	0.27	0.38	*	n.s.	*
	Total	3.59	5.31	4.88	4.02	0.68	0.96	*	n.s.	*
	Dry stover:									
	Leaf	1.81	2.38	1.74	2.45	0.28	0.40	n.s.	*	n.s.
	Stem	3.62	4.40	3.56	4.46	0.80	1.14	n.s.	n.s.	n.s.
	Total	5.42	6.78	5.29	6.91	0.98	1.38	n.s.	n.s.	n.s.
	Weeds	1.10	1.57	0.62	2.06	1.16	1.64	n.s.	n.s.	n.s.
	Total forage	17.07	16.65	18.71	21.11	2.35	3.32	n.s.	n.s.	n.s.
Farm 5	Thinnings:									
	Leaf	0.54	1.47	1.03	0.97	0.11	0.16	***	n.s.	n.s.
	Stem	0.91	2.39	1.68	1.62	0.21	0.29	***	n.s.	n.s.
	Total	1.45	3.85	2.71	2.59	0.30	0.42	***	n.s.	n.s.
	Dry stover:									
	Leaf	2.84	3.97	3.42	3.38	0.41	0.58	*	n.s.	**
	Stem	3.96	4.34	3.61	4.70	0.91	1.29	n.s.	n.s.	n.s.
	Total	6.80	8.31	7.03	8.08	1.17	1.66	n.s.	n.s.	n.s.
	Weeds	0.39	1.03	0.73	0.70	0.08	0.11	***	n.s.	n.s.
	Total forage	8.64	13.19	10.47	11.37	1.18	1.67	**	n.s.	n.s.
Farm 6	Thinnings:									
	Leaf	1.61	2.62	1.98	2.25	0.31	0.43	**	n.s.	n.s.
	Stem	1.89	2.91	2.26	2.54	0.28	0.39	*	n.s.	n.s.
	Total	3.49	5.54	4.24	4.79	0.39	0.56	*	n.s.	n.s.
	Dry stover:									
	Leaf	2.66	2.06	2.42	2.30	0.40	0.56	n.s.	n.s.	n.s.
	Stem	2.05	1.71	1.91	1.86	0.27	0.39	n.s.	n.s.	n.s.
	Total	4.71	3.77	4.32	4.16	0.62	0.87	n.s.	n.s.	n.s.
	Weeds	1.84	1.79	1.67	1.95	0.81	1.15	n.s.	n.s.	n.s.
	Leaf stripping	0.70	1.07	0.82	0.94	0.13	0.19	*	n.s.	n.s.
	Total forage	18.93	21.47	19.62	20.79	1.80	2.55	n.s.	n.s.	n.s.

Sed = Standard error of difference of means; n.s. = not significant (p > 0.05); * - p= <0.05; *** - p= <0.01

Table 9: *Percentage change in yields of forage sources in different treatments relative to the controls on farms in the short wet season.*

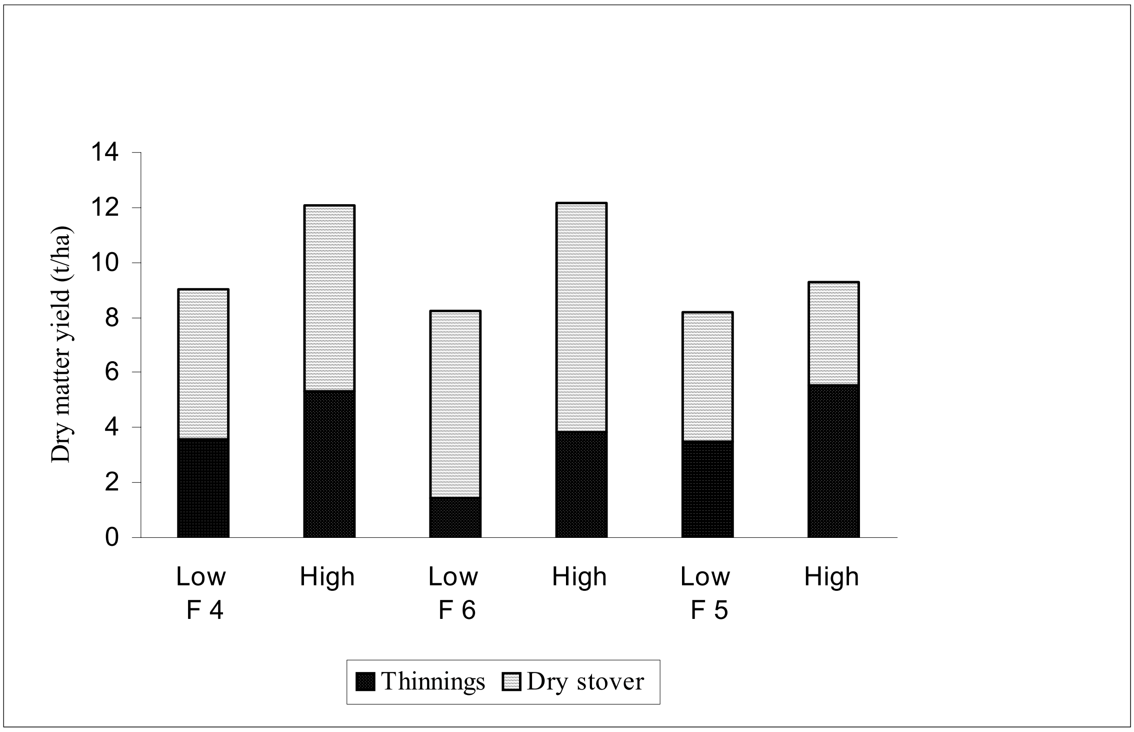
Farm	Parameter	SR1MR2	SR2MR1	SR2MR2
Farm 4	Thinnings:			
	leaf	-56	2	6
	stem	-57	-9	23
	total	-57	-5	17
	Dry stover:			
	leaf	51	111	89
	stem	78	73	65
	total	68	62	73
	Weeds	126	-18	283
	Bean haulm	-38	-23	-9
	Total forage DM	1	15	48
	Grain yield	75	53	61
	Bean yield	-38	-23	-21
Farm 5	Thinnings:			
	leaf	-24	123	137
	stem	-18	149	147
	total	-22	133	141
	Dry stover:			
	leaf	-47	-15	29
	stem	15	-4	40
	total	-16	-9	35
	Weeds	-22	132	141
	Total forage DM	-20	49	110
	Grain yield	-3	35	38
	Green maize yield	117	27	73
Farm 6	Thinnings:			
	leaf	66	128	107
	stem	34	81	81
	total	48	101	92
	Dry stover:			
	leaf	-6	-24	-26
	stem	-15	-28	-17
	total	-10	-26	-22
	Weeds	11	-8	14
	Leaf stripping	11	48	74
	Total forage DM	11	19	21
	Grain yield	-19	-27	-26

SR1MR2 - Farmer seed rate and modified manure rate

SR2MR1 - Modified seed rate and farmer manure rate

SR2MR2- Modified seed rate and manure rate

Figure 4: *Effects of seed rate on fodder production.*



F - Farm

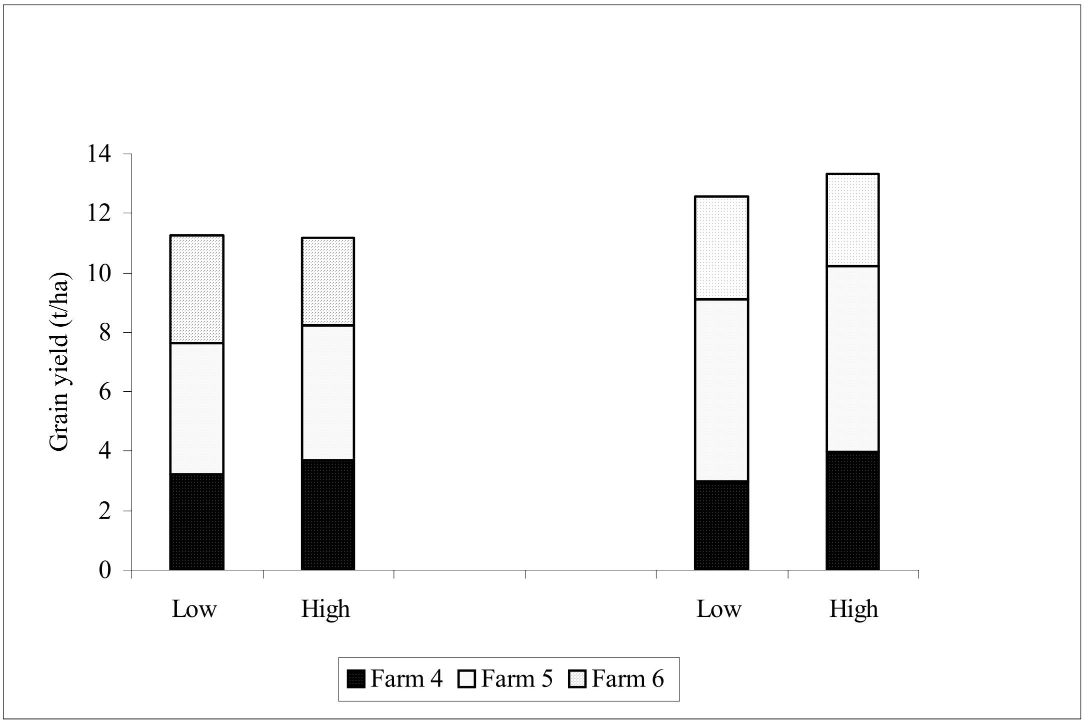
Low - Farmer seed rate (SR1)

High - Modified seed rate (SR2)

Maize grain and bean yields

A summary of grain yields is shown in Figure 5, whilst details of grain/bean yields, fresh/dry cob weights, and cob: grain ratios are shown in Table 10. Grain yields were only changed on farm 5, where increased seed rate resulted in a small decrease in yield ($p<0.01$), and increased manure/fertiliser rate ($p<0.01$) resulted in a small increase in yield. There was a non-significant reduction in grain yields in farm 6 in response to increased seed rate. The farmer increased plant density by only 17%, but had a heavy reliance on the maize crop for fodder. This may suggest that small increases in plant density, followed by intense thinning, could negatively affect grain yields. Farm 4 had the lowest increase in thinnings on the SR2 plots and there was a tendency for larger numbers of small cobs to be produced although the difference was not significant. This trend is not so evident for farms 5 and 6, where greater increases in thinnings were recorded.

Figure 5: *Effects of seed and manure rates on grain production.*



Low - Farmer rates

High - Modified rates

On farm 4, maize was intercropped with beans in the short wet season and showed yields that ranged between 1.4 and 1.6 t/ha. Differences between treatments were not significant. There was variation in cob sizes between all farms. There was a non-significant reduction in cob size on farms 4 and 5 in some treatments relative to the control. Farms 4 and 6 showed an increased in the number of cobs relative to the control on high-density and high-manure plots, whilst farm 6 recorded a reduced number of cobs relative to the control although the difference was not significant. Although results from different farms are not directly comparable, it is interesting to note that the smallest cobs were observed on Farm 5 where final plant densities were the highest. This farm also had the highest overall grain yields though the fodder DM off-take was the lowest. There is no clear trend in the cob: grain ratios.

Table 10: *Effects of seed and manure/fertiliser rates on Maize and bean yield components in the short wet season*.

	Parameter	Treatments				S. E. D of means		Significance		
		Seed rate		Manure rate		Main effect	Interaction (Seed x manure)	Seed	Manure	Seed x manure
		1	2	1	2					
Farm 4	Maize yield (t/ha)	2.36	4.12	3.62	3.80	0.55	0.78	n.s.	n.s.	n.s.
	Bean yield (t/ha)	1.64	1.79	1.57	1.43	0.26	0.36	n.s.	n.s.	n.s.
	Green maize (DM basis)[1]									
	Cob numbers/plot	54	76	53	66	3.56	5.07	n.s.	n.s.	n.s.
	Cob weight (DM g)	204	154	239	175	15	22	n.s.	n.s.	n.s.
	Grain : cob ratio	3.6 : 1	4.0 : 1	4.0 : 1	3.6 : 1	-	-	-	-	-
Farm 5	Maize yield (t/ha)	4.52	4.38	6.11	6.25	0.67	0.95	**	**	**
	Dry maize:									
	Cob numbers/plot	71	76	69	107	3.72	5.27	n.s.	**	n.s.
	Cob weight (DM g)	188	186	199	175	0.32	0.45	n.s.	n.s.	n.s.
	Grain : cob ratio	2.2 : 1	1.8 : 1	2.0 : 1	2.6 : 1	-	-	-	-	-
Farm 6	Maize yield (t/ha)	4.02	3.25	2.92	2.99	0.55	0.77	n.s.	n.s.	n.s.
	Dry maize:									
	Cob numbers/plot	44	49	36	43	3.59	5.07	n.s.	n.s.	n.s.
	Cob weight (DM g)	192	191	197	187	0.17	0.24	n.s.	n.s.	n.s.
	Grain : cob ratio	3.3 : 1	3.2 : 1	2.9 : 1	3.9 : 1	-	-	-	-	-

[1] - Green maize harvested at dough stage and yield converted on a DM basis.
1 - Farmer rates (SR1MR1)
2 - Modified rates (SR2MR2)
n.s. – not significant ($P > 0.05$); ** - $p<0.01$

Salvage crop dry matter production

On three farms (1,2 and 3), insufficient rainfall led to a failure in maize grain production. The crops were harvested for fodder to salvage something from the plantings. Means for total DM production are summarised in Table 11. Farmer 2, who owned one cow and a calf, sold half of the salvage fodder whilst the rest of the farmers harvested the crop little by little as they fed their cows over 32 days. The highest amounts of salvage crop were obtained on farm 1 located in the cooler upper midland zones.

Table 11: *Effects of seed and manure/fertiliser rates on total DM production (t/ha) in the salvage crop on farms in the upper midland zones.*

Farm	*Seed rate*		*Manure rate*		*Sed of means*		*Significance*		
	1	*2*	*1*	*2*	*Main effect*	*Interaction (seed x manure)*	*seed*	*manure*	*Seed x manure*
Farm 1	*7.31*	*6.66*	*6.30*	*7.67*	*1.09*	*1.55*	*n.s.*	*n.s.*	*n.s.*
Farm 2	*2.47*	*3.13*	*3.14*	*2.47*	*0.74*	*0.52*	*n.s.*	*n.s.*	*n.s.*
Farm 3	*0.96*	*1.67*	*1.39*	*1.24*	*0.32*	*0.22*	*	*n.s.*	*n.s.*

1 - Farmer rates

Modified rates

n.s. – not significant (p > 0.05); ** - p<0.01

CP contents

A summary of the CP contents of fodder is shown in Table 12. The salvage crop harvested at 49 DAP showed a higher CP content than thinnings harvested subsequently. Green leaves had a consistently higher CP value than stems, sheath and husks in both the salvage crop and maize thinnings. The maize/bean intercrop plots in the lower midland zone (Farm 4) showed consistently higher levels of CP in all fractions of the maize fodder. This may be due to N contribution from the beans (Willey, 1979). There were, however, no clear differences in CP contents between monocrop and intercropping systems in the high midland zones, where the maize was harvested as a salvage crop.

Table 12: *Crude protein (CP) contents (g/kg DM) of the salvage crop, maize thinnings and other fodder produced on farms in the lower and upper midland zones.*

Fodder type	Lower midland zone						Upper midland zone					
	Farm 1		Farm 2		Farm 3		Farm 4		Farm 5		Farm 6	
	Salvage crop						Maize thinnings					
	DM	CP	DM	CP	DM	CP	DM	CP	DM	CP	DM	CP
Stems	236	72	238	56	180	61	288	37	190	43	220	35
Green leaves	354	132	590	117	340	104	274	79	295	105	315	72
Dry leaves	670	60	886	53	897	61	650	41	821	48	905	40
Sheath	-	-	-	-	-	-	781	24	647	24	879	15
Husks	-	-	-	-	-	-	520	34	512	44	509	21
Tassels	550	66	332	120	750	129	501	62	584	76	497	55
Remains after harvest	-	-	-	-	-	-	-	47	904	48	922	29
Weeds	-	-	325	278	264	158	-	-	260	26	320	133
Bean straw	-	-	897	74	-	-	-	-	904	131	-	-

Pre-planting soil status

Data for soils sampled before planting are summarised in Table 13. The results show a wide variation in levels of N, P and Ca in the soils. Four farms 1, 2, 4 and 5 showed very low levels of P. All the farms had very high levels of magnesium (> 180 ppm). The pH values fell within the normal ranges (Roche *et al*., 1980; Okalebo *et al.,* 1989).

Table 13: *Analysis of soils sampled from experimental plots before planting*.

	SOIL NUTRIENTS						
Farms	**C**	**N**	**P**	**K**	**Ca**	**Mg**	**PH**
	(%)		**(ppm)**				
Upper midland zone							
1	2.46	0.30	8	371	2230	266	6.08
2	3.20	0.32	5	468	1678	218	5.71
3	2.84	0.26	24	178	1193	210	5.28
Low midland zone							
4	2.64	0.28	3	449	712	184	5.23
5	2.65	0.26	5	209	566	130	5.00
6	2.53	0.22	32	124	1219	216	5.46

Post-harvest soil status

Table 14 shows mean values for soil parameters analysed after harvesting the crop. The results show a general increase in N content and other nutrients relative to the levels before planting, but there is no clear trend between treatments.

Table 14: *Mean values for soil parameters analysed after harvesting the crop*.

Farm	Treatment	N	P	Ca	Mg	PH
		SOIL NUTRIENTS				
		(%)		(ppm)		
Upper midland zone						
1	SR1MR1	0.44	7	2688	239	5.85
	SR1MR2	0.40	8	2705	241	5.73
	SR2MR1	0.41	8	2792	248	6.08
	SR2MR2	0.39	9	2342	229	5.85
2	SR1MR1	0.35	8	1632	217	5.20
	SR1MR2	0.31	9	1565	226	5.32
	SR2MR1	0.34	8	1505	219	5.28
	SR2MR2	0.34	16	1876	236	5.41
3	SR1MR1	0.33	32	1135	196	4.95
	SR1MR2	0.36	34	1177	200	5.20
	SR2MR1	0.33	28	964	181	5.23
	SR2MR2	0.34	40	1201	209	5.13
Low midland zone						
4	SR1MR1	0.32	1	460	173	5.05
	SR1MR2	0.27	1	333	147	4.98
	SR2MR1	0.31	1	425	169	5.03
	SR2MR2	0.33	1	459	197	5.13
5	SR1MR1	0.29	21	460	117	4.70
	SR1MR2	0.28	19	603	131	5.03
	SR2MR1	0.29	20	573	142	4.88
	SR2MR2	0.30	36	923	205	5.13
6	SR1MR1	0.27	47	1064	207	5.50
	SR1MR2	0.28	35	1082	190	5.30
	SR2MR1	0.20	43	919	217	5.20
	SR2MR2	0.22	68	1060	212	5.20

SR1MR1 - Farmer seed and fertiliser/manure rates

SR1MR2 - Farmer seed and modified fertiliser/manure rates

SR2MR1 - Modified seed and farmer fertiliser manure rates

SR2MR2 - Modified seed and manure/fertiliser rates

Long Wet Season

Germination rates

Table 15 shows the germination rates on farms. High-density plots recorded lower germination rates than low-density plots on all farms except Farm 2. This explains why some of the high-density plots have the same number of plants per plot as low-density. However the reduction was significant ($p<0.005$) for Farms 1 and 6 only, which had simple design experiments. These two farms increased actual plant population by 70 and 35 *per cent* respectively. Low germination percentages on farms 3 and 4 explain why the same plant populations exist for SR2MR1 and the low-density plots at the start of thinning. Plant population development was also spread out on farm 2, due to germination differences between treatments.

Thinning patterns during the cropping season.

Farms, 2 and 3 in the upper midland zone and Farms 5 and 6 in the lower mid-land zone, started thinning in the long wet season in May, whilst on farm 4 in the lower midland zone thinning started in June. Thinning on farm 6, in the upper midland zone that borders on the highland zone, started in July. Thinning continued up to August on farms 2, 3, 4 and 6 and was extended up to October on farm 1, which might be due to the influence of altitude and cooler temperatures (Kiambu, 1994-1996) resulting in slow growth of maize. Data recorded on the farms showed that Farm 1 experienced lower temperatures.

Thinning on farms 2 and 3 in the upper midland zone was carried out six times between 63 and 155 DAP (Figure 6). The two farms recorded the highest thinning percentages of between 62 – 73 *per cent* and 41 – 63 *per cent*, respectively. Farm 2 recorded the highest increase in actual plant population (70 *per cent*) while Farm 3 had plant populations, in excess of 100,000 plants per ha on modified plots. The lowest number of thinnings was carried out on farm 4, before the farmer decided to harvest green maize for sale (Figure 7). This farmer thinned three times between 73 and 143 DAP and, as in the short season, the need for cash was likely to be the most important factor in this decision.

Table 15: *A summary of germination percentages recorded on farms in the long wet season.*

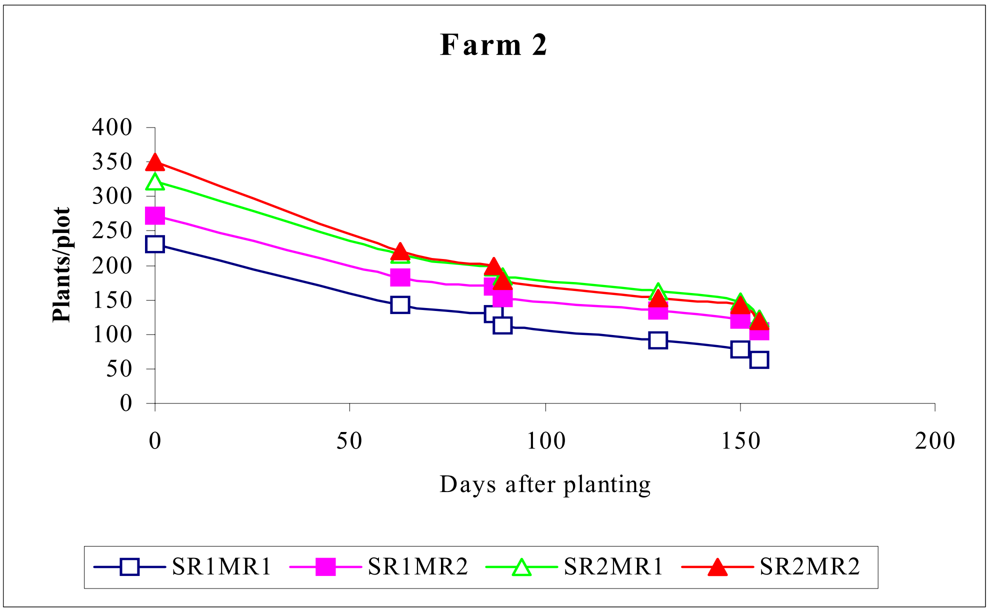
Farm	Seed rates		Manure rates		Sed of means		Statistical significance		
	1	2	1	2	Main effect %	Interaction (seed x manure)	seed	manure	seed x manure
Upper midland zone									
1 (simple design)	81.9	60.9	-	-	3.43	-	***	-	-
2	76.5	77.3	75.2	78.6	3.08	4.35	n.s.	n.s.	n.s.
3	80.9	64.2	68.8	76.4	4.76	6.73	n.s.	**	NS
Lower midland zone									
4	73.1	55.8	63.3	66.3	9.84	13.91	n.s.	n.s.	n.s.
5	80.8	75.8	74.5	82.1	4.86	6.88	n.s.	n.s.	n.s.
6 (simple design)	78.0	52.0	-	-	3.73	-	***	-	-

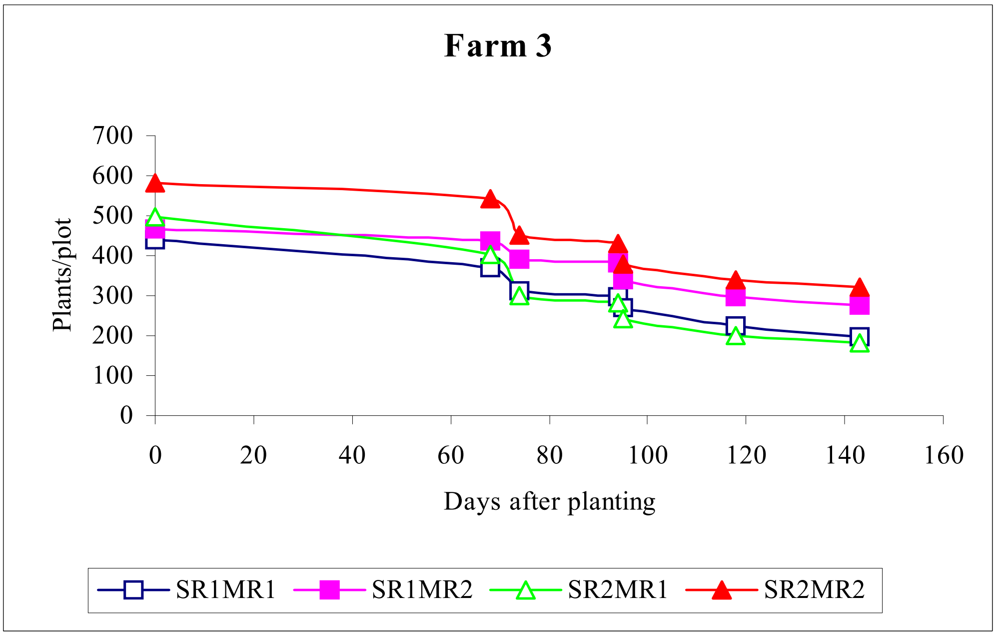
n.s. - Not significant (P > 0.05)

** - (p<0.05)

*** - (p<0.005)

Figure 6: *Thinning patterns on experimental farms in the upper midland zones*





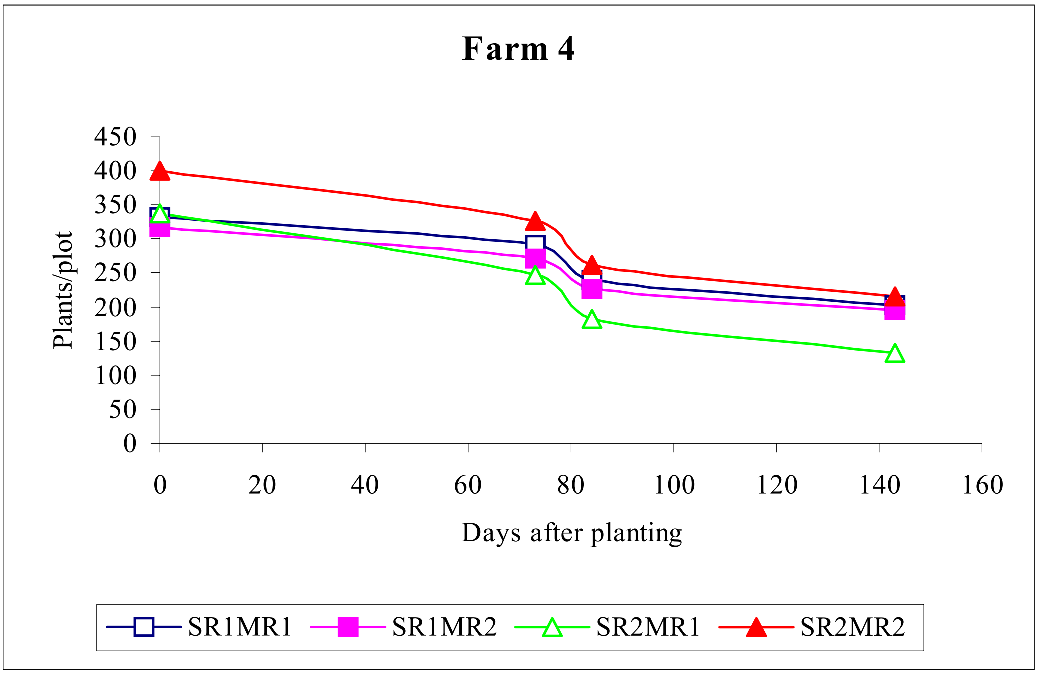
SR1MR1 - Farmer seed and fertiliser/manure rates

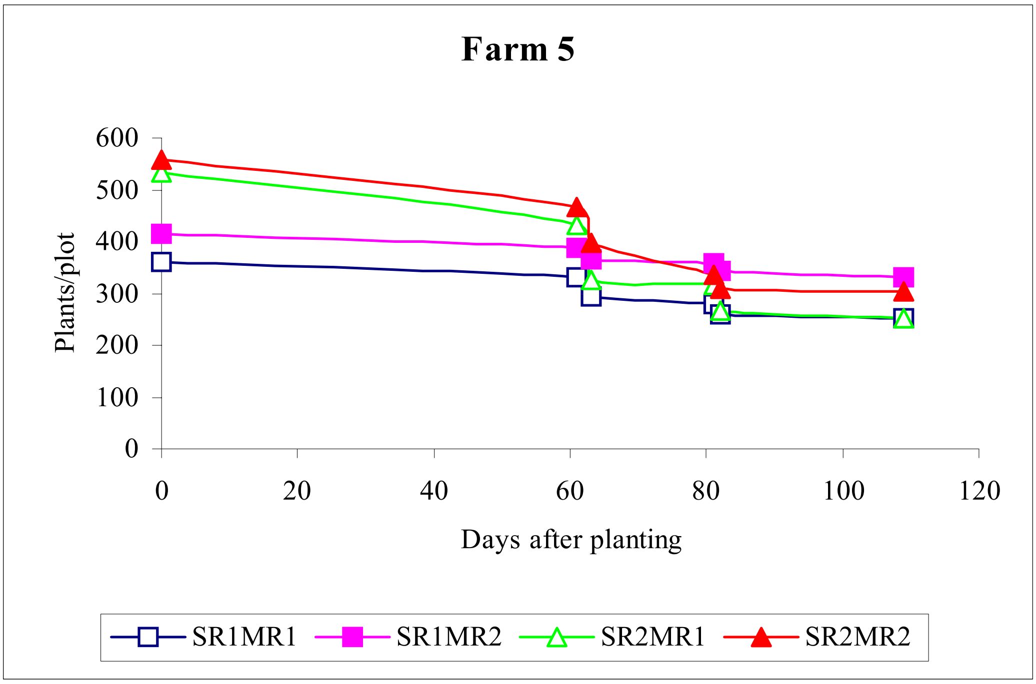
SR1MR2 - Farmer seed and modified fertiliser/manure rates

SR2MR1 - Modified seed and farmer fertiliser manure rates

SR2MR2 - Modified seed and manure/fertiliser rates

Figure 7: *Thinning patterns on experimental farms in the lower midland zones.*





SR1MR1 - Farmer seed and fertiliser/manure rates

SR1MR2 - Farmer seed and modified fertiliser/manure rates

SR2MR1 - Modified seed and farmer fertiliser manure rates

SR2MR2 - Modified seed and manure/fertiliser rates

Farmer 4 thinned the maize crop by 38 – 39 *per cent* and 44 – 61 *per cent* on low and high-density plots, respectively. Farmer 5 thinned five times between 61 and 109 DAP, before he made the decision to harvest the entire crop due to insufficient rainfall. The farmer continued to harvest the salvage crop through August into the first week of September. The maize crop on farm 5 was thinned by 21 - 30 *per cent* and 46 - 53 *per cent* on low and high-density plots, respectively.

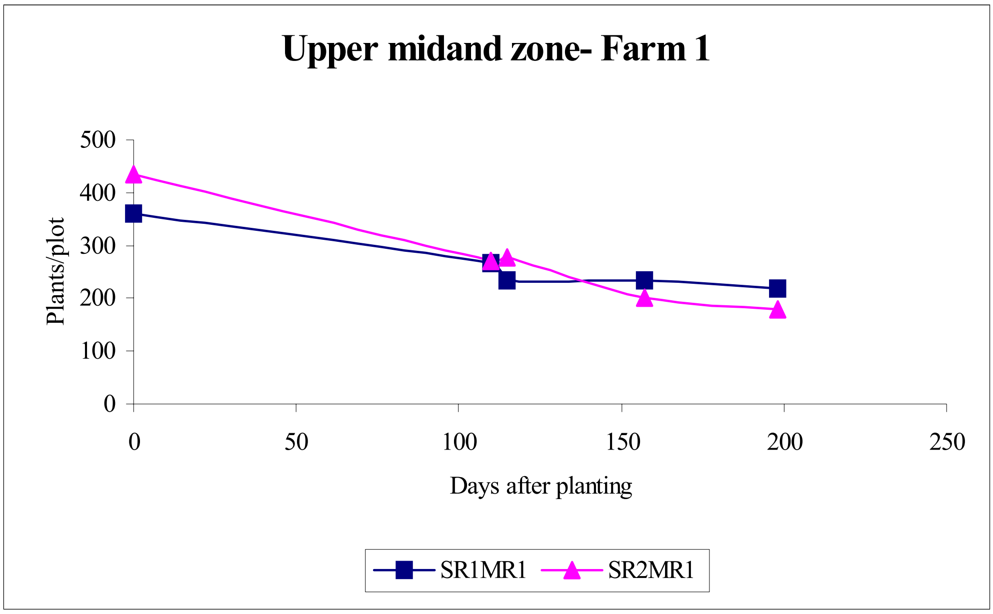
Thinning on Farm 6 in the upper midland zone was carried out four times between 110 – 198 DAP. This reduced the plant population by 40 and 59 *per cent* on low and high-density plots, respectively despite recording the highest percentage increase in plant population of 70 *per cent*. The crop may not have experienced moisture stress because the area is cool and often receives more rainfall than other areas of the zone. As in the short wet season, farm 6 was the first to start thinning, at 54 DAP and the farmer continued thinning up to 143 DAP; thinning 18 times in all (Figure 8). The farmer thinned the maize crop between 40 and 73 *per cent* on low and high-density plots, respectively. The farmer owns 1.8 ha of land, out of which half is under coffee and the remainder for food crops and fodder production reducing options available on-farm for other sources of fodder.

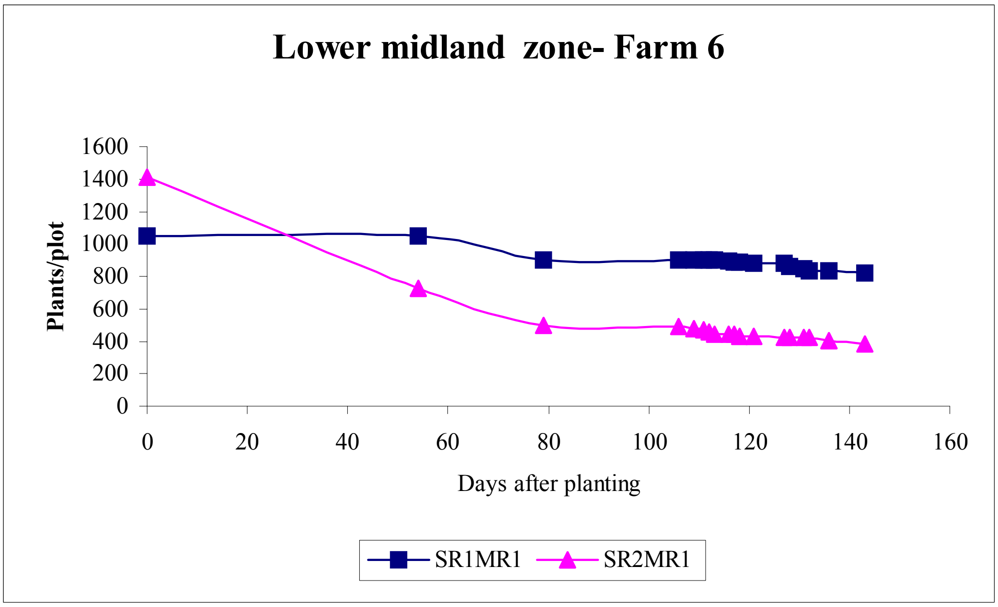
Results show that there is a more even thinning pattern on farmer-managed farm 6 (Figure 8) than on experimental plots, except on farm 2 where there is gradual thinning. This farmer owned four animals, the highest number on all the trial farms, and only 0.4 ha of Napier, suggesting that the farm relied heavily on the maize crop for fodder. On the remaining experimental farms, the reduction in plant population in plots was conducted in phases, suggesting that a significant amount of green matter was obtained at any given thinning. This may imply that thinning is influenced mainly by crop needs.

Maize fodder production

Two categories of green maize stover were obtained from the plots, plants without kernels and stover obtained at harvest of green maize cobs at the milk or dough stages for home consumption or sale. Farmers did not view this material strictly as maize thinnings, but rather green stover obtained from barren plants as a result of poor rains. Harvesting of green maize stover occurred from 118 – 163 DAP on experimental plots in the lower midland zone extending up to 198 DAP in the upper midland zone. The entire crop on Farm 5 was salvaged at 164 DAP due to insufficient rainfall.

Figure 8: *Thinning patterns on farmer-managed plots in the upper and lower midland zones*





SR1MR1 - Farmer seed and fertiliser/manure rates

SR2MR1 - Modified seed and farmer fertiliser manure rates

Means for DM production are shown in Tables 16, 17 and 18. Increasing plant density increased thinning DM production (p<005) on all farms relative to the control except Farm 1. The lack of effect on farm 1 may be as a result of a low germination percentage of (52 %) in high-density plots as compared to 78 *per cent* on low-density plots.

Intercropping systems (Farms 2 and 4) at thinning increased DM production relative to the control ($p<0.005$) by 46 - 58%, whilst in monocropping systems (Farm 3) higher rates of 58 – 119 *per cent* ($p<0.005$) were recorded. Farm 5, where the crop did not mature to produce grain, gave the lowest amounts of thinning. The farmer planted the H 625 variety which requires annual rainfall in excess of

800 mm, whilst the rest of the farmers opted for H 614, whose rainfall requirement is as low as 600 mm per annum (KARI, 1998).

Often there was an increase in thinnings and green stover with a resulting decrease in dry stover, which was significant for Farms 2, 3 and 6. In contrast, Farms 1 and 4, both of whom thinned infrequently, had an increase in stover production although this was only significant for Farm 1. It is interesting to note that these farms showed the greatest increases in numbers of cobs. Farms 1 and 4 recorded the lowest germination percentages on the high-density plots, which may have resulted in less moisture stress than was observed on the other farms.

Farms 2 and 3 (Table 15) produced the highest amount of barren green stover, an increase ($p<0.05$) of 42 *per cent* relative to the control. Farm 2 recorded the highest increase in plant population while Farm 3 had the second highest estimated plant population, which may explain the high proportions of plants without kernels. This could have been attributed to the severe moisture stress in the early stages of growth reported by the farmers. Farms 1 and 6 (Table 17), where farmers recorded data themselves, produced the lowest amount of barren plants, an increase ($p<0.05$) of only 37 *per cent* relative to the control despite the fact that Farm 6 had the highest estimated population.

Total forage production only increased significantly on Farm 4, where fodder was harvested green due to the sale of green maize. On the remaining farms increases were non-significant, except on Farm 6, where a significant decrease was observed. The percentage changes of the main parameters on farms relative to the control are shown in Tables 19 and 20.

Table 16: *Main treatment effects on mean DM production (t/ha), of fodder resources in the upper midland zones (see Table 17 for footnotes).*

Farm	Parameters	Seed rates		Manure rates		Sed of means		Significance		
		1	2	1	2	main effect	Interaction (seed x manure)	seed	manure	seed x manure
						DM (t/ha)				
2	Thinnings:									
	leaf	1.17	1.49	1.24	1.42	0.14	0.20	**	n.s.	**
	stem	0.95	1.31	1.05	1.21	0.13	0.19	**	n.s.	**
	total	**2.11**	**2.80**	**2.29**	**2.63**	**0.26**	**0.37**	**	n.s.	**
	Green stover:									
	leaf	1.84	2.24	2.02	2.06	0.39	0.55	n.s.	n.s.	n.s.
	stem	2.04	2.53	2.33	2.24	0.30	0.42	n.s.	n.s.	n.s.
	total	**3.88**	**4.78**	**4.35**	**4.30**	**0.65**	**0.93**	n.s.	n.s.	n.s.
	Dry stover:									
	leaf	1.66	1.20	1.22	1.64	0.19	0.27	**	**	n.s.
	stem	2.29	1.73	1.85	2.17	0.23	0.33	**	n.s.	n.s.
	total	**3.95**	**2.93**	**3.08**	**3.81**	**0.35**	**0.50**	**	**	n.s.
	Bean haulms	1.05	0.82	0.92	0.94	0.12	0.17	n.s.	n.s.	n.s.
	Total forage	10.99	**11.33**	**10.64**	**11.68**	**0.43**	**0.60**	n.s.	**	n.s.
3	Thinnings:									
	leaf	1.22	1.69	1.40	1.51	0.01	0.20	***	n.s.	n.s.
	stem	0.88	1.27	1.00	1.16	0.10	0.14	***	n.s.	n.s.
	total	**1.20**	**2.97**	**2.40**	**2.67**	**0.23**	**0.33**	***	n.s.	n.s.
	Green stover:									
	leaf	1.89	1.42	1.61	1.70	0.17	0.24	**	n.s.	n.s.
	stem	2.70	2.32	2.32	2.70	0.22	0.31	n.s.	n.s.	n.s.
	total	4.60	**3.74**	**3.93**	**4.41**	**0.35**	**0.49**	**	n.s.	n.s.
	Dry stover:									
	leaf	0.93	0.60	0.78	0.75	0.19	0.27	n.s.	n.s.	n.s.
	stem	1.45	1.24	1.22	1.47	0.11	0.16	n.s.	**	n.s.
	total	**2.38**	**1.84**	**2.01**	2.21	**0.24**	**0.33**	**	n.s.	n.s.
	Total forage	**8.77**	**9.39**	**7.91**	**9.18**	**0.53**	**0.74**	n.s.	n.s.	n.s.

Table 17: *Main treatment effects on mean DM production (t/ha), of fodder resources in the lower midland zone.*

Farm	Parameter	Seed rates		Manure rates		Sed of means		Significance		
		1	2	1	2	main effect	Interaction (seed x manure)	seed	manure	seed x manure
4	Thinnings:									
	leaf	0.79	1.09	0.96	0.92	0.08	0.12	***	n.s.	n.s.
	stem	1.33	1.85	1.61	1.57	0.14	0.20	***	n.s.	n.s.
	total	**2.12**	**2.94**	**2.56**	**2.49**	**0.21**	**0.29**	***	n.s.	n.s.
	Green stover									
	leaf	0.76	1.13	1.02	8.62	0.27	0.39	n.s.	n.s.	n.s.
	stem	1.34	1.82	1.58	1.58	0.40	0.56	n.s.	n.s.	n.s.
	total	**2.10**	**2.95**	**2.60**	**2.45**	**0.66**	0.93	n.s.	n.s.	n.s.
	Dry stover:									
	leaf	0.85	1.14	0.87	1.12	0.22	0.32	n.s.	n.s.	n.s.
	stem	1.03	1.54	1.08	1.49	0.25	0.36	n.s.	n.s.	n.s.
	total	**1.88**	**2.68**	**1.95**	**2.61**	**0.47**	0.66	n.s.	n.s.	n.s.
	Bean haulm	1.58	0.51	0.58	0.51	0.09	**0.13**	n.s.	n.s.	n.s.
	Weeds	1.84	1.60	1.22	1.22	0.40	0.56	n.s.	n.s.	n.s.
	Total forage	**7.50**	**10.68**	**8.91**	**9.28**	**0.92**	**1.30**	***	n.s.	n.s.

1 - Farmer rates
2 - Modified rates
Sed - Standard error of difference of means
** - p<0.05
*** - P<0.005
n.s. - Not significant
Note - footnotes also apply to Table 16 and 18)

Table 18: *Main treatment effects on mean DM production (t/ha), of fodder resources on farmer managed plots (see Table 17 for footnotes).*

Farm	Parameter	Seed rates		Sed of means	Significance
		1	2	Seed	
1	Thinnings:				
	leaf	1.61	0.63	0.25	**
	stem	1.44	0.58	0.20	***
	total	**3.05**	**1.22**	**0.44**	***
	Green stover:				
	leaf	0.29	0.23	0.03	n.s.
	stem	0.90	0.41	0.04	***
	total	**0.48**	**0.63**	**0.07**	**
	Dry stover:				
	leaf	6.12	5.68	0.27	n.s.
	stem	6.10	8.23	0.35	***
	total	**12.27**	**13.92**	**0.62**	**
	Total forage	**15.79**	**15.77**	**0.59**	n.s.
6	Thinnings:				
	leaf	1.03	1501	0.15	**
	stem	1.06	1524	0.12	**
	total	**2.09**	**3025**	**0.27**	**
	Green stover:				
	leaf	0.15	0.14	0.06	n.s.
	stem	0.12	0.22	0.08	n.s.
	total	**0.27**	**0.37**	**0.19**	n.s.
	Dry stover:				
	leaf	3.13	1.57	0.40	**
	stem	3.75	1.32	0.47	***
	total	**6.88**	**2.89**	**0.87**	**
	Weeds	0.61	0.46	0.14	n.s.
	Total forage	**9.97**	**6.89**	**0.52**	n.s.

Table 19: *Percentage change in yields of forage sources in different treatments relative to the controls*.

Parameters	Farm 2			Farm 3			Farm 4			Farm 5		
	SR1MR2	SR2MR1	SR2MR2	SR1MR2	SR2MR1	SR2MR2	SR1MR2	SR2MR1	SR2MR2	SR1MR2	SR2MR1	SR2MR2
Thinning:												
leaf	-11	1	41	10	41	50	14	60	37	22	134	114
stem	-16	4	52	23	53	69	9	53	38	16	142	123
total	**-13**	**2**	**46**	**15**	**46**	**58**	**11**	**56**	**38**	**19**	**138**	**119**
Green stover:												
leaf	7	28	25	-3	-32	-20	-21	42	25	-	-	-
stem	23	55	22	7	-22	0	0	36	36	-	-	-
total	**15**	**42**	**24**	**-27**	**3**	**-8**	**-8**	**38**	**32**	**-**	**-**	**-**
Dry stover:												
leaf	15	-42	-2	-7	-38	-38	4	9	65	-	-	-
stem	13	-28	-12	20	-14	2	5	15	92	-	-	-
total	**14**	**-34**	**-8**	**9**	**-24**	**-15**	**4**	**12**	**80**	**-**	**-**	**-**
Salvage crop:												
leaf	-	-	-	-	-	-	-	-	-	21	-31	10
stem	-	-	-	-	-	-	-	-	-	13	-28	9
total	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**16**	**-30**	**10**
Weeds	-	-	-	-	-	-	-6	82	89	-	-	-
Individual cob weight	-18	-31	-35	-9	-14	-9	-8	-23	-26	-	-	-
Total cobs	-	-	-	-14	-18	-13	29	34	23	-	-	-
Bean haulms	-8	-31	-20	-	-	-	2	2	-23	-	-	-
Total forage DM	**6**	**-0.3**	**13**	**7**	**-10**	**5**	**1**	**39**	**48**	**17**	**-10**	**23**
Grain yield	**-12**	**-52**	**-36**	**-2**	**-17**	**-9**	**44**	**24**	**21**	**-**	**-**	**-**
Beans	**9**	**12**	**-11**	**-**	**-**	**-**	**-6**	**-33**	**-20**	**-**	**-**	**-**

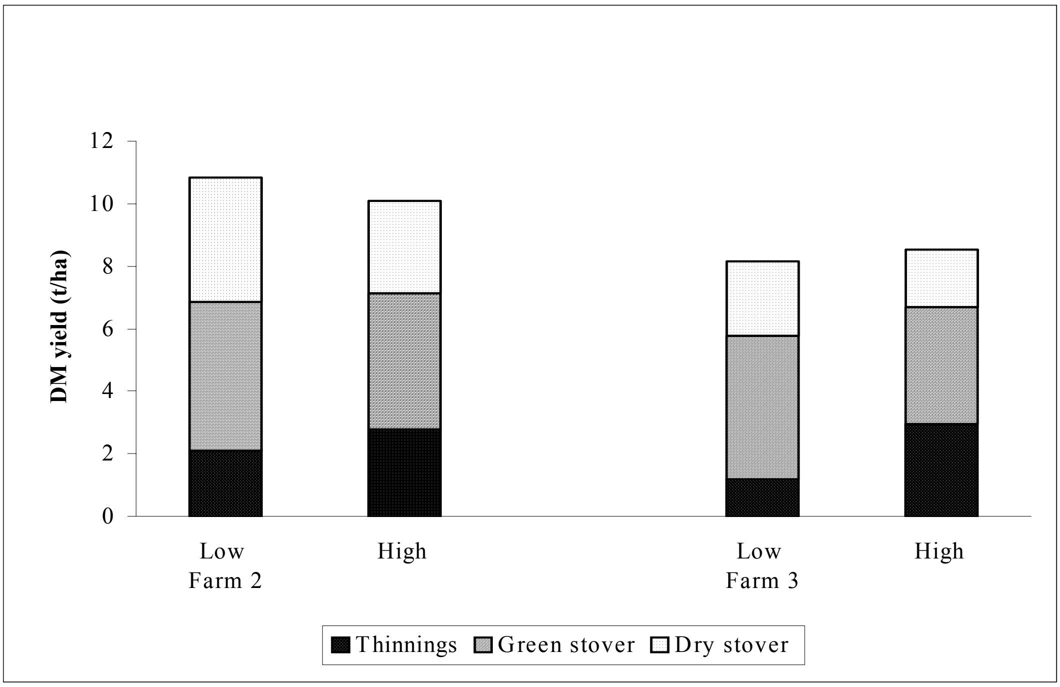
SR1MR1 - Farmer seed and fertiliser/manure rates
SR1MR2 - Farmer seed and modified fertiliser/manure rates
SR2MR1 - Modified seed and farmer fertiliser manure rates
SR2MR2 - Modified seed and manure/fertiliser rates

Table 20: *Percentage change in seed rate effect relative to the control on farmer-managed plots.*

Parameters	Farm 1	Farm 5	Farm 6
Thinning:			
leaf	-61	8	45
stem	-60	39	44
total	**-60**	**20**	**45**
Green stover:			
leaf	-22	-	-2
stem	119	-	86
Total	**33**	**-**	**37**
Dry stover:			
leaf	-8	-	-50
stem	35	-	-65
total	**13**	**-**	**-58**
Salvage crop:			
leaf	-	6	-
stem	-	-15	-
total	**-**	**-5**	**-**
Weeds	-	-	-26
Individual cob weight	-2	-	-8
Total cobs	-10	-	-5
Grain yield	**32**	**-**	**3**
Total DM	**0**	**-**	**31**

The overall effect of seed rate on fodder production in the long wet season shows that an increase in seed density increased the amount of green stover production. However, there were losses in dry stover production on farms with the highest increases in plant population, where large numbers of barren plants were removed as green stover (Figure 9). Weeds were the other type of fodder obtained on Farms 4 and 6 but the rest of the farms deferred the weeding exercise due to lack of rainfall. Bean haulms were an additional source of livestock feed.

Figure 9: *Effects of seed rate on fodder production on farms in the upper midland zone.*



Low - Farmer rates

High - Modified rates

Maize grain and bean yield

The mean grain production for the 2 X 2 factorial plots on Farms 2, 3 and 4, and the mean bean yields on Farms 2 and 4 that intercropped maize with beans, are shown in Table 21. Yields on farmer managed plots in Farms 1 and 6 are shown in Table 22. The results show non-significant grain yield differences for farms 3, 4 and 6, a significant decrease ($p<0.05$) for farm 2 and a significant increase for farm 1 ($p<0.001$). Figure 10 shows the effects of seed and manure rates on grain production whilst Figure 11 shows the effects of seed rate in farmer-managed plots. There was a wide variation in cob weights between farms. On all farms, cob weights decreased with increasing seed rate, but cob numbers/plot increased. However, differences were generally non-significant, except for cob weight on farm 4 and cob numbers/plot on Farm 6 (Tables 21 and 22).

Figure 10: *Effects of seed and manure rate on grain production.*

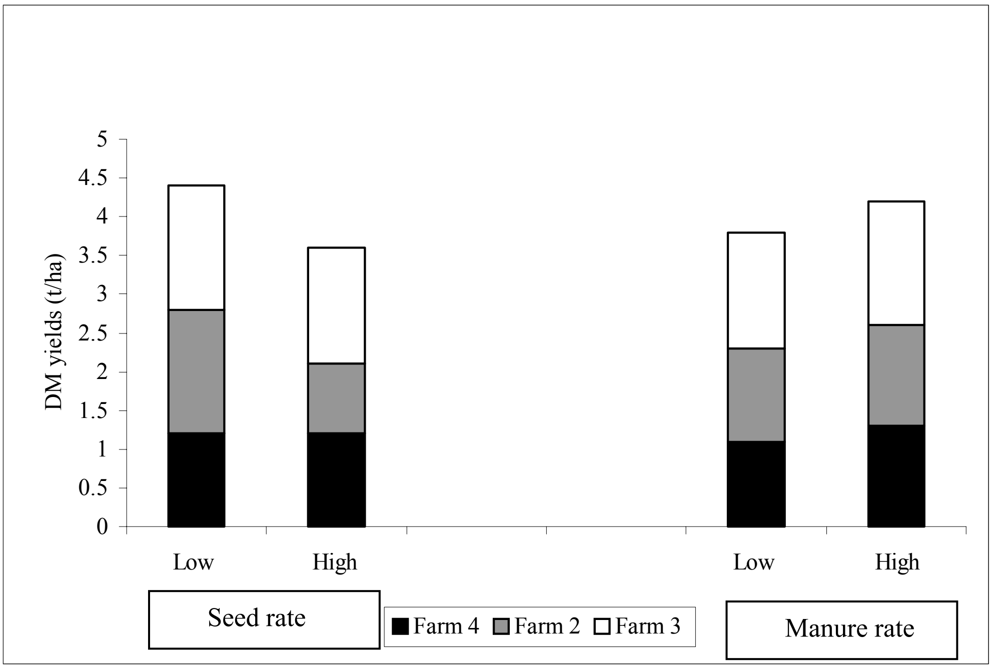
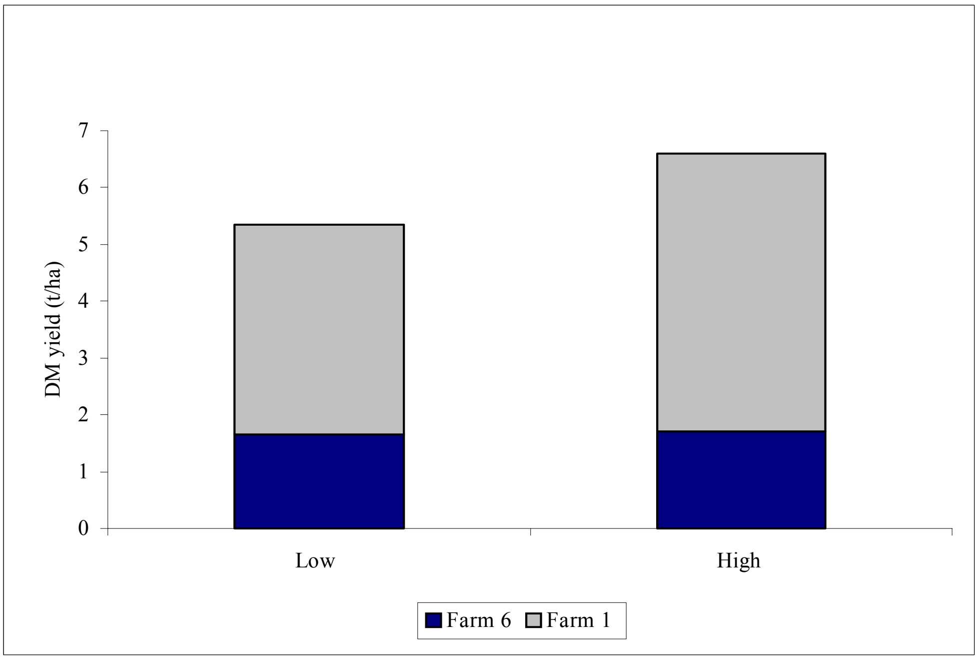


Figure 11: *Effects of seed rate on grain production on farmer-managed plots.*



Low	Farmer rates
High	Modified rates

Table 21: *Effects of seed and manure rates on maize and bean yields (t/ha)*

Farm	Parameters	Treatment				Sed of means		
		Seed rates		Manure rates		Main effects	Interaction (Seed x manure)	Seed
		1	2	1	2			
2	Maize yield (t/ha)	1.55	0.92	1.22	1.25	0.28	0.39	**
	Bean yield (t/ha)	1.04	1.00	1.05	0.98	0.14	0.19	**
	Dry maize							
	Cob numbers/plot	25	27	18	25	3.48	4.92	n.s.
	Cob weight (g)	166	135	114	108	19.78	27.98	n.s.
	Grain : cob ratio	3.9:1	4.5:1	3.8:1	3.9:1	-	-	-
3	Maize yield (t/ha)	1.63	1.43	1.50	1.56	0.15	0.21	n.s.
	Dry maize							
	Cob numbers/plot	49	50	48	48	3.11	4.40	n.s.
	Cob weight (g)	120	110	103	110	6.62	9.36	n.s.
	Grain : cob ratio	3.9:1	4.5:1	4.0:1	4.2:1	-	-	-
4	Maize yield (t/ha)	1.22	1.22	1.11	1.32	0.27	0.38	n.s.
	Bean yield (t/ha)	0.44	0.33	0.38	0.40	0.43	0.60	**
	Green maize							
	Cob numbers/plot	29	40	50	49	8.43	11.93	n.s.
	Cob weight (g)	308	284	238	229	25.6	36.2	*
	Grain : cob ratio	2.4:1	2.6:1	2.2:1	2.3:1	-	-	-

1 - Farmer rates
2 - Modified rates
Sed - Standard error of difference of means

n.s. – not significant (P > 0.05
* - P < 0.05
** - P < 0.01

Table 22: *Effects of seed rates on maize yields (t/ha) and components of yield on farmer-managed plots.*

Farm	Parameters	Seed rates		Sed of means	Significance
		1	2	Seed	
Upper highland zone					
1	Maize yield (t/ha)	3.7	4.9	0.18	***
	Dry maize:				
	Cob numbers/plot	191	239	10.4	**
	Cob weight (g)	122	120	4.46	n.s.
	Grain : cob ratio	3.7:1	5.4:1	-	-
Lower highland zone					
6	Maize yield (t/ha)	1.7	1.7	0.71	n.s.
	Dry maize:				
	Cob numbers/plot	152	164	45.5	n.s.
	Cob weight (g)	148	141	15.7	n.s.
	Grain : cob ratio	4.0:1	4.4:1	-	-

1 - Farmer rates

2 - Modified rates

Sed - Standard error of difference of means

* - p<0.05

*** - p<0.001

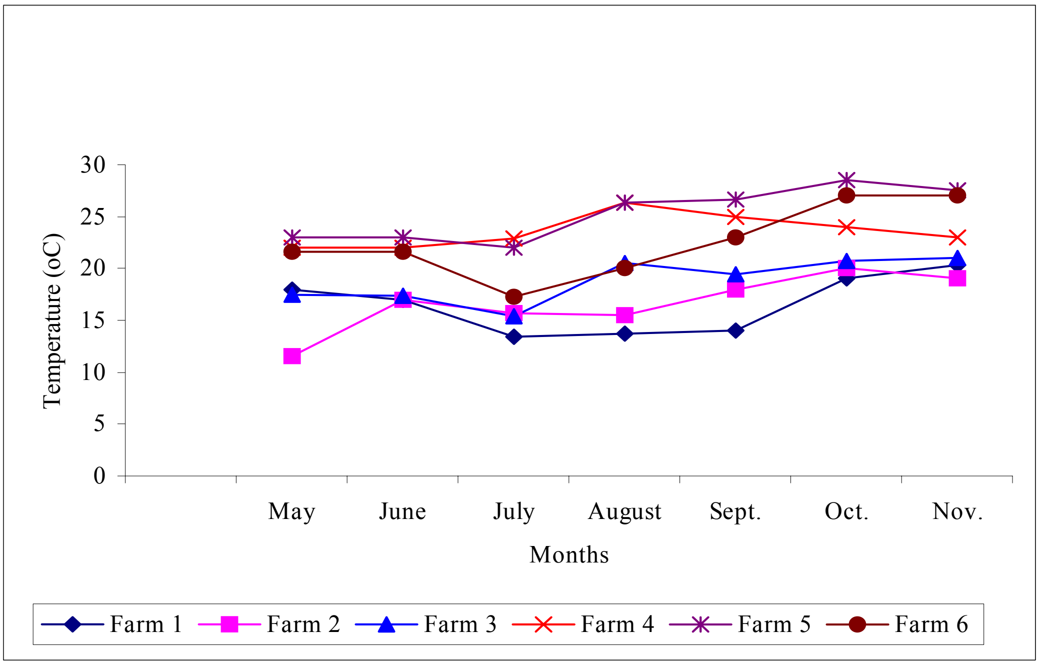
n.s. - not significant

The mean reduction in cob weight for high-density plots in the 2 x 2 factorial plots was 23 *per cent* (range 8- 35*per cent*), but only 2 - 5 *per cent* on farmer-managed plots. Cob numbers increased by 8 - 25 *per cent* relative to the control on all farms.

Salvage crop

Farm 5 harvested the entire plot as a salvage crop in the first week of August, when the farmer decided that it would not produce grain. The assessment criteria were the same as in the first season. The maize crop on this farm experienced severe moisture stress during this period. It is noteworthy that the highest mean monthly temperatures were on this farm (Figure 12). The salvage crop was harvested sequentially to spread fodder production over a longer period of time. The farmer stated that this was to allow Napier grass time to grow and to ensure that the fodder was green at the time of feeding. Yield data are presented in Table 23.

Figure 12: *A summary of mean monthly temperatures on farms in the long wet season.*



Up to 8.4 t DM/ha of the salvage crop was recorded in the 2 x 2 factorial plots, whilst up to only 1.3 t DM/ha was obtained from the farmer-managed plots. However, there is no evidence from the data to explain such a large difference.

Table 23: *Main effects of seed and manure rates on fodder resources on farms in the high midland zone.*

Farm	Parameters	Seed rates		Manure rates		Sed of means		Significance		
		1	2	1	2	main effects	Interaction (seed x manure)	seed	manure	seed x manure
Experimental plots										
5	Thinning:									
	Leaf	0.53	1.06	0.79	0.79	0.16	0.22	***	n.s.	n.s.
	stem	0.55	1.19	0.87	0.87	0.19	0.28	**	n.s.	n.s.
	total	**1.08**	**2.24**	**1.66**	**1.66**	**0.35**	**0.50**	***	n.s.	n.s.
	Salvage crop:									
	Leaf	3.56	2.88	2.71	3.72	0.41	0.58	n.s.	**	n.s.
	stem	4.26	3.62	3.44	4.44	0.51	0.72	n.s.	n.s.	n.s.
	total	**7.81**	**6.50**	**6.16**	**8.16**	**0.87**	**1.23**	n.s.	**	n.s.
	Total forage	**8.87**	**8.75**	**7.82**	**9.82**	**0.835**	**1.20**	n.s.	**	n.s.
Farmer managed plots										
5	Thinning:									
	Leaf	0.22	0.24	-	-	0.11	-	n.s.	-	-
	stem	0.13	0.18	-	-	0.08	-	n.s.	-	-
	total	0.35	0.42	-	-	0.19	-	n.s.	-	-
	Salvage crop:									
	Leaf	0.43	0.46	-	-	0.05	-	**	-	-
	stem	0.54	0.46	-	-	0.02	-	**	-	-
	total	**0.97**	**0.92**	**-**	**-**	**0.02**	**-**	n.s.	**-**	**-**
	Total forage	**1.32**	**0.34**	**-**	**-**	**0.20**	**-**	n.s.	**-**	**-**

1 - Farmer rates
2 - Modified rates
Sed - Standard error of difference of means
** -p<0.05
*** - P<0.001

Chemical analysis of fodder

Data from the chemical analyses of the fodder are shown in Table 24, giving an indication of the nutritive value of fodder harvested throughout the season. Fodder samples were collected and determined from days 67 to 223, when grain was harvested on the last farm. The stem had higher concentration of CP than the leaf component in all types of maize stover. The CP decreased while the DM, ADF and NDF increased as the fodder matures.

Table 24: *Crude protein, Nutrient and Acid Detergent fibre levels (g/kg) of maize plant parts and other fodder sources harvested from farms during the long wet season.*

Forage type	Average DAP (range)	Nutritive value parameters (g/kg)			
		DM	CP	NDF	ADF
Maize thinnings:					
Stem	85	110	104	598	383
Green leaf	(67 – 108)	200	125	674	418
dry leaf		690	41	683	441
Green stover:					
Stem	139	210	72	627	355
Green leaf	(135 –	370	81	616	442
dry leaf	143)	740	32	474	352
Dry stover:					
Stem		380	51	730	481
Green leaf	223	-	56	683	378
dry leaf		880	45	745	468
Maize grain	-	690	114	100	35
Cobs	-	720	30	-	-
Beans	117	850	290	380	90
Bean haulm	117	991	90	630	480
Weeds	28	894	261	306	227

DAP – Days after planting

CP - Crude protein

NDF - Nutrient detergent fibre

ADF - Acid detergent fibre

DM - Dry matter

Soil analysis

The Soil analyses indicated that post-harvest nutrient levels in the long wet season were generally higher than at pre-planting and post-harvest periods in the short wet season. However, there were wide variations in soil nutrients between farms and treatments within farms in the long wet season. The results show that Farm 1 had a high N level on the low density plots (Table 25), whilst in Farm 2 the high density plots showed the highest N content. The N levels on the other farms were more or less the same for all treatments (Table 26). P levels on experimental plots in the upper midland zone were higher than in the low midland zones, whilst on farmer-managed plots the P levels were higher in the low midland zone than in the upper highland zone. However, the P levels were higher in the topsoil (0 - 20) than in the subsoil (20 – 40) on all farms.

Table 25: *Soil nutrient levels on farmer-managed plots after harvesting.*

Farm	Treatments	Depth (cm)	SOIL NUTRIENTS					
			C	N	P	K	Ca	Mg
			%		Ppm			
Upper midland zone								
1	SR1MR1	0-20	3.68	0.24	17	634	1672	224
		20-40	3.76	0.23	4	534	1726	219
	SR2MR1	0-20	3.24	0.18	30	695	1794	250
		20-40	3.52	0.16	8	494	2138	246
Low midland zone								
6	SR1MR1	0-20	3.96	0.14	31	173	1306	226
		20-40	3.28	0.19	5	113	1644	260
	SR2MR1	0-20	2.92	0.18	53	173	1245	209
		20-40	2.88	0.15	10	153	1650	236

SR1MR1 - Farmer seed and fertiliser/manure rates

SR2MR1 - Modified seed and farmer fertiliser manure rates

Table 26: *Nutrient levels in soil on experimental plots after harvesting.*

Farms	Treatments	Depth	C	N	P	K	Ca	Mg	pH
			SOIL NUTRIENTS						
		cm	%			Ppm			
Low midland zone									
4	SR1MR1	0-20	3.13	0.30	7	688	1099	207	5.18
		20-40	2.95	0.25	8	708	1153	229	5.32
	SR1MR2	0-20	2.88	0.27	6	718	1107	220	5.21
		20-40	2.95	0.27	6	708	1144	226	5.25
	SR2MR1	0-20	3.00	0.30	21	733	1229	238	5.20
		20-40	3.13	0.27	9	728	1131	228	5.24
	SR2MR2	0-20	2.98	0.26	12	858	1217	258	5.32
		20-40	3.03	0.27	8	853	884	286	5.51
5	SR1MR1	0-20	3.00	0.28	9	228	699	133	4.80
		20-40	2.83	0.27	4	169	800	133	5.00
	SR1MR2	0-20	2.63	0.30	6	316	443	98	4.71
		20-40	2.58	0.28	3	188	619	92	4.71
	SR2MR1	0-20	2.73	0.28	9	208	673	119	4.72
		20-40	2.80	0.28	4	134	863	120	4.83
	SR2MR2	0-20	2.90	0.30	6	252	621	122	4.77
		20-40	2.50	0.28	3	193	707	108	4.81
Upper midland zone									
2	SR1MR1	0-20	4.35	0.37	26	853	2070	322	5.85
		20-40	3.85	0.37	12	828	2044	296	5.81
	SR1MR2	0-20	4.05	0.39	17	883	2197	359	5.99
		20-40	4.00	0.36	15	808	2199	327	6.01
	SR2MR1	0-20	3.75	0.32	14	818	2086	322	5.90
		20-40	3.90	0.37	13	798	2179	323	6.00
	SR2MR2	0-20	4.23	0.40	12	753	2002	317	5.93
		20-40	4.15	0.40	34	818	2014	314	5.77
3	SR1MR1	0-20	3.08	0.32	14	407	2243	240	5.88
		20-40	3.23	0.32	12	392	2278	254	5.94
	SR1MR2	0-20	3.45	0.33	16	517	2174	226	5.82
		20-40	3.20	0.32	9	462	2215	223	5.93
	SR2MR1	0-20	3.08	0.30	10	331	2027	220	5.74
		20-40	3.08	0.36	12	336	2079	220	5.92
	SR2MR2	0-20	3.13	0.31	12	361	1983	226	5.57
		20-40	3.15	0.30	11	336	2046	226	5.82

SR1MR1 - Farmer seed and fertiliser/manure rates
SR1MR2 - Farmer seed and modified fertiliser/manure rates
SR2MR1 - Modified seed and farmer fertiliser manure rates
SR2MR2 - Modified seed and manure/fertiliser rates

Appendix 6

Farmer's assessments of Field Experimentation to Examine Management Interventions for Improving the Supply of Fodder from the Maize Crop without Compromising Food Production

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Introduction

In order to follow-up on farmers' perceptions of the on-farm experiments, a participatory rapid appraisal (PRA) was conducted in two divisions of Kiambu District in the Central highlands of Kenya between May 1998 and September 1999. Participants in this appraisal were drawn from the farmers who had carried out on-farm experiments and also from groups of farmers around the experimental farms, who participated in the initial trials or who had followed them closely. The assessment was carried out to gather the practical experiences of farmers in experimentation, to determine potential advantages and problems encountered. It is anticipated that the information gathered will also be useful in future trials concerning adoption of interventions. The PRA was undertaken at the end of both trial seasons. Although the main objective was to assess the trials, it was decided, in addition, to gather more information on maize management practices, using farm walks, to build on the earlier PRA activities referred to at the beginning of Appendix 5. This filled in information gaps and permitted construction of decision- making pathways.

Materials and Methods

Group selection

The assessment appraisal was undertaken by (a) interview with trial farmers to obtain personal opinions on observations made in the maize experiments and (b) group interviews with neighbours around each experimental farm. Groups of farmers were informed of the assessment dates through advertisements at milk collection centres. However, farmers who had hosted the on-farm experiments also helped to announce the meetings through personal contact.

Assessment team

Once the objectives of the study were established, a planning meeting was held with extension staff of the District Livestock Office in Kiambu, to discuss the need for the study and its objectives. At this meeting, formal approval was sought from the government officer-in-charge of livestock to work with the farmers. This forum also enabled participants to constitute the study team that comprised farmers, members of the extension staff with knowledge of dairy/crop production and two research scientists (an agronomist and an animal nutritionist).

Implementation stage

In the assessment appraisals, the experimental farmers were interviewed separately to avoid farmer influence on each other when discussing individual factors affecting maize production, and to provide personal opinions on observations during the trials. The experimental farmers were interviewed before group meetings and informed before-hand that it would be helpful if they did not participate in group discussions until the end of the session, to avoid influencing other farmers. They would, however, be given the opportunity to share their experiences with other farmers at the end of the appraisal session, and could then respond to questions on the experiments. Group interviews in the assessment appraisals were held with neighbours around each experimental farm, except for two farms that were very close to each other. Here, the group interview was conducted jointly. Group interviews were held over five days. All six farmers were interviewed over three days, with two farmers being interviewed separately on each day.

Tools used in the appraisal process

A mapping exercise with systematic walks was undertaken on the six experimental farms with respondents observing, asking, listening, and looking at the farm lay-out with the aim of understanding the cropping patterns and availability of animal feeds. In the assessment appraisals, the checklist was divided into four sections:

- Section 1 captured general information on attendance and characterised the group in terms of gender and whether or not they were involved in milk production. Farmers who had attended the initial appraisal on maize management practices, participated in planting the maize experiments and followed the experiments closely were identified. This section clarified the reasons for participation, and was given only to the groups.

- Section 2 on maize crop management was given to both individual farmers and groups. Detailed information on how, why and when farmers make decisions on managing maize for fodder was collected. Other maize production practices discussed were weeding regimes and harvesting stages. This built on to the initial appraisal information and was used later to construct decision trees.
- Section 3 was discussed by both individual farmers and groups to determine the use of maize thinnings in relation to other fodder and crop residues available on farms.
- Section 4 dealt with honest observations and views of participating farmers on various treatments in the experiment, and the perceived reasons for observed differences between plots. It also asked for suggestions on modifications, which in the view of the farmers, could improve the treatments.

In the assessment appraisals, the six individual farmers used resource maps to describe their farms and indicate the use of plots. Blank sketch maps of individual farms, prepared at the start of the experiments, were reproduced for this mapping exercise. Farmers indicated, either by describing or drawing on paper, the various plots of crops planted on the farm at the time. They gave detailed explanations of variations in maize management between different plots and the reasons for the variability.

Results

Experimental process

Farmers who carried out both the 2 X 2 factorial arrangement and simple design trials expressed satisfaction in that they controlled the experiments themselves. This maintained their interest in collecting information and being in a position to explain what was going on. However, farmers who carried out only the 2 X 2 factorial arrangement trials, noted that they could not thin as often as they would have wished to, because of the need to weigh fodder together with the technician. They quoted instances of where they could not pick cobs for home consumption or even take a few plants for the cow at short notice. Whereas this indicated the interest of the farmers in the trials and in ensuring accurate results, it limited their freedom to thin the maize crop. It may also have resulted in delayed thinning, causing increased moisture competition between plants. This agreed with field technician observations that farmers who carried out the simple design in the long wet season and recorded the data themselves had a freer hand to make decisions on the experiments.

Farmers reported that they could only clearly tell the difference between low and high-density plots and not between those with different manure rates. Farmers using the 2 x 2 factorial trial stated that they were able to thin systematically in both seasons, so they did not miss out any plot. However, farmers with the simple design reported that it was easy for them to distinguish the low and high-density plots, which enabled them to make decisions on which treatment to thin, depending on whether the plants looked over-populated or the need for fodder.

Farmer analysis of potential advantages of and problems with high density planting

Potential advantages of high density planting

The analysis of potential advantages and their relative importance is summarised in Table1. Farmers observed that there was increased fodder production from the high-density plots in both seasons. They stated that this made a significant contribution to fodder supplies, leading to a reduced need to purchase feed off farm and allowed the Napier grass to grow. Farmers also noted that there was no significant difference in grain yield between low and high-density plots. However, on all farms where the crop matured to produce grain, they reported that there were a greater number of smaller cobs on the high-density plots. Cobs from the high-manure plots were larger when compared to low-manure plots. The farmers felt that the size of the cobs was not a problem where the maize was grown mainly for grain. However, it would be a problem for farmers intending to sell green maize commercially for roasting, since, for this purpose, large cobs are desired. Women farmers also noted that small cobs would require more time to thresh/shell for cooking. Farmers reported that weeding was not a problem on the high-density plots, although more weeds were observed on the high manure plots. Weeds were an important source of animal feed on all farms during the season.

Problems of high density planting and their relative importance

The farmers reported that in the long wet season, rainfall in 1999 was low and poorly distributed. This observation is confirmed by the weather data at Muguga in the study district, collected over the last twelve years. Except for the month of March, rainfall amounts were below mean rainfall figures recorded from 1888 – 1999. On three farms (Farm 2, 3 and 5), farmers observed that seeds were scorched and took too long to germinate in the high-manure plots. Farmers attributed this to delayed rainfall and high temperatures after planting of the maize in both seasons.

Table 1: *Analysis of potential advantages in the maize experiments by farmers who followed them closely.*

	Potential advantages	***Practical importance/opportunities***
1	More fodder obtained from the high density plots.	Increased fodder for those farmers with animals.
2	High density plots produced small-sized cobs, but many in number.	Farmers who intend to sell green maize for roasting will be disadvantaged and might require more labour to shell.
3	Grain yield from both low and high density plots were almost the same.	Useful for farmers with small pieces of land and less Napier grass who will obtain both grain and fodder.
4	Plants in the high manure plots germinated with vigor and grew faster in the initial stages.	Most farmers were concerned about producing enough manure from their farms to meet the increased requirement.
5	There were more weeds in the high-manure plots.	This generated more fodder from the plots but might require extra weeding (three times instead of twice).
6	Low density plots produced strong and healthy stover.	Might produce more fodder.
7	Reduction in plant population.	Reduce number of seeds to 4–5 from 6-7 as in the experiments. This will allow more light to penetrate in the crop.
8	Encourage dry planting.	The maize crop will maximise on early rains for faster germination.

Farmers noted that, on the high-manure plots, the plant roots did not penetrate deeply into the soil compared with the low-manure plots. This was particularly obvious on farms where the seeds were placed on top of manure at planting. Farmers thought this could be the result of using dry sheep and goat manure, as opposed to the wet manure they normally used from zero-grazing units

Farmers took the decision to reduce the spacing and increase further the number of seeds in the long wet season, following the good performance of the trials in terms of fodder and grain production in the short wet season. However due to insufficient rains, the farmers noted that the spacing used turned out to be too close to support the higher number of seeds (6-7) planted. The plants in the high-density plots were thinner. However, farmers did not find this a problem because, the plants were taller and yielded a greater amount of fodder. It was observed that high-manure/ low-density plots produced strong, robust plants but less fodder than the other treatments. The problems and their relative importance are summarised in Table 2.

Table 2: *Analysis of problems in the maize experiments by farmers who followed them closely.*

	Problems	***Practical importance / opportunities***
1	There was more lodging in the high-density plots.	Might be forced to use shorter; early-maturing varieties.
2	Inadequate rainfall throughout the season resulted in moisture stress. Unpredictable rainfall pattern.	Might require use of short season, early-maturing varieties where increased plant densities practiced.
3	High-density plots produced thinner stover.	Might be easier to feed and reduce wastage when offered to cows.
4	Spacing appeared too close in high-density plots.	Increase spacing of maize to 90 x 60 cm. This might allow for intercropping and greater light penetration in the crop.
5	There was no twinning of cobs in high-density plots.	Introduce practices that prevent moisture stress.
6	Yellowing of maize was reported on some plots.	Might be due to mineral deficiency in the soil or maize streak virus.
7	Reduced bean yield in intercropping systems.	Might be due to shading effect (but losses offset by increased fodder production).

Moreover, closer spacing would decrease light penetration and during hot days, there was likely to be moisture stress. Farmers noted that plants lodged in the high-density plots at cobbing stage. This was attributed to overcrowding of plants and poor root penetration into the soil. Even the slightest wind could therefore lodge the plants easily. A higher proportion of barren plants observed on high-density as compared to low-density plots, could have been due to a lack of moisture at pollination. Farmers observed that the tassels desiccated before silks were produced, thereby affecting pollination.

Farmers stated that they would normally observe twinning of maize cobs in the long wet season when there are sufficient rains, but this did not occur in the present study. Farmers could not suggest any reason for this, but twinning rate is usually associated with variety (IITA, 1999). On the farm, where yellowing of the crop in both high- and low-density plots was observed, the farmer could not provide an explanation for this observation. Yellowing of the maize crop may indicate a soil nutrient deficiency (Okalebo *et al*., 1993).

Two farmers intercropped maize with beans. Both farmers reported that high-density planting reduced bean yields. This was attributed to the shading effect of maize with increased density, and also to higher temperatures within the maize crop. Farmers suggested that, where increased plant density is practised in intercropping systems, spacing should be widened to allow more light and air to circulate in the crop. The two farmers, however, noted that they did not mind the loss in bean yield because the additional maize fodder from maize reduced the need to spend during the season to purchase fodder off-farm. Thus, they could afford to buy in beans for household use. Farmers, however, noted that high plant densities might limit intercropping with other crops, where the main emphasis is on food. Two farmers reported that grain-filling on cobs in the high-density plots was incomplete, and there were many grain gaps on the cobs. Again, this could partly have been due to insufficient rains during the season.

Follow-up assessment of the use of dense planting

Of six farmers, only one did not continue with the dense planting intervention in the following short wet season. That particular farmer (Farm 5) had the largest land holding (2.2 ha) and the crop did not mature to produce grain in the long wet season. The farmer gave the following reasons:

- There were signs of unreliable rainfall during the season and, given his experience in the previous long wet season, he did not want to take the risk of planting densely in the short wet season. Furthermore, the farmer felt he had enough Napier grass on the farm and few cattle to feed. He was, therefore, not under pressure to produce more fodder.

- It is easy to obtaining thinnings from the maize crop and, therefore, there is a tendency to neglect Napier grass management.
- He did not have the manure to increase manure/fertiliser rates. He had, however, already used high-density planting before the trials.

The main reason appears to have been that the farmer did not face a great demand for additional fodder. He had only two animals and his relatively large land holding gave him other options for obtaining fodder. He had Napier grass, eight other plots of maize and obtained cut grass from the coffee plantation, in addition to grazing areas within the farm.

Discussion

The idea of the present study was conceived from field observations during the sixteen-month longitudinal monitoring in the study area. It had been observed that farmers were planting densely and then thinning the maize crop to obtain fodder. Methu (1998) demonstrated on-station that dense planting had potential to increase fodder from maize however; this work did not reflect what would happen under farmers' management conditions. Land sub-division has led to reduced land sizes, and there was evidence from the groups interviewed during participatory appraisal that this trend was still continuing in Kiambu District. The hypothesis developed for the participatory appraisal was that as land sizes decrease farmers increasingly rely on the maize crop for fodder. The appraisal results indicated that farmers are already changing land management and cropping patterns. This trend has also been reported in other areas of Kenya where more farmers use 'cut and carry' production systems than 10 years ago. Some of the ways farmers have resorted to seemed to indicate that maize is being prioritised over napier grass, with napier grass being pushed to niches that don't interfere with cropping, for example planting napier grass on bunds rather than on plots. Other ways include a lot more intercropping, undersowing in the long wet season with early maturing crops and replacing woodlots with cropping. Some farmers chose to plant more land to napier grass while others chose to seek fodder elsewhere. One of the sources is maize. It has been reported that some farmers focus on napier grass and abandon maize (Thorne, 1999) but this is risky since focusing on one enterprise could result in severe feed shortage if there is a problem with napier grass and maize is not planted. Additionally, it could result in frequent harvesting of napier grass that could lead to reduced yields (Heisely and Mwangi, 1996). These could be some of the reasons why farmers view maize as a risk management crop in Kiambu District (Kaguongo *et al*., 1997), as a result farmers have very complicated decision-making processes on farms.

As a result of decreasing land size, farmers have had to make decisions on whether to grow food crops or to plant napier grass. They also have to consider the trade-offs. If farmers choose to produce their own maize and beans to avoid purchase, they may have insufficient land to grow all of their fodder requirements, and be forced to buy in animal feed. Alternatively, if they aim to produce enough fodder for their animals, they may have to buy in the staple crops to feed the family. The appraisal revealed that fodder was more expensive to buy than maize and beans, whilst the cash obtained from milk would be sufficient to buy in the food staples. This may be due to (a) high milk prices because of the proximity of Kiambu District to Nairobi (Omore *et al.,* 1999) and (b) a general shortage of animal feed on the farms. Estimated income from I ha of napier grass is US$ 1067 (napier grass = US$ 0.067/kg DM). One ha of napier grass yields 16t DM. On the other hand estimated income from I ha maize (grain + fodder) is US$ 368. Average grain and stover yields used were 1.6 and 1.15 t/ha DM respectively. The current market value of grain and stover was US$ 0.2 and 0.042/kg DM. As a result of this and in view of the fact that farmers are already considering dense planting, it is likely that they will increase densities further.

Implications of increasing seed rate on fodder supply and grain production

When deciding on planting geometry, the farmers considered two factors, a) the increased amount of manure, which filled almost three-quarters of the normal planting hole and (b) with the increased number of seeds, the need to avoid overcrowding. The practices adopted are consistent with the observations of Willey and Rao (1980) that it is usually necessary to adopt suitable planting geometry to accommodate increased density. However, the planting geometry varied between farms and seasons, due to the participatory nature of planting the experimental plots, which involved the opinions of neighbours (Table 3). This may explain some of the low germination rates observed on farms, which may have been as a result of overcrowding of seeds. However, the results showed that farmers changed the planting arrangement differently between mono cropping and intercropping systems. The farmers choice of appropriate planting arrangements may be because of deliberate effort to minimise both inter- and intra- specific competition, whilst allowing easy application of inputs as observed by (Srinivansan and Ahlawat, 1990).

In the short wet season, farmers increased spacing with increased seed rate achieving increases in plant density of between 1 – 103 *per cent* with the lowest increase in plant density on Farm 4, which had the highest increase in spacing. This agrees with findings of the appraisals that farmers increased plant density through altering spacing and increasing the number of seeds per hole. Farmers observed during the assessment of the trials that valuable cropping space was wasted as result of this. This may have prompted them to keep spacing the same with increased density in the long wet season. This would explain the high population densities noted on most farms. Table 3 summarises the effect of seed rate on fodder production, grain/bean yield and cob weight.

Considering both the short and long wet seasons, thinning was carried out over a cumulative period of eight months in all the zones suggesting that maize thinning could make a significant contribution to provision of livestock feed throughout the year. In both seasons, increasing seed rate increased the thinning production significantly by between 1.1 and 2.4 t DM/ha, representing increases of between 59 - 119 *per cent*. In an on-station experiment, Methu (1998) increased forage production through thinning by between 1.3 and 2.6 t DM/ha. In the present study, whilst the quantity of thinnings increased, total yields of dry stover showed a negative effect on Farms 2, 3 and 6, although the effect was not significant. The farms that recorded a positive effect on dry stover (Farms 1, 4 and 5), recorded the lowest number of thinnings except farm 6 implying that high thinning rate increased the proportion of green feed as a component of the total DM production on farms (Table 3). This in effect, increased good quality feed even though overall fodder DM increase was not significant. The chemical analysis of fodder in both seasons showed that the thinnings had a CP content of between 10.5 and 12.5 *per cent* and was, therefore, likely to have high digestibility and energy values (McDonald *et al*., 1988). This could result in an overall improvement in the quality of maize fodder on farms, since thinnings contained up to six times the CP of dry stover (Onim *et al.,* 1991). This would suggest that high-density planting could not only increase the quantity but also the nutritive value of fodder on smallholder farms.

Table 3: *Summary effect of seed rate on fodder production, grain/bean yield and cob weight***.**

Parameter	Season	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Modified plant density ('000/ha)	Short wet	90	90	157	75	62	75
	Long wet	220	81	165	63	72	126
% Increases in density	Short wet	50	39	30	31	40	7
	Long wet	29	70	19	13	37	35
Effect of seed rate on yields of thinning.	Short wet	-[1]	-[1]	-[1]	+ ve	+ ve	+ ve
	Long wet	- ve	+ ve	+ ve	+ ve	-[1]	+ ve
Effect of seed rate on green stover yields	Short wet	-[2]	-[2]	-[2]	-[2]	-[2]	-[2]
	Long wet	+ ve	n.s.	- ve	n.s.	-[1]	n.s.
Effect of seed rate on dry stover yields	Short wet	-[1]	-[1]	-[1]	n.s.	+ ve	n.s.
	Long wet	+ ve	- ve	- ve	n.s.	-[1]	- ve
Effect of seed rate on bean yield	Short wet	-[1]	-[1]	-[1]	n.s.	-[1]	-[3]
	Long wet	-	- ve	-	- ve	-[1]	-[3]
Effect of seed rate on cob weight	Short wet	-[1]	-[1]	-[1]	n.s.	n.s.	n.s.
	Long wet	n.s.	n.s.	n.s.	- ve	-[1]	n.s.
Effect seed rate on grain yield	Short wet	-[1]	-[1]	-[1]	n.s.	+ ve	n.s.
	Long wet	+ ve	- ve	n.s.	n.s.	-[1]	n.s.
Effect on weeds	Short wet	-[1]	-[1]	-[1]	n.s.	+ ve	n.s.
	Long wet	-[4]	-[4]	-[4]	+ ve	-[1]	n.s.

1 - Crop salvaged due to insufficient rainfall

2 - Stover treated as maize thinning

3 - Beans were not planted

4 - Weeding skipped

n.s. - Not significant

+ or –ve Positively or negatively significant

Only Farm 1, which recorded the highest plant density and thinned moderately (4 times) recorded a positive effect ($p< 0.05$) of seed rate on green stover in the long wet season. Increases in plant density increased green stover production, obtained as a result of harvesting green maize for sale or home consumption, by up to 0.4 t/ha. This represented an increase in green stover of 33 *per cent* relative to the control, with an average CP content of 7.2 %. However, large numbers of barren plants (42 *per cent*) at green stover harvest were observed on a 2 X 2 factorial arrangement plots in Farms 2 and 3 in the long wet season, as compared to 37 *per cent* on simple design plots. This could have been due to freer thinning regimes reported on simple design plots, that may have resulted in reduced moisture competition. This would suggest that the timing of thinning may be critical where dense planting is practised. However, the farmers did not view barren plants as a loss, but rather as the production of a valuable source of fodder. This shows how smallholder farmers use the maize crop as a risk-management technique (Kaguongo *et al*., 1997), to mitigate uncertainties such as rainfall failure in the long season.

Both Farms 2 and 3, thinned moderately (6 times). This could have contributed to moisture competition between plants. Additionally both farms started thinning after 60 days, which could have resulted in delayed thinning of the maize crop in the early stages of growth. This may have resulted in the negative effect ($p<0.05$) on grain production on farm 2. Delayed thinning has been found to increase plant competition (Duncan, 1972) and this may have been compounded by high moisture competition, due to insufficient rains, resulting in increased barrenness. Very high increases in plant density, followed by delayed thinning, could result in reduced grain yields and a high proportion of barren plants (Holliday, 1960).

The maize grain yields on farms fell in the ranges 2.36 - 6.25 and 0.92 - 1.63 t/ha respectively in the short and long wet seasons. Grain yields obtained under farmer management in other studies were 1.8 – 2.7 t/ha reported by Onyango *et al*. (1995) and 2.24 –3.6 t/ ha obtained on-farm by Kumwenda (1993). The high yield observed in the short wet season may be due to high increases in manure rates. There was no clear trend in the effect of seed rate on grain yield. In the short wet season, increased plant density increased grain yield on Farms 4 and 5, while losses were recorded on Farm 6, where plant density was increased by 17 %, with subsequent heavy thinning. In the long wet season, increased plant density increased grain yield on simple design plots (Farms 1 and 6) but losses were recorded on two farms (Farms 2 and 3) as observed above. This may indicate that farms with high increases in plant density might lead to grain losses, particularly in seasons with low rainfall. It is interesting to note that despite low rainfall, there were no grain losses on the simple design plots (Farms 1 and 6) where farmers had a free hand in thinning because they recorded the data themselves. This indicates that thinning frequency and timing could have a critical influence on grain yield where plant density is increased. This further indicates that farmers are faced with difficulties in decision-making on maize management, in view of unpredictable seasonal variations in weather.

There was no clear difference between mono cropping and intercropping systems on maize grain yield. On two farms (2 and 4) where beans were intercropped with maize, negative and positive effects on grain yields were recorded respectively, although on Farm 4 maize was harvested at the green maize stage. However, the results showed that there was a consistent negative effect on bean yields in both seasons. The reduction in yields ranged from 21 - 38 *per cent* and 6 - 33 *per cent*, respectively in the short and long wet seasons. Nevertheless, the effects were statistically significant ($p<0.05$) only in the long wet season. This may be a result of increased canopy cover and shading due to increased plant density, and also increased temperatures within the maize, (Dalal, 1994). The beans themselves could also have exerted additional competition for moisture (Chui, 1988), especially in the long wet season, when there were insufficient rains. Furthermore, the decrease in spacing in the long wet season may have contributed to the significant negative effect observed on bean yields. However, it should be noted that farmers practising intercropping (Farms 2 and 4) deliberately changed the planting pattern on high-density plots, to avoid the shading of beans by the maize. Apart from altering planting patterns in intercropping systems, ample spacing may be necessary when plant density is increased.

On all farms where the crop matured to produce grain, the high-plant density plots showed an average reduction in cob weights of 9 and 23 *per cent* in the short and long wet seasons respectively (Plate 1). However, the reduction in cob weights was only significant ($p<0.05$) for farm 4. Increased plant densities have been reported to reduce cob size due to a low accumulation of plant reserves resulting from the increased number of plants (Heisely and Edmeades, 1998). High plant densities may have resulted in higher moisture requirements that could have resulted in drought stress hence a reduction in cob size in the long wet season, which may explain why the lowest cob size was recorded on Farms 2 and 3, where plant populations were highest. In both seasons, cob numbers increased on farms despite the reported moisture stress. There was a consistent increase in cob numbers of 51 – 82 *per cent* and 8 - 25 *per cent*, in the short and long wet seasons, respectively. The increase in cob numbers was significant for Farm 1 only in the long wet season. This is contrary to observations by Grant *et al.* (1989), cited by Heisely and Edmeades (1998), which showed that cob numbers were reduced by 45 *per cent* when maize plants were moisture-stressed 2 – 22 days after silking. However, this experiment did not involve thinning regimes.

Plate 1: *Cob sizes in low-density (left) and high-density (right) treatments.*

Implications of increased seed rate on soil fertility

Manure and fertiliser applications have major implications for increased plant density as a means of obtaining fodder from the maize crop. Firstly, farmers rely on manure produced from their farms for all crop needs, although they are aware that increased plant densities require the use of more manure (Reynolds, 1999). These farms do not produce enough manure and this has limited farmers to using low application rates (Ikombo, 1984). During the initial participatory appraisals farmers expressed fear they could not afford additional manure/fertiliser although farmers applied manure selectively to crops. On farms that produced horticultural crops, manure was applied to vegetables, whilst farmers who produced milk applied more manure to the Napier grass and maize. Appraisal discussions revealed that high milk production was associated with a high demand for feed, because these farms have either more animals or higher yielding animals. In both cases, they will require more feed. Since milk is the main source of regular cash income for smallholder households, it influenced manure allocation to crops that provided fodder. However, farmers were categorical that where they have to make a choice, potatoes and vegetables took first priority, followed by maize. This appeared to be due to the fact that maize was often planted after potatoes, to take advantage of the residual effects of manure. Although experimental farmers increased the amount of manure applied in the experiments, they also pointed out that they did not produce enough for their entire crop needs and that buying manure was becoming increasingly expensive.

It has been reported that most smallholder farmers were reluctant to apply high levels of fertiliser due to the high cost (Heisely and Mwangi, 1996). It is not surprising that during the participatory interviews, farmers reported buying up to a maximum of 10 kg of fertiliser for all their crop needs in a cropping season, which represents 71 *per cent* of the estimated average fertiliser application rate on smallholder farms for all crop needs in sub-Saharan Africa (FAO, 1995). However, experimental farmers seemed to use higher rates (one handful per 4-5 holes) than those reported in the appraisal study (one handful per 5-6 holes). This may be because inputs were supplied to farmers. This may explain the high grain yield observed. They stated that they applied basal fertiliser only in the planting hole at sowing time, to provide the maize crop with nutrients to establish rapidly, which the manure does not. Plant organic matter decomposes relatively slowly in the soil and becomes available only gradually to plants in small amounts over a long time period (Woomer *et al.,* 1994).

Although farmers are trying, within their limitations, to replenish nutrient stocks in the soil, the fact that they crop throughout the year suggests that they remove more nutrients from the soil than they are putting back. However, smallholder farmers in Kiambu District continue to use the dense-planting practice, as long as the land provides them with sufficient food, fodder, and cash throughout the year. This situation may necessitate examination of strategies to replenish soil nutrients.

In both seasons, the percentage increases in inputs and plant population rates differed according to what farmers thought was feasible on their own farms. The differences in inputs between farms may be due to the complex interactions between maize management practices observed during the appraisals (Table 4). Farmers not only have to consider whether to manage the crop for fodder or grain, but also have to choose which crops will benefit from limited manure/fertiliser inputs.

Table 4: *Summary of fertliser /manure application rates (kg/ha)*

Parameter	Season	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Farmer fertiliser	Short wet	0.3	0.4	0.6	0.3	0.3	0.4
	Long wet	0.3	0.3	0.1	0.1	0.1	0.1
Modified fertiliser	Short wet	0.5	0.8	1.5	0.4	0.4	0.4
	Long wet	0.3	0.2	0.7	0.2	0.2	0.1
Farmer manure	Short wet	3.5	4.2	8.4	4.0	4.3	5.4
	Long wet	7.8	2.5	5.7	2.3	2.3	2.9
Modified manure	Short wet	6.9	8.4	16.9	8.1	8.5	16.1
	Long wet	7.8	3.8	8.6	3.4	3.4	4.3

Soil data from experimental plots showed high variability and lack of any clear trends, between pre-planting and post-harvest in the first season. Comparisons are only made between the results from pre-harvest first season and post-harvest second season. Large variations in soil chemical properties can occur even within areas as small as 10 m^2 (Landon, 1984). The post-harvest levels of N varied between regions, farms and treatments. This may be because levels of N, in the plant – available NH_4 and NO_3 forms, fluctuate during the cropping season and are dependant on such factors as rainfall pattern (Okalebo, 1993). N level was slightly higher post-harvest, although all values for both pre-planting and post-harvest on experiential farms fell within the medium range of 0.2 – 0.5 *per cent* quoted by Landon (1984). P levels varied between farms and treatments, although they were higher in the topsoil (0-20 cm) than in the sub-soil (20-40 cm). It is not unusual to encounter differences in specific chemical characteristics between comparable horizons taken from two profiles of the same soil type in the same field (Landon, 1984).

Differences between treatments could be attributed to the level of soil nutrients rising rapidly following the application of fertiliser/manure. The subsequent fall depends on the quantity applied and the soil nutrient reserves (Minson, 1990). Further, negative effects on soil nutrient depletion in continuously cropped soils may not be apparent over a short period of time. This is because nutrient depletion rates are field specific, depending on the way each particular field has been managed over decades. A combination of these factors and lack of clear trends in soil nutrient status suggests that it would be inappropriate to draw quantitative conclusions on how the treatments affected the soil fertility and *vice versa* across only two seasons. Although there were no conclusive results, soil effects might be expected to be more long term and any recommendations on increasing fodder through planting density would need to take this into account. This needs an in-depth study conducted over a period of several years to determine the effects of high population densities on soil fertility.

Implications of increased seed rate on moisture stress

Participatory appraisal results revealed that, although farmers were aware of the Ministry of Agriculture and Livestock Development recommendations for growing maize (Kiambu, 1994 – 1996), they had changed their maize management practices. The focus of the management decisions centred on the main purpose of the crop. Farmers in all appraisal sites reported the change in the rainfall pattern in recent years in the District that has led to unreliable cropping seasons. Indeed, this is supported by the annual rainfall data collected at Muguga weather station in the upper midland zone for the last 12 years. Farmers decided whether to manage individual plots mainly for grain or for fodder. Farmers are faced with this difficult decision because unreliable rainfall means erratic food supplies in these households, with wide variation between seasons. On the other hand, it can result in severe feed shortages.

It is worth noting that both short and long wet seasons were unusually dry and this had implications for germination, the effect of the manure (scorching) and probably effect of increased seed rate that could have resulted in moisture competition. In both seasons, farmers dry planted the maize crop, in anticipation that sufficient rains would come on time. However, there was a delay in rainfall of 23 and 14 days after planting the crop in the short and long wet seasons, respectively. This resulted in severe moisture stress in the crop in the germination stages. The soil moisture was usually sufficient to trigger the seed germination process, which takes 6-10 days, but the prolonged absence of rain after this stage interfered with germination, because this process requires additional water for its completion (IITA, 1999). In the short wet season, the district normally receives 800 – 1100 mm of rain, and in the long wet season 1200 – 1400 mm (Kiambu, 1994 - 96). However, the data obtained from the Muguga research station in the upper midland zone showed that the area received only 110 and 506 mm of rainfall in the short and long wet seasons, respectively.

Despite the low rainfall, farms recorded germination percentages of between 64 and 72 *per cent* in the long wet season, which falls in the range observed by Allan and Laycock (1976) of 65 -77 *per cent* when seed density was increased from one to eight per hole. Farmers observed that more seeds were 'scorched' in the high-manure plots compared to the low-manure plots. This was confirmed by the germination results, which showed that the high seed and manure plots recorded the lowest germination percentages. There may have been increased moisture absorption from the soil, as a result of an increase in manure application (Itabari *et al*., 1994). Better results could have been expected if the rains had been good. Due to the expected effect of increased seed rate on moisture competition, the practice of dense planting was more appropriate for the long rains when rains would normally be expected to be more reliable. Indeed, farmers made large increases in plant densities in anticipation of reliable rainfall in the long wet season.

Due to the drought, farmers postponed the second weeding in the long wet season, for fear of interfering with the rooting system of the maize when the moisture level was very low. The maize crop requires adequate moisture at leafing stage, 4-5 weeks after planting, which is also the stage when most adventitious roots form (Ritchie, 1984). Low rainfall at this stage may have retarded plant development. This might explain why the maize crop started wilting on most farms at this stage, especially on the high-density plots. Planting at high seed densities might be expected to require high moisture levels to support the increased plant population. However, the crop continued to receive unreliable and poorly distributed rainfall, accompanied by high temperatures, throughout the season in all the zones and this resulted in periodic moisture stress. Maize bears flowers in the tassels that produce pollen grains, which facilitate cross-pollination. Any condition that affects tasselling 55-60 DAP affects fertilisation and, hence, kernel formation (IITA, 1999). This would explain why the maize crop failed to mature to produce grain on the three farms in the upper midland zone during the short wet season, and on farm 5 in the long wet season, when severe moisture stress was experienced during this period.

Implications for seasonal distribution of fodder

The appraisal study revealed that most farmers have turned to the maize crop as an alternative source of fodder. Firstly, farmers plant maize at any time of the year after any rainfall, so long as they have space on the farm. Although Kiambu District is considered generally to have a bi-modal rainfall distribution, allowing two maize crops to be grown in a normal year (Thorne, 1999), farmers reported a lack of distinct rainfall seasons, with rains being delayed or failing. However, farmers take a risk and plant the maize crop at any time of the year, so that if the crop fails to produce an appreciable amount of grain, it can be harvested as a valuable source of fodder. Because of frequent planting of maize, fodder from maize is not available according to the seasonal calendars drawn by farmers during the appraisal, which coincided with the expected rainfall pattern. Secondly, farmers in Kiambu District planted more than one plot of maize and applied different agronomic practices to different areas. This is because they aimed to obtain both food and fodder from the maize crop. As a result, there was a wide variation in maize management practices between farms and between plots within farms.

Seasonal calendars drawn by farmers during appraisal interviews showed that different types of fodder from maize was available at different times in different zones although most would be available when other fodder were growing. In the present maize experiments, the availability of thinnings, leaf strippings, green stover (after harvest of green cobs), dry stover (after harvest of dry cobs) and salvage value (in the event of a grain failure) at different times offered a range of fodder options to the smallholder farmer. The provision of maize takes the pressure off the Napier grass and allows the grass to be managed better through resting at appropriate times in its growth cycle. Thus, Napier grass would be available for feeding at a later date, effectively evening out the effect of seasonality. It also reduced the need to purchase off farm fodder. This emphasises the complementarity between maize and napier grass.

In making the decision to thin in the present studies, participating farmers considered not only the need for fodder and the crop to be thinned, but also the need to spread the fodder over a longer period of time. The number of animals and the land size influenced the number of plots kept for either grain or fodder. Farmers with more animals faced a great need for animal feed and tended to manage the maize crop more for fodder. This may be because the cash incentive of high and regular returns from milk (Omore *et al.,* 1999) allows them to buy in food for the household as observed earlier. Appraisal discussions revealed that farmers with very small land areas were more inclined to manage maize for fodder, because they had fewer options for obtaining fodder on-farm, compared with those farmers with larger areas of land.

Farm 4 which had no livestock recorded the lowest thinning frequency in both seasons, making it likely that, here, the need to thin may have been influenced only by crop needs. Farm 5 also thinned only moderately in both seasons. Although there were livestock on this farm, it was the largest (2.2 ha) of all the experimental farms (Table 5). In both seasons, the farmer had more than five plots of maize, in addition to napier grass (0.1 ha). He also obtained cut grass from the coffee plantation. Farmer 1, who had the second largest farm size of 1.9 ha, thinned fewer times than farm 6, although these were farmer-managed plots. It is likely that the need to thin the crop on these farms was much less, because of access to other sources of fodder made possible by the larger land holdings. Farmers with larger land sizes tend to have larger plots of napier grass and could obtain more fodder from cut grass, weeds and banana pseudostems (Mwangi *et al.,* 1991).

In contrast to this, the smaller farms thinned most frequently. Farm 6, which had a land size of 1.8 ha with only one plot of maize and two of napier grass, thinned the highest number of times in both seasons. This was also the case with farms 2 and 3, which measured 0.7 and 1.1 ha, respectively, had more than two animals each and only 0.3 and 0.4 ha of napier grass respectively, in single plots. Thinning on these farms may have been driven by the need for fodder. This would explain the high dependency that the farms had on fodder from the maize crop, since they did not have alternative sources of fodder. This agrees with the observation of Sands *et al.* (1982) that the smaller the land size, the greater the contribution of crop residues to the feeding of cattle relative to the use of improved forages.

Table 5. *A summary of Land size, areas planted to maize and napier grass and herd sizes.*

Parameter	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Land size (ha)	1.9	0.7	1.1	1.3	2.2	1.8
Area planted to Napier grass (ha)	0.3	0.3	0.3	0.1	0.2	0.6[1]
Area planted to maize (ha)	0.8	0.4	0.4	0.5	0.4	0.3
Herd size TLU/ha	1.1	5.7	2.7	-[2]	0.9	1.1

1 - 0.3 ha of Napier grass newly planted

2 - Farm had no animals

TLU – Tropical livestock units

Thinning patterns varied between farms and seasons Thinning patterns on all farms in the short wet season showed a sharp drop at the end of thinning because the farmers removed all barren plants at the cobbing stage, to give productive plants ample space for good grain filling. Moisture and nutrient stress lessen the capacity of kernels to accumulate biomass (Heisely and Edmeades, 1998). Farmers may have realised that the plants were becoming congested and hence the need to remove unproductive plants suggesting that thinning at this stage was largely driven by crop needs. However, in the long wet season, thinning appeared to be more gradual as a result of heavy thinning towards harvesting, between 60 and 80 DAP to reduce plant populations, to remove severe moisture stress due to insufficient rains. In the short wet season, farmers did not start thinning soon after this stage to allow for pollination. Stress during this period may have reduced photosynthesis at flowering and delayed silk growth, which may have led to yield reductions and a high incidence of barrenness in the long wet season (Heisely and Edmeades, 1998). This may be because early maturing varieties used in the short wet season progress through this stage in a shorter time than late maturing varieties (IITA 1999).

In the both seasons, the thinning period in the lower midland zone lasted from 61 to 143 DAP, while in the upper midland region, the period extended up to 198 DAP (Table 6). Farmers (except for Farm 6) delayed thinning during the early growing stages due to insufficient rainfall, perhaps fearing that interference with the soil structure would increase evaporation (Ikombo, 1984) or possibly because they still anticipated further rainfall. When farmers eventually decided to start thinning, they found themselves having to thin fast and freely, as they needed to reduce moisture competition between plants (Schoper *et al.,* 1982). However, this was not possible, due to the need to weigh the fodder, which may have resulted in delayed thinning. Scrutiny of the literature did not provide any information on thinning patterns for comparison with results from the present study.

Table 6: *A summary of thinning characteristics across farms and seasons*

Parameter	Season	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Final plant density/ha ('000) - farmer	Short wet	-[1]	[1]-	[1]-	13.8	16.3	15.2
	Long wet	65.8	29.6	66.0	56.1	-[1]	85.3
Final plant density/ha ('000) - modified	Short wet	-[1]	-[1]	-[1]	12.8	24.3	20.1
	Long wet	54.0	56,0	107.0	39.9	-[1]	52.6
Number of thinnings	Short wet	-[1]	-[1]	-[1]	3	6	8
	Long wet	4	6	6	2	5	18
% Plants thinned - farmer	Short wet	-[1]	-[1]	-[1]	78	78	90
	Long wet	21	64	21	19	-[1]	84
% Plants thinned - modified	Short wet	-[1]	-[1]	-[1]	87	75	86
	Long wet	72	66	36	76	-[1]	68
Day started thinning	Short wet	-[1]	-[1]	-[1]	89	86	61
	Long wet	110	63	68	73	61	54
Day finished thinning	Short wet	-[1]	-[1]	-[1]	130	113	111
	Long wet	198	155	143	143	109	143

[1] - Crop salvaged due to insufficient rains

Some farmers salvaged the entire crop as a valuable source of fodder in the event of grain failure. This shows the degree of flexibility offered by the maize crop to small farmers (Kagoungo *et al*., 1997). In both seasons, the salvage crop was harvested in small amounts up to a period of 32 days. It allowed the crop to be harvested green when the quality was higher

Other types of fodder obtained from the experimental plots and used for livestock feed were weeds and beans haulms. There was a positive effect on production of weeds in all seasons except on farm 6 in the second season. Although in the assessment of the trials, farmers observed that this would necessitate weeding more than the normal twice, they valued the contribution of the weeds as a source of fodder. The fact that leaf stripping was carried out only on one farm in one season, was not surprising given the findings of the appraisal survey that leaf stripping was not common in the Kiambu region. The reason was not clear, but could be due to the labour required to harvest the leaves and the low yields.

The other reason could be the poor nutritional value of the senescent leaves. In the present study, leaves were stripped at 107 DAP when they were dry and had a CP content of 4 – 6 *per cent*. However, the results showed the practice had potential to increase fodder production. Quality could be improved if the leaves were harvested green when the CP content was 8 – 13 %. Abate and Lukuyu (1995) reported a CP of 9.2 –10.6 *per cent* when leaves were stripped at silking stage (60 – 80 DAP).

Role of on-farm research and farmer participation

The objective of maize experiments set up on six farms was to allow farmer involvement in design of treatments, to take management decisions according to their system and to allow thinning according to farmers needs. However they were not completely free because of the need to quantify fodder production from farms that required statistically designed experiments. This prevented them from obtaining little fodder at a time and whenever they wished. But the trials enabled collection of data that would not be possible to collect on-station and understanding farmer perceptions of the research. The participatory approach achieved two major goals. Firstly; it offered all participants (researchers, extensionists and farmers themselves) an opportunity to learn new lessons from the experiments (Franzel *et al*., 2000). Secondly, it made the whole process farmer-focused and farmer-driven, therefore relevant to farmer needs (Okali *et al.,* 1994).

Involvement of farmers in the design allowed those with the simplified design to thin according to their needs. For example, farmers were expected to select which treatments to thin but instead they worked systematically across the field, without choosing treatments. Following discussions with farmer after the short wet season trials, in order to try and solve this problem, a simplified design involving only two treatments was introduced in the long wet season. Farmers involved in the simple design (Farms 1 and 2) looked at the state of the crop in the long wet season and considered which treatments needed to be thinned. It was easier perhaps for farmers to compare two treatments, where they collected data themselves, than the four treatments used on the experimental farms. Additionally, the two farmers may have had more of a sense of ownership of the experimental plots.

The participatory approach also allowed farmers to identify and suggest solutions to some of the constraints observed in the trials (Okali *et al.,* 1994). The farmers evaluated the experiments in totality and considered a variety of potential benefits and problems related to high density planting that, they hoped, might be useful to improve fodder production from maize. Farmers highlighted factors that made it very difficult for them to make decisions on whether to manage the crop for fodder or grain and, hence on input levels and thinning regimes. However, farmers pointed out that, since some of these factors were beyond their control, they would be prepared to take risks to increase fodder. If the grain yield is affected, they could buy in grain, using cash from milk, or obtain it from the co-operative societies on credit against milk delivery. This appears to confirm the findings of the initial appraisal results, which showed that it is cheaper to buy maize grain than fodder in the study area.

Summary

In summary, the appraisal shows that reduced land sizes have led to feed shortages on farms. Farmers have, therefore, resorted to the maize crop for fodder production and, as a result, management strategies have changed. The interactions between the main agronomic factors, identified by farmers, that influence decisions to manage the maize crop for fodder production are complex. Although the main focus revolved around the principal purpose of the crop, the cropping season and the cropping system, there are a number of other factors that influence the decisions to manage the maize crop for fodder production, including the maize variety, spacing, seed rate, manure and fertiliser application rates. These are taken in the light of cost implications, food supplies to the household, and feed supply for livestock. This may explain the diversity in management decisions on different farms.

The present study also shows that maize provides flexibility to smallholder farmers in the feeding of their livestock and a means of overcoming risk. Farmers have options of feeding thinnings, leaf strippings, green stover, dry stover and the salvage value of the whole crop in the event of grain failure, which can allow them to respond to difficult times. There are no definitive decisions on when to feed maize fodder, rather it will depend on individual farm requirements and the conditions in each season. This makes maize a useful component of the intensive production systems in the Kenyan highlands, although it is not the answer to all of the problems.

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