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der Landwirtschaftlich-Gärtnerischen Fakultät
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DISSERTATION

The effect of the regrowth length of native and improved pastures on hay production and hay quality in the Adamawa plateau of Cameroon

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Dedication

This work is dedicated to my wife, Kate and our children, Agei Jim, Ma-Ndip Arah and Tabi, Enoh

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LIST OF ABBREVIATIONS

ADL	Acid detergent Lignin
ADIN	acid detergent insoluble nitrogen
ANOVA	analysis of variance
ASAE	Association of Agricultural Engineers (USA)
asl	above sea level
BR	*Brachiaria*
CF	crude fibre
CDOM	digestible organic matter after digestion in cellulase
CP	crude protein
DCP	digestible crude protein
DCPY	digestible crude protein yield
DDMY	digestible dry matter yield
d	potential degradation rate
df	degree of freedom
Dig.	digestible
DM	dry matter
EDTA	ethyl diaminetetracetic acid
EE	ether extract
ELOS	enzyme (cellulase) soluble organic matter
ELOSY	enzyme soluble organic matter yield
EULOS	enzyme insoluble organic matter
FU	feed unit (french)
g	gram
GE	gross energy
GLM	sas procedure for general linear models
h	hour
ha	hectare
HCl	hydrochloric acid
IRAD	Institute of Agricultural Research for Development
ILRI	International livestock research institute
IVDMD	*in vitro* dry matter digestibility
IVOMD	*in vitro* organic matter digestibility
Kcal	kilo calorie (s)
kg	kilogram
LSQ-Mean	least squares mean
LW	live weight

ME	metabolizable energy
ME_g	metabolizable energy for growth
ME_m	metabolizable energy for maintenance
MJ	mega joule
MP	metabolizable protein
No.	number
N	number of observations
NaOH	sodium hydroxide
ME	metabolizable energy
NE	net energy
Ne_g	net energy for growth
NE_l	net energy for milk production
NFE	nitrogen free extract
NIRS	near infra red reflectance spectroscopy
NP	native pasture
ns	not significant
PF	partition factor
PT	pasture type
q_m	feed metabolizability; actually ME/GE
RDP	rumen degradable protein
Regr.	regrowth
r	correlation coefficient
RSD	residual standard deviation
R^2	coefficient of determination
SAS	Statistical analysis system
SCFA	short chain fatty acids
SEC	standard error of calibration
SEC (V)	standard error of cross validation
s e m	standard error of the mean
SEP	standard error of prediction
spp.	species
SPSS	Statistical program for the social sciences
SiO_2	silica
wt	weight
wk	week (s)
Yr	year

1. INTRODUCTION

The Adamawa plateau is a vast region with a sudano-guinean savanna vegetation covering up to 100,000 km² in the northern parts of both the Republics of Cameroon and Nigeria. The main occupation of the inhabitants is cattle rearing. It covers a large part of the Adamawa Province of Cameroon. The Adamawa Province contains more than 28% of the cattle population of the country making it the first national producer of cattle (MINEPIA, 1996/97). It has a cool tropical climate (mean annual temperature of 22°C). There are 7-9 months of rainfall, and, this mainly, between March and October and a relative humidity of 40-60%. It lies between latitudes 6° and 8°N and longitudes 10° and 16°E.

The herbaceous vegetation cover of the Adamawa Province, like that of most tropical regions, is luxuriant early in the rainy season. The pastures grow rapidly with the on set of the rainy season but they become lignified after about 2 months. There is then a sharp drop in the energy and protein content of the forage species present. The pastures of the plateau range from shrub- grass (sudan) savanna with very few trees in the north of the escarpment to tree (guinea) savanna in the south at 800 m asl. The typical herbage species found belong to the Andropogoneae and the Poaceae tribes and consist mainly of tall grasses, (*Hyparrhenia* spp., *Andropogon gayanus, A. schirensis*, etc. *Brachiaria brizantha, B. mutica*, *Panicum spp***.** etc). These are 2 of the 28 tribes of the gramineae and they are characterised by having heights averaging 2 – 3 m. In the Vina division where Ngaoundere town and Wakwa Research Institute are located, the vegetation was originally typically sudan savanna (mainly grasses interspersed with a few dwarf trees). Nowadays it has tall (more 20 m) trees and the latter constitute more than 30% of the vegetation. The trees are increasingly invading grazing lands due to 3 main factors:

1) yearly bush burning in search of game and to encourage pasture regrowth,
2) overstocking without the appropriate rest periods and
3) lack of pasture management.

The latter activity should involve rotational grazing, respecting stocking rates according to pasture composition, removal of encroaching trees with bull dozers, pasture conservation and weeding of obnoxious species. Unfortunately since land is mostly communally grazed, pasture management is difficult to achieve since no person is motivated to invest in it. The pasture formations resulting from these circumstances contain woody plants that have adapted to the

milieu. These are notably dominated by two tree species: *Daniellia oliveri* Hutch and Dalz. and *Lophira lanceolata* Van Tiegr. Ex Keay (Letouzey 1968, 1985).

Precipitation determines the onset of the growth of pasture species and therefore the amount of biomass that can be produced. High temperatures can act as a limiting factor when precipitation is adequate (or inadequate) and determine the maturing process (tillering, flowering, pollination and seed formation). In the Adamawa plateau, all these conditions are optimal leading to rapid growth during the onset of rains (mid march to early April). The rainfall attains a peak in August or September and ends in October. Pasture growth follows the rainfall pattern. Pastures attain maximum biomass in September but the nutritive value is low. The windy conditions cause a loss of moisture and a further drop in the dry matter and quality of the forages. Occasional rains are however not rare in November and so hay making should be initiated only after weather forecasts preclude them.

The grassland is used by pastoralists and sedentary farmers partly as communal grazing and partly by sedentary farmers with exclusive user rights (IRZ/GTZ, 1989). Within the first two land use systems, a pasture improvement activity is difficult to be achieved. This overgrazing and bush burning of communal grazing lands leads to land degradation and to the disappearance of nutritive species and the appearance of low value grasses (*Loudetia kagarensis, Sporobolus pyramidalis* and *Pennisetum phragmitoides)* and woody plants (*Daniella oliveri and Lophira lanceolata)*. The appearance of trees further results in a reduction of grazing lands (Rippstein, 1985; Yonkeu, 1993).

The deterioration of the herbaceous vegetation cover of grazing lands, has led some sedentary livestock farmers to develop systems to combat the problem of limited year round feed availability. One such technique is deferred grazing. This can take the form of standing hay for grazing during the dry season or conservation via silage and hay. The preferred conservation method practised by sedentary farmers with user rights here is hay making. However good quality hay is not easy to be achieved. Problems of palatability and low consumption have been cited as the main factors leading to the poor condition of animals fed hay (Crowder and Chheda, 1982; Ranjhan, 1983).

Trials on the deferment of pasture for hay production on the plateau have neglected estimating the nutritive value of the deferred pastures grazed by the animals. It is intended that the animal, which is the final user of the pasture, be used to provide information on the digestibility of native and introduced pastures. This would be done through an *in situ* digestibility study. To provide

even more data on quality, the pepsin-cellulase *in vitro* estimate of the organic matter digestibility would also be employed.

The goal of this experiment is to define hay making methods to enable livestock farmers exploit hay to its maximum potential.

1.1. Problem statement

A farming systems survey carried out in 1989 by an IRZ/GTZ team revealed the desire by pastoralists in the Adamawa province to maintain their animals, particularly cattle, in good condition throughout the year (IRZ/GTZ, 1989). However, because of the seasonality in feed supply in this region where rainfall determines the length of the grazing season and little feed conservation is practised, the livestock loose weight by as much as 20% during the dry season. There is also a lowering of lactation yields, with lactating stock not even producing enough milk to maintain their young. Calving intervals are long and growth development of young stock is slow. The livestock thus have a low reproductive performance (Lhoste, 1967; Dumas and Lhoste, 1969).

The Institute of Animal and Veterinary Research (IAVR), Wakwa Station, implemented studies on the use of protein and energy concentrates as dry season supplements **(**Piot, 1975; Rippstein, 1980; Ottou et al., 1991), introduced legumes (Rippstein, 1979; Rippstein, 1985; Pamo and Tarawali, 1990; Enoh et al., 1999), woody plants (Piot and Rippstein, 1975; Yonkeu and Enoh, 1995) and conserved feeds (Enoh 1990; Ottou et al, 1991) for the maintenance of body weight and milk production of local zebu and cross-bred dairy and beef cattle, (CRZ Wakwa Annual Reports, 1985 – 1996). Most of the work was done on-station but a few on-farm. The evaluation of conserved feeds integrating several pasture regrowth lengths, and hay storage length and digestibility (*in situ* and *in vitro*) has not been measured.

Strategies to alleviate the adverse effects of seasonality of feed availability differ according to the production system. Since most livestock production systems found in the survey (IRZ/GTZ, 1989) were geared towards the need for constancy in feed supply, it is necessary to improve the production output by providing technical solutions that will not harm the long term production potential of land and water resources (Peters, 1999). For livestock systems in which the output function is only one amongst many (security, risk aversion, etc.) and which are limited in their development by the infra-structural and institutional environment, intensification will initially favour internal inputs (Peters and Tothill, 1988). External inputs involve the use of either agro-industrial by- products such as maize bran and cottonseed cake, mixed concentrates such as

urea/molasses or introduced forages to increase milk and meat production. However, there are several constraints in the process of intensification. Some of these are lack of cash, lack of access to livestock product markets and the cost-benefit situation (Mohamed-Saleem et al, 1986; IRZ/GTZ, 1989; Peters, 1999). Thus a less intensive system may be desirable for now while waiting for the above constraints to be progressively eradicated. The production system is thus beset with the seasonality in feed supply and the need to utilise production technologies for improving the use of existing feed resources as a way towards intensification through "internal inputs".

It is the intention of this study to provide information on ways to minimise the stress brought about by feed resource scarcity by providing information on hay quality and yields obtained using different lengths of regrowth and hay quality during storage.

1.2. Objectives

The main objectives of the present study were:

1. To assess the biomass available for hay making purposes from native (mainly *Hyparrhenia* species predominant) and introduced (*Brachiaria ruziziensis*) pastures
2. To determine the quality of the hay from the above pastures after being subjected to different lengths of re-growth (deferment)
3. To determine the effect of storage length on hay quality.
4. To compare the different methods for determining hay quality.

2. LITERATURE REVIEW

2.1. Problem of conserving pasture feed resources into the dry season

In many regions of the world the forage has to be conserved through harvest and preservation to feed animals during periods of forage scarcity or shortage of fresh forage. The primary goal in forage conservation is to maintain the crop dry matter (DM) and nutrients with minimal loss both during harvest and during storage (Rotz and Muck, 1994). Loss is influenced by type of forage species, size and type of equipment, storage facilities, and cost of the required technology. Costs of production must be balanced with system performance (including losses) to select the best forage systems for use in any environment. Many harvest and storage systems can be used: e.g. ensilage, haylage and fresh cut grass. In silviculture leaves and branches of trees are harvested and fed to the animals during the winter (dry season) months. However, the major options are dry hay and silage production. The cutting of pastures however has an effect on the sward. i.e. on the vegetation association, the yield in successive years and the nutrient export. To bring the grassland back to equilibrium, the following actions can be done:

1) yearly fertilisation
2) intermittent cutting during a growing season so as to give the pasture enough rest period for nutrient regeneration and
3) cutting once every 2 years, i.e. alternate grazing and cutting

Using grass for silage or hay making causes physical and physiological spoilage and nutritional leaching losses. This study investigates the process of hay production and, thus the following literature discussion will focus on hay.

Hay Harvest Losses

Losses during hay harvest and storage range from 15 to 100 % of the initial DM (Rotz and Muck, 1994). Under good drying conditions DM losses are between 15 and 18% only (Rees, 1982; Rotz and Abrams, 1988) and if rain damaged, up to 30 % DM. In general, average hay making processes lead to a 24 to 28% loss in forage DM yield most of which is during harvest and about 5% loss is during storage (Waldo and Jorgensen, 1981; Wilkinson, 1981, Buckmaster et al. a,b, 1989).

Baling Losses

The DM of the cut and field cured forage before baling is very important to guarantee that good hay with a good keeping quality can be obtained. Studies have shown that the DM content at baling for tropical grass hay e.g. *Digitaria decumbens* (Lieu et al, 1986) as well as for temperate hays e.g. *Lolium perenne* should not be less than 71%, i.e. it should not contain more than 29% moisture, otherwise it will tend to heat up and get spoiled by bacteria and moulds. In the Adamawa plateau, livestock farmers have always complained of hay that rots and cannot be eaten by their cattle. It was noticed that baling was often done at a high moisture content (IRZ/GTZ, 1989). Although differences between the DM yield of the standing crop and the DM yield of the harvested hay have not been quantified here, average productivities of 4 – 5 tons and 3.5 tons DM/ha for non fertilized *Brachiaria* and native pastures have been obtained here (CRZ Wakwa, 1985). Both pasture types have responded well with even higher yields when fertilized yearly (Pamo and Yonkeu, 1989). Studies on the quality of these pastures indicate that the type of rainy season management prior to dry season hay harvest is crucial in determining the yield and quality of the hay crop (CRZ 1997 Annual Report).

A study of native species and *Brachiaria* hay was carried out on farm (in the Vina division) as well as on station (at Wakwa) in November of 1995 and 1996 respectively, and in February 1997. The survey was carried out on large round baled hays left on the field and samples were collected and analysed in the laboratory for chemical content. Yields were also measured (CRZ 1997 Annual Report). The results were as follows:

1995/1996: only yield measurements were done that gave the following results: 2556 kg DM/ha, (on-station *Brachiaria* hay), 2700 kg DM/ha (on farm- *Brachiaria)* and 2485 kg DM/ha on-station native species hay plots, respectively.

February 1997: Chemical composition was determined as follows: *Brachiaria* on-station and on- farm) average crude protein (CP), neutral detergent fibre (NDF),acid detergent fibre (ADF), crude fibre (CF) and calculated net energy of lactation (NE_l), (3.22%, 70.75%, 44.18%, 37.07% and 3.06 MJ/kg DM). Native pastures hay values were: 1.98%, 78.85%, 49.15%, 41.92% and 1.57MJ/kg DM respectively.

The quality of the hay was determined only once in February because this is the month of the most drastic weight loss in animals and when supplementation with cottonseed cake is practised. Earlier, Rippstein (1985) had measured the weight of some baled hay after baling. He then determined on a few random samples the DM 2 months later. He noticed a drop in DM and quality. The hays were from native pasture plots only and the plots were not service

cut to ensure uniformity. These two studies show that yearly cutting for hay, a process whereby the machine cuts all vegetation close to the ground is detrimental to the survival and quality of the pasture species of the plateau. Other authors have confirmed this drop in the yield of the hay crop in successive years (Van Soest, 1994; McDonald et al., 1995).

In conserved feeds such as hay, the losses are caused by 1) physical detachment of forage material, 2) nutrient leaching by rain during harvest and 3) the internal depletion or degradation of plant nutrients and spoilage due to insufficient moisture reduction. Table 1 shows that there is a difference in quality between the grass before harvest and the hay crop. It also highlights the difference in quality between tropical and temperate grasses and their corresponding hays.

Table 1. Composition and nutritive value of some temperate and tropical hays hays

Item	CP (g/kg DM)	CF (g/kg DM)	ME (MJ/kg DM)
Temperate Grass+: *Lolium perenne* (1^{st} cut to 4^{th} cut)	180 - 97	212 - 312	13.1 - 8.9
L.perenne hay+ (1^{st} cut to 4^{th} cut)	113 - 96	298 - 337	8.9 - 8.8
Tropical Grasses* e.g. *Hyparrhenia rufa* (1^{st} cut to 4^{th} cut)	92 - 28	289 - 337	8.4 - 6.5
H. rufa hay* (1^{st} cut to 4^{th} cut)	56 -19.6	320 - 360	7.0 - 5.0

Samples collected from vegetative to flowering stage of development
+ Adapted from McDonald et al. (1995). * Adapted from Rippstein (1985)

These values are higher than those reported by Demarquilly et al., (1980) using the French net energy feed units system. They evaluated the energy content of temperate grassland hay harvested at the 1^{st} cut (young leafy) stage at 0.61 forage units for milk production (FU_l) and 0.51 forage units for fattening (FU_v), respectively. These values are equivalent to 4.1 MJ/kg and 3.5 MJ/kg DM NE_l, respectively, using the French forage unit (FU) system based on standard barley. 1FU contains 1650 Kcals/kg DM (or 6.897 MJ/kg DM) net energy. The French values seem somewhat low compared to those compiled in Table 1 considered as being representative of the true range of temperate as well as tropical grasses and their hays. It can be seen that there is an unavoidable loss of forage quality upon conserving the crop as hay for dry season use.

2.2. Problem of delaying maturity of pastures

One of the most important factors influencing the quality and quantity of the hay crop is the maturity of the pasture before hay harvest (Van Soest, 1982). With increases in the cell walls content in the forage, digestibility decreases (Marin et al., 1997). Delay in harvesting (long deferment) has been shown to lower DM digestibility of Ethiopian forages (Sileshi et al. 1995). Cutting age was also found to be positively correlated with yield but negatively correlated with nitrogen concentration (Tukue, 1991). Hay paddocks are traditionally grazed during the early rainy season, then closed to enable a regrowth of the herbage (bulking up) and then cut at the end of the growing season just before flowering. However for technical reasons or weather imperatives e.g. unexpected rains at harvest date, the harvest may be deferred. In the Adamawa plateau trials on the most appropriate cutting date have shown that for non fertilised native as well as introduced species such as *Brachiaria ruziziensis*, an 8 to 12 week period of deferment is appropriate before cutting hay (Rippstein, 1985; Yonkeu, 1993). The composition of the above two types of hay pastures was found to be very variable and the rainfall patterns influenced the yields and onset of flowering in different manners (Pamo and Yonkeu, 1986; Rippstein, (1985) summarised the results of trials done at Wakwa involving the effect of deferment length on *Brachiaria* under different fertilizer regimes as shown in Table 2.

Table 2. The influence of deferment length and different fertilizer (N-K-P) rates on the chemical composition values of *Brachiaria* hays from newly established plots, at Wakwa research station, DM basis

Regrowth (days)	30			30			30			70			100			180		
Fertilizer (kg/ha)	N	K	P	N	K	P	N	K	P	N	K	P	N	K	P	N	K	P
Units (kg/ha)	0	0	0	350	100	0	350	100	50	100	50	50	100	50	0	100	50	50
No.	4			5			18			1			1			5		
OM (%)	86.7			86.6			86.9			90.8			92.8			91.8		
CP (%)	10.8			12.1			11.6			3.7			2.6			5.4		
CF (%)	29.1			30.6			28.9			36.1			39.7			36.3		
EE (%)	1.7			1.5			1.7			0.6			1.3			1.4		
NFE (%)	45.1			42.4			44.6			50.4			49.2			48.7		
Ash (%)	13.3			13.4			13.1			9.3			7.2			8.4		
Silica (%)	4.0			3.6			3.9			2.0			1.7			2.6		
NE (FU/kg)*	0.6			0.6			0.6			0.5			0.4			0.5		
NE (MJ/kg DM)	4.138			4.138			4.207			3.311			3.035			3.449		

Adapted from Rippstein (1985, page 298)
* Calculated from Dutch Feed Tables where: 1 FU = 1650 kcal/kg DM or 6897 KJ/kg DM
No. = number of observations; OM = organic matter, NE= net energy
N- P -K = mixed fertilizer containing, nitrogen, potassium and phosphorus
OM = organic matter; CP = crude protein; CF = crude fibre; EE = ether extract; NFE = nitrogen free extract; NE = net energy.

From Table 2 it is clear that the nutritive value of *Brachiaria* is affected by both the age of the regrowth and fertiliser application rate. The CP content decreased with an increase in pasture regrowth length. Crude fibre content was on the contrary positively correlated with increase in regrowth length. The ash content appeared to increase with the fertiliser application rate as well as with increase in deferment length. The energy was estimated from calculations based on expected values of tropical feed units extrapolated from the French net energy values that use barley as the reference feed (INRA, 1978) and was underestimated probably by 0.2 – 0.3 feed units if the current values from INRA (1980) are taken into consideration. No digestibility estimates were however made on these hays.

In Ethiopia, Kidane et al. (1997) obtained significant ($P < 0.001$) differences in rumen nylon bag degradability between three treatments of native hays cut at 20-day intervals throughout the season. It reduced from 77.2% to 58%. Rumen degradable protein/metabolizable energy ratio (RDP/ME) also reduced from 7.5 to 3.7 g/MJ respectively. The authors concluded that

early harvest should be the starting point in improving the productivity of livestock in the Ethiopian highlands.

There is also the problem of the reduction in the energy concentration involved when forages are harvested late. Of particular importance is the crude protein to energy ratio that a feed possesses (unit: g/MJ /kg DM). It has been observed that this ratio is highest for pasture species before heading (up to 23 g CP/MJ kg^{-1} DM for legumes/alfalfa) and least at the flowering stage (12g CP/MJ kg^{-1} DM) (Menke and Huss 1980; ADAS, 1984; Van Soest, 1985; McDonald et al., 1995). The normal value a forage should contain is 18 g CP/MJ kg^{-1} DM. Such an energy concentration can cause a minimal production of 0.5 kg/day live weight gain in *ad libitum* fed bulls on a roughage ration. A voluntary DM intake of 2.5% of their live weight is also assumed. That means for 1 tropical livestock unit (TLU i.e. a 250 kg livestock), an intake of 6.25 kg DM per day is expected. Unless such forages are highly palatable, it may be difficult to achieve the above intake or weight gain without extra energy and protein supplements on tropical forages.

The ash content of forages has been found to increase with age (McDowell et al., 1983). However, some authors e.g. (Shäfer, 1996) found a negative correlation between ash and age of the cut of the some temperate grasses. The ash content increases generally with regrowth length before cutting. Some minerals are particularly needed for the growth of certain areas of the plant and can improve the CP content. Such is the case with nitrogen which applied as a dressing leads to an increase in leaf area and photosynthetic activity. This leads to an increase in plant CP content. Phosphorus for example causes shoot elongation and is retained mostly during the wet season. Its dose should therefore be reduced during the wet season. Calcium (Ca) on the contrary tends to be deficient in the soil during the wet season and accumulates during the dry season. Soil analysis has to be done in any locality so as to know about mineral deficiencies and thus how the different minerals can then be applied for maximum forage production and quality.

Studies on the Adamawa plateau (Yonkeu, 1993) and elsewhere (Varvikko et al., 1993) have shown an increase in the yield of *Brachiaria* and of native pasture hay with increase in the length of grazing deferment prior to cutting but they also report a slight decrease in biomass yield with an extended harvest delay. They reported a negative effect on crude protein (CP) and *in vitro* digestibility (IVDMD) percentage but a positive effect on cell walls with increase in length of deferment. The intake of hay from different lengths of regrowth periods fed to local Ethiopian Boran x cross bred (Friesian) bulls was lower for hay with longer regrowth,

probably due to the increase of fibre content in hay from a longer regrowth period (Kidane et al., 1997).

2.3. Problem of curing

Field curing of hay is subject to surprise rains even in regions with well defined rainy and dry seasons (Whiteman, 1980; Artus and Champanhet, 1987; Menke and Huss, 1980). Rain and extended manipulation of hay causes leaching of water soluble nutrients and increases chances of physical losses. Quick curing is dependent on:

- thin layers with a windrow,
- breakage of nodes to speed up the evaporation of cell moisture
- and appropriate turning of material

For example, frequently turned and tedded *Setaria anceps* hay required 50 – 70 hours curing to reach a moisture content of 25 % and had a DM loss of only 10 – 13% (Catpole, 1969). According to Rotz and Muck (1994), thin swards of hay need 3 – 5 days curing while heavier windrows require 6 – 7 days but surprise rains delay it several more days. After 2 weeks, the hay is not suitable for animal feeding anymore.

Respiration depends on the hydrolytic and respiratory enzymes present in the plant living cells. It reduces and stops at a moisture content of 40 and 26% respectively (Wood and Parker, 1971; Wolf and Carson, 1973). Prolonged field curing allows development of bacteria, yeasts, and fungi on the forage (Pizarro and Warboys, 1979). Their respiration increases overall respiratory activities, although small, but substantial over extended poor drying conditions. The substrate for respiration is mostly the soluble carbohydrates as shown hereunder:

$C_6 H_{12} O_6 + 6O_2 \rightarrow 6H_20 + 6CO_2 + 2870$ KJ heat (Parkes and Grieg, 1974).

The products of respiration, namely water, carbon dioxide and energy escape thus leading to a drop in the yield and energy content of the hay during field curing. The rate decreases when the readily available soluble carbohydrates are depleted, then proteins and fats are used. DM loss due to plant respiration is difficult to measure, however, when curing takes less than 4 days a value of 3 – 4% only was obtained for alfalfa dried under good weather conditions (Rotz and Sprott, 1984; Rotz et al., 1988). For the humid tropics, the loss is estimated to be equal to or greater than 10% (Artus and Champanhet, 1972; Morris, 1972;). In warmer climates, proteins are earlier degraded in this process to non - protein nitrogenous compounds

such as amides. It has been recommended that field curing in the humid tropics should not exceed 3 – 4 days and the best conservation DM of hay should be 75 – 85% (Zwaenepoel, 1986). In summary, plant respiration during field drying results primarily in the loss of peptides, carbon dioxide (CO_2),and soluble carbohydrates . Surprise rains can reduce the useable yields due to further loss of DM amounting up to 30% (Shukking and Overvest, 1979; Van Bockstale et al., 1979; Wilman and Owen, 1982; Collins, 1985) and up to 50% after heavy rains, (Collins, 1983).

According to Collins (1982) leaf loss has a minimal effect on temperate grass forages but a larger effect on legume forages. However, temperate legume forages are normally exposed to small losses due to their small leaves. For example alfalfa CP content dropped from 20% at cutting to 19.6% only. The same author pointed out that nitrogen loss from leaching on the contrary could vary from 10 to 50%. A typical value can be taken at about 30% of leached DM being CP. Fonnesbeck et al. (1986) found that DM leaching was composed of 10% soluble minerals and 10% total lipids. However, other authors have observed a lowering of the CP value of the hay crop in tropical pasture species with relatively large leaves and which suffer from serious leaf loss during curing, hay harvest and baling (Van Soest, 1982; Rippstein, 1985; CRZ Wakwa Annual Reports, 1985 – 1996).

2.4. Problem of storage and quality

When hay is brought in for storage below a DM content of 60%, respiration by the micro-organisms present on the hay continues (Rotz and Abrams, 1988; Rotz et al.; 1991). Hay can be stored either

- as loose heaps,
- as packed stacks or
- as bales (rectangular or large round)

The hay may either be stored outdoors or indoors. When outside it may be covered with sheets or simply uncovered. It may also be stored on tyres or any other device to minimise the effect of damp and termites. Good storage must ensure the following:

- protection against rain,
- protection against soil moisture and
- protection against radiation.

Loss of DM over time is different according to the storage method used and place of storage. The loss of DM appears to be lowest for the large round bales stored indoors. For example Buckmaster and Heinrichs (1993) obtained a 5% loss over six months storage on 2nd and 3rd cuts of alfalfa large round bales in rooms with open sides. On the contrary, there was a 15% and 9.6% DM loss on outside stored hay stacks and large round bales stored outside respectively, on the same crop. In another study on the effect of storage type on DM loss during storage, Brasche and Russell (1988) found a DM loss of 1% and 9.5% respectively when alfalfa brome grass was stored on tyres and covered with plastic sheets than when simply stored outside on the ground. Anderson et al. (1981) obtained a 14% loss for unprotected bales stored outside and only 3% for those stored inside. Both studies were done on large round bales. The above studies all show the importance of protecting the hay from too much radiation and soil contact.

In the sub-humid zone of Africa and particularly in the Adamawa plateau, there is the problem of the lack of plastic sheets to cover the hay stored outdoors. Labour cost involved in stacking the hay in the field is low. However, due to high radiation, bush fires, wandering cattle, goats and sheep because of the poor fencing of hay paddocks, the hay crop may all be lost. Indoor storage was thus recommended in the survey report based on the livestock farming systems survey in 1989 (IRZ/GTZ, 1989). In Europe, however, where labour costs are high but where the crop is produced in private farms that are well fenced and have the technical and financial means to store hay outside, the similarity in the DM losses from outside protected storage and indoor storage may make the former method acceptable for adoption (Brasche and Russell, 1988).

Studies on the effect of crop species on DM loss during storage (Rotz and Muck, 1994), type of species, native or introduced (Nelson, 1966; 1972) show that these parameters have no influence on DM and nutrient loss. Temperature and moisture affect DM loss and quality of white clover, alfalfa and rye grass in rather the same way (Greenhill, 1961). Crop maturity may affect respiration and the resulting storage losses inconsistently. For example, Nelson (1968) found 25% more heating and DM loss in bud stage alfalfa compared with more mature alfalfa but a nonsignificant difference ($P < 0.05$) between the half bloom and full bloom stage. This is a result of the fact that with increasing maturity the cell wall content increases and a higher DM content exists in the forage at both cutting and baling compared to a less immature crop. This higher DM acts as an impediment to nutrient loss via respiration and increased temperature upon storing the crop.

Mendez Cruz et al. (1988) studied the effect of deferment length and storage on the digestibility and voluntary intake of five tropical grasses using Holstein steersaged 1.5 to 2 years and weighing 200 to 250 kg. *Cynodon plectostachyus* had the lowest digestibility and DMI values. However for all 5 forages, average *in vivo* digestibilities over the 4 storage lengths studied (< 4 months, 4 – 8, 8- 12 and > 12 months) were 60.8%, 56.8%, and 55.0%. The CP contents of the 35day, 45 day and 55 day deferred samples were 17.0%, 15.4%, and 15.6%, respectively. Mean DMI declined from 1.47 to 1.11 kg/day, 1.31 to 0.90 kg/day and 1.50 to 0.82 kg/day respectively from the less than 4 months- to the more than 12 months-stored samples. This shows that there is a loss in quality with increase in deferment length and duration of storage. In another study, Buckmaster and Heinrichs, (1993) found a reduction in DM and *in vitro* dry matter digestibility (IVDMD) of up to 6% after 60 days storage in 2nd an 3rd cut alfalfa. In the same study CP, ADF and NDF were only increased by 1, 2 and 0 % respectively, over the same length of time. Other authors (Davies and Warboys, 1978; Collins et al., 1987) have also reported on the negligible decrease in CP content during storage of up to 60 days for low moisture hay. However, if hay is baled with moisture content above 50% there will be a very sharp drop in the CP content (Menke and Huss, 1980). Most data on effects of storage length on CP content is mostly limited to 60 days duration. It has been found that during the first month carbohydrate loss is great and protein loss small ($P < 0.05$), but the protein loss also increases with increases in the rate of loss of the carbohydrate (Lieu et al., 1986). The greatest CP loss is during months 6 – 9 of storage and it amounts to about 2.5% CP/kg DM for each month, for small untreated bales (Davies and Warboys 1978; Collins et al., 1987).

The chemical pathways causing losses are complex. Carbohydrate losses mainly affect the water soluble fraction which thus increases the relative proportion of cell walls (NDF) content during storage. Relative fibre content increases consistently as a result of the loss of the non fibre constituents. Indeed there is absolutely no loss of NDF, ADF, CF, lignin and ash during storage (Buckmaster et al., 1989; Rotz and Abrams 1988). Loss of water soluble proteins leads to a relative increase of water insoluble nitrogen and acid detergent insoluble nitrogen (ADIN) concentrations (Rotz and Abrams, 1988). In all, for hay with a low moisture content, there is a relatively small change in quality during the first 60 days of storage. For example, Rotz and Abrams, (1988) reported a 10 – 20 g/kg drop in the digestible dry matter (DDM), no change in the digestible crude protein (DCP) content and only a 10 – 20g/kg increase in NDF content in alfalfa hay stored over 6 months. However, for high moisture hays, the resulting heating that occurs causes an increase in ADIN (acid detergent insoluble nitrogen) via

Maillard reactions (polymerisation of sugars and other substances with free amino groups) and this seriously reduces storage quality. ADIN reduces the digestible dry matter (DDM) and DCP content of stored hay (Thomas et al. 1982). Energy might remain the same since there might be no great change in the digestible fibre content (Rotz and Abrams, 1988). The former author also confirmed that quality changes markedly occurred only in the first month of storage especially for high moisture hays and this reduces voluntary intake.

No studies have been conducted in the Adamawa plateau located in the sub humid zone of Africa, comparing the effect of storage length on DM recovery and the quality of hay. However, the DDM of the hays on the plateau may be low . In Australia, Playne (1978) measured the average DDM of tropical hays at only 49.6%.

2.5. The position of stored hay in feeding systems

The intake of hay particularly among cattle has been shown to be dependent on the quality of the crop (CP, cell wall content etc.), how well preserved it is and the leaf to stem ratio (Brasche and Russelll, 1988). As demonstrated earlier by Thornton and Minson (1973) the level of cell walls (NDF) appears to be negatively correlated with DMI for dried forages (hay) but not so for fermented forages (silage). However as pointed out by Brasche and Russelll (1988), no correlation will exist between NDF and DMI if the hay is not fed *ad libitum*. This means that the total diet of the animal has a primordial effect on determining total DMI and performance of animals. It is thus not un-reasonable to expect little or no production on a solely hay diet particularly of tropical grass hays, given the energy and CP content of the material and the DM loss resulting from making hay (Menke and Huss, 1980). The following are typical examples of feeding systems based on hay

1. At the Wakwa research station located in the sub humid zone of Africa, the feeding system practised is based on rainy season grazing of native or improved pastures. During the dry season, silage and hay are fed as the basal feed and some pastures that were not cut for hay are fed as standing hay or roughage supplement. Native pastures are mostly made up of *Hyparrhenia spp., Andropogon spp.*, *Brachiaria brizantha* and improved pastures of *Brachiaria ruziziensis*. Concentrates fed as supplements have varying proportions of feed ingredients but a typical one is made up of 50% maize, 26% cottonseed meal, 20% rice meal, 2% bone meal and 2% mineral premix. Protein concentrates are offered year round to the lactating dairy cows, dairy calves and pregnant beef cows, but not to beef calves (which run with their dams) or breeding bulls. The dairy calves are kept in a barn and fed

milk and concentrates and forage till weaning at 90 days or a body weight of about 70 kg. The system places emphasis on maximising grazing and giving an extra energy and protein source during periods of forage scarcity only (Lhoste, 1977; Rippstein, 1985; CRZ Wakwa Annual Reports, 1985 – 1996). This minimizing of production costs leads to a lower productivity but systems have to be adapted according to the socio-economic environment.

2. In Egyptian small ruminant systems, the use of hay as a winter feed but sometimes also as a bulk feed at the beginning of the growing season is evident. El - Basiony et al. (1997) tried combinations of milk only, or in combination with berseem hay and concentrates and showed that in Egyptian conditions goat kids and lambs on a creep feed diet consisting exclusively of milk, had the best growth performance. However after weaning, the costly milk could entirely be replaced by concentrates and hay and still lead to fattening as well.

3. With respect to the maintenance requirements and production performance possible on hay based systems, it was shown by Ikhatua and Olubajo (1983) in southern Nigeria, at the University of Ibadan animal farm, that the digestible crude protein (DCP) required to maintain German Brown x N'dama steers fed hay and concentrates to be 1.38 ± 0.14g/kg $^{0.75}$. The hay was from a sample of the hay offered to cattle kept at the University farm. In addition to the hay, the above breed of cattle are offered protein concentrates (20 – 44% CP) during the dry season. This diet has been shown to lead to dry season weight maintenance or even moderate weight gain. DM intake is however lower when the total amount of protein concentrate fed is low.

4. In the developed world the concern of farmers is a bit different since high quality feed is available. Even here, the exact pasture management system that ensures making of hay and silage at the right stage of maturity is a pre-occupation of the livestock farmers just like their other counterparts world wide. For example in France, in a country wide feed system study, Bossis (1996) found that the main problem of farmers was the absence of knowledge of the botanical composition of their pastures, how to control forage surpluses and conserved feed deterioration, and pasture management.

5. In the US, Harrigan et al. (1994) studied the effect of storage losses on different hay feeding systems based on lucerne (alfalfa) using the "dairy forage analysis system" (DAFOSYM) and found that the most benefit from the use of hay was making large round bales and feeding the hay as chopped hay mixed with the total ration. In western Europe, Canada and the United States a more intensive system is practiced. The emphasis is on zero grazing and maize silage as well as *Medicago sativa* (lucerne) hay plus concentrates

are the feeds of choice for maximum milk and meat yield (Bossis, 1996). Here too, the economics of scale are important because the investment in machinery (fixed costs) and the running costs involved in the conservation process must be considered.

Research work conducted by Brännäng and Persson (1990) in Ethiopia determined the values for the maintenance needs of 1 TLU (250 kg cow) following energy balance studies with African cattle breeds as follows:

Daily ME_m = 35 MJ; 215g DCP; 30g calcium (Ca) and 12g phosphorus (P).

French researchers proposed the following requirements for 1 TLU:

ME requirement: 35 MJ/day, and the feed should contain 3.1 MJ/kg NE or 3.9 MJ ME/kg DM, (assuming an efficiency of ME conversion to NE of 80%, and a CP content of 6.45% DM basis or 25g DCP) (Demarquilly and Weiss, 1970).

According to German norms, growing bulls weighing up to 300 kg, with a growth rate of 0.5 – 0.8 kg/day need 12 – 20g CP/MJ kg^{-1} DM ME feed concentration; while breeding bulls require a minimum 9 % CP feed content (Kirchgeßner, 1998).

In all, it is seen that a good quality, highly palatable roughage is assumed to be available whose consumption will be optimal in order to cause the expected response in the animal. This may not be the case with the more fibrous tropical forage hay having a long ruminal retention time which leads to low intake and to poor response from consumed hay (Hovell et al., 1986; Ørskov et al., 1988).

2.6. Methods of determining quality

The nutrient availability in a feed can be determined by the chemical composition of the feed (Van Soest, 1982). Chemical analysis attempts to provide information firstly with respect to the concentration of available and the unavailable compounds and secondly through the organic components and the inhibitors that may limit the availability of components with which they are associated. Chemical analyses thus only provide the potential value of a feed for the supply of a particular nutrient. The actual value of the feed can only be known after making allowances for losses during digestion, absorption and metabolism. This value can be obtained in *in vivo* trials but in the absence of the latter, other methods both chemical e.g. the indicator method or *in vitro* techniques (use of cellulases and fungal enzymes and the so called two – stage method of Tilley and Terry (1963)) can be employed. An *in situ* method using nylon bags too has been employed over the past 30 years to determine the rate and

extent of ruminal digestion of ruminant feeds giving close correlations with the *in vitro* method of De Boever et al. (1986).

Proximate Analytical Methods

The first attempt to determine the quality of feeds was made in 1809. It was the hay equivalent system whereby various feeds were quoted in terms of the amounts that could replace 100 pounds of hay. It was introduced by Albrecht Thaer (1754 – 1826) (Van Soest, 1994). The use of chemicals to fractionate feeds into chemical entities such as ash, protein, fibre and the lipids and oils was introduced by Henneberg and his associate Stohmann in 1860. The Weende analysis as it is otherwise known is actually a proximate analytical system. It is the conventional method that is used to give a rough idea of the chemical composition of feedstuffs.

The *Weende analysis* consists of 5 main steps:

1) determining the DM of the feed at 105°C over a 24 hour period
2) determining on separate portions of the feed, the ash and nitrogen contents with the CP = 6.25 *N content
3) doing an ether extraction of the sample after drying at 65° over 48 hours in order to obtain the oil and lipids fraction or ether extract (EE)
4) refluxing the sample successively for 30 minutes each with 1.25% HCl and 1.25% sodium hydroxide (NaOH), the insoluble residues being dried, ashed and the insoluble organic matter reported as crude fibre (CF), and finally,
5) calculating the percent nitrogen free extract (NFE) as the difference 100 – (ash + CP + CF + EE).

Detergent Feed Analysis

In 1964, another proximate analytical system based on the use of detergents for the differentiation of carbohydrates and especially fibre was introduced (Goering and Van Soest, 1965). It is based on the use of detergents in order to fractionate feed into three main classes:

1) a totally available fraction with 90 plus percentage digestibility (i.e. soluble carbohydrates, starch, organic acids, proteins and pectin),
2) incompletely available components such as cellulose and hemicellulose and

3) totally unavailable components such as silica, cutin and lignin.

A neutral detergent solution consisting of sodium lauryl sulfate and ethyl diaminetetracetic acid (EDTA) is added to the sample dissolving the cell contents to give the so called neutral detergent fibre (NDF). The insoluble part consists of the acid detergent fibre (ADF) i.e. the cellulose, lignin and lignified N and the part that is soluble in acid detergent (hemicellulose and fibre bound protein). ADF is recovered after boiling the residue in acid detergent (cetyl trimethylammonium bromide in 1N H_2SO_4) for 1 hour. The unavailable N is determined on the ADF via Kjeldahl procedure and consists mostly of Maillard products and lignified N. Acid detergent lignin (ADL) is the precipitate obtained by treating the ADF with 72% H_2SO_4 at 20°C for 3 hours. Cellulose is obtained upon ashing the ADF. Silica (SiO_2) is the residue remaining after adding concentrated HBr (48%) dropwise to ADF for 1 h at 25°C. Hemicellulose is obtained as (NDF – ADF).

This system like any chemical composition–based system, does not truly tell us the changes that occur to the feed during rumen fermentation (Tamminga et al., 1990). The use of empirical values based on chemical composition of feeds for determining the quality of forages and conserved feeds has drawbacks, especially since it does not consider the digestion of the feed within the animal itself and, thus, leads to poor animal response estimates (Van Soest, 1982; Tamminga et al., 1990; Bediye et al., 1998).

Energy Estimation

The above chemical composition determination methods all aim to characterise feed so as to give us an insight into protein and energy availability. The total energy of a feed may be obtained via bomb calorimetry. The feed is oxidised in a bomb, a strong metal chamber of the instrument. The quantity of heat produced during its oxidation is measured from a rise in the temperature of the water that surrounds the calorimeter. However, this value is of limited importance because after digestion, an important part of the gross energy is lost via the faeces.

Gross energy – faecal energy = digestible energy. When the energy lost via urine and methane release is added to the faecal energy and subtracted from the gross energy we have the apparent metabolizable energy.

Gross energy – (faecal, urinary and methane energy) = apparent Metabolizable energy (ME)

However, there is also some loss of endogenous energy in the faeces and urine e.g. as products of protein metabolism and this tends to make ME to be underestimated. When this loss is subtracted from ME the true ME is obtained.

European countries have 3 main systems for estimating energy of feeds: They are: the French forage unit (FU) net energy system based on barley as the standard feed, the Scandinavian feed unit system that is similar to the French system, and the metabolizable energy system as practised in Britain, Germany and most other European countries. In Germany, the NE system is used for determining energy requirements for milk production. All other production requirements are based on ME. The latter is a more relevant feed evaluation system for the tropics especially since it is based on the use of forages and a limited use of concentrate feedstuffs. The Americans use the net energy system mostly based on work carried out by Armsby in 1921 (Van Soest, 1982). Here the net energy is measured according to what productive response it can produce e.g. hair, milk, meat, etc. The main difference between ME and NE being that for the latter, the value of the heat increment (energy released during eating and digestion) is subtracted from the ME value. The resulting energy (NE), is the energy that is stored in body tissues. To obtain the heat increment, two sets of trials are needed: one to determine the ME at two levels of intake and the second to determine body gain (Me_g) and composition. Heat increment is then the ME – Ne_g.

In vivo Digestibility

In *in vivo* digestibility determinations either small ruminants, (mainly wethers) or steers are used (Osuji et al., 1993). When the purpose of the determination is to rank feeds only, 2 or 3 animals are required. The animals are usually conditioned to the feed to be tested for at least 14 days. The collection of faeces and urine is carried out for the next 7 days usually with the animals wearing a harness and faecal collection bag. This is usually done in a metabolism cage. Ten percent of each day's total feed fed and faeces is usually collected and frozen and at the end of the collection period, mixed and subjected to chemical composition and DM content determinations. For sheep all the faeces is collected. The urine is also collected and preserved using 0.2N HCl in order to prevent loss of N. The quantity of the feeds fed and all left overs is measured, and DM and chemical analytical determinations done. Apparent DM digestibility (DMD) is then calculated as follows:

$$DMD = \left(\frac{\text{Feed fed x \% DM} - \text{Faeces x \% DM}}{\text{Feed fed x \% DM}}\right) \times 100$$

The digestion coefficients for all other nutrients are calculated using the DMD and the percentage of the nutrient in the feed, refusals and faeces on a DM basis. Urine is analysed also to determine the amount of nutrients lost through it and thus provide a truer picture of the apparent digestibility. However, *in vivo* methods have not proved to be so accurate as

previously thought, since the feed consumed during the trial may vary in composition from that eaten by the grazing animal. The apparent digestibility coefficient from *in vivo* trials may therefore be overestimated and as has been shown to be poorly correlated with live weight gain (Ørskov and McDonald, 1979; McDonald et al. 1995).

Other Methods of determining Feed Metabolizability

These include the indicator method (where markers are used in the feed and the proportion excreted in the faeces is used to estimate the digestibility of the feed), fungal enzymes, the two stage digestibility method of Tillery and Terry, the nylon bag method (a de facto *in vivo* method), the Menke *in vitro* gas production technique and the pepsin cellulase method. Discussion will be limited to the last three methods because they are used for the calculation of energy and thus ME required by ruminants and give the best correlations with *in vivo* digestibility trials (Blümmel et al., 1997; Kirchgeßner, 1998).

Nylon Bag (In sacco) Method

This method involves the use of nylon bags that are incubated in the rumen of fistulated cattle or sheep for varying lengths of time, withdrawing the bags and determining the DM lost at the different times. It gives a dynamic description of fermentation (Mehrez and Ørskov, 1977). Ørskov and McDonald (1979) developed a formula to describe degradation parameters and this has been used in describing the degradability of most substrates since then. The formula is:

$Y = a + b\,(1 - \mathrm{Exp}^{-ct})$

where: Y = degradability at time (t), a = intercept, b = potentially degradable fraction c = rate of degradation of b. Here the asymptote is represented by a + b and it represents the potential degradability. If fermentation proceeds without delay, then the value a can be considered as consisting of immediately soluble material.

The *in sacco* technique was first reported to have good correlations with voluntary DMI intake by Chenost et al**.** in France (Chenost et al., 1970). They found a correlation at the 24 hour degradation value of 0.82 with voluntary intake of roughages compared with only 0.79 for the *in vivo* technique. This technique has a possibility for a high adoption rate in developing countries because of its low technical inputs: no need for sophisticated chemicals or instruments, its low labour input, little use of electricity and its high ability to estimate rate and extent of digestion.

The requirements for carrying out a nylon bag trial are as follows:

- Nylon bag
- Nylon string/cord
- A drying oven
- A dessicator
- Fistulated cattle or sheep (about 3 in number)
- Feed for the animals to assure energy and protein at maintenance level and
- Facilities for washing the bags (a tap or washing machine)

There is a need for standardising this procedure as the results obtained may not be similar if attention is not paid to the ration composition of the fistulated animals used, the ratio of sample to be incubated to the bag size, the pore size of the bags, the position of the bags in the rumen and the washing procedure. The ratio of the amount of feed (g) put in the bags to the surface area of the bag (cm^2) should range from about 15mg/cm^2 to 25mg/cm^2. Also the ratio of width to length of bags should be between1:1 and 1:2.5. This ratio allows all the feed to have free movement within the bag and to be properly incubated while in the rumen. The detailed procedure used can be modified depending on the availability of the required materials. However the agreed procedure adopted by the International Livestock Research Institute (ILRI)'s lab in Addis Ababa, Ethiopia and recommended for use in most developing countries and which respects the afore-mentioned basic pre-conditions involves the following steps:

- The feeds are ground through a 2 mm screen (mesh) in a hammer mill
- DM is determined on a portion of the feed at 105° C/24h
- About 3g of previously dried feed (65° C/48h) are placed in a 10cm x 15cm internal diameter bag for each incubation hour (12, 24, 48 and 72h) and for each of the fistulated animals
- Tying the bags with nylon twine firmly and lowering them into the ventral sac of the rumen , if possible holding them in place with weights
- Removing the bags after incubation, washing them until the rinse water is clear, weighing them after drying (65°/48h) and
- Calculating the degradation (disappearance) rate from the relation,

$$\% \text{ Degradation} = \frac{(Swa - BW) \times DMa - (SWb - BW) \times DMb}{(Swa - BW) \times DMa} \times 100$$

where:

Swa = weight of the original sample + nylon bag, BW = weight of empty nylon bag, SWb = weight of the sample + nylon bag after incubation, DMa = dry matter of feed sample and DMb = dry matter of residue sample.

The model of DM degradability proposed by Ørskov and McDonald (1979) is then fitted to summarise the data and in order to derive the degradation parameters usually using any computer programme e.g SAS or SPSS that can fit non linear models to data.

One advantage of the use of the nylon bag in estimating feed digestibility is that unlike the *in vivo* method, it doesn't suffer from the bias often encountered in *in vivo* trials where the feed fed the trial animals often differs in composition from the true feed a grazing animal might select (selective grazing) when put out to pasture (Hovell et al., 1986; Ørskov et al. 1988). Reid et al. (1988) using the Ørskov and McDonald (1979) equation to describe the degradability characteristics of hay also found better correlations with voluntary food intake of steers compared with *in vivo* values. A review of the best correlations with performance parameters (liveweight gain, efficiency of gain, ME, etc.,) using cattle showed that the best correlations were often obtained with the 48h degradation (Blümmel et al., 1997). In all these studies, a rumen outflow rate of 2.2 litres/hour was assumed for low feed intake conditions (ARC, 1984; Tewatia and Bhatia, 1998).

In vitro Methods

In vitro techniques such as the Hohenheim Gas Test (HGT) (Menke et al., 1979; Steingass and Menke, 1986) and the two stage method (Tilley and Terry, 1963) are also widely used to predict the digestibility of the incubated substrate. According to Blümmel et al., (1997), *in vitro* methods for laboratory estimation of feed degradability, measure 1) fermentation products of microbial mass, short chain fatty acids (SCFA) or gas volumes or 2) substrate disappearance by quantifying incubation residues. The above two methods require fistulated ruminants and a supply of carbon dioxide. In the HGT, the substrate is incubated in ruminal fluid and the amount of gas so produced is measured. The different volumes of gas produced over say 0, 6, 12, 24, or 48h, can then be used to predict ME and generally follow an exponential pattern. The two stage method (Tilley and Terry, 1963) is similar to the HGT the only difference being that DM loss and not gas production describes the amount of substrate fermented. As for the gas test, its main draw back is that it reflects only SCFA production and an inverse relation can exist between gas volumes (or SCFAs) and microbial biomass production which increases the intestinal protein supply to the animal and thus causes reduced ammonium production (Beever, 1993; Leng, 1993; Van Soest, 1994). In contrast to the gas

test, the nylon bag or *in sacco* method measures both the supply of substrate for biomass, SCFA and gas produced. Also a and b are not inter-correlated in *in sacco* measurements, but are in gas measurements. Similar findings have been obtained demonstrated by Blümmel and Ørskov (1993). Blümmel and Bullerdieck (1997), even go further and recommend that there is a need to determine the residues from *in sacco* measurements to improve the prediction of voluntary intake of hays. They found that *in vitro* determinations explained 0.373, whereas using the a and b values of the degradation curve explained 0.668 of the variation in DMI of temperate forages (19 legume and grass hays). Here the term "partition factor" (PF) was first introduced. It is the ratio between degradability and gas volumes at 24 and 48 hours. Hays with a high 24 and 48 hour degradability but a comparatively little gas production (high partition factor) had high intakes because of probably more of the fermented matter being incorporated into microbial cells leading to an increase in supply of intestinal protein and this increases intake (Preston and Leng, 1987; Blaxter, 1989). The 24 hour incubation time was chosen to calculate the PF because all substrate cell solutions should have been fermented but microbial biomass yield should be close to peak yield. However, residue microbial contamination in *in sacco* determinations results in a biased 24 hours value compared to the 48 hours value (Blümmel et al., 1994). The diet of the fistulated animals must be based mainly on the forages to be analysed and some protein and mineral supplement to ensure maintenance and not any special weight gain. It is another source of variation in results of *in situ* techniques and special attention should be paid to it (Linberg, 1985; Nocek, 1988; Sebek and Everts, 1999). This is because microbial activity increases with increase in protein level and this causes an increase in ATP concentration in the residue and so inaccurate digestibility estimates can be obtained, (Stritzler et al. 1998).

Cellulase Digestibility

The method as used here (Naumann and Bassler 1976, with an update in 1997) is an adaptation of the method of De Boever et al. (1986) involving a pre-incubation phase with 1N HCl in pepsin at 40° over 24h. This is then followed by a high temperature treatment: 80° over 40 minutes. These two treatments mimic the action of rumen bacteria which degrade first the feed proteins and then the carbohydrates. Thereafter, the sample is filtered and the residue attacked by buffered cellulase enzyme solution whose role it is to dissolve the cell wall and make its contents available like the cellulase enzyme found in rumen bacteria.. The undigested residue is then dried and ashed and its value subtracted from the original sample weight, to give the organic matter solubility in cellulase (ELOS). It has been found to have

close correlations with voluntary feed intake and *in vivo* values (> 0.90) , in feeds, particularly mixed feeds (De Boever et al., 1986). Enzyme from *Trichoderma reesei* is usually used. In temperate regions, this method has been used in deriving regression equations for ME estimation (Robowsky and Rücker, 1996; Potthast et al. 1997; Kirchgeßner, 1998), organic matter digestibility, Houcourt (1993), and predicting *in vivo* digestibility of maize silage (Potthast, 1997). Compared to the nylon bag method, it has been shown not to be useful for estimating the rate but useful for estimating the extent of digestion (López et al. 1998). The explanation being that *in vitro* incubation with a commercial cellulase only mimics part of the complex processes taking place in the rumen. Microbial attachment and the activity of several enzymes, which digest not only cellulose but also other substrates, would result in a greater extent of digestion as measured under conditions more like those in the rumen, a thing the *in situ* technique does.

Kirchgeßner (1998) used the cellulase method to develop several regression equations for ME estimation of extensive as well as intensive pastures, roughages, hay, silages, mixed feeds and concentrates with high coefficients of determination ($R^2 > 0.88$). For pastures, it was found that the ME was best estimated when ELOS, ash and CP were incorporated, while for the hay, ELOS, CF and EE were used in these regressions (Potthast et al. 1997; Kirchgeßner , 1998).

Near infra red reflectance spectroscopy

Near infra red reflectance spectroscopy (NIRS) is a rapid non chemical method for determining the nutritive value of feeds (Paul and Schild, 1982; Shenk and Westerhaus, 1994; Lyons and Stuth, 1991; Robowsky and Rücker, 1996; Tillmann, 1996; Amari and Abe, 1997). Although some earlier authors used it mainly for the estimation of the ash content of roughages e.g. work done by Mainka (1991); Kamoum (1995) and Vasquez et al., (1996), it was shown later on that it could also be used for further predictions. It involves first running a very wide variety of samples covering all the chemical composition and digestibility values likely to be encountered and thus making a calibration curve, then correlating samples being investigated with measured values. For example, Amari and Abe (1997), used 388 grass hay (n = 126), silage (n = 120) hay-silage mixtures (n = 60) and corn silage (n = 142) samples for the calibration equation. The remainder 115 samples out of the total of the 503 samples, were then used for validation. They found correlations with the chemical contents. They then used the NIRS to predict the total digestible nutrients (TDN). Borcardi et al. (1997) investigated more than 5000 forage samples from different environmental conditions in Italy (from sea level to alpine sites) and has a large spectral base that could be used for estimating the

nutritive value of samples grown under similar conditions. Kjos (1991) used NIRS to evaluate fresh forages, silages and hay in Norway and accurately predicted the CF value of grasses. However, for late cuts, values tended to be overestimated and there was also poor prediction of the IVDMD. With respect to tropical hays, only a few studies have been carried out. For example Brown et al. (1990) used producer hays representing 4 tropical grasses with an unknown range of maturities, fertilization schemes, weather conditions and hay making and storage procedures and developed equations for CP, *in vitro* and organic matter digestibilities (IVOMD) and NDF. Standard error of calibration (SEC) and standard error of prediction (SEP) ranged from 0.73 to 0.96 % and 0.74 to 0.92% for CP; 2.30 to 3.14 and 1.87 to 4.17% for IVOMD; 1.45 to 1.71 and 1.45 to 2.18% for NDF. It was concluded that broad based calibrations analysed the nutritive value of individual species with a degree of accuracy in species-specific calibrations. Tukue (1991) analysed grass and legume samples grown at two altitudes in Ethiopia and in Germany, using an NIRS device. He had correlation coefficients (r) of 0.96, 0.91, 0.93 and 0.80 between laboratory and NIRS estimates of CP, ADF, NDF and IVDMD.

With respect to the cellulase solubility rate (ELOS) and NIRS, De Boever et al. (1986) also obtained good correlations with NIRS values (R^2 = 0.96, SEP = 1.52). Lecomte et al. (1992) obtained an R^2 of 0.96 and an RSD of 1.56 between cellulase digestibility values and NIRS values. They concluded that NIRS could be used to determine fast and accurately as well as reproducibly the energy value of the main fodders used in ruminant feeding. They also developed two equations as follows:

1) $DOM_{in\ vivo}$ = 22.09 + 0.644* CDOM - 1.174*X R^2 = 0.88 and RSD = 1.56, for fresh forages. DOM is the digestible organic matter, x is regrowth length and CDOM is the cellulase digestibility of the organic matter.

2) $DOM_{in\ vivo}$ = 22.80 + 0.602*CDOM R^2 = 0.85 and RSD = 1.77 for preserved fodders.

Feed regressions on the basis of chemical composition for the nutritive value prediction of the quality of tropical roughages

The most currently used regressions for estimating the feed quality of tropical roughages are shown in Table 3.

Table 3. Some Feed Quality Regressions for Nutritive Value estimation of Tropical Forages

Item	Equation	Type of Feed	Country of Origin	Author (s)
DCP (g/kg DM)	DCP = -12.32 + 0.98 x CP (%)	Leguminous forages	India	Virk et al. (1992)
DCP (g/kg DM)	DCP = 9.29 x CP (%)	Roughages for Ruminants	France	Verite and Geay (1987)
DCP (g/kg DM)	DCP = 0.915 x CP – 3.67	Roughages for Ruminants	Great Britain	ADAS (1984)
OMD	OMD = 25.5 + 0.66 CDOM	Tropical grasses	New Caledonia	Hourcourt (1993)
ME				
ME (MJ/kg DM)	ME = 0.016 x DOMD	Roughages for Ruminants	Great Britain	AFRC (1990)
ME (MJ/kg DM)	ME (MJ/kg DM) =0.3724 x EE + 0.01548 x CF - 0.0004919 x EE x CF - 0.000367x ELOS x CF - 0.00001611 x ELOS x ELOS - 1.04.	Hay	Germany	Potthast et al. (1997)
	ME = 2.756 + 48 hour degradability x 0.173	Hay	Great Britain	Ørskov and Ryle (1992)
NE_l (MJ/kg DM)	NE_l = 10.78 - 0.146 x CF/OM	Hay	Germany	DLG (1991)

DOMD = g digestible organic matter/kg DM; OM = organic matter
In the formulae above, all chemical constituents are in g/kg DM; OM = organic matter

These regressions have been recommended by their respective authors to be used in the absence of *in vivo* digestibilty trials. It should be noted that interactions between feeds influence their digestibility and assimilation by the animal for maintenance and production purposes. Therefore it is only possible for all the different quality estimates to be analysed and regressions made for the particular conditions of the experiment.

In summary, it can be stated that of all the regressions used in estimating the energy content of roughages, the most reliable ones are those based on the cellulase method (Potthast et al,

1997; Kirchgeßner (1998) and nylon bag degradation constants (Ørskov and Ryle, 1992). For the net energy estimation of hays and the estimation of the feed intake of a TLU on a basal forage diet, the German Foodstuffs Society's " Deutsche Landwirtschaftsgesellschaft für Lebensmitteln) formula (DLG, 1991) and those published by Ørskov and Ryle (1992) appear to be the most appropriate.

3. MATERIALS AND METHODS

3.1. Description of the experimental site

The experiment was carried out from May 1995 to April 1997 at the Wakwa centre of the Institute of Agricultural Research for Development (IRAD) near Ngaoundere town in the Adamawa plateau of northern Cameroon (Fig 1).The Wakwa Animal Research centre is located 10 km south east of Ngaoundere, the Adamawa provincial headquarters, at an altitude of 1200m asl (longitude 7° 19' N and latitude 13° 34' E).

Fig. 1 Map of Cameroon showing the experimental area !

3.1.1. Climate

Wakwa is located in the sub humid zone of Cameroon. It has a sudano-guinean climate that is typical of the climate of the northern part of the plateau. The climate is marked by a dry season of 3 - 5 months from November to March and a rainy season of 7 – 9 months from March to November (Suchel, 1972). The particularities of this climate, are evidenced in the following:

An average precipitation of 1700 mm per annum.
Annual monthly average temperature of 22°C: monthly minimal and maximum temperature of 10-19°C and 27-34°C, respectively.
A relative humidity during the rainy season of 70-90% and 40 - 50% during the dry season
An daily average evapo-transpiration rate during the rainy season of 65mm and 152mm during the dry season.
The rainfall and relative humidity (RH) values during the period of the experiment (May 1995 - April 1997) are shown in Figure 2; (further details in the annex).

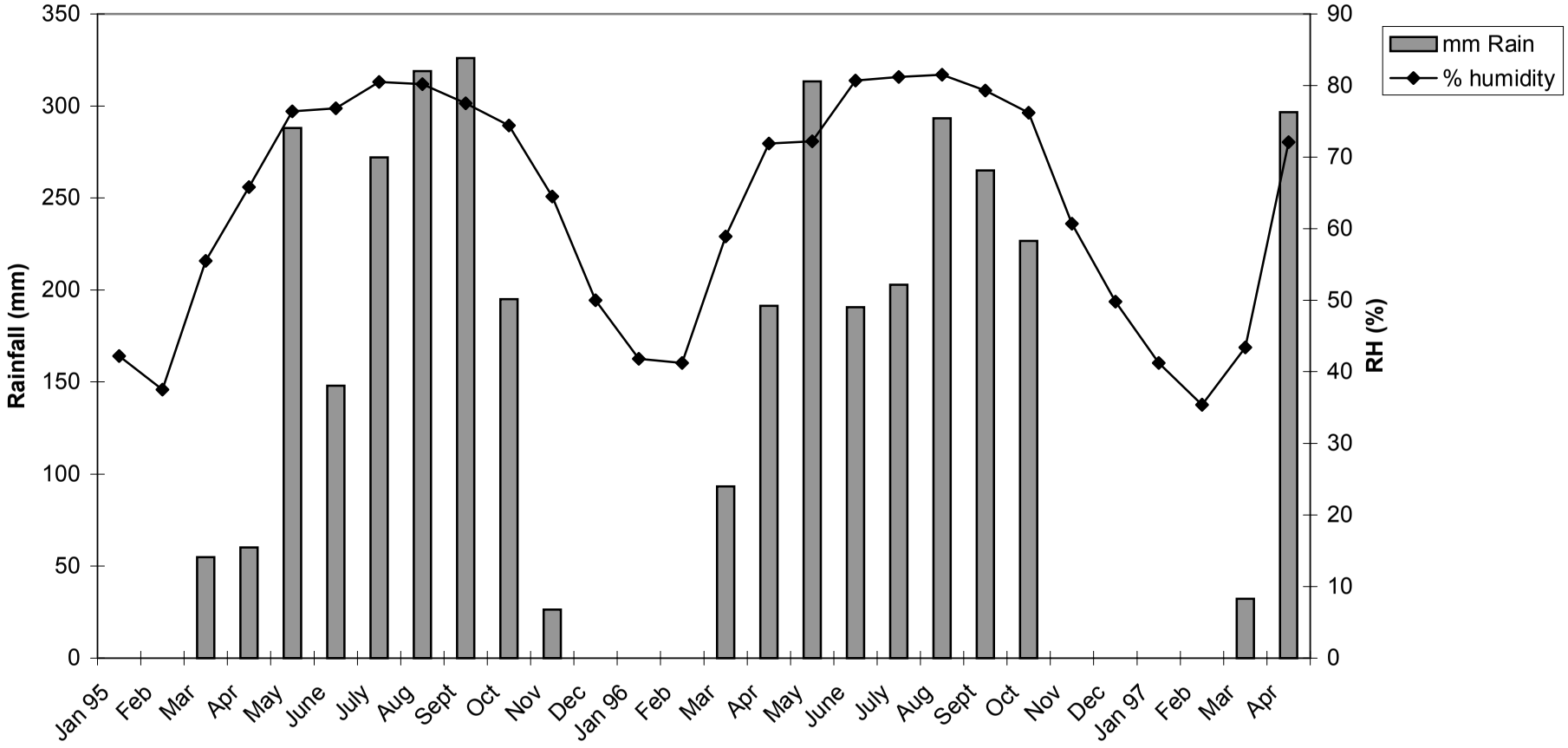


Fig. 2 Rainfall and Relative Humidity (RH) Pattern during the Experimental Period

The total rainfall of 1995, 1996 and 1997 was 1689.5, 1775.5 and 1621.5mm respectively. During this time the RH on average 65.08, 66.28 and 64.87%, respectively (see annex for details). During the months of pasture regrowth after the zero timing, i.e. August to October in 1995 and 1996, August obtained (319.4 and 293.3 mm), followed by September (326.3 and 264.9mm) and lastly by October (195.3 and 226.6mm), respectively, (Fig. 2). It was also observed that the relative humidity for August was highest (80.2 and 81.5) compared with 77.5 and 79.3% for September and 74.4 and 76.2% for October, respectively.

During the period of hay making and storage (November – April) the following was observed:

1) Besides only 26.4 mm of rain in November 1995, November 1996 had no rain.

2) Rains started in March 1995 and 1996.

3) Like most dry seasons, the RH dropped abruptly from the month of October to an average of 62.5% in November and continued to decrease during the rest of the dry season.

4) Even with the advent of the rains in March, the RH was only 58.9 and 43.4% in March 1996 and 1997, respectively, increasing only substantially in April with the true onset of the rainy season. This rainfall and humidity pattern is typical of the climatic pattern that exists in this part of the plateau and is the most important factor that determines the onset of pasture regrowth after the dry season, seed formation and flowering time and thus the quality of the pasture for hay making purposes.

3.1.2. Soils

The soils at the Wakwa research station are ferralsols and based on either granitic or basaltic parent rock substrata (Humbel, 1971). Ferralsols are reddish soils with a deep and intensive (1m or more) weathered horizon. An Fe – Al deposit exists below that hardens when exposed to oxygen (O_2) leading to the formation of a solid crust. This limits the growth of some types of plants on such soils. Mineral leaching is common in these soils when located in high rainfall regions. The leached soil usually has a reddish colour due to a high iron content. The experimental paddocks were paddocks F3, R1 and R7 for the native pastures and paddocks T3, R11 and T3 for the *Brachiaria*, and are all located on basaltic rock substrata. These types of pasture usually have a higher biomass yield compared to those based on granitic parent rock (Rippstein, 1985; Yonkeu, 1993). A study of their characteristics carried out two years before the experiment began (Pamo and Pieper, 1995) showed that the soils in the study area had a pH of

5.55, and a C/N ratio of 17 values typical of ferralsols. However, these soils were low in exchangeable bases as well as assimilable phosphorus (P. Olsem = 26 ppm).

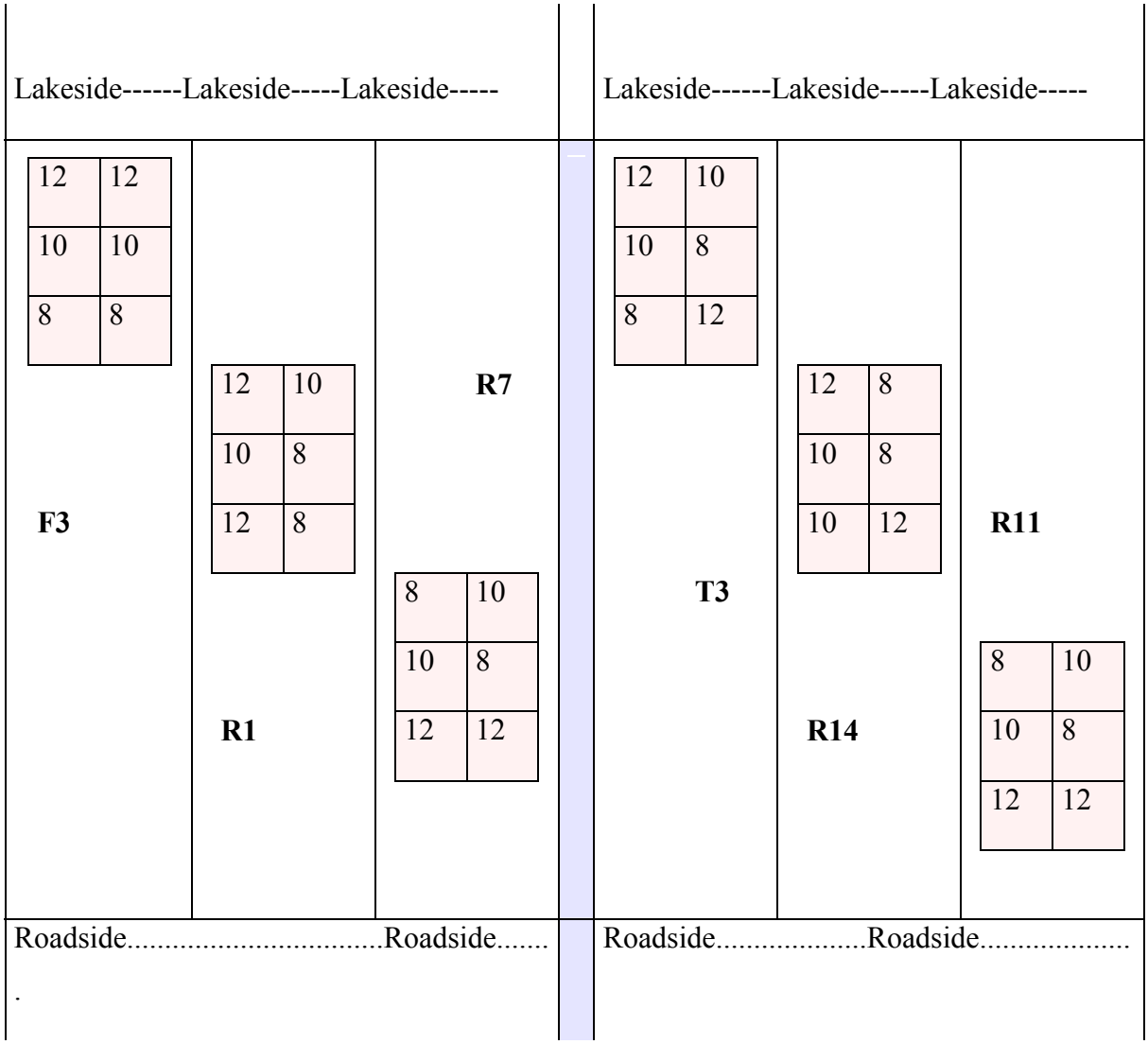
3.1.3. Vegetation

The vegetation of the native pastures was mostly made up of the following grasses and legumes species: *Andropogon gayanus, Pennisetum hordeoides, Hyparrhenia rufa, H. diplandra, Imperata cylindrica, H. bracteata, Setaria repens, Urelythrum thyrsioides, Panicum phragmitoides,, Sporobolus pyramidalis, Chloris pyconthrix, Desmodium uncinata, Loudetia arundinacea, Paspalum spp*. Indeed the first four grass species found here are most characteristic of this type of native forages found on basaltic soils (Rippstein, 1985). In all paddocks of the station for hay making, shrubs and trees were cut off and uprooted and their places colonised by the grasses and the legumes. Some of the above species were also found in the *Brachiaria* paddocks, (less than 5%). The improved pastures contained *Brachiaria* with some regrowths of the native pasture species (< 5%).

3.2. Experimental design

The experiment is a randomised block design with 2 pasture types and three blocks of deferment length (Fig. 3). Treatment combinations of pasture type and regrowth length were distributed as shown below:

- three paddocks per pasture type,
- two replicates per regrowth treatment,
- three hay storage lengths, and
- two years of experimentation.



10	12
8	10
12	8

A typical bloc with subplots containing different lengths of regrowth (12, 10 and 8 weeks)

Fig. 3 Schematic representation of the layout of the experimental plots

3.3. Implementation procedures

The experiment had two phases. Firstly, the determination of grass yield after the different regrowth periods and secondly, the determination of hay quality during storage. The regrowth trial was preceded by a pre-experimental grazing period using two herds of growing bulls.

3.3.1. Pre-experimental grazing and service cutting (zero timing)

Pre-experimental grazing was conducted before the imposition of the deferments in order to use the early rainy season vegetation. This is normal practice since hay is usually made only at the end of the rainy season after a growing season of 7 months (April to October). To enable both types of pasture to have the same grazing pressure a fixed stocking rate of 375 kg liveweight/ha was practised. This rate is suitable for both native and *Brachiaria* pastures of the plateau (Rippstein, 1985).

After the removal of the animals in early August, a block of 6 subplots measuring 40m x 40m (1600m²) was randomly partitioned out within each of the six paddocks (see Figure 3). Each subplot had 2 replications of deferment length. Subplots belonging to the same deferment lengths were service cut (zero-timed) 12, or 10 or 8 weeks before cutting i.e. on 14th August, 28th August and 11th September of 1995 and 1996 respectively, in order to have 12, 10 or 8 week re-growths of vegetation at hay harvest time on November 6 of 1995 and 1996 respectively, (Table 4).

3.3.2. Grass harvest and curing

On 5th November, biomass yield estimates were made using the clipping method inside each subplot at 10 cm from the ground (Table 4). They were then subjected to DM and chemical analytical determinations. The 36 plots were all cut on 6th November using a tractor driven grass cutter. Harvesting was done first along the 160m perimeter of each plot and then inwards. There was a 5m margin between plots so as to ensure that the tractor could turn without trampling the vegetation on any of the adjacent plots. The cut herbage was then left on the ground to dry. After 2 days on the field, the hay in each plot was turned and made into windrows. DM measurement done on day 3 (November 9) gave an average content of 86.7% DM, sufficient to give a hay with a good preservation potential.

Table 4. Experimental plan

Date	Activity	Regrowth Length (wk)			No. of Pooled Samples Available/year
		12	10	8	
14.8.1995/96	Service cut	XO	-	-	12
28.8.1995/96	Service cut	-	XO	-	12
11.9.1995/96	Service cut	-	-	XO	12
5.11.1995/96	Yield determination	X	X	X	36
6.11/1995/96	Grass cutting	O	O	O	-
8.11.1995/96	Turning of grass	-	-	-	-
9.11.1995/96	DM of grass determined	X	X	X	36
10.11.1995/96	Baling and storage	-	-	-	-
20.11.1995/96	Weighing of hay and sampling	*	*	*	18
12.2.1996/97	Sampling of hay	*	*	*	18
20.4.1996/97	Sampling of hay	*	*	*	18
Total no. of samples /year					162

X = sampling using 0.5 x 0.5m quadrats thrown three times within each 40 x 40m subplot;
O = cutting back to 15cm from the ground using forage harvester
* sampling with coring device

3.3.3. Hay making and storage

Baling of hay was done after 4 days of field curing, i.e. on 10th November of 1995 and 1996 respectively, Table 4. The hay was baled into round bales (minimum weight, 150 kg) using a rented baler. The hay from similar replicate combinations within each paddock were baled together, because of the lack of sufficient mass in some 8 week regrowth treatments. The bales were carefully labelled according to the plot treatment and all stored indoors in a building with wide windows and unrestricted air ventilation.

3.4. Measurements

Measurements included grass and hay yields, chemical composition of the grass and hay, digestibility measurements via the pepsin – cellulase method and *in situ* methods, and NIRS.

3.4.1. Pasture and hay yield

Measurement of the vegetation yield in each paddock was determined by using a 1 x 0.5m iron frame to collect 20 samples per paddock, cutting the herbage therein at 15cm from the ground, and weighing it with a Roman balance (Shaw, et al., 1976). The yields of similar subplots under the same treatment combinations were added to give the overall yield for the regrowth and pasture type.

With respect to the determination of hay yield, bales were weighed on 20th November of 1995 and 1996 respectively after 10 days of storage.

3.4.2. Quality measures

The quality measurements were: 1) chemical composition using the Weende analysis for ash, CP, CF, EE and NFE percentages, 2) NDF, ADF and ADL percentages via the Van Soest detergent system, 3) the ruminal degradation via the nylon bag method, 4) cellulase solubility percentage (ELOS, CDOM and EULOS) via the pepsin cellulase method and 5) NIRS regressions with composition values

3.4.3. Sampling techniques and sample preparation

The composition of the different species in the pasture clippings was determined by separating the fresh forage into the different species present, identifying and then weighing them. Thereafter, the samplings from all the quadrants of each paddock were mixed in the laboratory and about 2 kg of fresh sample per paddock was used for drying. Half was dried at 105°C for 24 hours and the other half at 65 °C for 48 hours for chemical analysis. After removal from the hot air oven, pooled samples were all ground to pass a 1mm sieve in a hammer mill, left to equilibrate in the air overnight, re-mixed, sealed in plastic bags and kept in a cool and dry place (Van Soest and Robertson, 1985).

After 10 days of storage, hay samples were collected from each bale on 20th November or week 0 of storage, on 12th February or week 12 and on 10th April (week 20 of storage), see Table 4. Using a coring device samples were obtained from the sides, top and bottom of each bale. Samplings were pooled from corresponding treatment replicates (pasture x regrowth).

3.4.4. Methods of chemical analysis

For the proximate analyses, i.e. Weende analysis and Van Soest's detergent method, the method used was accoding to AOAC (1985) and as found in the up date of 1997 of Naumann

and Bassler (1976). Pepsin - cellulase method was also done according to Naumann and Bassler (1976). Nylon bag degradability was measured according to ILRI's modification of the procedure of Ørkov and McDonald (1979) as found in Osuji et al., (1993). Near infrared reflectance spectroscopy (NIRS) was determined using the method described by Lyons and Stuth (1991) and adapted by Robowsky and Rücker (1996) and Tillmann (1996).

3.4.5. Methods of determining digestibility

Two methods were used: the nylon bag *(in situ)* and the pepsin cellulase digestibility methods.

3.4.5.1. Nylon bag (*in situ*) method

The nylon bag method was used to measure degradation rates of pasture and hay samples using two 3 year old fistulated local zebu Gudali steers, weighing of 240 and 260 kg, respectively. The steers were housed in a shed and fed a basal diet of both types of hay ad libitum as well as cottonseed cake at a rate of 100g/100kg live-weight per day to cover maintenance requirements (Table 5) as determined by on-station trials at the research centre (Dumas and Lhoste, 1969; CRZ Wakwa Annual Reports, 1970 - 1985). Feeding of a hay mixture was done in order to have a rumen environment that reflected the type of samples to be analysed (Chenost et al, 1970; Ørskov and McDonald, 1979). Water and a trace mineralised salt block (Table 6) were offered ad lib. The animals were thus on an adequate maintenance diet.

Table 5. Average composition of the hay and cottonseed cake fed the fistulated steers, DM basis

Item	Cottonseed cake	Grass hay mixture
CP (%)	42.6	4.4
CF (%)	9.8	33.4
ME (MJ/kg DM)	10.6	7.1
Estimated DMI (kg/d)*	0.25	5.75

[+]. Average composition values from feeding trials at Wakwa (CRZ Wakwa, annual reports, 1970 - 1985).
*Assuming voluntary daily consumption of hay at 2.3% of liveweight

Table 6. Composition of the 100 kg trace mineralised salt block

Ingredient	% Composition
Commonsalt (NaCl)	40
Bone meal	55
Trace mineral pre - mix	4
Cement (as binder)	1
Total (%)	100

Animals were fistulated with a 10 cm wide rubber fistula from Bar Diamond Inc. of Parma, Idaho, USA. Nylon bags (20 x 10 cm, with 53 µm pore size) were also obtained from the same firm and filled with 3 g of sample and tied with nylon thread at the top giving an effective internal diameter of 15 x 10 cm and thus a 20 mg/cm^2 sample to bag surface ratio. Two replicates of samples of each treatment were incubated in the ventral sac of the rumen of each animal for each incubation time by adding them successively and withdrawing all the bags in each steer on the last day. There was a maximum number of 60 bags in any animal by the last incubation hour. This is called sequential addition and leads to a lesser disturbance of the rumen. Incubation hours were 12, 24, 48 and 72 hours respectively. The zero hour bags were soaked in water at 39 °C for 1 hour. All bags were washed by hand carefully in running tap water for about 10 minutes, by which time the rinse water was clear, squeezed, dried for 48 hours at 65 °C and weighed. Similar treatments were then mixed and dried for DM determination. The loss in weight after incubation was taken as the DM that had been digested or ”disappeared”. In order to derive the degradation constants of the different feeds, use was made of the model of DM disappearance proposed by Ørskov and McDonald (1979) as follows:

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

where:

Y = degradability at time (t)

a = intercept

b = potentially degradable fraction

c = rate of degradation of b

Here the asymptote is represented by a + b and it represents the potential degradability

The DM disappearance values obtained at the various incubation times were used in estimating degradability using the non-linear model of the SAS Program (SAS, 1991). Estimates of the derived degradation constants were then used in estimating feed quality parameters.

3.4.5.2. Pepsin cellulase digestibility method

Pepsin-cellulase digestibility was done according to a modification of the method of De Boever et al., (1986). It involved a pre-incubation in water at 80°C for 45 minutes before the addition of the cellulase (Naumann and Bassler, 1976). Cellulase "Onuzuka R-10" from *Trichoderma reesei* with a cellulase activity of 1.0 U/mg was used (courtesy of Boehringer Ingelheim Co., Heidelberg, Germany). The solubility of the organic matter in cellulase (ELOS), the cellulase digestibility of the organic matter (CDOM) and the insoluble organic matter in cellulase EULOS) were derived as follows:

ELOS (%) = % DM - % Ash – Loss upon ashing (%)

CDOM (%) =(ELOS x 10^2/ 100 – Ash %)

EULOS (g/kg) = 1000 – Ash (g/kg DM) – (ELOS % x 10)

3.4.6. Near infrared reflectance spectroscopy (NIRS) analysis

The facilities of the Paulinenaue Teaching and Research Institute for Pastures and Rangeland Management (Versuchsanstalt für Grünland und Futterwirtschaft e.V.) were used for the NIRS study. A calibration curve was done using 94 samples that represented pasture and hay samples on an NIRS system 5000 device from the firm PERSTORP, using the NIRS 2 version 3.00 software. Thereafter, 58 pooled samples not used in the calibration curve estimation, were chosen and run. It was noticed that 2 samples were outliers, so they were eliminated and the estimates for the NIRS equations to estimate the chemical composition redone. This was according to the methods described by Paul and Schild (1982) and Lyons and Stuth (1991), and adapted by Robowsky and Rücker (1996) and Tillmann (1996).

3.5. Comparison of determination methods

A comparison of the different quality measurements was made. Regressions within and between the individual methods and yield parameters were calculated.

3.5.1. Chemical analysis

The values obtained from the chemical analysis for the CP, CF, NDF, ADF and ADL were compared for their different inter- relationships. Correlation coefficients were thus obtained. They were also estimated using the NIRS technique using the regressions feature of the instrument. Since the sample size (60) of the validation was not big enough, NIRS estimates

could not therefore be used in the analysis of variance. However, the R^2 obtained using NIRS was an indication of the usefulness of the latter for a quick estimation of nutritive value

3.5.2. Nylon bag and pepsin – cellulase method

Correlation coefficients were also obtained using the results of these two digestibility methods. ELOS values were compared with NIRS estimates. However the nylon bag degradation values have not been used in regressions with NIRS extensively, so no data base existed to enable a calibration curve to be drawn and the validation equations derived. Organic matter cellulase solubility (ELOS) was also regressed with the value obtained via NIRS. The lack of enough data could not make this estimate to be used in the ANOVA.

3.6. Statistical analysis

Data entry was done using Dbase IV+. The general linear model (GLM) procedure of SAS (SAS, 1991) was used.

3.6.1. Models

There were two models used, one for the pasture yield and the other for the storage length of hay.

MODEL I. For the yield measurements, there were 36 data sets per year i.e. 72 data sets over 2 years.

$$Y_{ijklm} = \mu + A_i + B_j + C_k + D_l + (A*B)ij + (A*C)ik + (B*C)jk + \in_{ijkl}$$

where Y is an observed variable, μ is the overall mean, A_i is the fixed effect of year i, B_j is the fixed effect of pasture type j, C_k is the fixed effect of regrowth length k, D_l is the fixed effect of plot l, A*B is the interaction between year and pasture type, A*C is the interaction between year and regrowth length, B*C is the interaction between pasture type and regrowth length and $\in_{ijkl}$ is the experimental error.

The hay yield at cutting was analysed according to this model.

MODEL II. There were a total of 108 hay samples from both pasture types that were analysed, i.e. 54 per year.

The Model was: $Y_{ijklm} = \mu + A_i + B_j + C_k + D_l + E_m + (A*E)_{im} + (B*E)_{jm} + (A*B*E)_{ijm} + \in_{ijkl}$

where Y is an observed variable, μ is the overall mean, A_i is the fixed effect of year i, B_j is the fixed effect of pasture type j, C_k is the fixed effect of regrowth length k, D_l is the fixed effect of plot l, E_m is the fixed effect of the week of storage, A*E is the year x week interaction B*E is the pasture type * week interaction, A*B*E is the year*pasture type*week interaction, and $\in_{ijkl}$ is the experimental error.

Tests of significance were done using the Type III sums of squares of SAS.

3.6.2. Comparison of methods of quality determination

Regression analysis was used for showing inter-relationships between the independent (main effects) and the most relevant dependent variables (CP, CF, NDF, ELOS, 48h degradation value, 48h DM yield, 48h CP yield, CP yield and ELOS yield). The coefficient of determination R^2 as well as the extent of the relationship among the different variables (the correlation coefficient, (r) was also derived using the CORR procedure of Statistical Analysis System (SAS, 1991).

4. RESULTS

4.1. Yield of pasture and hay

4.1.1. Pasture yield before cutting

In the analysis of variance the main effects of year, pasture type, duration of deferment (regrowth length), plot within pasture type as well as the interaction effects of year and pasture type, year and regrowth, and pasture type and regrowth were considered (Table 7). The model explains 89 % of the variation of the pasture dry matter yield and the coefficient of variation was only 4.35 %. Only year, pasture type, deferment length as well as the interaction effects of year and deferment length, and pasture type and deferment length, respectively, had significant effects on dry matter yield. Least squares mean DM yield over both years was 2017 ± 87.78 kg/ha

Table 7. Results of analysis of variance (ANOVA) for effects of year, pasture type and deferment length on the yield of native and cultivated pastures

EFFECT	df	DM Yield
Year	1	***
Pasture Type	1	***
Regrowth	2	***
Plot within Pasture Type	4	ns
Year x Pasture Type	1	ns
Year x Regrowth	2	*
Pasture Type x Regrowth	2	*
R^2		0.89
CV (%)		4.35
Mean (kg DM/ha)		2017.3
s e m		87.78

*** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; ns = not significant; df = degrees of freedom

Least squares means and standard errors of the DM yield are presented in Table 8. It was observed that in 1995 the pastures had a significantly higher DM yield compared to 1996, P < 0.001.

Table 8. Influence of year, pasture type and deferment length on the yield of native and cultivated pastures; DM basis; (LSQ- means ± SEM)

EFFECT	N	DM Yield (kg DM/ha)
Year		
1995	36	2104.7[b]
1996	36	1929.9[a]
s e m		87.8
Pasture Type		
Native	36	1926.3 [a]
Brachiaria	36	2108.3 [b]
s e m		14.6
Regrowth Length		
8 weeks	24	1798.2[a]
10 weeks	24	2021.4 [a, b]
12 weeks	24	2232.4 [b]
s e m		17.9

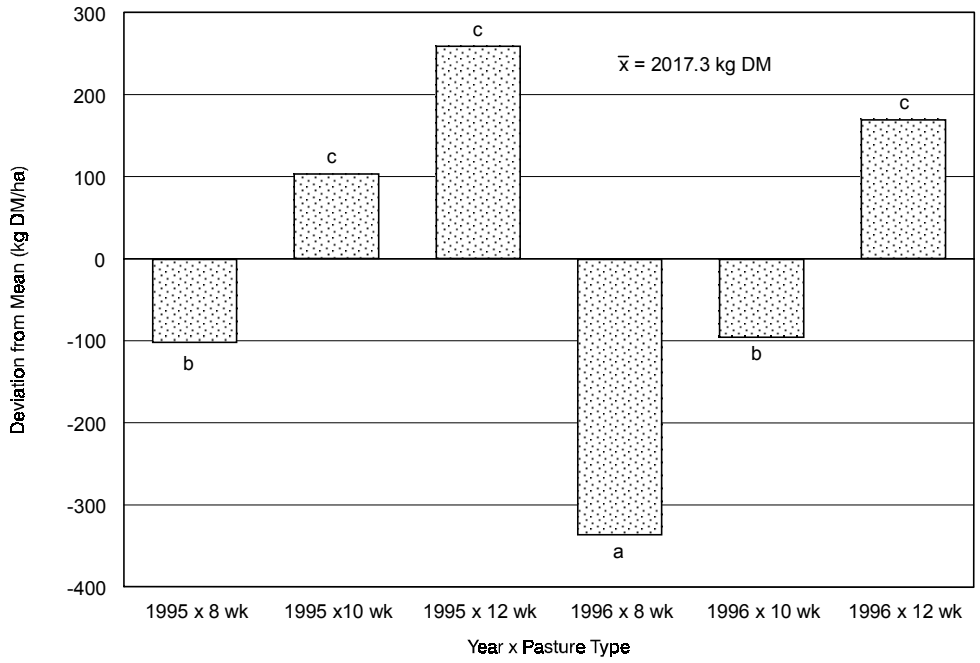
Different letters within the same columns indicate significant differences, $p \leq 0.05$

The *Brachiaria* pastures had a significantly higher yield (2108.3 kg) compared to the native pastures (1926.3 kg DM/ha), $P < 0.001$. There were also significant differences ($P < 0.001$) between the 8 week on the one hand and the 10 and 12 week regrowths on the other, respectively, (Fig.4), following a linear increase in DM production with extended length of the regrowth phase.

Different letters denote significant differences, $P \leq 0.05$

Fig 4 Effect of Regrowth Length on Grass Yield, LSQ- Means

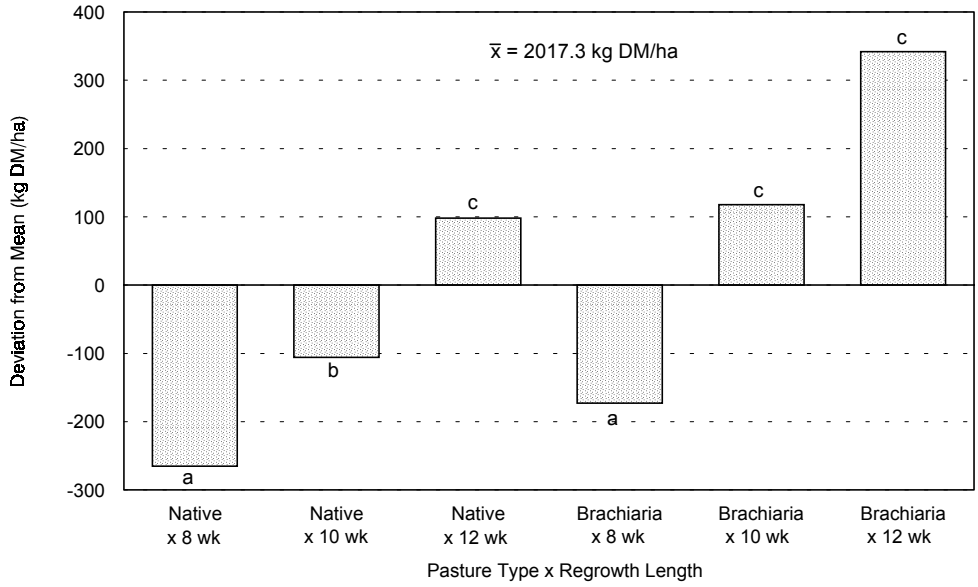
With respect to the interaction effect year x regrowth length, (Fig. 5), it can be seen that the highest herbage production was obtained on the 1995 12 week regrowths followed by the 1996 12 week regrowths and lastly by the 1995 10 week regrowths, $P < 0.05$. Length of regrowth had different effects on the cutting yields. The very low yield in the 8 weeks regrowth treatment during 1996 clearly shows the risk of reduced yields when the rains stop earlier.



Different letters denote significant differences, $P \leq 0.05$

Fig. 5 Effect of Year x Pasture Interaction on Grass Yield, LSQ Means

Figure 6 illustrates the interaction effect between pasture type and length of regrowth caused by the superior yield response of *Brachiaria* pasture in longer regrowth phases. The *Brachiaria* x 12 week regrowth length interaction had the highest positive deviations from the mean followed by the *Brachiaria* x 10 week regrowth and native pasture x 12 week regrowth ($P < 0.05$). All other interactions gave negative deviations from the mean.



Different letters denote significant differences, P ≤0.05

Fig. 6 Effect of Pasture Type x Regowth Length on Grass Yield; LSQ Mean- Deviations

4.1.2. Yield of hay at baling

Results of the analysis of variance on the % DM and hay DM yield after baling on November 10 of both 1995 and 1996 are compiled in Table 9.The model explains 70% of the variation. The coefficient of variation was only 5.06 %. The main effects of pasture type, regrowth length and week of storage had a significant effect on this parameter. Variation in DM yield is significantly affected by year and pasture type ($P < 0.05$) and by length of regrowth ($P < 0.001$). 88% of all variation are explained in this model.

Table 9. Analysis of Variance (ANOVA) for effects of main and interaction effects on % DM and yield at baling hay

EFFECT	df.	% DM	DM Yield (kg/ha)
Year	1	ns	***
Pasture Type	1	*	***
Regrowth	2	***	***
Plot within Pasture Type	4	ns	ns
Year x PT	2	ns	ns
Year x Reg.	2	ns	ns
PT x Reg	2	ns	ns
R^2		0.70	0.88
CV (%)		5.06	7.11
Mean		88.85	1773.5
s e m		0.03	18.33

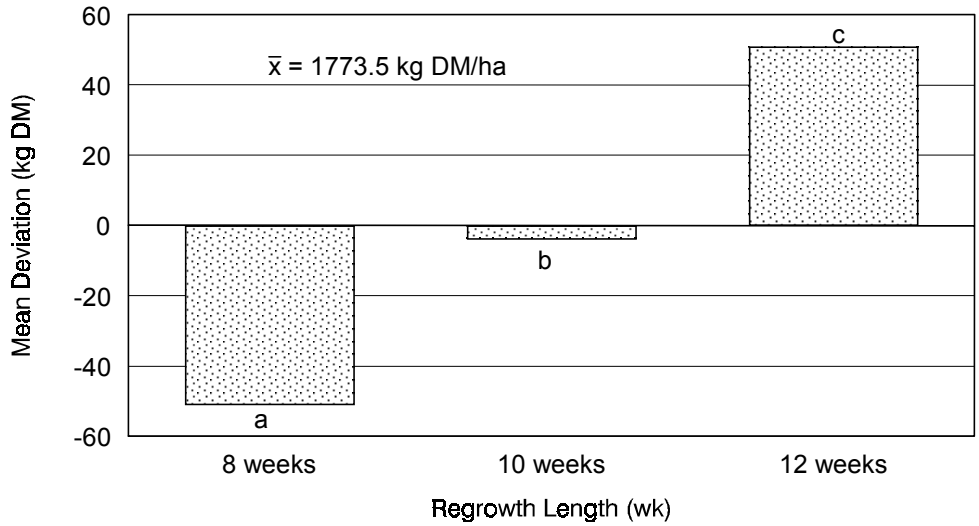
*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; ns = not significant; df = degrees of freedom

The least squares means for the DM yield and % DM of the hays are shown in Table 10. The first year (1995) had both a higher % DM and DM yield compared to the second year (1996) of the experiment ($P > 0.05$) and ($P < 0.05$) respectively. *Brachiaria* hay out yielded native hay ($P < 0.05$) but had a slightly but significant ($P < 0.05$) lower DM % The 8 week plots had the lowest % DM and DM yield and the 12 week regrowth obtained the highest values for these 2 parameters ($P < 0.01$). The deviations from the mean yield obtained in the different regrowth phases are illustrated in Figure 7 and show a linear increase in hay yield with extended regrowth periods.

Table 10. Effect of Main and Interaction Effects on the % DM and Yield of Hay at Bailing % DM basis; (LSQ-Means ± SEM)

EFFECT	N	% DM	DM Yield (kg/ha)
Year			
1995	54	89.8 [b]	1846.1[b]
1996	54	87.9 [a]	1700.8 [a]
se		0.03	17.41
Pasture Type			
Native	54	89.0 [b]	1746.1[a]
Brachiaria	54	88.1 [a]	1800.6[b]
se		0.03	17.41
Reg. 8 wk	36	87.5 [a]	1722.5[b]
Reg 10 wk	36	88.9 [b]	1769.5[a]
Reg. 12 wk	36	90.3 [c]	1828.4[c]
se		0.04	18.46

Different letters within the same columns indicate significant differences, $P \leq 0.05$



Different letters denote significant differences, P ≤0.05

Fig 7 Effect of Regrowth Length on Hay Yield, LSQ-Means ± SD

4.2. Quality of pasture and hay

4.2.1. Chemical composition of the pastures before cutting

The analysis of variance of the influence of the main effects stated earlier (i.e. year, pasture type, regrowth length and plot) as well as the 2 level interaction effects on the chemical composition of the pastures is shown in Table 11. The model can explain between 24 and 92 % of the variation in various quality traits. The lowest coefficient of variation was observed for the neutral detergent fibre (NDF) percent (2.24%) and the highest value on the crude protein (CP) percent (10.27%).

Year effect was only significant for crude fibre ($P < 0.01$) and acid detergent lignin (ADL) ($P < 0.05$) contents. There was a very strong influence ($P < 0.001$) of pasture type on all parameters except ash percent. Regrowth length had a strong influence ($P < 0.01$) on ash percent as well as on CP, CF, neutral detergent fibre (NDF) and acid detergent (ADF) contents ($P < 0.001$).

Plots within pasture type had no effect on dependent variables. The interaction effects of year x pasture type and pasture type x regrowth length, respectively, had no significant influence on chemical composition. The interaction effect of year and regrowth length did only influence ether extract (EE) and NDF percents ($P < 0.001$).

Table 11. Results of analysis of variance (ANOVA) for Influence of main and interaction effects on the chemical composition of the native and cultivated pastures

EFFECT	df.	Ash	CP	CF	EE	NFE	NDF	ADF	ADL
Year	1	n s	n s	**	n s	n s	n s	n s	*
Pasture Type	1	n s	***	***	***	***	***	***	***
Regrowth	2	**	***	***	n s	**	***	***	n s
Plot within Pasture Type	4	n s	n s	n s	n s	n s	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s	n s	n s	n s	n s
Year x Regrowth	2	n s	n s	n s	n s	n s	***	n s	n s
Pasture Type x Regrowth	2	n s	n s	n s	n s	n s	n s	n s	n s
R^2		0.24	0.71	0.88	0.56	0.92	0.90	0.86	0.74
CV (%)		5.69	10.27	3.80	9.91	5.43	2.24	4.37	8.76
Mean (% DM)		8.45	5.32	32.99	1.01	52.23	68.19	38.33	5.30
s e m		0.48	0.55	1.25	0.10	1.20	0.90	1.67	0.46

CP = crude protein, CF = crude fibre, EE = ether extract, NFE = nitrogen free extract, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent lignin

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; df Degrees of freedom

Least squares means and standard errors of the chemical composition values are shown in Table 12. Both crude fibre and ADL percent were significantly higher in 1996 ($P < 0.05$).

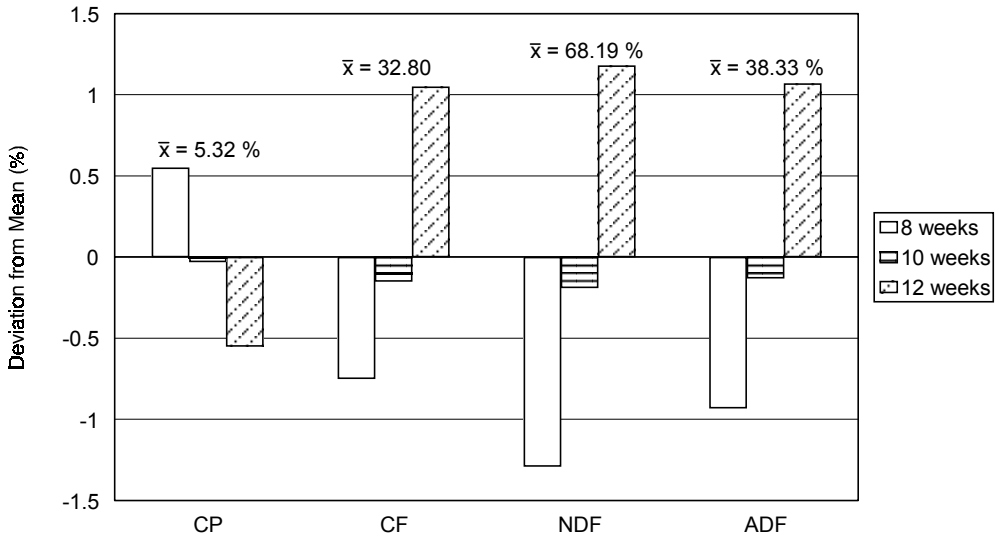
Brachiaria pasture had a higher CP, EE and NFE content than the native pasture ($P < 0.05$) and had a lower fibre (CF, NDF, ADF content) as well as ADL compared with the native pasture ($P < 0.05$). With respect to the regrowth lengths the following trends were observed: ash content was highest ($P < 0.05$) on the 12 week samples, crude protein percent decreased with regrowth length ($P < 0.05$), while CF, NDF and ADF showed the opposite trend ($P < 0.05$) to CP. NFE semed not to be affected by regrowth length.

Table 12. Influence of main and interaction effects on the % chemical composition of the pastures; % DM basis; (LSQ-means ± SEM)

	N	Ash	CP	CF	EE	NFE	NDF	ADF	ADL
Year									
1995	36	8.5[a]	5.4 [a]	32.5[a]	1.0[a]	52.4[b]	68.0[a]	38.1[a]	5.2[a]
1996	36	8.5[a]	5.3[a]	33.4[b]	1.0[a]	51.8[a]	68.4[a]	38.6[a]	5.4[a]
s e m		0.48	0.09	0.21	0.02	0.19	0.25	0.28	0.08
Pasture Type									
Native	36	8.5[a]	4.8[a]	35.8[a]	1.0[a]	49.8[a]	72.0[b]	41.9 [a]	6.0[b]
Brachiaria	36	8.4[a]	5.9[b]	30.2[b]	1.1[a]	54.5[b]	64.4[a]	34.7[b]	4.6[a]
s e m		0.08	0.09	0.21	0.02	0.19	0.25	0.28	0.08
Regrowth Length									
8 weeks	24	8.6[b]	5.9[b]	32.2 [a]	1.0[a]	52.3[a]	66.9a	37.4a	5.2[a]
10 weeks	24	8.2[a]	5.32[b]	32.8[b]	1.0[a]	52.3[a]	68.0[b]	38.2[a]	5.3[a]
12 weeks	24	8.5[b]	4.8[a]	34.0[c]	1.0[a]	51.7[a]	70.0[a]	39.4[b]	5.4[a]
s e m		0.10	0.11	0.26	0.20	0.24	0.31	0.34	0.09
Year x Regrowth									
1995 x 8 weeks	12	8.7[a]	5.9c	32.1a	1.0 [a]	52.3 [b]	67.4 [a]	37.2 [a]	5.1 [a]
1995 x 10 weeks	12	8.1[a]	5.3[b]	32.5 [a,b]	1.0 [a]	52.4 [b]	68.4 [b]	37.8[a,b]	5.2 [a]
1995 x 12 weeks	12	8.5[a]	4.8 [a]	33.1[b,c]	1.0 [a]	52.5 [b]	68.3 [b]	39.2[b,c]	5.2 [a]
1996 x 8 weeks	12	8.5[a]	5.9 [c]	32.1 [a]	1.0 [a]	52.3 [b]	66.5 [a]	37.6[a,b]	5.3 [a]
1996 x 10 weeks	12	8.4 [a]	5.3[b]	33.1[b,c]	1.0 [a]	52.3 [b]	67.5[a,b]	38.7 [b]	5.4 [a]
1996 x 12 weeks	12	8.5 [a]	4.7 [a]	34.8[c]	1.1 [a]	50.9 [a]	71.1 [b]	39.6[c]	5.6[b]
s e m		0.14	0.16	0.36	0.03	0.39	0.44	0.48	0.13

N = number of observations; CP = crude protein, CF = crude fibre, EE = ether extract, NFE = nitrogen free extract, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent lignin
Different letters within the same columns indicate significant differences, P ≤ 0.05

The interaction year x regrowth length on NDF depicts a wider range of values betweeen the regrowth periods in 1996. The mean percentage deviation of regrowth lengths on various quality traits is shown in Figure 8.The 8 week regrowth had the highest CP content. The correlation coefficient between regrowth length and CP was -0.52 ($P < 0.001$). The indicators of fibrousness (CF, NDF and ADF) are markedly affected by regrowth length with a sharp increase in CF in the 12 week regrowth length. NDF and ADF both increase linearly with extended regrowth periods. Their respective correlation coefficients with regrowth length were:for CF, $r = 0.23$ ($P < 0.05$), for NDF, $r = 0.26$, ($P < 0.05$) and for ADF, $r = 0.20$, ($P < 0.05$). ADL was also positively correlated with regrowth length ($r = 0.1$ ($P > 0.05$).



Different letters denote significant differences, P ≤0.05

Fig 8 Mean Deviations of chemical compostion values as influenced by Pasture Regrowth lengths

4.2.2. Pasture digestibility at cutting

The digestibility of the pastures was measured via the nylon bag (*in situ*) method and via the pepsin-cellulase method.

4.2.2. Pasture cellulase solubility (ELOS) parameters

The analysis of variance of the main effects as well as the interaction effects for cellulase digestibility parameters of the pastures are shown in Table 13. The model explains 92% of the variation. The coefficient of variation ranged from 4.31 to 5.86 % for insoluble organic matter in a cellulase solution (EULOS) and the cellulase digestibility of the organic matter, (CDOM), respectively.

Of all main and interaction effects considered, only pasture type ($P < 0.001$) and regrowth length ($P < 0.05$) significantly affected the cellulase parameters shown.

Table 13. Results of analysis of variance (ANOVA) for Influence of main and interaction effects on the cellulase digestibility parameters of native and cultivated pastures; DM - basis; (LSQ- means ± S E M)

EFFECT	df.	ELOS (%)	CDOM (%)	EULOS (g/kg)
Year	1	n s	n s	n s
Pasture Type	1	***	***	***
Regrowth	2	*	*	*
Plot within Pasture Type	4	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s
Year x Regrowth	2	n s	n s	n s
Pasture Type x Regrowth	2	n s	n s	**
R^2		0.92	0.92	0.92
CV (%)		5.78	5.86	4.31
Mean		38.4	41.69	530.25
s e m		2.04	2.46	27.72

ELOS = organic matter solubility in cellulase solution, CDOM = cellulase digestibility of the organic matter, EULOS = insoluble organic matter in a cellulase solution

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF = Degrees of freedom

The least squares means and the standard errors of the influence of pasture type and regrowth length on the cellulase parameters are shown in Table 14. There was a significantly higher solubility of the samples in cellulase (ELOS) as well as the calculated cellulase digestibility of the organic matter (CDOM), ($P < 0.001$) respectively. The insolubility of the organic matter in cellulase (EULOS) followed an inverse relationship with the native pasture having a higher value, 597.1 g/kg DM, compared with 464.3 g/kg DM for *Brachiaria*($P < 0.05$). These values show clearly that *Brachiaria* is more digestible than the native pastures. With respect to the deferment length, there was a significantly higher ($P < 0.05$) cellulase solubility of the 8 and 10 week pastures compared to the 12 week pastures. The CDOM followed the same trend as the ELOS while the EULOS values were highest for the 12 week deferred plots.

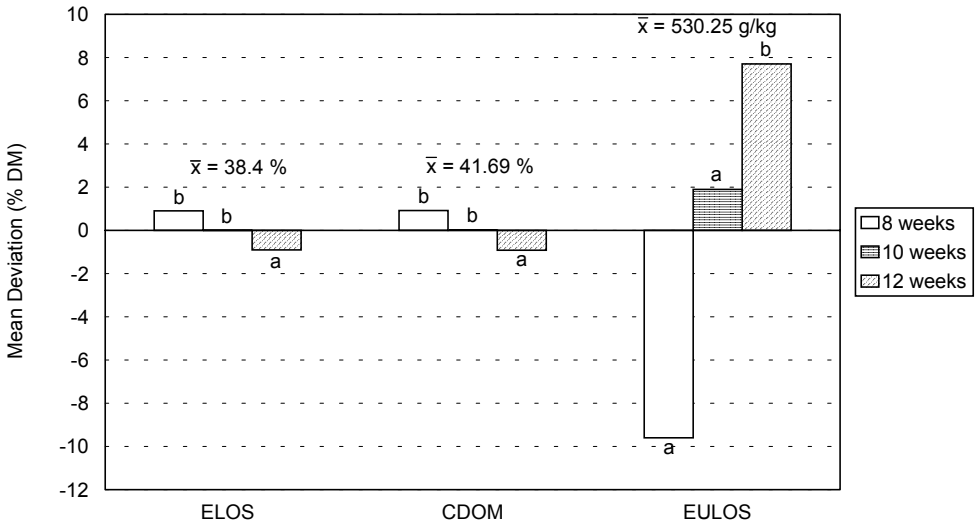
Table 14. Effects of main and interaction effects on cellulase solubility parameters of the pasture samples; DM basis; (LSQ-Means ± S E M)

EFFECT	N	ELOS (%)	CDOM (%)	EULOS (g/kg)
Year				
1995	36	38.1 [a]	41.5 [a]	533.7 [a]
1996	36	38.8 [a]	41.8 [a]	527.6 [a]
s e m		0.42	0.41	4.29
Pasture Type				
Native	36	31.7[a]	34.6 [a]	597.1 [b]
Brachiaria	36	45.2 [b]	48.8 [b]	464.3 [a]
s e m		0.42	0.41	4.29
Regrowth Length				
8 weeks	24	39.3 [b]	42.6 [b]	521.1 [a]
10 weeks	24	38.4[b]	41.7 [b]	532.6 [a]
12 weeks	24	37.7 [a]	40.8 [a]	538.4 [b]
s e m		0.46	0.50	4.64

ELOS = organic matter solubility in cellulase solution, CDOM = cellulase digestibility of the organic matter, EULOS= insoluble organic matter in a cellulase solution

Different letters within the same columns indicate significant differences, $p \leq 0.05$

The percentage deviations from the mean of the effect of the regrowth length on the cellulase parameters (ELOS, CDOM and EULOS) are shown in Fig. 9. For both ELOS and CDOM, significant but small deviations exists, whereas for EULOS regrowth length had a significant and quantitatively large effect. In summary, it is seen that there was a slight but negative relation between regrowth length and both ELOS and CDOM, but a positive relation in the case of EULOS.



Different letters denote significant differences, P ≤0.05

Fig. 9 Effect of regrowth length on pasture cellulase parameters; LSQ-Means ± SD

4.2.2.2. Pasture degradation rate

The results of the analysis of variance on nylon bag degradation rates from 0 hour up to 72 hours of the pastures are compiled in Table 15. The model explains 73 to 98 % of the variation. The coefficient of variation was 2.07% for the 12 hour and 10.03% for the 24 hour incubated samples, respectively.

Main effects had very significant differences for all incubation times, ($P < 0.001$) while, except for the interaction effect pasture type x regrowth length, the others had little or no effect on the degradation rate.

Table 15. Results of analysis of variance (ANOVA) for main and interaction effects on percentage degradation of nylon bag samples from native and cultivated pastures

EFFECT	D. F.	Washing Loss (0 h)	After 12 h	After 24 h	After 48 h	After 72 h
Year	1	***	***	n s	**	***
Pasture Type	1	***	***	**	***	***
Regrowth	2	***	***	***	***	***
Plot within Pasture Type	4	***	***	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s	**
Year x Regrowth	2	n s	n s	n s	n s	n s
Pasture Type x Regrowth	2	n s	n s	**	**	***
R^2		0.98	0.96	0.73	0.89	0.93
CV (%)		3.60	2.07	7.62	2.74	2.13
Mean		18.67	35.42	43.45	50.95	51.87
s e m		0.67	0.73	3.31	1.40	1.10

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF = Degrees of freedom

The linear and interaction effects on the degradation rates of the pastures are shown in Table 16. In the first year (1995) there were significantly higher differences in the degradation rates for all incubation hours than in the second year. The curves were however similar in shape (Fig. 10).

The *Brachiaria* pasture had a significantly higher ($P < 0.05$) degradation rate than the native pastures over all periods tested. The curves were similar in shape (Fig. 11) but clearly different in scale. With increase in regrowth length, there was a reduction in degradation rate. The curves followed an exponential pattern (Fig. 12) as was the case for the year and pastures curves.

The regressions of ruminal degradation rates with regrowth length for the 8, 10 and 12 weeks, were all significant $P < 0.05$) and clearly indicate a high correlation ($r > 0.98$)

The interaction effect of pasture x regroth length (Fig. 13) was significant for all degradations above 24 h and was caused by the large difference between the pasture types.

Table16. Influence of main and interaction effects on the % nylon bag degradation rates of regrowth pasture harvested in November (% DM basis); (LSQ-Means ± SEM)

EFFECT	N	0h	After 12h	After 24h	After 48h	After 72h
Year (Y)						
1995	36	19.2[b]	36.2[b]	43.3[a]	51.5[b]	52.7[b]
1996	36	18.1[a]	34.7[a]	43.6[b]	50.5[a]	51.0[a]
s e m		0.11	0.12	0.55	2.30	0.18
Pasture Type (PT)						
Native (NP)	36	15.9[a]	34.5[a]	42.3[a]	49.8[a]	50.3[a]
Brachiaria(BR)	36	21.4[b]	36.4[b]	44.6[b]	52.1[b]	53.5[b]
s e m		0.11	0.12	0.55	0.23	0.18
Regrowth Length (R)						
8 weeks	24	22.5[b]	38.2[b]	49.5[c]	54.5[c]	55.02[c]
10 weeks	24	17.5[a]	36.3[b]	42.0[b]	51.6[b]	52.7[b]
12 weeks	24	16.0[a]	31.8[a]	38.8[a]	46.8[a]	47.9[a]
s e m		0.14	0.15	0.68	0.29	0.22
Year x Pasture Type						
1995 x NP	18	16.4[a]	35.3[a,b]	42.1[a]	50.0[b]	50.7[a,b]
1995 x BR	18	22.0[b]	37.1[b]	44.4[b]	52.9[b]	54.7[b]
1996 x NP	18	15.4[a]	33.7[a]	42.5[a]	46.6[a]	49.9[a]
1996 x BR	18	20.8[b]	35.6[a,b]	44.8[b]	51.4[b]	52.2[b]
s e m		0.16	0.17	0.78	0.33	0.26
Pasture Type x Regrowth						
NP x 8 weeks	12	18.2[c]	37.2[c]	48.2[c,d]	52.6[c]	52.7[c]
NP x 10 weeks	12	15.4[b]	35.5[b]	39.5[b]	51.0[b]	51.3[b,c]
NP x 12 weeks	12	14.2[a]	30.8[a]	39.3[a,b]	45.8[a]	46.8[a]
BR x 8 weeks	8	26.9[d]	39.2[d]	50.8[d]	56.4[d]	57.3[d]
BR x 10 weeks	10	19.5[c]	37.1[c]	44.6[c]	52.1[b,c]	54.1[c]
BR x 12 weeks	12	17.9[a,b]	32.8[a,b]	38.3[a]	47.9[a,b]	49.0[b]
s e m		0.19	0.21	0.96	0.40	0.32

Different letters within the same columns indicate significant differences $p \leq 0.05$

Fig. 10 The effect of year on DM ruminal degradation of the pastures
Fig. 11 The effect of pasture type on DM ruminal degradation of the pastures

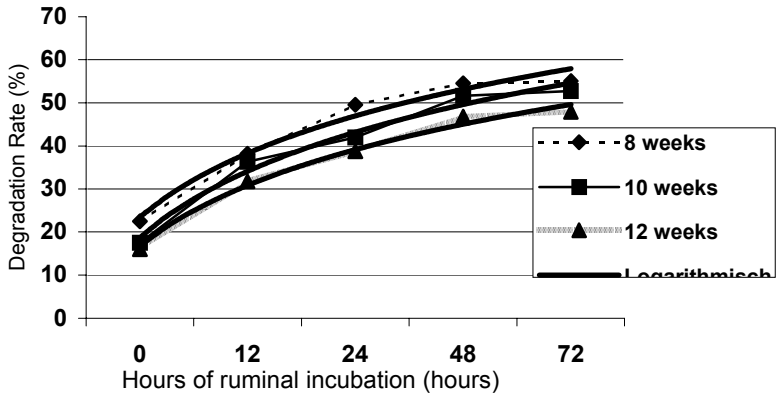


Fig. 12 The effect of regrowth length on DM ruminal degradation rate of the pastures

Fig. 13 The effect of pasture type x regrowth length on DM ruminal degradation rate of the pastures

Pasture degradation constants

The results of the analysis of variance (ANOVA) for the values obtained using the exponential model according to Ørskov and McDonald (1979) are compiled in Table 17.

Table 17. Results of ANOVA for nylon bag curve constants from pasture samples

EFFECT	df.	a	b	c	d
Year	1	*	n s	n s	n s
Pasture Type	1	***	***	***	***
Regrowth	2	***	***	**	***
Plot within Pasture Type	4	n s	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s
Year x Regrowth	2	n s	n s	n s	n s
Pasture Type x Regrowth	2	n s	n s	n s	n s
R^2		0.86	0.71	0.77	0.74
CV (%)		10.03	4.30	12.19	5.06
Mean		18.68	34.34	0.056	53.02
s e m		1.87	1.48	0.01	2.68

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF = Degrees of freedom
a, b, c, and d are the exponential curve characteristics (ØRSKOV and MCDONALD, 1979) where, a is the intercept on the y axis, b is the non-degraded but potentially degradable material, c is the slope of the curve and d = a + b is the degradability at time t

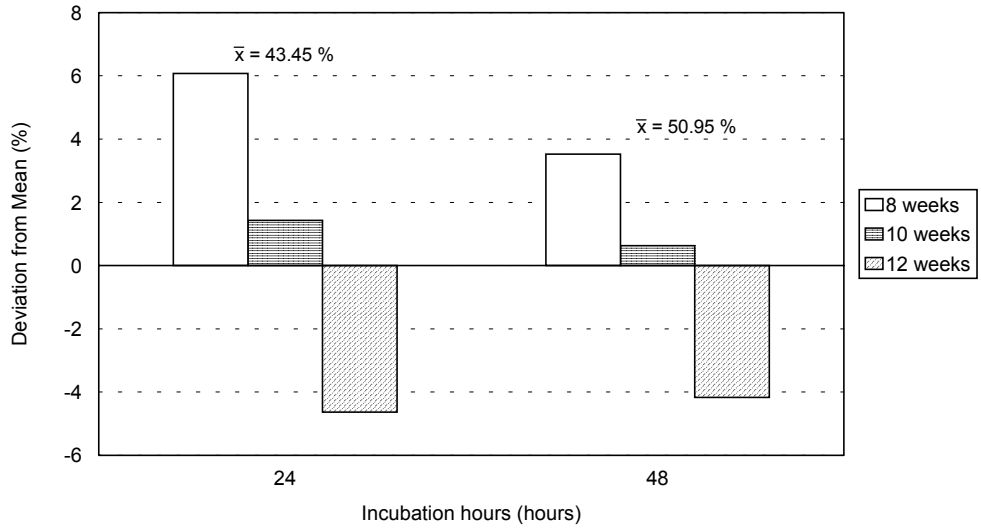
The model explains 71 to 86% of the variation. The coefficient of variation was 4.30 for the non-degraded but potentially degradable material (b) and 12.19 for the rate (c) at which the substrate is degraded. Year had a significant effect on the intercept value (a) only ($P < 0.05$). Pasture type and regrowth length significantly affected them all ($P < 0.001$).

Table 18 shows the least squares means and their standard errors for the curve constants of the pastures. With regards to the pasture types, the *Brachiaria* had a higher intercept value (a), a lower potentially degradable fraction (b) and a higher potential degradability percent (d or a + b), ($P < 0.05$). These derived values were similar to the measured values (cf Table 16). The rate constant (c) was higher ($P < 0.05$) for the native pastures, as can be seen in the degradation curves of the previous section. With regards to the regrowth periods the 8 week plots irrespective of the pasture type had the highest a and a +b values ($P < 0.05$), whereas there was no particular trend for the b and c values.

Table 18. Influence of main and interaction effects on nylon bag degradability curve constants from pasture samples; % DM basis, Mean ± SEM

EFFECT	N	a	b	c	d
Year					
1995	18	19.3[b]	34.5[a]	0.054[a]	53.8[a]
1996	18	18.0[a]	34.2[a]	0.058[a]	52.2[a]
s e m		0.44	0.35	0.002	0.63
Pasture Type					
Native	18	16.0[a]	35.3[b]	0.061[b]	51.3[a]
Brachiaria	18	21.4[b]	33.4[a]	0.054[a]	54.8[b]
s e m		0.44	0.35	0.002	0.63
Regrowth Length (R)					
8 weeks	12	21.5[c]	34.2[a]	0.061[b]	55.7[c]
10 weeks	12	18.4[b]	35.8[a]	0.047[a]	54.2[bc]
12 weeks	12	16.1[a]	33.1[a]	0.051[ab]	49.2[a]
s e m		0.54	0.43	0.002	0.77

Different letters within the same columns indicate significant differences p ≤ 0.05



Different letters denote significant differences, P ≤0.05

Fig. 14 Effect of Regrowth Length on Degradation Rates of the Pastures LSQ-Means

LSQ- mean deviations are shown in Fig 14 for the regrowth effect. For the 24 and 48 incubation hour there was a positive deviation obtained on the 8 and 10 week samples and a strong negative deviation on the 12 week samples, $P < 0.05$. This means that there was a slower ruminal degradation of the 12 week regrowths compared to the 8 and 10 week regrowths ($P < 0.05$).

4.2.3. Chemical composition of hay at baling

Results of the analysis of variance for the main and interaction effects on the chemical composition values of the hay at baling (i.e. week 0 storage) are shown in Table 19. The model used explains 31 to 92% of the variation. A low coefficient of determination was estimated for NDF, the highest was obtained for ADL. This low (CV) for the NDF content was also observed on the pasture samples. Year had no effect on ash content but significantly affected CP, CF, NFE, NDF and ADF (see section 4.2.1). The influence of pasture type on chemical composition was strong for all parameters shown ($P < 0.001$), except ash content ($P > 0.05$) and ether extract ($P < 0.05$). Regrowth length, too, significantly influenced all chemical parameters ($P < 0.05$) except EE content ($P > 0.05$).

All interactions were mostly non significant ($P > 0.05$), except the year x regrowth interaction that significantly affected NDF ($P < 0.001$). A similar situation was also obtained on the pasture samples.

Table 19. Results of analysis of variance (ANOVA) for effects of year, pasture type and deferment length on the chemical composition of hay (at baling)

EFFECT	df.	Ash	CP	CF	EE	NFE	NDF	ADF	ADL
Year	1	n s	*	***	*	***	*	*	n s
Pasture Type	1	n s	*	***	n s	***	***	***	***
Regrowth	2	***	**	***	n s	***	***	***	***
Plot within Pasture Type	4	n s	**	***	n s	n s	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s	n s	n s	n s	n s
Year x Regrowth	2	n s	n s	n s	n s	n s	***	n s	n s
Pasture Type x Regrowth	2	n s	n s	n s	**	n s	n s	n s	n s
R^2		0.31	0.91	0.91	0.61	0.92	0.89	0.88	0.71
CV (%)		5.74	2.67	3.78	10.11	4.51	2.22	4.17	9.24
Mean		8.06	4.37	35.76	1.01	49.69	71.57	41.85	5.98
s e m		0.48	0.50	1.25	0.10	1.20	0.86	1.59	0.44

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF Degrees of freedom
Degrees of freedom half that of pastures design because of pooling of treatment combinations in order to have enough mass for baling (details in materials and methods)

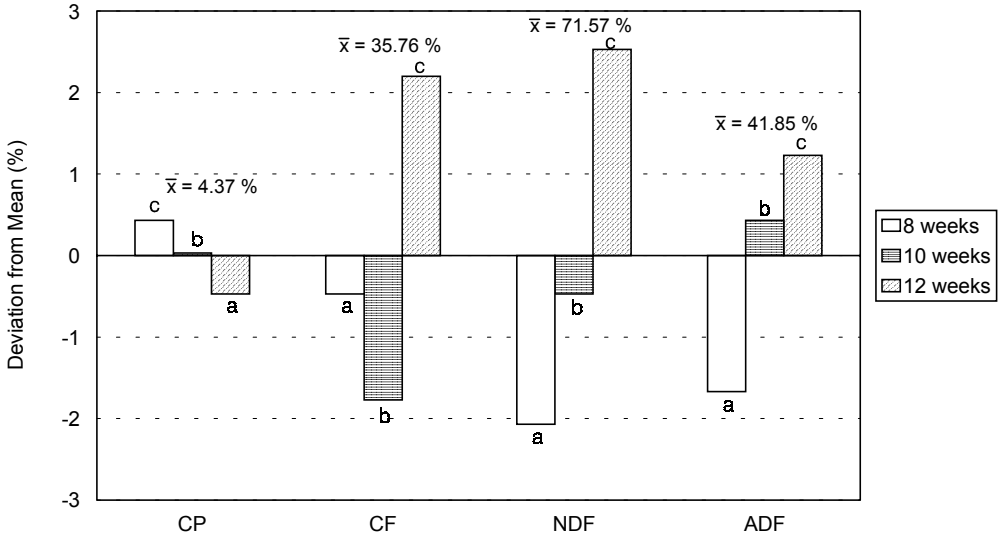
Table 20 shows the LSQ-means of the effects of the main and interaction effects on the chemical composition of the hays at baling. It is seen that the values obtained in 1995 are lower than those from 1996 in CP CF, EE, NFE and ADF contents ($P < 0.05$). *Brachiaria* hay had a higher ash, CP, NFE ($P < 0.05$), but lower CF, NDF, ADF and ADL content than the native pasture ($P < 0.05$).

Table 20. Influence of main and interaction effects on the % chemical composition of hay (at baling) % DM basis; (LSQ-means ± SEM)

	N	Ash	CP	CF	EE	NFE	NDF	ADF	ADL
Year									
1995	18	8.1 [a]	4.3 [a]	34.8 [a]	0.9 [a]	48.8 [a]	70.7 [b]	40.9 [a]	6.0 [a]
1996	18	8.0 [a]	4.4 [b]	36.8 [b]	1.12 [b]	50.6 [b]	68.4 [a]	42.8 [b]	5.9 [a]
s e m		0.12	0.08	0.28	0.21	0.26	0.30	0.33	0.10
Pasture Type									
Native	18	8.1 [b]	4.3 [a]	37.5 [b]	1.0 [a]	48.7 [a]	73.70 [b]	45.0 [b]	6.5 [b]
	18	8.0 [a]	4.4 [b]	34.1 [a]	1.0 [a]	50.7 [b]	69.5 [a]	38.7 [a]	5.4 [a]
s e m		0.12	0.08	0.28	0.21	0.26	0.30	0.33	0.10
Regrowth Length									
8 weeks	12	7.9 [a]	4.8 [c]	33.0 [a]	0.9 [a]	50.6 [c]	69.5 [a]	40.2 [a]	5.8 [a]
10 weeks	12	8.1 [b]	4.4 [b]	34.3 [b]	1.0 [a]	50.2 [b]	71.1 [b]	42.3 [b]	6.0 [a]
12 weeks	12	8.2 [c]	3.9 [a]	37.0 [c]	1.0 [a]	48.3 [a]	74.1 [c]	43.1 [c]	6.1 [a]
s e m		0.13	0.11	0.31	0.26	0.31	0.34	0.38	0.11

Different letters within the same columns indicate significant differences, P ≤ 0.05
Degrees of freedom half that of pastures design because of pooling of treatment combinations in order to have enough mass for baling (details in materials and methods)

The deviations of the means of the chemical composition values (Fig. 15), again demonstrate that hay from the 12 week regrowths has markedly higher fibrous constituents (CF, NDF and ADF), (P < 0.05). A similar relationship, though somewhat of lower magnitude, exists between the regrowth periods for ADL (P <0.05). CP and NDF showed an opposite trend with the highest positive deviation from the mean being obtained for the 8 week regrowths and the lowest (negative deviations) obtained for the 12 week regrowths (P < 0.05).



Different letters within the same columns indicate significant differences p ≤ 0.05

Fig. 15 Deviations from mean of chemical constituents of hay at baling as influenced by regrowth length

4.2.4. Hay digestibility (at baling)

The digestibility measurements with hay at baling were like those done with pasture samples and included the pepsin-cellulase solubility rate as well as the nylon bag degradability rates and their derived degradation constants a, b, c and d (a + b) (Ørskov and McDonald (1979). Correlations with DM yield were also made using the step-wise regression technique.

4.2.4.1. Hay cellulase digestibility parameters (at baling)

The results of the analysis of variance for the effects of the main and interaction effects on the cellulase solubility (ELOS) as well as the derived estimate of cellulase digestibility (CDOM) and the indicator of cellulase indigestibility (EULOS) are shown in Table 21. The model explains 89 to 92% of the variation. The coefficient of variation (CV) was low and ranged from 4.31 for EULOS to 5.78 for ELOS. A similar range was obtained on the pasture samples (see 4.2.2.1). All linear effects (year, pasture type and regrowth length) significantly influenced cellulase digestibility parameters. Interaction effects were not significant.

Table 21. Results of analysis of variance (ANOVA) for influence of main and interaction effects on the cellulase digestibility parameters of hay (at baling)

EFFECT	df.	ELOS	CDOM	EULOS
Year	1	*	*	***
Pasture Type	1	***	***	***
Regrowth	2	**	**	***
Plot within Pasture Type	4	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s
Year x Regrowth	2	n s	n s	n s
Pasture Type x Regrowth	2	n s	n s	n s
R^2		0.92	0.89	0.89
CV (%)		6.02	5.98	7.11
Mean		31.45	34.40	604.4
s.e.m.		2.01	2.42	25.21

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF = Degrees of freedom

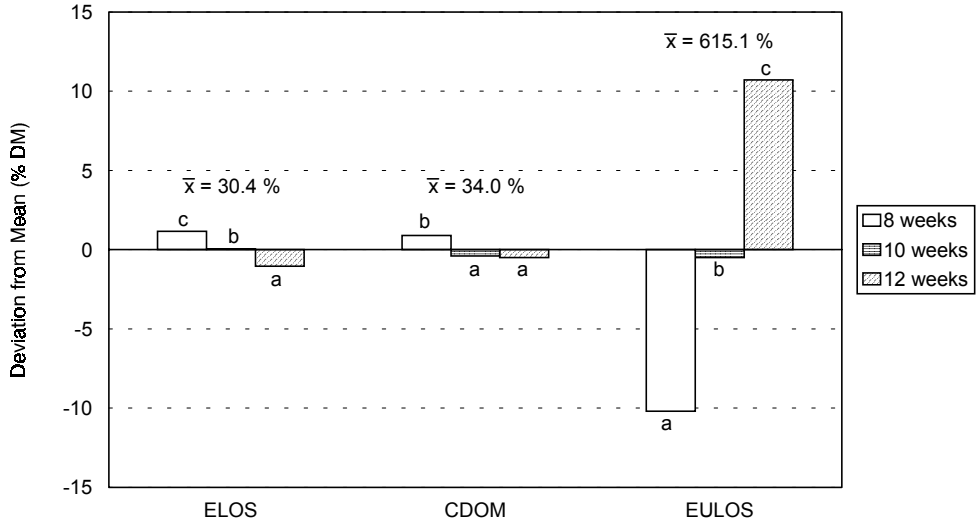
Least squares mean values of the effect of the main and interaction effects on ELOS and its derived parameters (CDOM and EULOS) are found in Table 22. ELOS and CDOM were higher ($P<0.05$) in 1995 than in 1996. *Brachiaria* had higher ELOS and CDOM ($P <0.05$) but lower EULOS ($P <0.05$) than the native pasture hay, a situation similar to their respective grasses. There was less cellulase solubility ($P <0.05$) with increase in regrowth length.

Table 22. Effects of main and interaction effects on cellulase solubility parameters of hay (at baling); (% DM), (LSQ-Means ±SEM)

EFFECT	N	ELOS	CDOM	EULOS
Year				
1995	18	32.4[b]	35.5[b]	594.6
1996	18	30.6[a]	33.4[a]	614.2[b]
s.e.m		0.40	0.41	5.02
Pasture Type				
Native	18	25.2[a]	28.4[a]	666.2[b]
Brachiaria	18	37.8[b]	40.4[b]	542.6[a]
s e m		0.40	0.41	5.02
Regrowth Length				
8 weeks	12	32.6[c]	35.3c	594.6[a]
10 weeks	12	31.5[b]	35.3[b]	603.9[b]
12 weeks	12	30.4[a]	34.0[a]	615.1[c]
s e m		0.46	0.49	5.61

ELOS = organic matter solubility in cellulase solution, CDOM = cellulase digestibility of the organic matter, EULOS= insoluble organic matter in a cellulase solution.
Different letters within the same columns indicate significant differences, $p \leq 0.05$

The effect of regrowth length on ELOS and CDOM, depicted in figure 16 show small positive deviations from the mean in the 8 week regrowths only, while the 10 and 12 week regrowths were negatively deviated from the mean ($P < 0.05$). The opposite deviation trend was as expected obtained on the indicator of indigestibility (EULOS) where the most positive deviation from the mean was observed on the 12 week samples, a slight negative deviation existed for the 10 weeks, and a big (-10%) deviation from the mean was observed on the 8 week regrowths ($P < 0.05$).



Different letters denote significant differences p ≤ 0.05

Fig. 16 Influence of Regrowth length on cellulase solubility parameters of hay (at baling)

4.2.4.1. Degradation rates of hay at baling

The results of the analysis of variance for the main and interaction effects on the degradation rates of the hay (at baling) are shown in Table 23. The model explains 71 to 96% of the variation. The coefficient of variation had a wider range from 2.10 for the 72h to 7.98 for the 12h degradation rate compared to the pastures at cutting (2.07) for the 12h to 7.62 for the 24h degradation rate.

Pasture type and regrowth length all significantly influenced the dependent variables P < 0.05). Only the washing loss (0h) and the degradation at 24h were not significantly influenced by year (P > 0.05).

The interaction effects (Table 23) for the most part did not significantly influence degradation rates (P > 0.05). Like with the pastures at cutting, there was a similarity in the effect of pasture type x regrowth length on the 24h, 48h and 72h degradation rates.

Table 23. Results of analysis of variance (ANOVA) for the effect of main and interaction on percentage degradation of nylon bag samples from hay (at baling)

EFFECT	df.	Washing Loss (0 h)	After 12 h	After 24 h	After 48 h	After 72 h
Year	1	n s	***	n s	**	*
Pasture Type	1	***	***	*	***	***
Regrowth	2	***	***	*	***	***
Plot within Pasture Type	4	***	n s	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s	**
Year x Regrowth	2	n s	n s	n s	n s	n s
Pasture Type x Regrowth	2	n s	n s	**	**	**
R^2		0.96	0.71	0.77	0.90	0.90
CV (%)		3.51	7.98	7.25	2.77	2.10
Mean		15.41	31.65	39.21	47.48	50.37
s e m		0.77	0.80	2.72	2.17	1.22

*** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; n s for not significant; DF = Degrees of freedom

The least squares means of the main effects and their interactions on the degradation rates of the hays at baling are compiled in Table 24. Year effect was apparent because although there was a similar washing loss for both 1995 and 1996, there were differences in the rates of

degradation making the end point (asymptote, 72h) to be different, $P < 0.05$) with a higher value being obtained in 1995 as in 1996 (Fig. 17). With respect to pasture types, the native pastures had a lower washing loss (Table 24) and although both pasture types had a similar degradation pattern (Fig. 18) the asymptote was still higher for the *Brachiaria* ($P < 0.05$). There was also a similarity in the degradation pattern between the regrowth lengths as shown in Fig. 19. Differences obtained at the beginning (0h) were maintained through all incubation hours 12, 24, 48 and 72 hours with the 8 hours having the highest value (54.1%).

Table 24. Influence of main and interaction effects on the % nylon bag degradation of hay (at baling) (% DM basis); (LSQ-Means ± SEM)

EFFECT	N	(0 h Bag)	After 12h	After 24 h	After 48 h	After 72 h
Year (Y)						
1995	18	15.7	32.6 [b]	39.3 [a]	49.0 [b]	51.8 [b]
1996	18	15.1	30.7 [a]	39.1 [b]	46.2 [a]	48.9 [a]
s e m		0.24	0.14	0.50	0.26	0.18
Pasture Type (PT)						
(NP)	18	13.4 [a]	30.3 [a]	38.3 [a]	46.6 [a]	49.0 [a]
(BR)	18	17.4 [b]	33.1 [b]	40.1 [b]	548.5 [b]	51.8 [b]
s e m		0.24	0.14	0.50	0.26	0.18
Regrowth Length (R)						
8 weeks	12	18.9 [c]	32.8 [b]	40.6 [c]	50.8 [c]	54.1 [c]
10 weeks	12	16.2 [b]	31.5 [a,b]	39.2 [b]	48.4 [b]	52.0 [b]
12 weeks	12	11.3 [a]	30.7 [a]	37.8 [a]	43.5 [a]	45.1 [a]
s e m		0.28	0.19	0.64	0.31	0.22
NP x 8 wk	6	15.2	32.5	39.2 [a,b]	47.1 [a]	49.7 [a]
NP x 10 wk	6	13.9	30.1	38.1 [a]	46.4 [a]	48.7 [a]
NP x 12 wk	6	11.2	28.2	37.7 [a]	46.3 [a]	48.5 [a]
BR x 8 wk	6	22.6	34.8	41.0 [b]	48.2 [b]	52.1 [b]
BR x 10 wk	6	18.5	32.8	40.0 [b]	48.8 [b]	52.0 [a,b]
BR x 12 wk	6	11.1	31.6	39.3 [a,b]	47.6 [a,b]	51.2 [b]
s e m		0.31	0.25	0.72	0.41	0.33

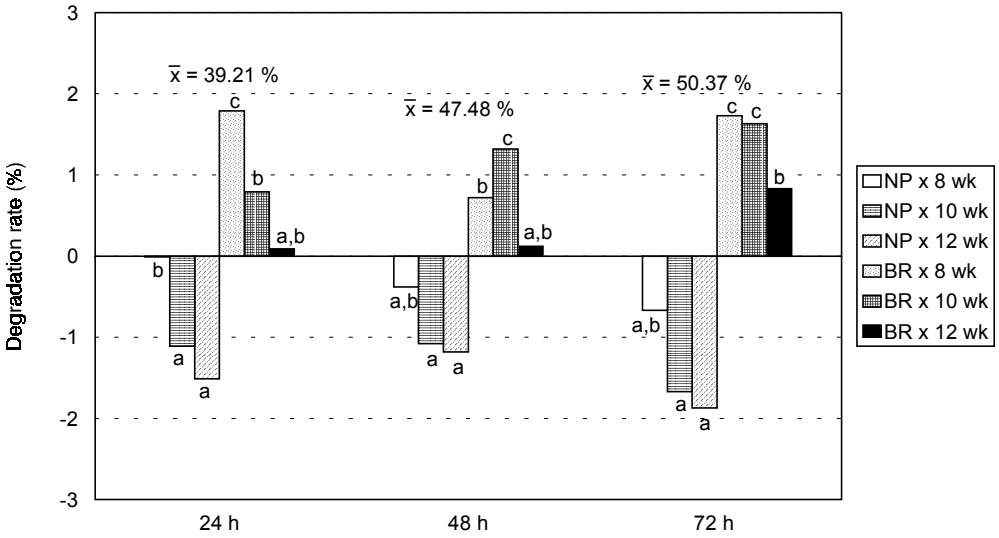
Different letters within the same columns indicate significant differences $p \leq 0.05$

Fig. 17 Effect of pasture type on ruminal degradation rate of the hays (at baling)
Different letters denote significant differences, $P \leq 0.05$

Fig. 18 Effect of regrowth length on ruminal degradation rate of the hay (at baling).

The effect of the interaction between pasture type x regrowth length for the incubation hours 24, 48 and 72 hours illustrated as deviations from the mean are shown in Fig. 19. The following trends can be observed:

1. the linear effects of pasture type, with the native pasture hay having a lower degradation rate than *Brachiaria* hay,
2. the linear effect of regrowth length with a clear reduction in degradation rates with extended regrowth length,
3. a different pattern between native and *Brachiaria* hay regrowth samples indicating a much better degradation in 10 week regrowth of *Brachiaria* hay for 48 and 72h degradation rates.



Different letters denote significant differences, P ≤0.05

Fig. 19 Influence of Pasture Type x Regrowth Interaction on Rumen Degradation Rate of Hay (at baling)

Degradation constants of the hay (at baling)

Table 25 shows the results of the analysis of variance of the degradation constants of hays at baling. The model explains 76 to 90% of the variation. The coefficient of variation (CV) was lowest on b and highest on c, the rate constant.

Among the main effects, pasture type and regrowth length all significantly affected the rate constants ($P < 0.05$), whereas plot within pasture and all the interactions had no significant influence. Year significantly ($P < 0.05$) affected "d" only. These effects were, in general, similar to those obtained on the pastures as shown earlier.

Table 25. Results of ANOVA for nylon bag curve constants from the hay (at cutting)

EFFECT	df.	a	b	c	d
Year	1	n s	n s	n s	*
Pasture Type	1	***	***	***	***
Regrowth	2	***	*	*	**
Plot within Pasture Type	4	n s	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s
Year x Regrowth	2	n s	n s	n s	n s
Pasture Type x Regrowth	2	n s	n s	n s	n s
R^2		0.90	0.78	0.81	0.76
CV (%)		9.98	4.52	11.03	6.14
Mean		17.92	36.13	0.052	54.04
s e m		1.81	1.57	0.001	2.16

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF = Degrees of freedom.
a , b, c, and d are the exponential curve characteristics (Ørskov and McDonald, 1979) where, a is the intercept on the y axis, b is the non-degraded but potentially degradable material, c is the slope of the curve and d = a + b is the degradability at time t.

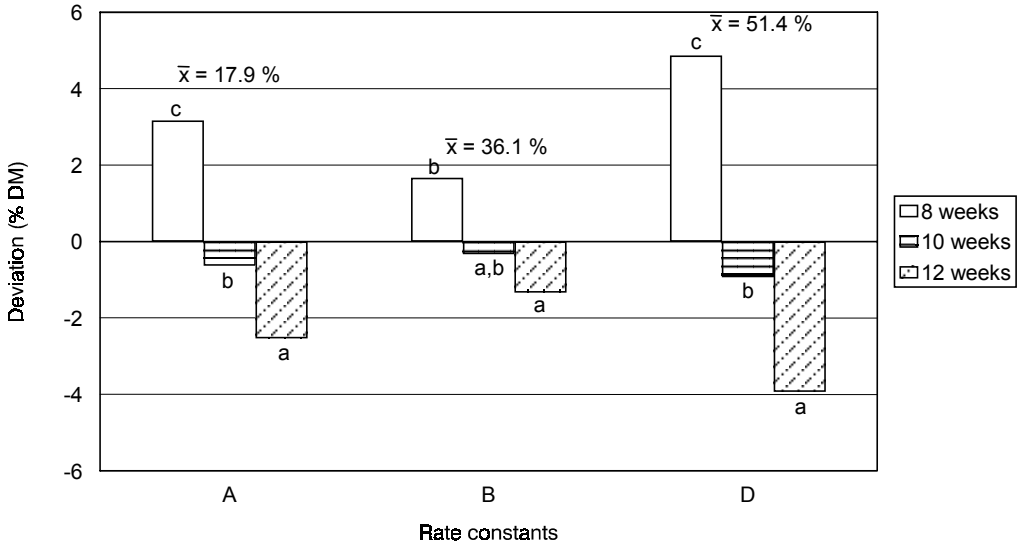
Table 26. Effects of main and interaction effects on nylon bag degradability curve constants from the hay (at baling); % DM basis, (LSQ-Means ± SEM)

EFFECT	N	a	b	c	d
Year (Y)					
1995	18	18.7 [b]	38.1 [b]	0.054 [a]	56.8 [b]
1996	18	17.2[a]	34.2 [a]	0.050 [b]	51.3 [a]
s e m		0.30	0.38	0.001	0.62
Pasture Type (PT)					
(NP)	18	15.0 [a]	37.5 [b]	0.058 [b]	51.3 [a]
(BR)	18	20.8 [b]	34.8 [a]	0.046 [a]	52.5 [b]
s e m		0.30	0.38	0.001	0.62
Regrowth Length (R)					
8 weeks	12	21.1 [c]	37.8 [b]	0.060 [c]	58.9[c]
10 weeks	12	17.3 [b]	35.8 [a,b]	0.054 [b]	53.1 [b]
12 weeks	12	15.4 [a]	34.8 [a]	0.042 [a]	50.1 [a]
s e m		0.35	0.42	0.002	0.80

Different letters within the same columns indicate significant differences $p \leq 0.05$

The least squares means of the effects of the influence of the main and interaction effects on the rate constants of the hays at baling are shown in Table 26. All the levels of significance observed for the effect of year, pasture type and regrowth length obtained on the pastures

were also obtained here for the estimate of washing loss (a) and the estimate of the degradability asymptote (d = a + b).



Different letters denote significant differences $p \leq 0.05$. A, B, D and are the degradation constants a, b, d, but are shown here in capitals to avoid confusion with levels of significance D = A + B

Fig. 20 Influence of Regrowth Length on degradation constants of hay at baling: Deviations from the mean

Figure 20 shows the deviations from the mean of the effect of regrowth length on the degradation constants of the hays (at baling). The biggest positive deviation from the mean was obtained on the 8 week regrowths of the asymptote (d). In general it is seen that there was a significant difference in all degradation constants with the asymptote (d) having the largest deviation between the regrowth periods.

4.3.Nutrient yield of pasture (at cutting) and hay (at baling).

4.3.1.Calculated digestible DM yield of the pastures (at cutting)

Table 27 shows the results of the analysis of variance on calculated digestible DM yields of the pasture samples using the degradation rates. Digestibilities were based on the degradation rates after 12 to 72 hours ruminal incubation (cf. materials and methods for their derivation). R^2 was highest on both the 12 h and 72 h DDM yields (0.86) and lowest on the 24 h value (0.55). CV ranged from 4.71 to 9.27% for the 12 h and 24 h DDMY values, respectively. Year and pasture type have highly significant influences on the calculated digestibility

measurements. Regrowth length also affects the calculated digestibility of DM for the 12 and 48h incubation times, whereas no effect was measured at 24 and 72h.

Table 27. Results of analysis of variance (ANOVA) for effects of main and interaction effects on calculated digestible dry matter yield of the pastures

Effect	D F.	DDMY after 12h	DDMY after 24 h	DDMY after 48 h	DDMY after 72 h
Year	1	***	***	***	***
Pasture Type	1	***	***	***	***
Regrowth	2	***	n s	***	n s
Plot within Pasture Type	4	**	n s	n s	n s
Year x Pasture Type	1	n s	n s	*	n s
Year x Regrowth	2	**	n s	**	n s
Pasture Type x Regrowth	2	*	*	n s	n s
R^2		0.86	0.55	0.78	0.86
CV (%)		4.71	9.27	5.53	4.92
Mean		711.39	869.58	1023.90	1043.36
s e m		33.50	80.65	56.67	51.34

DDMY = digestible DM Yield after 12, 24, 48 or 72 h ruminal incubation
*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant

Least squares means of the digestible DM yields (nylon bag degradation - rate - based) are shown in Table 28. It was noticed that like in the case of the DM yields of the pastures, year had an effect on all the yields at all incubation hours ($P < 0.05$). The values of 1995 were all higher than those of 1996. With regards to the pastures, like with the DM yields, the *Brachiaria* had consistently higher yield at all incubation hours.

The influence of regrowth lengths affected the digestible DM yields depending on the respective degradation rates. For example, the yield differed between 687.3kg DM/ha for the 12 week regrowths, 735.8 kg DM/ha for the 10 weeks and 711.1 kg DM/ha for the 12 week value ($P < 0.05$).

Table 28. Effects of main and interaction effects on calculated digestible nutrient yield of the pastures; kg DM/ha, (LSQ-Means ± SEM)

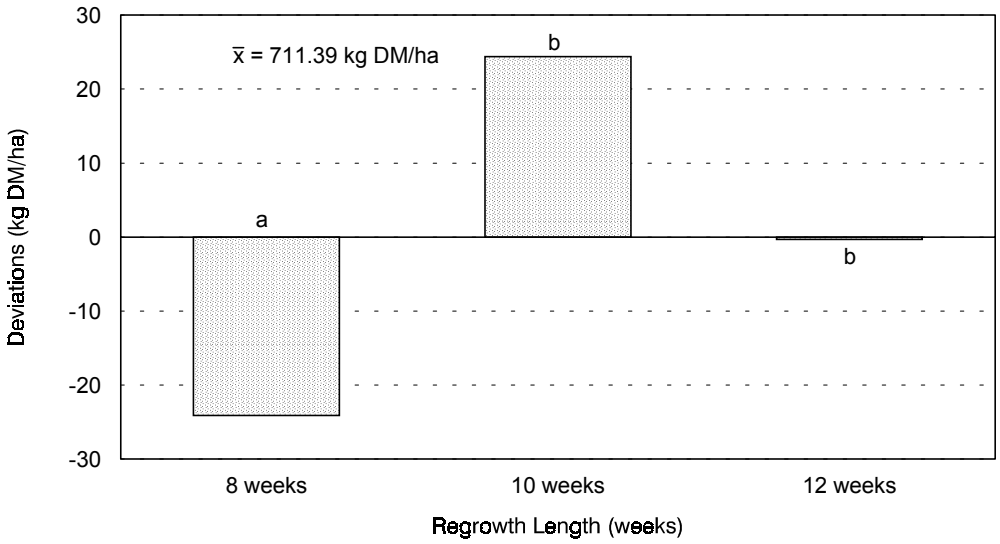
EFFECT	N	12h DDM Yield	24h DDM Yield	48h DDM Yield	72h DDM Yield
Year					
1995	18	758.5 [b]	904.6 [b]	1079.2 [b]	1107.1 [b]
1996	18	664.3 [a]	834.5 [a]	968.6 [a]	979.6 [a]
s e m		5.58	13.44	9.44	8.55
Pasture Type					
Native	18	660.8 [a]	810.7 [a]	955.0 [a]	965.1 [a]
Brachiaria	18	761.9 [b]	928.4 [b]	1092.8 [b]	1121.6 [b]
s e m		5.58	13.44	9.44	8.56
Regrowth Length					
8 weeks	12	687.3 [a]	890.6 [a]	981.5 [a]	991.7 [a]
10 weeks	12	735.8 [b]	852.3 [a]	1043.7 [b]	1068.0 [a]
12 weeks	12	711.1 [c]	865.8 [a]	1046.4 [c]	1070.4 [a]
s e m		6.85	16.46	11.57	10.48
Year x Pasture Type					
95 1	9	700.2 [a,b]	835.2 [a,b]	995.4 [b]	1009.2 [b]
95 2	9	816.8 [b]	974.0 [b]	1162.9 [c]	1205.0 [c]
96 1	9	621.4 [a]	786.3 [a]	914.7 [a]	921.1 [a]
96 2	9	707.1 [a,b]	882.8 [a,b]	1023.0 [b,c]	1038.2 [,b,c]
s e m		7.00	19.01	13.36	12.10
Year x Regrowth					
95 8 weeks	6	746.7 [c]	947.6 [c]	1060.4 [c]	1073.1 [b,c]
95 10 weeks	6	790.5 [d]	898.0 [b]	1109.4 [d]	1142.7 [c]
95 12 weeks	6	738.3 [c]	868.3 [a,b]	1067.7 [c]	1105.5 [c]
96 8 weeks	6	628.0 [a]	833.6 [a,b]	902.7 [a]	910.3 [a]
96 10 weeks	6	681.0 [b]	806.7 [a]	978.0 [b]	993.3 [b]
96 12 weeks	6	683.8 [b]	863.4 [a,b]	1025.2 [b,c]	1035.3 [b]
s e m		9.67	23.28	16.36	14.82
Pasture Type x Regrowth					
NP 8 weeks	6	651.5 [a]	844.9 [a,b]	921.8 [a]	924.5 [a]
NP 10 weeks	6	678.3 [a,b]	755.6 [a]	975.3 [a,b]	981.4 [a,b]
NP 12 weeks 45	6	652.2 [a]	831.7 [a,b]	968.0 [a,b]	989.6 [a,b]
BR 8 weeks	6	723.2 [a]	936.3 [b]	1041.3 [b]	1058.0 [b,c]
BR 10 weeks	6	792.7 [ab,c]	949.1 [c]	1112.2 [c]	1154.7 [c]
BR 12 weeks	6	770.0 [c]	899.9 [b]	1124.8 [c]	1151.2 [c]
s e m		9.67	23.28	16.36	14.82

Different letters within the same columns indicate significant differences $p \leq 0.05$
NP = native pasture; BR = *Brachiaria*

The derived deviations from the mean 12h DM yields showed that the highest positive deviation was obtained on the 10 week regrowths (Fig. 21). Calculated 24h digestible DM yield of the 24h degradtion rates was highest on the 8 week regrowths, intermediate for the 10 week regrowths and least on the 12 week regrowths. The deviations from the mean (Fig. 22) showed that there was a significantly positive effect on yield of digestible nutrients of the 8

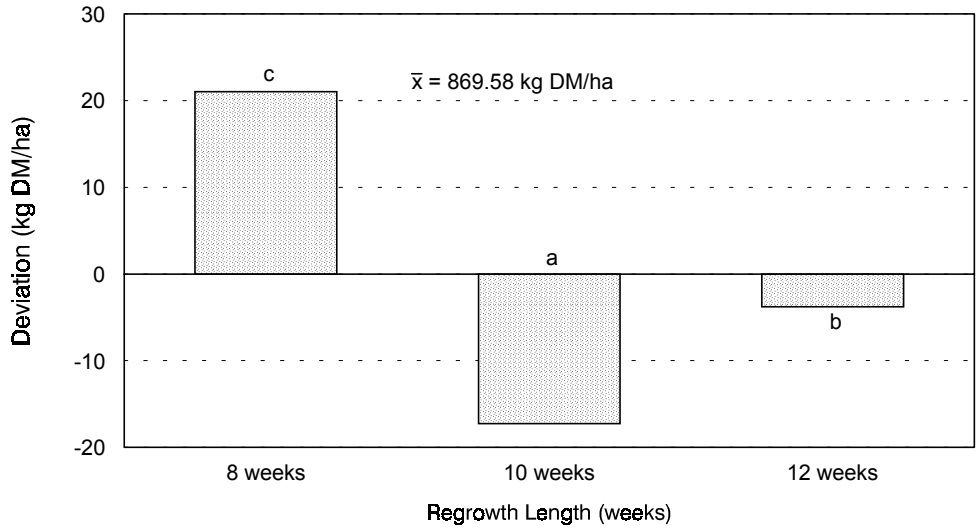
week regrowths compared to the negative deviation obtained on the 12 week regrowths ($P < 0.05$). Digestible nutrient yield increased with increase in length of pasture regrowths for the 24h and 72h digestible DM yields. Differences between the 10 week and 12 week regrowths were however non significant (Figs. 22 and 23).

From the above results, it can be said that, in general, there was an increase in digestible nutrients yield with prolonged incubation duration (to obtain nylon bag degradability rates). *Brachiaria* pasture hay out-yielded native hay and at 72h incubation no significant differences existed between hays of different regrowth periods.



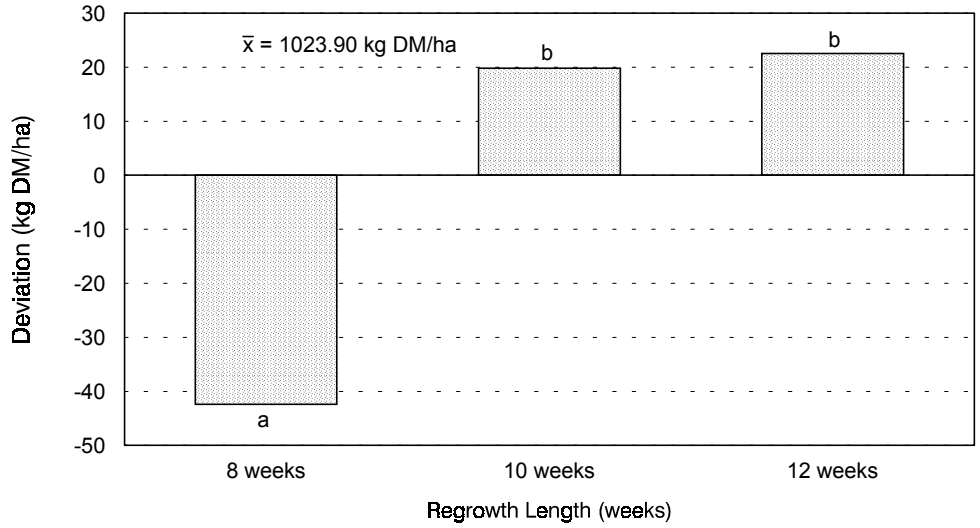
Different letters denote significant differences, $P \leq 0.05$

Fig. 21 Influence of Regrowth Length on 12h digestible DM Yield of the Pastures



Different letters denote significant differences, P ≤0.05

Fig 22. Deviations from the Mean of Effect of Regrowth length on 24h Digestible DM Yield of the Pastures



Different letters denote significant differences, P ≤0.05

Fig. 23 Deviations from the Mean of Effect of Regrowth Length on Pasture 48h dig. DM Yields

4.3.2. Calculated digestible DM yield of hay at baling

The ANOVA results for the 24h and 48h DM yields of the hay (at baling) are shown in Table 29. The coefficients of determination was 0.78 and 0.62, respectively. These were lower than the corresponding values obtained on the DM yields of the hays. The CV was lower on the 24h value compared to the 48h value. All main effects had a significant influence (P <0.05) on both parameters. The effect of plot was non significant (P <0.05) while the year x regrowth

length interaction affected only the DDMY after 48h significantly (P <0.05). The pasture type x regrowth length only influenced the DDMY at 24h significantly (P <0.05).

Table 29. Results of analysis of variance (ANOVA) for effects of main and interaction effects on calculated digestible dry matter yield of the hay (at baling)

Effect	df.	DDMY after 24 h	DDMY after 48 h
Year	1	***	***
Pasture Type	1	***	***
Regrowth	2	*	***
Plot within Pasture Type	4	n s	n s
Year x Pasture Type	1	n s	n s
Year x Regrowth	2	n s	**
Pasture Type x Regrowth	2	*	n s
R^2		0.78	0.62
CV (%)		4.93	8.99
Mean		695.44	844.85
s e m		78.67	55.78

DDMY = digestible DM Yield after 12, 24, 48 or 72 h ruminal incubation
*** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; n s for not significant

Table 30 shows the least squares means of the main and interaction effects on the 24h and 48h DM yields of the hays (at baling). For both parameters yields in 1995 were higher than those from 1996 (P <0.05). *Brachiaria* produced more (P < 0.05) than the native pastures. The 10 week regrowths produced the highest digestible DM at the 24h (P >0.05) but at the 48h yields it was the 8 week regrowths which reached the highest digestible DM yields (P <0.05) followed by the 10 week regrowths. This is indeed interesting and shows that the high degradability rate for the 8 week regrowths had an influence in the high nutrient yield and not just the DM yield of the regrowths on which these calculations were based.

Table 30. Effects of main and interaction effects on calculated digestible nutrient yield of hay (at baling); kg DM/ha, (LSQ Means ± SEM)

EFFECT	N	24h DDM Yield	48h DDM Yield
Year			
1995	18	725.87[b]	904.77[b]
1996	18	665.01[a]	784.92[a]
s e m		12.68	8.64
Pasture Type			
Native	18	669.10[a]	814.03[a]
Brachiaria	18	722.22[b]	874.01[b]
s e m		12.68	8.64
Regrowth Length			
8 weeks	12	699.68[a]	875.72[a]
10 weeks	12	693.47[a]	855.73[b]
12 weeks	12	690.05[a]	796.12[c]
s e m		15.65	10.71

Different letters within the same columns indicate significant differences, a,b; b,c; cd = $p \leq 0.05$

4.3.3. Calculated CP and ELOS yields of the pastures (at cutting)

The results of the analysis of variance on the yield of digestible nutrient (CP - and ELOS - based) yield of the pastures are found in Table 31. The model explains 68 to 92% of the variation. Coefficient of variation (CV) ranged from 7.84 for the ELOS yield to 13.29% on the 24h digestible CP yield. The CV 's were higher than those obtained on the DM yield and on the CP and ELOS, which were used to calculate these digestible nutrients. As noticed in the table, there was a significant influence of all the main effects on all the parameters shown ($P < 0.05$). The interaction effects (except for the pasture type x regrowth length) as well as the plots within pasture did not have influence on the values.

Table 31. Results of the analysis of variance for effects of main and interaction effects on calculated digestible CP and ELOS yield of the pastures at cutting

EFFECT	df.	CPY	Dig. CP Yield after 24h	Dig. CP Yield after 48h	ELOSY
Year	1	***	**	ns	***
Pasture Type	1	***	***	***	***
Regrowth	2	***	***	***	***
Plot within Pasture Type	4	n s	n s	n s	n s
Year x Pasture Type	1	n s	n s	n s	n s
Year x Regrowth	2	n s	n s	n s	n s
Pasture Type x Regrowth	2	*	*	*	**
R^2		0.68	0.76	0.79	0.92
CV (%)		12.03	13.29	11.93	7.84
Mean		106.93	46.63	54.83	788.27
s e m		12.87	6.20	7.24	61.79

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant

Table 32 depicts the least squares means of the main and interaction effects on the digestible CP nutrient and ELOS yields of the pastures. 1995 had significantly higher values for CP yield, 24h, 48h digestible CP yield as well as ELOS yield, $P < 0.05$. Also there was a significantly higher yield of these nutrients in the *Brachiaria* compared to native pastures hay ($P < 0.05$).

With respect to the regrowth lengths there was near parity between the 8, 10 and 12 week for CP yield, mean yields being 106.2, 107.9 and 106.7 kg DM/ha for the 8, 10 and 12 week regrowths, $P < 0.05$. The highest yield of digestible crude protein (dig. CPY) based on the 24h and 48h degradabilities were obtained with 8 week regrowth ($P < 0.05$) followed by the 10 week regrowth and 12 week regrowth ($P < 0.05$). However, the highest yield of cellulase - soluble organic matter (ELOSY) was obtained with the 12 week regrowths ($P < 0.05$) followed by the 10 week and 8 week regrowths ($P < 0.05$).

Table 32. Influence of main and interaction effects on the CP yield, Dig CP yield and ELOS yield of the Pastures; kg DM/ha, LSQ-Means ± SEM

Effect	N	CP Yield	24h DCP Yield	48h DCP Yield	ELOS Yield
Year					
1995	18	112.4 [b]	49.0 [b]	58.8 [a]	808.1 [b]
1996	18	101.5 [a]	44.3 [a]	58.3 [a]	751.6 [a]
s e m		2.14	1.03	1.21	10.30
Pasture Type					
(NP)	18	91.4 [a]	38.6 [a]	45.7 [a]	608.7 [a]
(BR)	18	122.5 [b]	54.6 [b]	64.0 [b]	950.9 [b]
s e m		2.14	1.03	1.21	10.30
Regrowth Length					
8 weeks	12	106.2 [a]	52.9 [c]	58.4 [c]	709.3 [a]
10 weeks	12	107.9 [c]	45.8 [b]	56.0 [b]	780.9 [b]
12 weeks	12	106.7 [b]	41.3 [a]	50.1 [a]	849.2 [c]
s e m		2.63	1.27	1.48	12.61
Year x Pasture Type					
95 x NP	9	98.7 [a,b]	41.6 [a,b]	49.5 [a,b]	622.8 [a,b]
95 x BR	9	126.0 [b]	56.3 [b]	67.0 [b]	993.3 [b]
96 x NP	9	84.1 [a]	35.7 [a]	41.8 [a]	594.6 [a]
96 x BR	9	119.0 [b]	52.9 [b]	61.0 [b]	908.6 [b]
s e m		3.03	1.46	1.71	14.56
Year x Regrowth					
95 x 8 weeks	6	114.0 [b]	56.8 [c]	63.8 [b]	748.1 [b]
95 x 10 weeks	6	113.4 [b]	48.2 [b,c]	59.6 [b]	811.1 [b,c]
95 x 12 weeks	6	109.6 [b]	41.9 [a,b]	51.4 [a,b]	865.0 [c]
96 x 8 weeks	6	109.6 [b]	49.0 [b,c]	53.0 [a,b]	670.5 [a]
96 x 10 weeks	6	98.4 [a]	43.3 [b]	52.3 [a,b]	750.7 [b]
96 x 12 weeks	6	102.4 [a,b]	40.6 [a]	48.8 [a]	833.5 [c]
s e m		3.71	1.79	2.09	17.83
Pasture Type x Regrowth					
NP x 8 weeks	6	91.0 [a]	44.0 [a,b]	48.0 [a,b]	572.7 [a]
NP x 10 weeks	6	92.8 [a]	36.5 [a]	47.7 [a,b]	611.1 [b]
NP x 12 weeks 45	6	90.4 [a]	35.3 [a]	41.3 [a]	642.3 [b,c]
BR x 8 weeks	6	121.5 [b]	61.7 [c]	68.8 [c]	845.9 [c]
BR x 10 weeks	6	123.1 [b]	55.0 [b,c]	64.3 [c]	950.7 [c,d]
BR x 12 weeks	6	123.0 [b]	47.2 [b]	58.9 [b]	1056.2 [d]
s e m		3.71	1.79	2.09	17.84

No replicates of treatment types here. Samples from both replicates pooled before being incubated.
Different letters within the same columns indicate significant differences, a,b; b,c; cd = $p \leq 0.05$;

4.3.4. Calculated digestible CP and ELOS yield of the hay (at baling)

Table 33 shows the results of the analysis on the digestible crude protein yield (DCPY) based on the 24h and 48h nylon bag degradability rates as well the ELOS yield of the hay obtained after baling (week 0 of storage). The 72h values were not included in nutrient yield calculations because of their non relevance in nutritive value determination studies, (see

materials and methods, 2.6). The model explains 71 to 78% of the observed variation. The CV was highest on the CP yield (11.23) and lowest on the ELOS yield (8.26). Pasture type and regrowth length have highly significant effects on both variables. R^2 values of 0.71, 0.77 and 0.74 for CPY and 0.90 for ELOSY clearly indicate the large effect of the above treatments

Table 33. Results of the analysis of variance for effects of main and interaction effects on calculated digestible CP and ELOS yield of hay (at baling)

EFFECT	df.	CPY	Dig. CP Yield after 24h	Dig. CP Yield after 48h	ELOSY
Year	1	***	**	ns	***
Pasture Type	1	***	***	***	***
Regrowth	2	***	***	***	***
Plot within Pasture Type	4	n s	n s	ns	n s
Year x Pasture Type	1	n s	n.s	ns	n s
Year x Regrowth	2	n s	n.s	ns	n s
Pasture Type x Regrowth	2	**	n.s	*	**
R^2		0.71	0.77	0.74	0.90
CV (%)		11.23	12.17	10.63	8.26
Mean		77.46	30.38	36.89	558.24
s e m		10.98	6.44	7.04	11.79

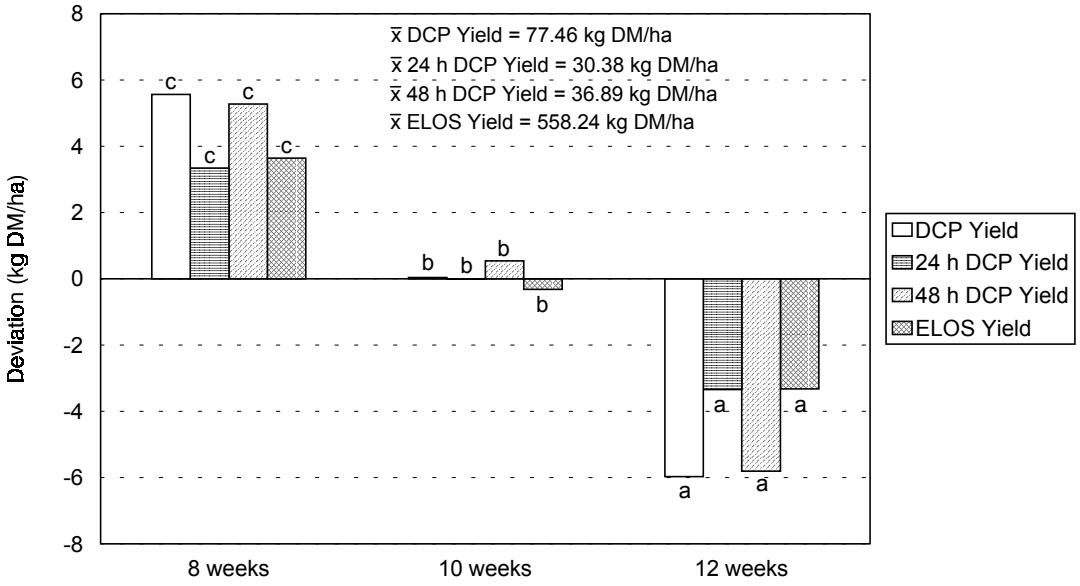
*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant

LSQ means for year, pasture type and regrowth length are listed in Table 34. Differences between years are reflections of rainfall related pasture regrowth conditions. *Brachiaria* pasture hay out yielded native hay in every yield determination. Regrowth length had an almost linear negative effect on yield measurement (Fig. 24) which is of some significance in determining the grazing deferment time for quality hay production.

Table 34. Influence of main and interaction effects on the CP yield, Dig CP yield and ELOS yield of hay at baling; kg DM/ha, (LSQ - Means ± SEM)

EFFECT	N	CP Yield	24h DCP Yield	48h DCP Yield	ELOS Yield
Year					
1995	18	79.57 [b]	31.29 [b]	39.00 [a]	598.69 [b]
1996	18	75.35 [a]	29.46 [a]	34.77 [a]	519.93 [a]
s e m		2.04	1.18	1.43	9.85
Pasture Type					
Native	18	75.78 [a]	29.04 [a]	35.33 [a]	440.72 [a]
Brachiaria	18	79.13 [b]	31.74 [b]	38.41 [b]	679.91 [b]
s e m		2.04	1.18	1.43	9.85
Regrowth Length					
8 weeks	12	83.02 [c]	33.72 [c]	42.21 [c]	561.88 [b]
10 weeks	12	77.50 [b]	30.37 [b]	37.48 [b]	557.92 [a]
12 weeks	12	71.49 [a]	27.04 [a]	31.13 [a]	554.92 [a]
s e m		2.78	1.86	1.59	11.83

No replicates of treatment types here. Samples from both replicates pooled before being incubated.
Different letters within the same columns indicate significant differences, a,b; b,c; cd = p ≤ 0.05.



Different letters denote significant differences, P ≤0.05

Fig. 24 Deviations from the mean of effect of regrowth length on the nutrients CP, 24h and 48h dig. CP as well as ELOS Yields of the hays (at baling)

4.4. Quality of hay during storage

The quality of hay was determined during a 20 week storage period (20th November to 20th April) of 1996 and 1997 respectively. As seen in the materials and methods section, the statistical analysis of hay quality was done basically as for the grass yield but included the additional independent variables, storage week, and the interaction year x pasture type x storage week.

Storage length (week) had a highly significant (P <0.001) effect on ash, CP and CF, a significant (P <0.05) influence on NFE and NDF, and a non significant effect on EE, ADF and ADL. With extended storage duration the CP content is reduced, markedly after the 12th week of storage. Ash, crude fibre and NDF all have increased values and again mainly change after 12 weeks of storage. ADF is already markedly increased within the first 12 weeks and thereafter does not change any more. NFE increases with extended storage and attains highest values at 20 weeks of storage (Fig. 25).

Table 35. Results of ANOVA for effects of main and interaction effects on the chemical content of stored hays at Wakwa centre

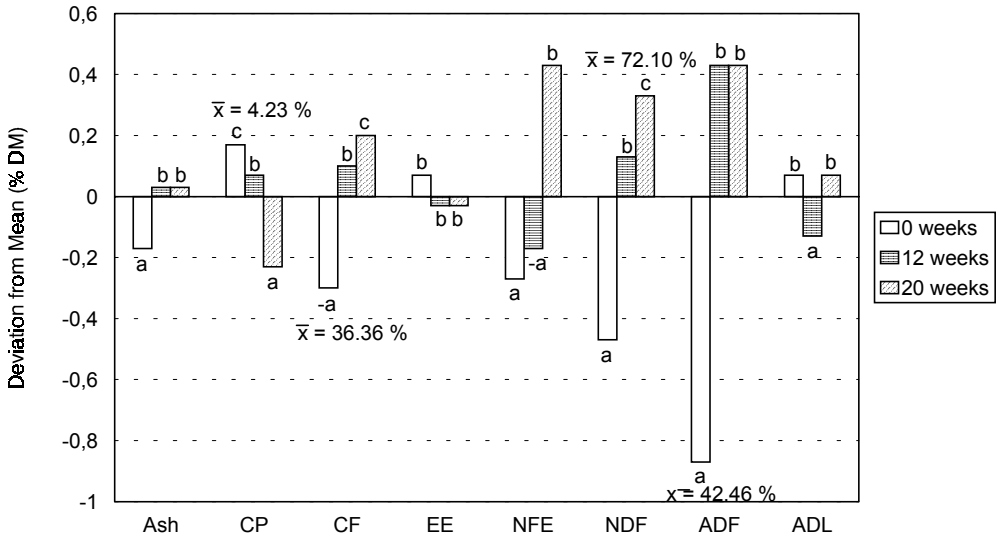
EFFECT	df	Ash	CP	CF	EE	NFE	NDF	ADF	ADL
Year	1	n s	**	***	***	***	**	n s	n s
Pasture Type	1	***	*	***	***	***	***	***	***
Regrowth	2	**	***	***	n s	***	***	n s	***
Plot within Pasture Type	4	n s	**	***	n s	*	n s	n s	n s
Week	2	***	***	***	n s	*	*	*	*
Year x Week	2	n s	***	***	n s	***	n s	*	*
Pasture Type x Week	2	n s	n s	n s	n s	n s	n s	n s	n s
Y x PT x week	3	n s	n s	n s	n s	n s	n s	**	**
R^2		0.56	0.92	0.92	0.55	0.92	0.90	0.67	0.63
CV (%)		6.25	2.80	2.80	12.75	2.08	2.04	4.47	7.47
Mean		8.27	4.23	36.67	0.92	49.97	72.10	42.46	5.94
s e m.		0.51	0.21	1.03	0.12	1.04	1.47	1.90	0.14

*** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; n s for not significant; DF Degrees of freedom.

Table 36 Influence of main and interaction effects on the chemical content of stored hays at Wakwa centre, % DM basis, (LSQ-Means ± SEM)

EFFECT	N	Ash	CP	CF	EE	NFE	NDF	ADF	ADL
Year 1	54	8.3	4.2 [a]	37.7 [a]	1.0 [b]	48.9 [a]	72.5 [b]	42.6	6.0
Year 2	54	8.2	4.3 [b]	35.7 [b]	0.8 [a]	51.0 [b]	71.7 [a]	42.4	5.9
s e m		0.07	0.03	0.14	0.02	0.14	0.20	0.26	0.06
Native	54	8.6 [b]	4.2 [a]	38.2 [b]	1.0[b]	48.0 [a]	75.0[b]	44.8[b]	6.3[b]
Brachiaria	54	7.8 [a]	4.3 [b]	35.1 [a]	0.9 [a]	52.0 [b]	69.2 [a]	40.5 [a]	5.6 [a]
s e m		0.07	0.03	0.14	0.02	0.14	0.20	0.26	0.06
Reg. 8 wk	36	7.9 [a]	4.5[c]	33.8 [a]	0.9 [a]	52.7[c]	68.6 [a]	41.9 [a]	5.6 [a]
Reg 10 wk	36	8.2 [a,b]	4.4 [b]	36.7 [b]	0.9 [a]	50.0 [b]	72.8 [b]	42.7 [b]	6.1 [b]
Reg. 12 wk	36	8.5 [b]	3.7 [a]	39.6 [c]	1.0 [b]	47.2 [a]	74.9 [c]	42.9 [c]	6.1 [c]
s e m		0.87	0.04	0.17	0.12	0.17	0.25	0.32	0.07
Week 0	36	8.1 [a]	4.4[c]	36.4 [a]	1.0	49.7 [a]	71.6 [a]	41.6 [a]	6.0 [b]
Week12	36	8.3 [b]	4.3 [b]	36.8 [b]	0.9	49.8 [a]	72.2 [b]	42.9 [b]	5.8 [a]
Week 20	36	8.4[c]	4.0 [a]	36.9[c]	0.9	50.4 [b]	72.4[b]	42.9[c]	6.0 [a]
s e m		0.09	0.04	0.17	0.12	0.17	0.25	0.32	0.07
Y 1 wk 0	18	8.2	4.3	37.3	1.0	49.2	72.2	41.8 [a]	6.0 [a,b]
Y1 wk 12	18	8.2	4.2	37.9	1.0	48.7	72.5	43.0 [b]	5.8 [a]
Y1 wk 20	18	8.4	4.0	37.8	1.0	48.9	72.7	42.9 [b]	6.2 [b]
Y2 wk 0	18	8.0	4.6	36.4	0.9	50.2	71.1	41.5 [a]	6.1 [b]
Y2 wk 12	18	8.3	4.4	35.6	0.8	50.9	72.0	42.8 [b]	5.8 [a]
Y2 wk 20	18	8.2	4.0	35.0	0.8	51.9	72.1	42.9 [b]	5.8 [a]
s e m		0.12	0.05	0.24	0.03	0.25	0.35	0.45	0.10
Y 1 PT 1 wk 0	9	8.6	4.3	39.0	1.1	47.0	75.3	44.0 [b]	6.1 [b]
Y 1 PT 1 wk 12	9	8.5	4.1	39.5	1.0	46.9	74.7	45.5 [c]	6.1 [b]
Y 1 PT 1 wk 20	9	8.6	3.9	39.2	1.0	47.4	75.1	44.8 [b,c]	6.7 [c]
Y 1 PT 2 wk 0	9	7.7	4.4	35.6	1.0	51.3	69.0	39.6 [a,b]	5.8 [a]
Y 1 PT 2 wk 12	9	8.0	4.2	36.3	0.9	50.6	70.2	40.6 [a,b]	5.5 [a]
Y 1 PT 2 wk 20	9	8.2	4.1	36.4	0.9	50.4	70.4	41.0 [b]	5.7 [a]
Y 2 PT 1 wk 0	9	8.7	4.3	38.0	1.0	47.9	74.5	43.9 [b]	6.8 [c]
Y 2 PT 1 wk 12	9	8.9	4.4	37.2	0.9	48.7	75.3	45.3 [b]	6.1 [b]
Y 2 PT 1 wk 20	9	8.6	4.1	36.5	0.8	50.1	74.7	45.2 [c]	6.1 [b]
Y 2 PT 2 wk 0		7.3	4.6	34.7	0.9	52.5	67.6	39.0 [a]	6.4 [b]
Y 2 PT 2 wk 12	9	7.7	4.4	34.1	0.8	53.0	68.6	40.3 [a,b]	5.6 [a]
Y 2 PT 2 wk 20	9	7.9	4.0	33.6	0.8	53.8	69.5	40.6 [a,b]	5.4 [a]
s e m		0.17	0.07	0.34	0.04	0.35	0.49	0.63	0.70
s e m		0.17	0.07	0.34	0.04	0.35	0.49	0.63	0.70

Different superscripts within the same columns indicate significant differences, a,b; b,c;cd = $p \leq 0.05$; a,c; b,d = $p \leq 0.01$; a,d = $p \leq 0.05$



Different letters denote significant differences, P ≤0.05

Fig. 25 Influence of Storage length on chemical composition of stored hay, Mean ± SD

4.4.2. Digestibility measurements on stored hay

4.4.2.1. Cellulase digestibility (ELOS) parameters

Year, pasture type and regrowth length had significant effects on ELOS, CDOM and EULOS contents of the hay (Table 37). Week of storage affected ELOS, $P < 0.05$, and the interaction effecs were of no influence on the variables. R^2 values were 92 and 93% indicating that the model used was adequate in explaining the variations in the variables shown. CV was also low, only 3.19 for EULOS and 6.59 for ELOS.

Table 37. Results of ANOVA for main and interaction effects cellulase on solubility parameters of stored hay

EFFECT	df	ELOS	CDOM	EULOS
Year	1	***	n s	***
Pasture Type	1	***	***	***
Regrowth	2	***	***	***
Plot within Pasture Type	4	*	n s	**
Week	2	*	n s	n s
Year x Week	2	n s	n s	n s
Pasture Type x Week	2	n s	n s	n s
Y x PT x wk	3	n s	n s	n s
R^2		0.93	0.92	0.92
CV (%)		6.59	6.34	3.19
Mean		30.75	33.97	610.32
s e m.		2.06	2.56	19.50

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; df = Degrees of freedom.

In Table 38 are the least squares means of the influence of the main and interaction effects on the cellulase parameters. With respect to week effect, there was only a small drop in the ELOS value from the 0 week to the 12 week of storage, ($P < 0.05$) EULOS followed an opposite trend.

Table 38. Effects of main and interaction effects on the chemical content of the stored hays, (LSQ Means ± SEM)

EFFECT	N	ELOS (% DM)	CDOM (% DM)	EULOS (g/kg DM)
Year 1	54	30.1^{a}	33.8^{a}	616.6^{b}
Year 2	54	31.4^{b}	34.2^{b}	604.1^{a}
s e m		0.28	0.29	2.65
NP	54	24.3^{a}	27.5^{a}	670.9^{b}
BR	54	37.3^{b}	40.4^{b}	549.8^{a}
s e m		0.28	0.29	1.59
Reg. 8 wk	36	32.0^{c}	35.3^{c}	601.5^{a}
Reg 10 wk	36	31.0^{b}	34.3^{b}	607.6^{b}
Reg. 12 wk	36	29.3^{a}	32.3^{a}	621.9^{c}
s e m		0.34	0.36	1.25
Week 0	36	31.5^{b}	34.4^{a}	605.4^{a}
Week12	36	30.8^{b}	33.6^{a}	609.5^{a}
Week 20	36	30.0^{a}	33.9^{a}	616.0^{a}
s e m		0.19	0.26	1.25

Different superscripts within the same columns indicate significant differences, a,b; b,c; cd = $p \leq 0.05$; a,c; b,d = $p \leq 0.01$; a,d = $p \leq 0.05$

4.4.2.2. Degradation rates of stored hay

Results of the ANOVA of the degradation hours are shown in Table 39. The model explained 0.57 to 0.91 of the variation in degradability rate. The CV ranged from only 6.0 (72 hour incubation rate) to 9.43 (0 hour).

Year had a mixed effect on the degradation hours being non significant on the 0 and 24 hours but significant for the other hours ($P < 0.05$). In contrast to this observation, the other main effects, pasture type, regrowth length and week of storage significantly affected incubation hour values.

Table 39. Results of analysis of variance (ANOVA) for effects of main and interaction effects on percentage degradability of nylon bag samples from the stored hay

EFFECT	df	0 h	12 h	24 h	48 h	72 h
Year	1	n s	*	n s	*	***
Pasture Type	1	***	n s	*	***	***
Regrowth	2	***	***	***	***	***
Plot within Pasture Type	4	**	n s	n s	***	***
Week	2	***	***	*	**	***
Year x Week	2	**	n s	n s	n s	n s
Pasture Type x Week	2	n s	n s	n s	n s	n s
Y x PT x wk	3	n s	**	n s	n s	n s
R^2		0.91	0.73	0.63	0.57	0.58
CV (%)		9.43	8.58	7.74	6.90	6.00
Mean	107	14.56	30.02	38.26	46.27	47.86
s e m		1.37	2.58	2.96	3.19	2.87

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant; DF. Degrees of freedom.

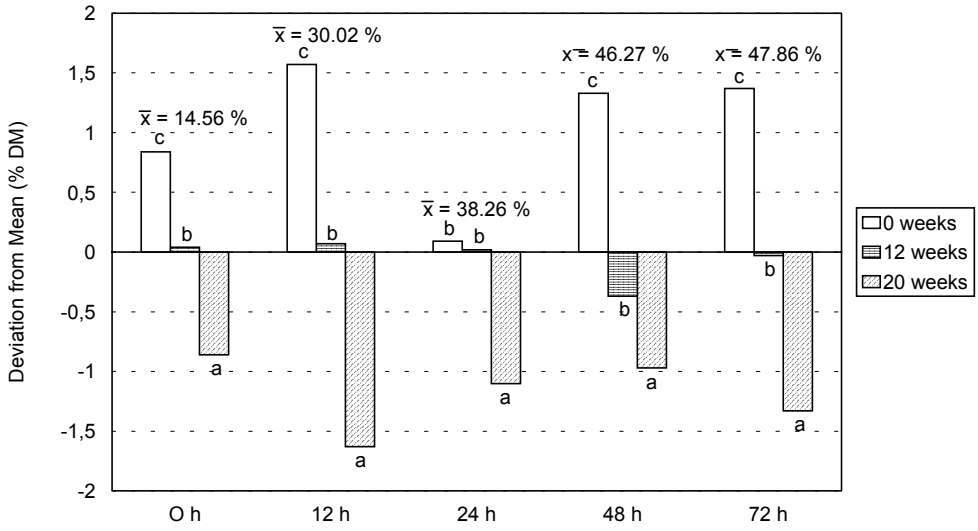
With respect to the week of storage (Fig. 26), it can be seen that it negatively ($P < 0.05$) influenced degradation rate, but there was a smaller rate of change between the 12th and 20th week of storage. The interaction effects had little influence on the response variables.

Table 40. Influence of main and Interaction effects on the percentage degradability of nylon bag samples from stored hays, DM basis; (LSQ-Means ± SEM)

EFFECT	N	0 h	12 h	24 h	48 h	72 h
Year 1	54	14.8[a]	30.6[b]	38.3[a]	47.0[b]	48.5[b]
Year 2	54	14.4[a]	29.4[a]	38.2[a]	45.6[a]	47.2[a]
S e m		0.19	0.35	0.40	0.43	0.39
PT 1	54	13.1[a]	30.1[b]	37.7[a]	44.9[a]	46.50[a]
PT 2	54	16.0[b]	29.9[a]	38.9[b]	47.7[b]	49.2[b]
s e m		0.13	0.35	0.40	0.43	0.39
Reg. 8 wk	36	18.4[c]	32.7[c]	41.9[c]	49.2[c]	50.4[b]
Reg 10 wk	36	15.4[b]	32.1[b]	39.0[b]	47.0[b]	48.4a
Reg. 12 wk	36	9.8[a]	25.3[a]	34.0[a]	42.6[a]	44.9[a]
s e m		0.23	0.43	0.49	0.53	0.48
Week 0	36	15.4[c]	31.6[c]	39.2[b]	47.6[c]	49.2[c]
Week12	36	14.6[b]	30.1[b]	38.5[b]	45.9[b]	47.8[b]
Week 20	36	13.7[a]	28.4[a]	37.2[a]	45.3[a]	46.5[a]
s e m		0.23	0.43	0.49	0.53	0.47
Y 1 wk 0	18	16.3[c]	32.9[b]	40.0[b]	48.4[c]	50.2[c]
Y1 wk 12	18	14.5[b]	30.3[b]	38.2[a]	46.8[b]	48.5[b]
Y1 wk 20	18	13.5[a]	28.6[a]	36.7[a]	45.8[a]	46.8[a]
Y2 wk 0	18	14.5[b]	30.3[b]	38.3[b]	46.9[b]	48.4[b]
Y2 wk 12	18	14.8[b]	29.9[a]	38.6[b]	44.9[a]	47.3[a,b]
Y2 wk 20	18	13.8[a]	28.1[a]	37.6[a]	44.8[a]	46.0[a]
s e m		0.32	0.61	0.69	0.75	0.25
PT 1 wk0	18	13.8[a]	31.0[b]	39.4[c]	46.4[b]	47.9[b]
PT 1 wk 12	18	13.2[a]	30.7[b]	37.7[b,c]	44.1[a]	46.5[a]
PT 1 wk 20	18	12.5[a]	28.7[a]	37.0[a]	44.1[a]	45.2[a]
PT 2 wk 0	18	17.0[b]	32.3[c]	40.0[c]	48.9[c]	50.7[c]
PT 2 wk 12	18	16.1[b]	29.6[a]	39.2[b]	47.7[b,c]	49.3[b,c]
PT 2 wk 20	18	14.9[b]	28.0[a]	37.4[a]	46.5[b]	47.7[b]
s e m		0.32	0.61	0.70	0.75	0.25
Y 1 PT 1 wk 0	9	14.5[a,b]	32.2[c]	39.1[b]	47.1[b]	48.8[b]
Y 1 PT 1 wk 12	9	13.1[a]	29.7[b]	37.4[b]	45.4[a]	47.1[a]
Y 1 PT 1 wk 20	9	12.2[a]	28.0[a]	36.2[a]	44.7[a]	45.6[a]
Y 1 PT 2 wk 0	9	18.0[c]	33.5[c]	41.0[c]	49.6[c]	51.6[c]
Y 1 PT 2 wk 12	9	15.9[b]	31.0[b]	39.0[b]	48.2[c]	49.9[c]
Y 1 PT 2 wk 20	9	14.9[a]	29.2[b]	37.2[a]	46.9[b]	48.0[b]
Y 2 PT 1 wk 0	9	13.1[a]	29.7[b]	37.7[b]	45.7[b]	46.9[b]
Y 2 PT 1 wk 12	9	13.3[a]	31.7[c]	37.9[b]	42.8[a]	46.0[a]
Y 2 PT 1 wk 20	9	12.8[a]	29.4[b]	37.7[b]	43.5[a]	44.8[a]
Y 2 PT 2 wk 0		15.9[b]	31.0[b]	39.0[b]	48.1[c]	49.8[a]
Y 2 PT 2 wk 12	9	16.2[b]	28.1[a]	39.4[b,c]	47.1[b]	48.6[b b]
Y 2 PT 2 wk 20	9	14.8[a,b]	26.7[a]	37.6[b]	46.1[a,b]	47.3[a,b]
s e m		0.46	0.86	0.99	1.06	0.35

PT 1 = Native pasture, PT 2 = *Brachiaria*; Reg. = regrowth, N = number of observations.

Different superscripts within the same columns indicate significant differences, a,b; b,c; c,d = $p \leq 0.05$; a,c; b,d = $p \leq 0.01$; a,d = $p \leq 0.05$



Different letters are significantly differerent, $P \leq 0.05$

Fig. 26 Effect of storage length on ruminal degradation rates of stored hays, Mean ± SD

4.4.2.3. Degradation constants

The ANOVA for the effects of the main and interaction effects on nylon bag rate constants is shown on Table 41. The model explained 0.40 – 0.92 of the variation. R^2 varied from 4.46 (on a + b) to 8.20 on a. This trend was similar to that obtained for the 72 and 0 hour degradation rates shown on Table 27. Year had mostly a significant effect on all parameters except c, the rate constant, $P < 0.05$. As for pasture type and regrowth length effects, they affected all the rate constants significantly, $P < 0.05$. The effect of week varied. (b) and (c) were not significantly affected by it ($P > 0.05$).

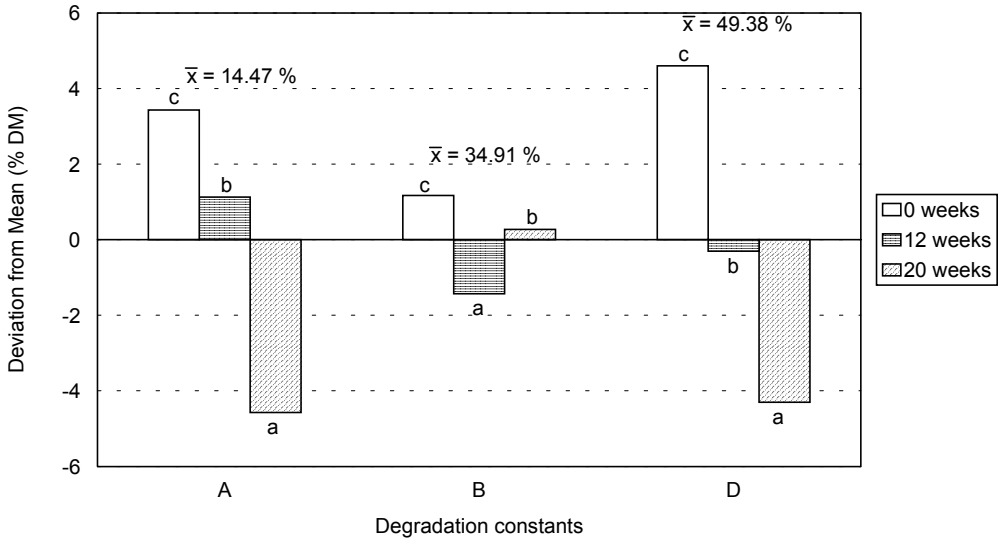
With regards to the interaction effects they had little influence, $P > 0.05$. Except for year x week interaction the others did not significantly affect the constants. One important observation here is that whenever a main or interaction effect significantly affected (a) but not (b), there is a high likelihood it also did not affect (d).

Table 41. Results of analysis of variance (ANOVA) for effects of main and interaction effects on the nylon bag curve characteristics from stored hay

EFFECT	df	a	b	c	d = a +b
Year	1	**	n s	*	**
Pasture Type	1	***	***	***	***
Regrowth	2	***	***	*	***
Plot within Pasture Type	4	***	n s	n s	n s
Week	2	***	n s	n s	***
Year x Week	2	***	n s	*	n s
Pasture Type x Week	2	n s	n s	n s	n s
Y x PT x wk	3	n s	*	n s	n s
R^2		0.92	0.40	0.47	0.83
CV (%)		8.20	6.17	6.12	4.46
Mean		14.47	34.91	0.051	49.38
s e m		1.19	2.60	0.01	2.20

*** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; n s for not significant; df = Degrees of freedom.

In Table 42 are the least squares means of the effect of the main and interaction effects on the degradation constants. There was a decrease in the value of the constants with increase in storage length (week). The interaction year x week is explained by a much higher zero storage value for (a) in 1995 comparared to 1996. In both years storage length decreased (a) but more so in 1995. At week 20 the a - value is similar for hay of both years.



Note: The vertically shown A, B and D on the x- axis denote the respective rate constants. Significance levels are shown in bold print as follows: ***c*** p ≤ 0.001; ***b*** p ≤ 0.01; ***a*** p ≤ 0.05; n s for not significant

Fig. 27 Effect of week of storage on mean deviations of degradation constants of stored hay, Mean ± SD

Table 42. Influence of main and interaction effects on the nylon bag curve characteristics from stored hay

EFFECT	N	a	b	c	d = (a +b)
Year1	54	14.8 [b]	35.2 [a]	0.049 [a]	50.0 [b]
Year 2	54	14.1 [a]	34.7 [a]	0.052 [b]	48.8 [a]
s e m		0.16	0.29	0.001	0.30
Native (PT 1)	54	13.2 [a]	34.1 [a]	0.056 [b]	48.0 [a]
Brachiaria (PT 2)	54	15.7 [b]	35.7 [b]	0.045 [a]	51.4 [b]
s e m		0.16	0.29	0.001	0.30
Reg. 8 wk	36	17.9 [c]	36.1 [c]	0.052 [b]	54.0 [c]
Reg 10 wk	36	15.6 [b]	33.5 [a]	0.052 [b]	49.1 [b]
Reg. 12 wk	36	9.9 [a]	35.2 [b]	0.047 [a]	45.1 [b]
s e m		0.20	0.36	0.001	0.37
Week 0	36	15.5 [c]	35.1 [c]	0.050 [a]	50.6 [c]
Week12	36	14.5 [b]	34.8 [a]	0.052 [b]	49.3 [b]
Week 20	36	13.4 [a]	34.9 [b]	0.050 [a]	48.3 [a]
s e m		0.20	0.36	0.001	0.37
Y 1 wk 0	18	16.4 [c]	34.8 [b]	0.051 [a]	51.3 [b]
Y1 wk 12	18	14.5 [b]	35.4 [b]	0.049 [a]	49.9 [b]
Y1 wk 20	18	13.5 [a]	35.2 [a,b]	0.047 [a]	48.7 [a]
Y2 wk 0	18	14.5 [b]	35.4 [b]	0.049 [a]	50.0 [b]
Y2 wk 12	18	14.5 [b]	34.1 [a]	0.056 [b]	48.6 [a]
Y2 wk 20	18	13.4 [b]	34.6 [a]	0.053 [b]	48.0 [a]
s e m		0.28	0.51	0.002	0.52
Y 1 PT 1 wk 0	9	14.7 [a,b]	35.0 [a]	0.055b	49.5 [b]
Y 1 PT 1 wk 12	9	13.2 [a]	35.0 [a]	0.052 [a,b]	48.2 [a,b]
Y 1 PT 1 wk 20	9	12.1 [a]	34.9 [a]	0.051 [a,b]	47.2 [a]
Y 1 PT 2 wk 0	9	18.1 [c]	35.8 [a,b]	0.047 [a]	53.0 [c]
Y 1 PT 2 wk 12	9	15.9 [b]	35.4 [a,b]	0.047 [a]	51.7 [b]
Y 1 PT 2 wk 20	9	14.8 [b]	35.0 [a]	0.044 [a]	50.2 [b]
Y 2 PT 1 wk 0	9	13.1 [a]	32.5 [a]	0.052 [a,b]	48.2 [b]
Y 2 PT 1 wk 12	9	13.4 [a]	32.5 [a]	0.066 [b]	45.9 [a]
Y 2 PT 1 wk 20	9	12.8 [a]	35.6 [a,b]	0.060 [b]	45.3 [a]
Y 2 PT 2 wk 0	9	15.9 [c]	35.7 [a,b]	0.045 [a]	51.6 [b]
Y 2 PT 2 wk 12	9	15.5 [c]	35.7 [b]	0.046 [a]	51.1 [b]
Y 2 PT 2 wk 20	9	14.0 [a]	36.7 [b]	0.046 [a]	50.7 [b]
s e m		0.40		0.003	0.74

PT 1 = Native pasture, PT 2 = *Brachiaria*; Reg. = regrowth, N = number of observations.
Different superscripts within the same columns indicate significant differences, a,b; b,c; cd = $p \leq 0.05$; a,c; b,d = $p \leq 0.01$; a,d = $p \leq 0.05$

The deviations from the means of the influence of storage length (week) on the degradation rate constants are shown in Figure 27. There was a significant difference between the 0 week and 12 week storage lengths ($P < 0.05$) in the washing loss estimate "a" as well as in "d" (a + b) the estimate of total degradation ($P < 0.05$) The b value was positively deviated for the 0 week storage, then negatively deviated on the 12 week storage length and once more

positively deviated on the 20th week storage value, P <0.05. For c, it was noticed that there was non significance between the 0 week and the 12 week storage but the negative deviation on the 20th week storage was significantly lower than the previous two values, P < 0.05. The washing loss estimate a and the the potential degradability rate "d" were highly positively correlated (r = 0.86, P <0.001).

4.5. Near infra red spectroscopic (NIRS) analysis

4.5.1. The calibration samples

A total of 155 samples were used for the NIRS analysis. A total of 97 were used for the calibration of the instrument (Table 43). The samples with extreme values were discarded making the chemical composition characteristics to have different sample numbers. The characteristic with the broadest range was ELOS (9.63 – 42.86%). Samples with very low CP values e.g. as low as 1.86, were also among those used. They did not actually belong to the experimental samples having been collected from vegetation growing outside the experimental plots area but being of similar composition to them. The standard error of calibration (SEC) ranged from 0.21 for CP to a high of 4.09 for ELOS. The best fit was for the CP and NDF values, with R^2 's of 0.99 and 0.96, respectively (P < 0.05). However, although the SEC of the CF was up to 0.86, which is high for NIRS calibrations, it gave a good R^2 value of 0.94, (P < 0.05). The worst calibration correlations were obtained on the ELOS and ADL values, respectively.

Table 43. Calibration statistics

Characteristic	N	Mean ± s e m	Range	SEC	SECV	R^2
CF	94	35.08 ± 3.48	27.84 - 43.06	0.86*	0.98	0.94*
CP	90	4.54 ± 1.71	1.86 - 10.33	0.21*	0.25	0.99**
ELOS	87	30.65 ± 8.70	9.63 - 42.86	4.09	4.38	0.78
NDF	96	71.25 ± 4.33	61.51 - 80.88	0.91*	1.08	0.96**
ADF	97	41.20 ± 4.16	32.79 - 53.38	1.37	11.62	0.91
ADL	96	5.68 ± 1.05	3.33 - 7.85	0.68	0.70	0.58

* = Good; ** = very good
SEC = Standard error of calibration; SECV = Standard error of cross validation

4.5.2. The validation samples

Table 44. NIRS Validation Data

Characteristic	N	Lab Value (Mean ± SD)	NIRS value (Mean ± SD)	SEP	Bias	SEP(C)	R^2
CF	58	36.20 ± 3.14	36.20 ± 3.14	1.72	-0.57	1.64	0.74
CP	34	4.39 ± 0.90	4.41 ± 1.08	0.51	-0.02*	0.52	0.77
ELOS	52	33.75 ± 6.19	33.51 ± 6.19	3.28^{+}	0.27*	3.32	0.72
NDF	51	71.75 ± 3.54	72.19 ± 3.39	1.22	-0.44	1.15	0.90
ADF	51	41.12 ± 3.07	42.62 ± 3.04	2.08	-1.50^{+}	1.46	0.78
ADL	51	5.47 ± 0.95	5.82 ± 0.50	0.87	-0.36*	0.80	0.29

SEP = Standard error of prediction; SEP(C) =SEP (corrected); + = Acceptable limit was surpassed

The validation data are shown in Table 44. The laboratory values obtained here are very similar to the average of the pasture and hay samples (see their respective means in earlier results sections). Also there is a striking similarity between the laboratory means and the derived NIRS means. The standard error of prediction, an indicator of the goodness of the estimation process, varied from 0.51 for CP to a high 3.28 for ELOS. This gave a low bias of prediction for CP The bias of the other variables differed but the highest value was not obtained on the ELOS but rather on the ADF. When all the biases are looked at, overall good biases are obtained for the CP, ELOS and ADL. The corresponding coefficients of determination (R^2) were highest on the NDF (0.90) followed by the ADF (0.78), the CP (0.77) and the least was on the ADL value.

4.6. Comparison of methods used in determining hay quality

4.6.1. Chemical composition values

Chemical composition of stored hay

Chemical composition values alone are hardly used for estimating the nutritive value of hay. From the literature it has been seen that combined with digestibility measures such as ELOS they can be used to provide reasonable estimates of the ME of hay, (Kirchgeßner, 1998) particularly the types of hay under the conditions of this study. Some correlation coefficients were also obtained with digestibility percentages of the hays.

Chemical composition of hay and NIRS estimates

With respect to the NIRS study, among all the chemical composition values, it was seen that the CP and NDF had the best standard error of calibration (SEC) explanation of variation (R^2

= 0.99 and 0.96, respectively, followed by the CF (R^2 = 0.94). The worst calibration curve of all of them was obtained for ADL (r = 0.76; R^2 = 0.76). The results of the validation curve also confirmed that the CP could be well estimated (SEP (corrected) = 0.52; R^2= 0.77). However, the next best estimate from the validations were ADL (SEPC = 0.80; R^2 = 0.29), NDF (SEPC = 1.15; R^2 = 0.90, CP (SEPC = 0.52; R^2 = 0.77) and lastly ADF (SEPC = 1.46; R^2 = 0.78). The afore-going therefore shows that it is necessary to still carry out all the above chemical composition.

4.6.2. Pepsin cellulase values

Correlations between ELOS and the chemical composition values of the hay.

Table 45 shows the correlation between ELOS and the most important dependent variables. It can be seen that there was a negative correlation between ELOS and fibrous components as CF, NDF and ADF as well as EULOS and ADL ($P < 0.05$). CP and CDOM were, as expected, positively correlated with ELOS, ($P < 0.001$).

Table 45 Correlations between ELOS and chemical composition values as well as CDOM and EULOS

ELOS	Dependent Variables						
	CDOM	EULOS	CP	CF	NDF	ADF	ADL
	0.97	1.0	0.38	-0.70	-0.81	-0.64	-0.61

ELOS and NIRS

The ELOS SEC value of the calibration curve (SEC = 4.09, R^2 = 0.78) and the SEPC value of the validation curve (SEPC = 3.32; R^2 = 0.72) were both above acceptable limits. ELOS does not appear in this study to have NIRS results that can be used in quality prediction of stored hay. Further ELOS determinations are needed in order to be incorporated in data bases for NIRS to be used for predicting ELOS well.

4.6.3. Nylon bag values of hay

Correlation coefficients between sdegradation characteristics and some chemical composition and ELOS values are listed in Table 46. CP was significantly correlated ($P < 0.001$) with most degradation characteristics except b and c. All the degradation rates were negatively correlated with indicators of fibre, (CF and NDF), ($P < 0.001$), but the rate constants with the

exception of a, were all positively correlated with CF and NDF, $P < 0.05$. The most important correlation between ELOS and the degradation rates was with the 12 hour rate and the least was with the 48 and 72 hours. ELOS was negatively correlated with both b and c, $P < 0.01$.

Table 46. correlation coefficients between degradability parameters and stored hay quality variables (0 - 20 weeks of storage)

Dependent Variables	CP	CF	NDF	ELOS
Deg 0h	0.74***	0.79***	-0.74***	0.59**
Deg. 12h	0.64***	-0.50***	-0.51***	0.93*
Deg. 24h	0.70***	-0.51***	-0.50***	0.30*
Deg. 48h	0.71***	-0.52***	-0.54***	0.25*
Deg. 72h	0.72***	-0.50***	-0.62	0.25*
A	0.76***	-0.75***	-0.77***	0.51**
B	- 0.10	0.24*	0.30*	-0.37**
C	-0.18	0.40***	0.35**	-0.25*
D	0.69***	-0.60***	0.59***	0.30**

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n s for not significant

4.6.4. Multivariable analysis of quality parameters of the hay after curing/baling

The analysis of the inter-relationships between the most important quality variables of hay at baling are shown in Table 47**.** Quality indicators with a strong correlation with degradation rates were the 24 hour and 48 hour CP yields ($P < 0.05$). The intercept (a) had the most significant relationship with these indicators and the inclusion of (b) to give the total degradability value did not lead to any improvements in its significance. Overall, the correlations of the indicators with the degradation parameters was poor. Similarities were found between CP and CPY and between 0 h and a as well as between d (a + b) and 72 hour degradation values. The CP, CF and NDF values all showed strong correlations with CP yield parameters. As expected ELOS correlated well with ELOS yield, ($r = 0.93$ ($P < 0.001$).

Table 47 Correlations of nylon bag degradation and other quality variables of the hay (at baling)

Ind. Variables	Dependent Variables												
	a	b	c	d = a + b)	0h	12h	24h	48h	72h	CP	CF	NDF	ELOS
DM Yield	-0.14a	-0.20a	-0.52c	-0.24a	-0.22a	-0.43c	-0.51c	-0.45c	-0.34b	-0.14a	-0.22ns	-0.13ns	0.20ns
24h DMY	0.44c	-0.14a	-0.04c	0.36c	0.46c	0.29a	0.56c	0.29a	0.37c	0.37b	-0.50c	-0.49c	0.50c
48h DMY	0.34b	-0.63c	-0.56c	0.32b	0.46c	0.29a	-0.10a	0.20a	0.29a	0.32b	-0.58c	-0.49	0.57c
CP Y	0.56c	-0.17a	-0.48c	0.46c	0.49c	0.30a	0.11a	0.34b	0.42b	0.78c	-0.80c	-0.66c	0.20
24h CPY	0.37c	-0.02a	0.06a	0.73c	0.84c	0.75c	0.80c	0.81c	0.81c	0.92c	-0.67c	-0.67c	0.56c
48h CPY	0.81c	0.63c	-0.63c	0.78c	0.81b	0.74c	0.59c	0.84c	0.84c	0.97c	-0.73c	-0.73c	0.63c
ELOS Yield	0.38c	-0.37c	-0.40c	0.18a	0.35b	0.03a	0.02a	0.05a	0.15a	0.37c	-0.65c	-0.65c	0.93c

[c], $p \leq 0.001$; [b] ,$p \leq 0.01$; [a] ,$p \leq 0.05$; n s for not significant; Ind. for Independent; Degrees of freedom

5. DISCUSSION

5.1. Grass and hay yield

5.1.1. Grass yield

The difference in yield between the *Brachiaria* and the native pastures was expected. Wherever *Brachiaria* has successfully been introduced, it has always had a higher yield than most of the native pastures (Barnes, 1996; Basuala and Le Joly, 1989, Ezenwa et al., 1996). These authors reported that the introduced crop was usually fertilised and weeded of invading species. This obviously gave it an advantage over the native pastures that were not given a similar treatment. It was therefore designed to truly compare the two sets of pastures in this experiment 1) to use old swards of *Brachiaria* and 2) not to apply any special inputs such as fertiliser or weeding. Although *Brachiaria* still had on average a higher yield, its regrowths did not always produce significantly more biomass ($P > 0.05$) than the corresponding native pasture treatments, a direct effect of a limited moisture availablilty during the regrowth period at the end of the rainy season.

The large difference in yield between the 8 and 12 week regrowth length was as expected due to the shorter growing period and the delayed deferment phase with less soil moisture and little rainfall. Added to the lower rainfall are the increasing temperatures that are common with the approach of the dry season and the lower humidity. These factors accelerate maturity and the establishment of more structural material particularly in the mid rib of the leaves and the stems. However, there is also the risk of a drop in nutrient yield occurring when pastures are deferred for too long before harvest, (Van Soest, 1982; Varviko et al, 1993). The pastures then reach the full flowering stage and have increased crude fibre and reduced digestibility.

The variable influence of year on pasture yield could be attributed to the differences in the weather pattern of both years of the experiment. Rainfall has been shown to influence pasture yield and quality (Van Soest, 1982; Rippstein, 1985; Pamo and Yonkeu 1986). Between August and the end of October (the regrowth period of the experiment), the rainfall totalled 841 mm in 1995 and 784.8 mm in 1996. These values are however within the norm (Pamo and Yonkeu, 1986), thus, variations in yield are expected.

5.1.2. Hay yield

Brachiaria hay had a higher DM yield than native hay. All treatment combinations underwent the same handling procedures. Hay yields as expected also increased with increase in regrowth length, like grass yield. The baling loss was however lower with increase in deferment length as seen by the increase in DM recovery in the baled products: (75.70% for the 8 week regrowths, 87.54% for the 10 week regrowths and 81.9% for the 12 week regrowths). The increase of DM recovery with increase in regrowth length noticed here is similar to findings by Zwaenepoel (1986) and is probably due to the fact that older regrowths being more mature contains a larger proportion of stems. The less mature regrowths contain more leaves and the latter are not easily picked up during harvest.

As expected, hay yield was higher in 1995 compared with 1996 ($P < 0.05$) a reflection of the grass yield.

5.2. Chemical composition of the pastures and hay

5.2.1. Chemical composition of the pastures

The rather low quality for both forages in this study compares with results obtained before on non fertilised native or introduced pastures on the plateau (Piot and Rippstein, 1975; Rippstein, 1985).

There was a negative relationship between CP and length of regrowth. It was however non significant. This has been reported before (Rotz and Muck, 1994; Kidane et al., 1997), who reported that the drop in CP was mostly due to the formation of structural carbohydrates at the expense of non structural entities such as soluble carbohydrates and protein. Crude fibre was positively correlated with regrowth length ($P < 0.05$) but negatively correlated with DM yield ($P > 0.05$). The negative relationship between CF and DM yield is controversial but several findings (Menke and Huss, 1980, Rotz and Muck, 1994; McDonald et al., 1995) confirm that it is possible particularly for the type of pasture species in the relatively old swards used in this study. Indeed, the average CF content of 33% found in this study is not atypical for tropical forages like those under the present experimental conditions.

There was a clear difference in the NDF content between the pastures, $P < 0.05$. In this study it has been shown that the cell walls (NDF) of the native pastures were very high indeed. For all regrowth lengths, they were significantly different ($P > 0.05$) from the values of the equivalent *Brachiaria* samples, $P < 0.05$, (see Fig. 8). High NDF values indicate a high cell

wall content in forages which lowers digestibility (Van Soest, 1994). The different growth patterns led to a significant interaction of the year x regrowth length on the NDF content. The highly positive deviations occurring in the 1996 12 week regrowths was no surprise, given the lower rainfall during the period of vegetation growth in 1996. In this experiment it was also found that NDF and DM yield were negatively correlated, r = - 0.04, ($P > 0.05$) a relation that was weak but also similar to findings elsewhere in the tropics (Crowder and Chheda, 1982; Artus, 1985).

The ash content of the pastures was lower than that reported by Rippstein from *Brachiaria* pastures in Wakwa in the 1980's (Rippstein, 1985). This is because ash content increases with the age of a sward and the values of the ash content of both pastures used for hay making are within the range of most tropical grass swards (McDonald et al.,1995; Ranjhan, 1982). It generally increased ($P > 0.05$) with regrowth length of pastures, as confirmed by the above authors.

The NFE content was higher in the *Brachiaria* than in the native pastures. NFE reduced with regrowth length for both types of pasture in this study. However there was no pasture type x regrowth interaction effect on this value. That means that the NFE contents of both pastures were similarly affected by the different regrowth lengths. It should be noted that the NFE represents a good amount of soluble carbohydrate, and some some non-protein nitrogen residues amongst others (Van Soest, 1982). The higher the NFE content, the better the nutritive value of the forage. The values obtained here, 51.7% – 52.3% for the 8 – 12 week deferments are comparable to values obtained for pastures on the plateau and in other tropical forages deferred for similar lengths of time (McDowell, 1983; Wakwa Annual Reports, 1985 – 1996)

The quality of the pastures was influenced only slightly by the year since the only characteristic among the chemical composition parameters that varied significantly between years was the crude fibre (CF) content ($P < 0.05$). This shows that, although there were yield differences from year 1 to year 2, other factors were more important in determining their quality. The types of pasture species present are important in determining how a sward may react to a set of external factors such as management, temperature, light and humidity.

5.2.2. Chemical composition of the hay at baling

The CP difference between grass at cutting and hay at baling was higher for the *Brachiaria* (5.9% to 4.5%), ($P < 0.05$) compared to the native pastures (4.8% to 4.4%). This difference might be related to different stem: leaves ratios in both forages. The *Brachiaria* pastures might have consisted of more leaves than the native pastures hayand during hay making leaves are easily shattered leading to reduced leaf proportion in hay. And as pointed out by Van Soest (1982), this loss of leaves results in a lowering of the hay CP content. *Brachiaria* has more leaves and thus is more prone to a relatively higher loss of leaves during curing and hay making than the less leafy native pastures. Indeed the very high CF (37.5%) and NDF content (73.7%) of the native pastures, make it to be virtually of straw quality (Van Soest, 1994).

Extended regrowth length caused the CP content to be reduced, as expected. This is similar to findings by Rippstein (1985) and McDonald et al, 1995).

5.3. Digestibility determinations of pastures and hay

5.3.1. Cellulase digestibility of pastures

The wide difference in ELOS percentage between the native pasture and the *Brachiaria* pasture of the present study seems to indicate that % ELOS is very low indeed for *Hyparrhenia – species* predominant pastures. The calculated cellulase digestibility (CDOM) of only 41.7 ± 2.46% for both pastures (34.6% and 48.8% for the native and *Brachiaria* pastures, respectively) is markedly lower than the CDOM found in temperate grasses which is expected to be above 60% (Houcourt, 1993; Andrieu and Demarquilly, 1987). The very low % ELOS and CDOM of these native pastures might be explained by the existence of an inherent genetic characteristic that makes the cell walls of most tropical native pastures to resist attack by cellulase enzyme even after the hemi-cellulose has been solubilised by the acid (hydrochloric acid)- pepsin pre treatment. The above authors also suggested sing longer acid (HCl) pre incubation times than the 24h standard time being used on tropical forage investigations, or varying the concentration of the acid using instead 0.1N HCl instead of 0.01N HCl and then hydrolysing the substrate with starch (30 minutes at 80° C) after pre-treatment with pepsin in order to improve the organic matter solubility of roughages. It may also be that the particular type of cellulase used in this study from the yeast *Tricoderma reesei* is not suited for the type of pastures investigated in this study.

With respect to the effect of the regrowth length on % ELOS and CDOM, it was observed that most change occurred between the 8th and 10th week of deferment ($P < 0.05$), with a non significant change between the 10th and 12th week ($P > 0.05$). The marked drop in digestibility already between the 8th and 10th week regrowths is an indication of the fast maturing process of the tropical pastures involved in this study, which have been shown to flower after 60 days of regrowth (Yonkeu, 1993). Besides, given the constant sunshine in the tropics irrespective of season, early setting of seed is a phenomenon which more than any other effect brings about the sudden drop in the quality of grass cut late (Ranjhan, 1982; Preston and Leng, 1987).

The regression of ELOS with DM yield was shown to be low (section 4.6.4, results) and thus little variation in the latter could be attributed to ELOS. On the other hand the cellulase digestibility parameters (CDOM and EULOS) were well correlated with CP. The close correlation among digestibility parameters led in the first place to the creation of quality estimation equations based on crude protein in the absence of digestibility studies (McDonald et al., 1995).

Unlike the case with the % CP, there was a lower % ELOS ($P >0.05$) in 1995 compared with 1996. CDOM followed the same trend, 41.5% and 41.8% ($P >0.05$), respectively. This may reflect the fact that in reality the closeness of the % CP of 1995 (5.4%) and of 1996 (5.3%) and the similarity in other entities such as NFE and ADL, could still make the 1996 samples to have about the same digestibility ($P >0.05$).

5.3.2. Cellulase solubility (ELOS) percentage of the hay (at baling)

The same pattern of a much higher percentage ELOS ($P <0.05$) that was observed on the *Brachiaria* pastures compared to the native pastures was also obtained on their respective hays, CDOM being 40.4% and 28.4% respectively ($P < 0.05$). The overall mean CDOM was 34.40 ± 2.42%. and was lower than the CDOM of the grasses as seen in 5.3.1. This finding confirms the fact that the digestibility of pastures are higher than that of their hays as a result of losses upon cutting and curing forages (Ranjhan, 1982; Ross and Muck, 1994; Van Soest, 1994; McDonald et al., 1995). The same authors reported a drop in organic matter digestibility with the length of regrowth of the pastures prior to hay harvest. This finding was confirmed in this study. The drop in the CDOM (9.6%) from the 8 week (35.4%) to the 12 week (34.0%) regrowths was similar to finding by Ross and Muck (1994) who reported an

influence of pasture regrowth length on hay quality but not so great if proper curing is carried out.

1995 had a higher % ELOS and CDOM (35.5%) than 1996 (33.4%), ($P < 0.05$). Both values were noticed to be the within the range expected for tropical hays (Van Soest, 1994).

5.3.3. Nylon bag (*in situ*) parameters of the pastures

The potential degradability (a + b) or (d) was 51.3% and 54.8% for the native and *Brachiaria* pastures respectively, $P < 0.001$). The wide difference of CDOM values obtained in the pastures was not obtained in the hay, meaning that the nylon bag method appeared not to suffer from shortcomings of the cellulase method that uses chemicals, since it takes place within the animal itself (Ørskov and McDonald, 1979). There was also a reduction of the 48 hour nylon bag degradability as well as (d) with increase in regrowth length of both pastures. However, when one compares the above degradabilities of these forages with the forages from the temperate zone, it is clear that the native and *Brachiaria* pastures of this study were of low nutritive value. The shape of their degradation curves nonetheless were typically exponential like that of grasses elsewhere (Hovell et al., 1986; Ørskov et al., 1988) Their degradation rates constants could therefore be derived according to the exponential model of Ørskov and McDonald, (1979). As found in studies on quality determination using the nylon bag method, a good correlation existed between the degradation rate and the rate constants. Using then the potential degradation rate (d) it was of interest to note the closeness between the asymptote (a + b) and the 72 hour degradation rate on the one hand and between the 0 hour value and the intercept on the y axis, (a) on the other. This confirms further that the nylon bag constants such as (d) and the washing loss could be used for predicting forage quality as shown in this study.

5.3.4. Nylon bag (*in situ*) parameters of the hays (at baling)

The wide differences between (d) and CDOM observed in the pastures was also observed in their respective hays, both with respect to the pasture types (*Brachiaria* having a higher d, $P < 0.05$) and the regrowth length (CDOM being highest on the 8 and lowest on the 12 week regrowths, $P < 0.01$). Kidane et al. (1997) obtained potential degradation (d), of 58% on native pasture hays, although pasture composition and management prior to hay making were different from that of the present study.

With regards to degradation rates, unlike the grass where the highest 48h degradation rate was obtained on the 8 week deferments, in the hay the 10 week regrowths had the highest value followed by the value of the 8 week regrowths. The lowest degradation rate was observed on the 12 week regrowths ($P < 0.05$). This finding is interesting and shows that the 48h value quoted as the most relevant value in estimating the rumen degradability rate and quality of roughages needs to be determined in nylon bag studies of fibrous –high NDF feeds (Lindberg, 1985; Nocek, 1988; Sebeck and Everts, 1999). Interaction effects had hardly any influence on nylon bag degradation rates and the rate constants meaning nearly all the variation observed was due to the main effects.

In this study, the rumen degradability rate continued past the 48 hour mark and this could be due to the high NDF contents particularly of the native pasture hay. High NDF content reduces passage through the rumen (Blümmel et al., 1994). The 12 hour or 24 hour value might not therefore be too appropriate for a feed quality evaluation study of these hays. Since the diet of the fistulated animal influences the nylon bag method, the animals used were fed to permit their maintenance only and no weight gain. At constant passage rate and turnover rate, it is known that microbial biomass is at a maximum at 24^{th} hours of ruminal incubation and this leads to an overestimation of the degradability of the feed being measured if the 24h value is used as reported by the above authors. Hours above the 48h incubation time, e.g. the 72 hour value, are considered to be too extreme because too much extraneous matter from the rumen tends to be attached to the bags biasing the true non digested matter weight. Taking all these into account, the fistulated steers of this study were fed a 50:50 (*Brachiaria* : native pasture combination) and just enough concentrate (100g of cottonseed cake/100kg liveweight) ration to ensure maintenance only and minimise excess microbial build up.

5.4. Nutrient yield of the pastures and the hays

5.4.1. Nutrient yield of the pastures

The digestible DM yields of the pastures based on the nylon bag degradability rates all showed the strong influence of the degradability rate on the total nutrient yield. The highest digestible DM yields were thus obtained twice on the 8 week regrowths (the 12h and 24h values) and once on the 10 week regrowth on the 48h degradation rate. Thus although the 12 week regrowths produced the highest , they did not necessarily produce the most digestible nutrient DM.

Taking the CP yield, the 48h DM yield and the ELOS yields into consideration, it was clearly shown in this study that the 10 week regrowths appear to have the best balance of yield and quality. This is important because as pointed out by Van Soest, (1986) intake is influenced by the morphology of the forage and too fibrous and coarse roughages, e.g. the 12 week regrowths, might not be well consumed by ruminants, leading to poor performance. Extra protein sources, such as urea, blood meal, and minerals, have to be fed to animals on such feeds and thereby increasing the cost of producing a unit response from them (McDowell, 1983; Iwuanyanwu et al., 1990.

5.4.2 Nutrient yield of the hay (at baling)

The yield of the *Brachiaria* hay was higher than that of the native pastures hay ($P < 0.05$). Both hays had enough dryness after the 4 days field curing to make a good hay for storage purposes. The baling DM content of 89% found in this study compares very favourably with values obtained on similar native forage species e.g. *Digitaria decumbens* and temperate grass swards (Lieu et al., 1986). This means the hay making process was a success and the curing length of 4 days selected is appropriate for drying hay in the plateau.

With respect to the nutrient yields of the hays (at baling) it is seen that the *Brachiaria* produced more CP yield and the 48h – based degradable CP yield compared to the native pastures($P <0.05$). Also, that for each of these two parameters the highest nutrient yields were obtained on the 8 week regrowths followed by the 10 weeks and lastly by the 12 week regrowths, ($P <0.05$). It was seen that the same trend was maintained for ELOS yield. The highest ELOS yield was obtained on the 8 week regrowths ($P <0.05$). The absence of significance in ELOS yield in yield between the 10 and the 12 week regrowths can be explained by the non significant yield differences ($P >0.05$) between the 10 week and the 12 week regrowths observed on their hays

The significant effect of year on pasture yield was carried over to the hay with 1995 having a significantly higher yield than 1996 ($P <0.05$). This reflected the higher vegetation yield of the first year and also meant that the hay making process was identical in both years. DM loss upon baling was 12.3 and 11.9 % for 1995 and 1996 respectively. These losses were mechanical, i.e. from the machine which cannot pick up all the vegetation, and also due to the inevitable curing losses. They were even lower than the tolerated harvest losses limit of 15 - 18% prescribed for temperate pastures hay (Rees, 1982; Rotz and Abrams, 1988).

5.5. Quality of hay during storage

5.5.1. Chemical composition of the hays during storage

The species effect was once again very obvious in the quality of the hay with the *Brachiaria* being less fibrous and containing more crude protein and NFE than the native pastures hay. This finding agrees with the results of similar studies carried out here (CRZ Wakwa Annual Reports, 1985 - 1996). The effect of progressing maturity on the quality of the hays manifested itself through a reduction in CP and NFE contents with regrowth length of the pastures from which the hay was derived, and an increase in cell walls and ADL contents, $P < 0.05$. This is in agreement with findings by several authors (Rippstein and Piot, 1975; Sileshi et al. 1995; Marin et al., 1997).

There was a steady increase in cell walls, ash, NFE, and ADF contents from the onset of storage (week 0) to the 20^{th} week. CP and ether extract contents on the other hand decreased. These findings corroborate those of Mendez Cruz et al. (1988) and Buckmaster and Heinrichs (1993) using tropical grasses, and alfalfa, a temperate legume, respectively. The influence of the year x week interaction was on the CP, CF, NFE, NDF and ADL contents only and once more reflected the variation of these parameters as a result of the difference in the climate during the two storage periods.

5.5.2. Cellulase solubility (ELOS) content of hay during storage

The small drop in percent ELOS ($P > 0.05$) between week 0 and 12 of storage but a more important drop between the 12^{th} and the 20^{th} week could be explained by the weakness of the regression between ELOS and storage length ($r = -0.07$). ELOS was strongly correlated with CDOM, $r = 0.97$, and that means CDOM values and trends could also be used in quality estimation of the hays of the Adamawa plateau. The effect of long storage length on the digestibility of hay is known. Digestibility eventually drops over time as shown in this study and as already demonstrated in temperate hays (Davies and Warboys, 1978; Buckmaster and Heinrichs, 1993).

5.5.3 Nylon bag degradation parameters of the hays during storage

The rate of decrease of potential degradation, "d" between week 0 and week 12 of 9.97% and only 2.07% between week 12 and 20 of storage is low and demonstrates a slow down in the rate of quality decline typical of well preserved hays. However, as observed by Van Soest

(1994) and Playne (1978), these degradation rates are still low compared to those of temperate species. Van Soest (1994) points out that only slight improvements in overall digestibility are to be expected from tropical swards if a careful selection of the cultivars with good inherent digestibility is not done, even in good sward management conditions.

5.6. Comparison of methods used to predict hay quality

Chemical composition

The high coefficients of determination (R^2) for the calibration curve obtained on CP, NDF and CF in descending order, confirm findings that chemical entities tend to have good potential for NIRS calibrations. The standard errors of calibration and prediction of CP and NDF obtained in this study are similar to those obtained by Brown et al. (1994) using 4 tropical grasses with similar chemical compositions to the forages of this study. Tukue (1991) working with tropical grasses and legumes grown in Ethiopia at different locations and altitudes also obtained similarly good correlations between the laboratory and NIRS estimates.

Pepsin-cellulase (ELOS) percentage

The weak correlations of ELOS with chemical entities of this study and its poor estimation using NIRS seem to indicate that ELOS alone cannot be used in prediction equations on determining hay quality for tropical grass species. This finding may have to be validated only after *in vivo* studies are carried out, because some authors (Lecomte et al. 1992) claim ELOS has the best correlations with the latter and high possibility for determining the ME of temperate fodders.

Nylon bag

From the degradation curves, their deviations from the means and their inter-relationships with yield and other entities (Tables 46 and 47, results) it is seen that the nylon bag method seems to be best suited for predicting the feed quality of tropical pastures as well as hay. Furthermore, it was noticed from this study that there was a similarity between the degradation rates and the calculated degradation rate constants. This has been observed in nylon bag studies by other authors before (Ørskov and McDonald, 1979; Hovell et al., 1986; Carro et al., 1991; Blümmel and Ørskov, 1993) and lends credence to the use of the exponential model to describe the degradability of the hays of the tropical hays as used in the present study. Among all degradation constants, it was "a", the intercept on the y axis, i.e. the

derived washing loss, that was most significantly influenced by all the main effects ($P < 0.05$. From this study, it was shown that the intercept value "a" is very closely related to the actual value or washing loss ($r = 0.86$). Therefore the chosen incubation hours (0, 12, 24, 48 and 72) were appropriate for the material under test.

5.7. NIRS

It had been shown in earlier studies that NIRS instruments can be calibrated to measure cell walls (NDF) accurately (Van Soest (1982). The present study proves this. On the contrary, the SEC and R^2 were poor for ELOS which is an estimate of digestibility. Such parameters which describe vague chemical entities, are poorly estimated via the use of NIRS. They do not represent entities that can absorb the NIR energy and are thus determined poorly.

The good standard error of calibration (SEC) for the CP, CF and NDF fractions were similar to findings that NIRS predicts accurately entities such as these that represent the chemical composition (Shenk and Westerhaus, 1994). These same entities produced the best R^2 values after cross validation,.

With respect to the actual prediction of the values of the measured variables, i.e. the validation, it was striking to note the closeness between laboratory and NIRS values. The entities best predicted, were the CP, NDF, CF, ADF and ADL in descending order. Their respective R^2 were 0.99, 0.96, 0.98, 0.91, 0.78 and 0.58, (Table 44). A similar finding was published for tropical C3 and C4 forages in Ethiopia by Tukue (1991). He stated that there was also no difference in the degree of accuracy for the method between temperate and tropical grasses nor between legumes and grasses. The most important factor leading to the accuracy of the estimation lies more with the calibration and the representativeness of the samples used to calibrate it (Shenk and Westerhaus, 1994, Robowsky and Rücker, 1996; Tillman; 1996; Amari and Abe, 1997). Tukue (1991) found R^2's of 0.96, 0.91, 0.93 and 0.80 for CP, ADF, NDF and *in vitro* dry matter digestibility and also confirmed that NIRS results could be used in a model instead of the chemical composition values, a view also held by authors such as Borcadi et al., (1997).

In summary, it can be said that the NIRS was successfully used to predict the quality of the roughages of the present study. More work has to be done on other pasture types in the tropics and sub tropics before NIRS can be considered a standard such as the proximate analysis presently is.

6. CONCLUSION AND RECOMMENDATIONS

This study has shown the methodological approach for successful hay making in the Adamawa plateau. The climatic environment and vegetation communities that exist at the Wakwa research centre are typical of the Adamawa plateau. The introduction of *Brachiaria* on- station some 30 years ago and its success was widely acclaimed by settled livestock farmers who have embraced its cultivation in earnest since the introduction of the first pilot fodder bank on-farm in the late 1980s. This study of the hays produced under all relevant regrowth and storage conditions has given an up to date information on the yield and quality not only of *Brachiaria* but also of the existing native pastures. The highlights of the findings of this study are shown hereunder.

1. Grass and Hay Yield

The dry matter yields (DMY) of the *Brachiaria* and native pastures were 2108.3 kg DM/ha and 1926.3 kg DM/ha, ($P < 0.05$) at cutting, and 1800.6 kg DM/ha and 1746.1 kg DM/ha ($P < 0.05$), at baling after an 8 - 12 week regrowth period. Between cutting and baling DM yield declined from 2017.3 ± 87.78 kg DM/ha to 1773.5 ± 81.33kg DM/ha, ($P < 0.05$). Dry matter content (%) of the hay after curing and at week 0 of storage was 86.7 and 88.9%, respectively ($P > 0.05$). The 12 week deferred plots had the highest yields ($P < 0.05$) followed by the 10 week and lastly, by the 8 week plots. *Brachiaria* pasture always had higher yieldsthan native pastures ($P < 0.05$). From this study, it is concluded that as far as bulk is concerned, the 12 week regrowths gave the highest DM yield.

2. Quality of Hay and Grass

Quality parameters followed an opposite trend to the yield. Among all the main affects, pasture type (native or *Brachiaria*), regrowth length as well as duration of storage accounted for most of the variation in the quality variables. Year effects were negligible. There was a clear pasture type effect both among the grass and hay samples. Crude protein, NDF, CDOM and potential degradability for grass samples at cutting were: 4.8 and 5.9%; 72.0 and 64.4%; 34.6 and 48.8% and 51.4 and 54.8% for native and *Brachiaria* pastures, respectively. Quality reduced from the grass to the hay stage. Lower values were obtained for these parameters after baling the hay crop.

The following conclusions on grass and hay quality can be drawn:

- The *Brachiaria* had a higher % CP, cellulase digestibility of the organic matter (CDOM), ruminal degradation rate, and a lower cell wall content than the native pastures.
- The 8 week regrowths had the best overall quality both with respect to the grass and hay samples.
- There was a better forage quality in the first year of the experiment compared to the second year, a combined effect of weather conditions and non replenishment of soil nutrients (absence of rest periods and/or fertilisation).
- There is a need for another variation of the method used for the determination of cellulase solubility using the same set of pastures to validate the results obtained in this study.

3. Nutrient Yields of Grass and Hay

ELOS yield, the digestible DM and CP yield based on the 48 hour nylon bag degradability value were higher for 1995 than for 1996. They were also highest on the 10 week deferred plots for each pasture type. This reflected the intermediate DM yield and relatively higher CP and ELOS values of the 10 week deferments. *Brachiaria* samples had the higher values ($P < 0.05$) for each of the nutrient yields compared to the native pastures. It was seen that the best balance of DM yield and quality i.e. nutrient yield lay with the 10 week regrowths.

It is concluded that the 10 week regrowths had the highest nutrient yields.

Nutrient yield is reduced in succeeding years when hay is produced on the same piece of land due to the effect of cutting on the sward or species combination and on nutrient availability if not fertilized. It is therefore recommended that fertilisation of plots destined for hay making be done yearly or the plots shifted between grazing and hay making every other year in order to maintain yield and quality.

4. Quality of hay during storage

There was a clear drop in quality during storage, ($P < 0.05$). The most important drop in quality occurred only as from the 12^{th} week of storage. The wide variation between CDOM and nylon bag degradability rate that was obtained on the grass and hay crops was also obtained during all the weeks of storage of the hay. Year had no significant effect on storage length, CP, nylon bag or cellulase digestibility (CDOM).

That the native pasture- and the *Brachiaria* - hay were similarly affected by storage. In door stored hay should not be much beyond 12 weeks, since thereafter major nutrient losses do occur.

5. Comparison of methods for determining hay quality

With respect to the different quality determination methods, it was seen that there was a good correlation between the chemical composition values and the digestibility estimates (cellulase and nylon bag degradation methods). There was also a good correlation among the latter two methods. In this study, the importance of paying careful attention to the way the nylon bags are washed particularly in obtaining the washing loss value was seen.

NIRS values accurately predicted the most important chemical entities (CP, CF, NDF, ADF and ADL), but poorly estimated indicators of digestibility such as cellulase solubility percent (ELOS).

It is recommended that *in vivo* and *in vitro* determinations be carried out on more tropical pasture material and hays of different composition in order to enable the establishment of regression equations for feed quality prediction in this environment. The results of the two digestibility methods used in this experiment namely the pepsin - cellulase and nylon bag methods, as well as the NIRS method, were deemed satisfactory to predict the forage quality of the forages as used in this study. They could thus be used for quality determinations of the more pastures and different types of hay that exist in the Adamawa plateau of Cameroon.

7. SUMMARY

Key words: Hay, grass, *Hyparrhenia spp*., *Brachiaria ruziziensis*, Germain and Evrard, Poaceae, yield, chemical composition, quality, nylon bag degradability, pepsin-cellulase, digestibility, NIRS, regrowth, storage.

This experiment was carried out between 1995 and 1997 at the Wakwa Institute of Agricultural Research for Development (IRAD) centre. It is located in the sub-humid zone of Cameroon and in the province that produces the most beef and dairy products in the country. The vegetation, soils and climate of Wakwa are typical of this zone and research conducted here has much relevance to other cattle producing regions of the tropics with a similar agro-ecology.

The main objective of this study was to test methods for hay making technology under low input conditions. Its specific objectives were: 1) to evaluate the yield and quality of native (*Hyparrhenia spp*.-predominant) and introduced (*Brachiaria ruziziensis* Germain and Evrard) pastures and their hay subjected to different lengths of grazing deferment, 2) to evaluate the effect of storage on the quality of the hays from these pastures, and 3) the applicability of various quality determination methods to the evaluation of the hays produced in the Adamawa plateau of Cameroon.

Both sets of pasture were grazed at a fixed stocking rate of 375 kg/ha from May to August in a set of 3 paddocks located within each set of pastures. After the removal of the young bulls, a block of six 40 x 40m sub plots was mapped out in each of the 6 paddocks. The 6 sub plots contained two replications of 3 regrowth lengths (12, 10 and 8 weeks) during which the vegetation had to bulk up before being harvested for hay. A mower was used to cut all the vegetation at 10 cm from the ground (zero timing) at each deferment period. The hay crop was field dried for 4 days, made into large round bales within each sub plot and then taken to an indoor storage location. Since the regrowth was not sufficient in some subplots the hay from the two replications belonging to the same treatment was baled together. This gave a total of 18 sets of bales/ year or 36 sets for the two experimental years. The bales were stored for a period of 20 weeks.

The yield measurements on the pastures was done with the quadrat method. The bales were only weighed at entry into storage. The hay from each bale was sampled after an initial 10 day equilibration period in week 0 of storage in November, in week 12 of storage in February and in week 20 of storage in April. There was a total of 108 pooled samples collected from the 3 hay sampling periods (54 per year).

The number of samples available for chemical and statistical analysis was as follows: for the deferment trial, 36 per year and 72 for the two years of the experiment; 36 samples for hay yield and 108 samples (i.e. 54/year) for the storage length trial. Nutrient yields of grass and the hay were derived from DM yield and 48h degradation rates.

Data were entered using Dbase IV and analysed using the general linear models (GLM) procedure of SAS. Correlations between the different variables was also done. Nylon bag data were analysed using the non linear regression feature of SAS.

Dry matter (DM) was determined at 105° C after 24 hours and expressed in kg/ha. Samples for chemical analysis and digestibility studies were dried at 65° C for 48 hours. Quality measures used were proximate and detergent analyses, nylon bag and pepsin cellulase method. Near infra red spectroscopic (NIRS) analysis was done on both pasture and hay samples and values obtained compared with laboratory values.

Dry matter yield obtained was 2017.3 ± 87.78 kg DM/ha. It is lower than normal yield of biomass of these pastures on the plateau since only the regrowth biomass was measured. There were significant differences between pasture types, regrowths and the interaction pasture type x regrowth length, and between years ($P< 0.05$). The *Brachiaria* pasture produced more dry matter (2108.3 kg/ha) than the native pastures, 1926.3 kg/ha, ($P< 0.05$). 12 week deferments had the highest yield, (2232.4 kg) and 8 weeks the lowest, (1798.2 kg/ha). The value of the 10 weeks was intermediate but non significantly different ($P> 0.05$) from the 12 week deferred plots. There was no significant interaction effect of year x pasture type or year x regrowth length on the dependent variables. Only the pasture type x regrowth length interaction had a significant influence on the yield parameter, ($P< 0.05$).

All fixed effects influenced DM yield of the hay. The mean DM yield of hay (1773.5 ± 18.33 kg DM/ha) was markedly lower than the DM yield at cutting. *Brachiaria* hay also produced ($P <0.05$) significantly more DM (1800.6 kg/ha) compared to the native pastures hay (1746.1 kg/ha). Like the grass yield, yield also increased with the increase in regrowth length of pastures ($P <0.05$). Percentage recovery of DM of the hay after curing (at baling) was 86.7 %. There was no significant change in % DM between year, pasture type or regrowth length meaning that both forages were sufficiently dry after 4 days of field curing.

Grass crude protein (CP) content was non significantly ($P >0.05$) affected by year as well as the interaction pasture type x regrowth length. There was a significant difference between the CP contents of the *Brachiaria* and native pastures (5.9 versus 4.3%) as well as between the 8 week (5.9%) and the 12 week deferments (4.8%). CP in *Brachiaria* hay was 4.4%, in the native pastures hay, 4.3%, ($P <0.05$). Grass and hay CP values were rather low and reflected the fact that non fertilised plots were used to mimic the situation that exists on the plateau. They were less than the minimum of 6.45% CP a forage should have in order to serve as a basal diet. Crude fibre (CF) content was high, 35.8% and 30.2% for the native pastures and *Brachiaria* grass samples, and 37.5% and 34.1% for their respective hays ($P >0.05$). Crude

fibre, NDF and ADF contents increased with regrowth length both for the grass and the hay ($P < 0.05$).

Forty eight (48) hour nylon bag percent degradation rate was 50.3% and 53.5% for the native pastures and the *Brachiaria* grass samples ($P<0.05$) and 46.6% and 54.8% ($P < 0.05\%$), respectively for hay samples. Main effects had a significant influence on this parameter for both the grass and the hays but the interaction effects (except pasture type x deferment length) had no influence on this value. In both grass and hay the 8 week regrowths were significantly more degraded than the 10 and the 12 week regrowths ($P< 0.05$). There was a big difference in the 48h nylon bag degradability rate between the 8 week regrowths (54.5%) and the 12 week regrowths (38.8%) in the grass, as well as a noticeable difference $P< 0.05\%$ between the *Brachiaria* (52.1%) and the native pastures (49.8%). The potential degradability rate (a +b) followed a similar pattern to the 48h degradation rate and was similarly influenced by the fixed variables. These same patterns were obtained for the hays.

Enzyme soluble organic matter (ELOS) percentage followed a similar trend as the nylon bag values. The difference between the value for *Brachiaria* % ELOS (45.2%) and for native pastures (31.7%) was very large (13.5%). The difference was also large in the hay. These ELOS values are still below the expected digestibility values, particularly when compared to the high nylon bag degradation rates obtained in this study. It is necessary to repeat ELOS determination on another set of pastures to confirm the existence of such the low ELOS values obtained in this study. It may also be that modifications of the ELOS method currently in use elsewhere may yield higher ELOS values if tried.

Nutrient yields of the grass and the hay were significantly affected by all main effects and non significantly influenced by the interactions. The 48h- degradation rate- based digestible DM yield, CP yield and 48h- degradation rate- based digestible ELOS yields were for the grass samples as follows: 955.0 kg/ha, 91.4kg/ha and 788.3 kg/ha for the native pastures; and 1092.8 kg/ha, 122.5 kg/ha and 950.9 kg/ha for the *Brachiaria*. Nutrient yield varied with deferment length but in general it was seen that the 10 week regrowths produced the highest nutrient yield. For both the grass and the hay, the 10 week *Brachiaria* regrowths attained the best yields.

Quality of hay dropped ($P < 0.05$) during storage particularly after the 12th week of storage. CP, CF, ELOS and potential degradability rate (a + b) was 4.4%, 36.4%, 31.5% and 50.6% for week 0; 4.3%, 36.8%, 30.8% and 49.3% for week 12 and 4.0%, 36.9%, 30.0% and 48.3% for week 20 of storage. In both grass and hay, quality declined with regrowth length. *Brachiaria* hay was less fibrous and more digestible than the native pastures ($P < 0.05$).

NIRS accurately predicted CP, NDF, CF and ADF ($R^2 > 0.90$), less accurately ADL, but poorly predicted ELOS. The existing data base for ELOS calibration was small as well; this also contributed to poor standard errors of validation.

Multivariate regression analysis of the interrelationship between the quality variables of the hays showed that the intercept, a, of the degradation curve and the potential degradation rate (a +b) had the most significant relationship with most quality indicators. The correlations between ELOS and the chemical composition values were 0.38, -0.70, -0.81 et –0.64, for CP, CF, NDF and ADF, respectively. DM yield was correlated poorly with a, ($r = -0.14$, $P > 0.05$), with a + b, ($r = -0.24$, $P < 0.05$), with CP ($r = -0.22$, $P < 0.05$) and with ELOS ($r = 0.20$, $P < 0.05$). CP had good correlations with degradation rate at 0, 12, 24, 48 and 72h ($r > 0.80$, $P < 0.05$).

This study has shown that there is a higher production of forage with increase in the regrowth length of the pastures, with *Brachiari,* pasture, even when non fertilised, producing more herbage for hay making purposes than native pastures. The 10 week regrowths had the highest nutrient yield. There is a reduction in the quality of indoors stored hay, particularly between week 12 and 20 of storage.

It was also shown that the nylon bag method more accurately predicted the digestibility of both grass and hay samples. The pepsin-cellulase method on the other hand needs some modification particularly with respect to the duration of the acid pre-incubation and the source of the cellulase. More formations on tropical pastures are needed to increase the calibration spectrum of NIRS to make it to be used with more accuracy in forage quality determination on tropical roughages.

8. ZUSAMMENFASSUNG

Schlagworte: Heu, Gras, Hyparrhenia spp., *Brachiaria ruziziensis*, Germain und Evrard, Poaceae, Ertrag, chemische Zusammensetzung, Qualität, *in situ*-Abbaubarkeit, Pepsin-Zellulase, Verdaulichkeit, NIRS, Nachwachs, Lagerung

Diese Arbeit wurde zwischen 1995 und 1997 am Wakwa Institute of Agricultural Research for Development (IRAD) durchgeführt. Das Institut befindet sich in der sub-humiden Zone Kameruns in jener Provinz in der die meisten Rinder und Milchprodukte produziert werden. Die Vegetation, der Boden und das Klima sind typisch für diese Zone, so daß die hier durchgeführte Forschung auch für andere Rinder produzierende Regionen der Tropen mit ähnlicher Agroökologie relevant ist.

Das Hauptziel dieser Arbeit bestand im Testen von Methoden zur Heuproduktion unter ungünstigen Bedingungen. Die spezifischen Ziele waren: 1) den Ertrag und die Qualität des natürlich vorkommenden Grases (*Hyparrhenia spp*. dominierend) und des eingeführten Grases (*Brachiaria ruziziensis* Germain und Evrard) sowie ihre Beziehung zu unterschiedlichen Längen von Weidenachwuchsperiode (WNP) am Ende der Regen zeit auf den Ertrag und Qualität von Heu zu bewerten, 2) den Einfluß der Lagerungsdauer auf die Heuqualität zu bewerten und 3) die Anwendbarkeit verschiedener qualitätsbestimmender Methoden zur Bewertung von Weide- und Heuqualität zu beurteilen.

Beide Weidetypen wurden auf 3 innerhalb der Weidetypen angelegten Koppeln mit der gleichen Besatzdichte von 375 kg/ha von Mai bis August begrast. Nach der Entfernung der Jungbullen von den Koppeln, wurden 6 Flächen von 40 x 40 m auf jeder Koppel abgesteckt. Diese Flächen beinhalteten zwei Wiederholungen dreier WNP (12, 10 and 8 Wochen), von deren Weidenachwuchs Heu geerntet wurde. Bei Beginn der WNP wurde die Vegetation in einer Höhe von 10 cm (zero timing) gemäht. Der Weideschnitt aller Versuchsflächen erfolgte zur gleichen Zeit . Nach 4 Tagen des Feldtrocknung erfolgte die Heuwerbung mittels Rundballen und eine Lagerung in einem überdachten Lagerraum. Da der Nachwuchsertrag einiger Flächen nicht ausreichend war, wurde das Heu der zwei Wiederholungen einer WNP zusammen geborgen. Das ergab insgesamt 18 Ballensätze/Jahr bzw. 36 Sätze für 2 Versuchsjahre. Die Ballen wurden über 20 Wochen gelagert.

Die Messungen des Weidenertrages vor dem Schnitt wurden mittels der Quadratmethode durchgeführt. Die Ballen wurden nur zu Beginn der Lagerung gewogen. Nach einer 10tätigen

Lagerung wurden von jedem Ballen in den Wochen 0 (November), 12 (Februar) und 20 (April) Heuproben genommen.

Die Anzahl der Proben, die zur chemischen und statistischen Analyse zur Verfügung stand, ergaben sich aus 36 Proben/Jahr für den Weidenachwuchsperiode-Versuch, 36 Proben des Heuertrages und 54 Proben/Jahr für den Lagerungsdauerversuch. Die Nährstofferträge für Gras und Heu wurden vom Trockenmasseertrag und Abbaubarkeitsraten über 48h abgeleitet.

Die Daten wurden mit Hilfe von Dbase IV gespeichert und mit dem allgemein-linearen Modell (GLM) des Softwarepaketes SAS statistisch ausgewertet. Korrelationen zwischen den verschiedenen Variablen wurden ebenfalls berechnet. Die erhaltenen Daten aus den Nylonbeutelversuchen wurden mittels des linearen Regressionsmodels von SAS analysiert.

Die Trockensubstanz (TS) wurde über 24 Stunden bei 105°C bestimmt und in kg/ha angegeben. Proben zur chemischen Analyse sowie den Verdauungsversuchen wurden bei 65°C über 48 Stunden getrocknet. Als Qualitätsparameter wurden die Weender- und Detergenzanalyse sowie die Nylonbeutel- und Pepsin-Zellulasemethode benutzt. Nahe-Infrarotspektroskopie (NIRS) wurde an Weide- und Heuproben durchgeführt und mit erhaltenen Laborwerten verglichen.

Die erhaltenen Trockensubstanzerträge betrugen 2017.3 ± 87.78 kg TS/ha. Das ist geringer im Vergleich zur normalen Biomasse dieser Weiden auf dem Adamawa Plateau, zumal sie spezifischen WNP ausgesetzt waren. Des weiteren wurden signifikante Unterschiede zwischen den Weidetypen, der Weidennachwuchsperiode und der Wechselwirkung Weidetyp-Nachwuchsperiode zwischen den Jahren festgestellt ($P<0.05$). Die *Brachiaria*-Weide hatte einen signifikant ($P<0.05$) höheren Trockensubstanzertrag (2108.3 kg/ha) als die natürliche Weide 1926.3 kg/ha. Die 12wöchige WNP hatte den höchsten Ertrag (2232.4 kg/ha) und jene mit 8 Wochen den geringsten (1798.2 kg/ha). Der Ertrag der 10wöchigen WNP intermediär, aber war gegenüber der 8wöchigen WNP abweichend ($P<0.05$). Es wurden keine signifikanten Wechselbeziehungen zwischen x Weide oder Jahr x WNP für die abhängigen Variablen festgestellt. Nur die Wechselbeziehung zwischen Weidetyp und WNP hatte einen signifikanten Einfluß auf den Ertrag ($P<0.05$).

Alle Behandlungen und festgestellten Effekte beeinflussten den Trockensubstanzgehalt des Heus. Der mittlere Trockensubstanzgehalt des Heus (1773.5 ± 18.33 kg DM/ha) lag deutlich unter dem des Grases. *Brachiaria*-Heu zeigte einen ebenfalls signifikant ($P<0.05$) höheren Trockensubstanzgehalt (1800.6 kg/ha) im Vergleich zum Heu der natürlichen Weide (1746.1kg/ha). Wie der Grasertrag, erhöhte sich ebenfalls der Ertrag der Weiden ($P<0.05$) mit

der Zunahme der Weidenachwuchsperioden. Die relative Trockensubstanz des Heus betrug nach der Behandlung 86.7%. Zwischen Jahr, Weidetyp und der Weidenachwuchsperiode wurden keine signifikanten Veränderungen im Trockensubstanzgehalt (TS) festgestellt, was bedeutet, daß alle Versuchsvarianten nach 4 Tagen Feldtrocknung ausreichend trocken waren.

Der Eiweißgehalt für *Brachiaria*-Heu betrug 4.4% und jener für Heu der natürlichen Weide war 4.3% ($P<0.05$). Die Eiweißgehalte für Gras und Heu waren eher niedrig und reflektieren die vorhandene Situation ungedüngter Flächen auf dem Plateau. Sie unterschritten den minimalen Eiweißgehalt, den Futter auf diesen Flächen haben sollte um seinen Grundanforderungen zu entsprechen. Signifikante Unterschiede (0.9%) wurden sowohl zwischen dem Eiweißgehalt von *Brachiaria* und den natürlichen Weiden (5.9%) als auch zwischen den 8wöchigen und 12wöchigen (4.8%) WNP festgestellt. Der Rohproteingehalt (RP) des Grases war nicht signifikant durch das Jahr beeinflusst ebenso wie die Wechselwirkung Weidetyp – Weidenachwuchsperiode. Der Rohfasergehalt (RF) war hoch und betrug 35.8% für natürliche Weiden und 30.2% für Proben von *Brachiaria* sowie 37.5% und 34.1% für die jeweiligen Heusorten ($P<0.05$). Der Rohfasergehalt, NDF- und ADF-gehalte erhöhten sich mit der Nachwuchslänge für Gras und Heu ($P<0.05$).

Die Abbaubarkeitsrate nach der Nylonbeutelmethode betrug nach 48 Stunden 50.3% für natürliche Weiden und 53.5% für *Brachiaria* Weiden ($P<0.05$), bzw. 46.6% und 54.8% für die jeweiligen Heuproben ($P<0.05$). Sowohl Gras als auch Heu Weide hatten nach der 8 Wochen Weidenachwuchsperiode eine höhere Abbaurate als jene der Perioden 10 und 12 Wochen ($P<0.05$). Eine hohe signifikante Differenz ($P <0.05$) war für die 48h Nylonbeutel-Abbaubarkeitsrate zwischen den 8wöchigen (54.4%) und den 12wöchigen Weidenachwuchsperioden (38.8%) für *Brachiaria* Gras (52.1%) und den Naturweiden (49.8%), festzustellen. Die potentielle Abbaubarkeitsrate (a+b) folgte einem ähnlichen Verlauf wie der 48h Abbaubarkeitsrate und war durch unabhängige Variable ähnlich beeinflußt. Die gleichen Verläufe wurden für Heu erhalten.

Die enzymlösbaren organischen Substanzprozente (ELOS) folgten einem ähnlichen Trend wie die Nylonbeutel-Abbaurate. Die Differenz zwischen dem ELOS-Wert für *Brachiaria* (45.2%) und die natürliche Weide (31.7%) war sehr hoch (13.5%). Der Unterschied für Heu war ebenfalls groß. Diese ELOS-Werte liegen jedoch unter den erwarteten Verdauungswerten, insbesondere wenn sie zu den mit den in diesen Studien erhaltenen Abbaubarkeitsraten der Nylonbeutel verglichen werden. Es ist notwendig, die ELOS-Bestimmung an weiteren tropischen Rauhfutterproben zu wiederholen, um die Existenz

derartig niedriger ELOS-Werte, wie sie bei diesen Untersuchungen erhalten wurden, zu überprüfen.

Die Nährstofferträge von Gras und Heu wurden signifikant durch alle Haupteffekte beeinflusst während Wechselwirkungen zwischen den Haupteffekten keine signifikant Auswirkung zeigten. Der Trockensubstanzertrag, der Eiweißertrag und die ELOS-Erträge, alle auf der 48h-Abbaubarkeitsrate basierend, betrugen für die Grasproben 955.0 kg/ha, 91.4kg/ha und 788.3 kg/ha für natürliche Weiden und 1092.8 kg/ha, 122.5 kg/ha und 950.9 kg/ha für *Brachiaria*. Obgleich der Nährstoffertrag mit der Abbaubarkeitslänge variierte konnte generell festgestellt werden, dass *Brachiaria* ertragreicher als die natürliche Weide ist und mit einer10wöchigen WNP die höchsten Nährstofferträge mit Heu zu erreichen waren.

Die Qualität des Heus veränderte sich während der Lagerung insbesondere ab der 12. Woche ($P<0.05$). RP, RF, ELOS sowie die potentielle Abbaubarkeitsrate (a+b) betrugen 4.4%, 36.4%, 31.5% und 50.6% für die Woche 0; 4.3%, 36.8%, 30.8% und 49.3% für die 12. Woche und 4.0%, 36.9%, 30.0% und 48.3% für die 20. Woche der Lagerung. Die Qualität für Gras und Heu verringerte sich mit der längeren Weidenachwuchsperiode, während das *Brachiaria*-Heu einen geringen Rohfasergehalt und höhere Verdaulichkeit als jenes von natürlichen Weiden ($P<0.05$) aufwies.

NIRS bestimmte mit hoher Genauigkeit RP, NDF, RF und ADF ($R^2 >0.90$), weniger genau ADL ($R^2 = 0.29$) und ELOS ($R^2 = 0.72$).

Multivariate Regressionsanalysen zu Wechselwirkungen zwischen der Qualitätsvariablen des Heus zeigten, daß der Intercept (a) der exponentiellen Abbau-Kurve sowie die potentielle Abbaubarkeitsrate (a+b) eine hohe signifikante ($P <0.05$) Beziehung mit den meisten Qualitätsindikatoren hatten. Die Korrelationen (r) zwischen ELOS und den Werten der chemischen Zusammensetzung waren jeweils $r = 0.38$, $r = -0.70$, $r = -0.81$ und $r = -0.64$, für RP, RF, NDF und ADF. Der Trockensubstanzgehalt korrelierte schwach mit "a" ($r = -0.14$, $P >0.05$), mit "a + b", ($r = -0.24$, $P <0.05$), mit RP ($r = -0.22$, $P <0.05$) und mit ELOS ($r = 0.20$, $P < 0.05$). RP hatte gute Korrelationen mit der Abbaubarkeitsrate in 0, 12, 24, 48 und 72h ($r >0.80$, $P <0.05$).

Diese Arbeit hat gezeigt, daß die Heuwerbung unter subtropische Standortbedingungen durch Anwendung einer Weideruhe bzw. Weidenachwuchsphase am Ende der Regenzeit möglich ist. Der Heuertrag und die Qualität werden durch die Länge der WNP beeinflusst. In diesem Versuch erzielte die 10wöchige WNP den höchsten Nährstoffertrag, eine 12wöchige WNP

den höchsten Masseertrag und eine 8wochige WNP die höchste Nährstoffqualität. *Brachiaria* Weiden produzierten mehr Heu von besserer Qualität als natürliche Weiden. Die Heulagerung führt erst nach 12 Wochen zu Qualitätsbeeinträchtigung. Es konnte weiterhin gezeigt werden, daß die Nylon-beutelmethode die Verdaulichkeit von Gras- und Heuproben genauer bestimmte. Die Pepsin-Zellulasemethode sollte insbesondere in Bezug auf die Dauer der Säure Pre-Inkubation und der Herkunft der Zellulase modifiziert werden. Weitere Informationen über tropische Weiden sind für die Erhöhung des Kalibrierungsspektrums der NIRS notwendig, um es in höherer Genauigkeit zur Futterqualitätsbestimmung für tropisches Raufutter anwendbar zu machen.

9. RESUME

Mots clés: Foin, herbe, *Hyparrhenia spp. , Brachiaria ruziziensis* Germain et Evrad, Poacées, rendement, composition chimique, qualité, degradabilté *in sacco*, pepsine-cellulase, digestibilité, NIRS, repousse, conservation.

Cette expérience a été conduite à l'Institut de la Recherche Agricole pour le Développement (IRAD) au centre de Wakwa. Le centre est situé dans la zone sub-humide du Cameroun dans la province qui produit la plus grande quantité de viande et de produits laitiers du pays. La végétation, les sols et le climat de Wakwa sont représentatifs de cette zone et la recherche conduite là-bas pourrait avoir une signification dans les autres régions inter-tropicales productrices du bétail.

L'objectif principal de cette étude était de fournir l'information sur la technologie de production du foin dans les conditions artisanales. Les objectifs spécifiques étaient 1°) d'évaluer le rendement et la qualité des pâturage naturels (l'un à prédominance *Hyparrhenia spp*.) et introduits (*Brachiaria ruziziensis* Germain et Evrad) qui ont été subi à des durées de repousses différentes 2°) d'évaluer les effets de la durée de stockage sur la qualité des foins de ces pâturages et 3°) l'applicabilité des différentes méthodes de détermination de qualité des foins produits sur le plateau de l'Adamaoua au Cameroun.

Les pâturages ont été broutés avec une charge de 375 kg/ha par un groupe de taurillons à partir du mois de mai jusqu'en août. Ils ont été mis en rotation dans chaque série de 3 parcs

appartenant à chaque type de pâturage. Après le retirage des taurillons, des placeaux de 40 x 40m ont étaient délimitées au harzard à l'intérieur de ces 6 parcs la. Les 6 placeaux constituaient 2 répétitions des durées de repousses, respectivement 12, 10 et 8 semaines avant la récolte éventuelle du foin le 6 novembre. Un gyro-broyer a était utilisé pour couper la végétation à 10cm au dessus du sol successivement pour réaliser les périodes de repousse citées plus haut. Après la récolte du foin à l'intérieur de chacun de ces placeaux, suivi par le séchage à terre) d'une durée de 4 jours et le bottelage en grandes balles cylindriques, le foin a été transporté le 10 novembre à un hangar pour le stockage interne. La repousse n'étant pas suffisante dans certains parcelles, le foin des mêmes répétitions sus-jacentes a été bottelé ensemble. Ceci a donc produit un ensemble de 18 balles/an ou 36 pour les deux années d'expérimentation. Les balles de foin ont été stockées pendant 20 semaines.

Le rendement des pâturages a été déterminé par la méthode de points quadrats. Les balles n'étaient pesées qu'en début du stockage. Après une période d'équilibration de 10 jours, des prélèvements du foin ont été effectués le 10 novembre (semaine 0 de stockage) le 12 février (semaine 12 du stockage) et le 20 avril (semaine 20 du stockage). Il y'avait un total de 108 échantillons prélevés `a partir de ces 3 périodes de prélèvement.

La matière sèche a été déterminée à 105°C pendant 24 heures et exprimée en kg/ha, alors que les échantillons pour l'analyse chimique ont été chauffés à 65° C pendant 48 heures. L'analyse labo et de digestibilité a été faite de 1995 à 1998. Les analyses de qualité consistaient en l'analyse bromatologique et de détergents, la méthode de sacs Dacrons (*in sacco*) et la méthode pepsine-cellulase. La Spectrométrie dans le proche infra rouge a été faite et les valeurs obtenues comparées avec celles du labo.

Le rendement en nutriments de l'herbe et du foin a été dérivé à partir du rendement de la matière sèche et le taux de dégradation à 48h. Les données ont été saisies avec Dbase IV et analysées avec le programme GLM du SAS. La régression à étapes a été utilisée pour déterminer les corrélations entre les variables. Les données issues de la méthode *in sacco* ont été analysées par la procédure de la régression non linéaire du SAS.

Le rendement moyen en matière sèche (MS) des deux années était de 2 017,3 ± 87,78 kg/ha. Il est plus faible que la biomasse de ce type de pâturages sur le plateau de l'Adamaoua parce que les placeaux ont été broyés entre les mois d'août et septembre. Il y avait donc une période de repousse plus courte comparée à celle utilisée pour calculer la biomasse épigée. Il y avait des différences significatives entre les années, les pâturages, les repousses et l'interaction

pâturage x durée de repousse (P <0,05). L'année 1995 avait un rendement de la MS plus élevé que l'an 1996. Le *Brachiaria* a produit plus de la matière sèche (2 108,3 kg/ha) que les pâturages naturels, 1926,3 kg/ha, (P <0,05). Les repousses de 12 semaines avaient le plus haut rendement (2 232,4 kg/ha) et celles de 8 semaines le plus faible, (1 798,2 kg/ha). La valeur des repousses de 10 semaines a été intérmediare mais non significativement différent (P >0,05) de celle des repousses de 12 semaines. L'effet année x type de pâturage ou bien de l'année x durée de repousse n'a pas d'influence sur les variables dépendantes. Tous les effets principaux ont influencé le rendement de la MS du foin. Ce dernier a un moyen de 1 773,5 ± 18,33 kg MS/ha, plus faible que celui de l'herbe. Chez le foin le *Brachiaria* a également produit plus de la MS (1800.6 kg/ha) que le pâturage naturel, 1746,1 kg/ha (P <0,05). Comme chez l'herbe, le rendement a augmenté avec la durée de repousse de l'herbe. Le pourcentage de la MS du foin après le séchage (au bottelage) était de 86,7%. Il n'y avait pas de changement significatif dans le pourcentage de la MS entre les années, le type de pâturage ou la durée de repousse, indiquant que les foins étaient suffisamment secs après 4 jours de séchage.

Les matières azotées totales (MAT) étaient non significativement (P >0,05) affectées par l'année et l'interaction pâturage x durée de repousse. Il y avait une différence (0,9%) significative (P <0,05) entre les MAT du *Brachiaria* et le pâturage naturel pour les repousses de 8 semaines (5,9%) et les repousses de 12 semaines (4,8%). Les MAT du foin étaient en moyen 4,3 ± 0,50%, avec le *Brachiaria* ayant des MAT plus élevées que le pâturage naturel. Les MAT des herbes et des foins étaient plutôt base et reflètent la situation au plateau où les pâturages ne sont pas fertilisés. Elles étaient moins que la valeur de 6,45% MAT qu'un forage doit avoir pour être considéré comme une ration de base. Le pourcentage des celluloses brutes (CB) était élevé, respectivement, 35,8% et 30,2%, avant la récolte pour le pâturage naturel et le *Brachiaria* et respectivement, 37,5% et 34,1 pour leurs foins (P > 0,05). Le pourcentage des CB, les contenus pariétaux (NDF) et l'acide détergent fibre (ADF) des pâturages et des foins a augmenté avec la durée de repousse, P <0,05.

La dégradation *in sacco* à 48h était de 50,3% et 53,5% pour le pâturage naturel et le *Brachiaria* (P <0,05) et 46,6% et 54,8% pour leurs foins respectifs. Les effets principaux ont significativement influencé ce paramètre aussi bien chez les échantillons d'herbe que chez le foin, mais a part l'interaction pâturage x durée de repousse, les interactions ne l'ont pas. Chez l'herbe et chez le foin la repousse de 8 semaines était significativement plus dégradée que celles de 10 et de 12 semaines (P <0,05). Il y'avait une grande différence dans le pourcentage

de dégradation à 48h de la repousse de 8 semaines (54,4%) et celle de 12 semaine (38,8%) chez l'herbe, aussi bien q'une différence importante entre le *Brachiaria* (52,1%) et le pâturage naturel (49,8%), P <0,05%. Le taux de la dégradabilité potentielle (a + b) a suivi une tendance similaire à celle de la dégradation à 48h et elle était également influencée par les effets principaux. Ces mêmes tendances ont été obtenues chez le foin. La solubilité cellulosique de la matière organique (SCMO) a suivi la même tendance que la dégradation *in sacco*. La différence entre le pourcentage SCMO du *Brachiaria* à la récolte (45,2%) et celle du pâturage naturel (31,7%) était très grande (13,5%). Cette grande différence a été également obtenue chez le foin. Toutefois, ces valeurs sont en dessous de celles attendues, compte tenu des valeurs relativement élevées de la dégradation *in sacco*. Il est donc nécessaire d'analyser les pâturages similaires à ceux de cette étude avec d'autres procèdures à pepsine-cellulase pour valider ces résultats.

Le rendement des nutriments d'herbe et du foin a été significativement influencé par tous les effets majeurs et non significativement par les interactions. Le rendement digestible de la MS basé sur la dégradation à 48h, le rendement en MAT et la digestibilité cellulosique sur la base de la dégradabilité a 48h étaient respectivement 955,0 kg/ha, 91,4 kg/ha et 788,3 kg/ha pour le pâturage naturel; et respectivement 1092,8 kg/ha, 122,5 kg/ha et 950,9 kg/ha pour le *Brachiaria*. Le rendement en nutriments a varié avec la durée de repousse mais d'une façon générale, c'est la durée de repousse de 10 semaines qui a donné un équilibre meilleur de rendement et de qualité. Chez l'herbe et chez le foin, il est noter que les repousses de 10 semaines du *Brachiaria* ont eu le meilleur rendement en nutriments.

La qualité a baissé (P <0,05) pendant le stockage en particulier après la 12é semaine du stockage. Les MAT, CP, SCMO et la dégradation potentielle (a + b) étaient respectivement 4,4%, 36,4%, 31,5% et 50,6% pour la semaine 0; 4,3%, 36,8%, 30,8 et 49,3% pour la 12é semaine et 4,0%, 36,9%, 30,0% et 48,3% pour la 20é semaine du stockage. Comme chez l'herbe et le foin, la qualité a baissé avec l'accroissement de la durée de repousse, le foin du *Brachiaria* contenant moins de fibre mais étant plus digestible que le pâturage naturel (P <0,05).

La procédure NIRS a exactement prédit les MAT, NDF, CB et ADF (R^2 >0.90), moins exactement l'ADL, mais encore moins, la SCDO. La base des données courante pour la calibration de la SCMO est limitée; ceci a également contribué à son mauvais écart type de validation .

La régression multivariable du rapport entre les variables d'estimation de la qualité des foins a revelé que l'intercepte a de la courbe de dégradation et la dégradabilité potentielle (a + b) avaient le rapport le plus significatif parmi toutes les variables d'estimation de la qualité. Les corrélations (r) entre la SCMO et les valeurs de la composition chimique étaient respectivement 0,38, -0,70, et -0.81 pour les MAT, CB, NDF et ADF. Le rendement de la MS était peu corrélé avec "a", (0,14, $P < 0,05$), avec (a + b), (-0.24, $P < 0,05$), avec les MAT (-0,22, $P < 0,05$) et avec SCMO (0,20, $P < 0,05$). Les MAT avaient des bonnes corrélations avec le taux de dégradabilité à 0, 12, 24, 48 et 72h ($r > 0,80$, $P < 0,05$).

Cette étude montre qu'il y a une croissance importante avec l'augmentation de la durée de repousse d'herbe, le *Brachiaria* même non fertilisé produisant plus de la biomasse pour le fanage que le pâturage naturel. Aussi, que les repousses de 10 semaines ont le plus de nutriments. Il y a une diminution de qualité pendant le stockage interne du foin particulièrement entre la 12^{e} semaine et la 20^{e} semaine du stockage. La méthode *in sacco* s'est revelé très bonne pour la prédiction de qualité de l'herbe aussi bien que du foin. Par contre, il a été demontré que la méthode pepsine-cellulase devrait être modifiée, en particulier, en ce qui concerne la durée de la pre-incubation avec l'acide et la source de la cellulase. Il est nécessaire d'utiliser plus d'échantillons prélevés dans d'autres formations pastorales pour permettre à la méthode NIRS de prédire plus exactement la qualité des fourrages tropicaux.

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11. APPENDIX

Appendix 10.1. ANOVA Table for yield of pastures

Souurce of variation	df	Mean square	Pr > F
Year	1	549448.97	0.0001
Pasture type	1	595922.64	0.0001
Regrowth length	2	1131256.40	0.0001
Plot within Pasture Type	4	9433.98	0.3105
Year x Pasture type	1	18685.67	0.1249
Year x Regrowth length	2	34335.64	0.0158
Pasture type x Regrowth length	2	36243.22	0.0128
Error	58	7706.16021073	
Pasture type x Regrowth length	2	36243.22	0.0128
R^2 0.89			
C.V. 4.35			

Appendix 10.2 ANOVA Table for yield of hay

Source of variation	df	Mean square	Pr > F
Year	1	13708.5001235	0.0001
Pasture type	1	36207.6743251	0.0001
Regrowth length	2	516.064001	0.1127
Plot within Pasture Type	4	5423.1655421	0.0001
Year x Pasture type	1	1261.431122	0.0237
Year x Regrowth length	2	18.48361	0.9175
Pasture type x Regrowth length	2	82.108611	0.6855
Error	22	213.721001	
R^2 0.88			
C.V. 7.11			

Appendix 10.3. ANOVA Table for CP content of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	0.07475556	0.6184
Pasture type	1	22.00005556	0.0001
Regrowth length	2	7.68403889	0.0001
Plot within Pasture Type	4	0.05643472	0.9430
Year x Pasture type	1	1.93388889	0.0135
Year x Regrowth length	2	0.00637222	0.9789
Pasture type x Regrowth length	2	0.4372222	0.2390
Error	58	0.298031	
R^2 0.96			
C.V. 3.44			

Appendix 10.4. ANOVA Table for CF content (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	12.9032000	0.0058
Pasture type	1	573.249800	0.0001
Regrowth length	2	19.7709555	0.0001
Plot within Pasture Type	4	0.25327778	0.9571
Year x Pasture type	1	3.20888889	0.1583
Year x Regrowth length	2	3.49511667	0.1173
Pasture type x Regrowth length	2	3.39526667	0.1244
Error	58	1.57125345	
R^2 0.88			
C.V. 3.80			

Appendix 10.5. ANOVA Table for NDF content (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	2.21902222	0.3331
Pasture type	1	1031.79102222	0.0001
Regrowth length	2	46.32194306	0.0001
Plot within Pasture Type	4	4.78795556	0.0984
Year x Pasture type	1	1.09027222	0.4966
Year x Regrowth length	2	27.98274306	0.0001
Pasture type x Regrowth length	2	1.22716806	0.5932
Error	58	2.32896576	
R^2 0.90			
C.V. 2.24			

Appendix 10.6. ANOVA Table for ELOS content (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	7.40057	0.2304
Pasture type	1	2850.12232	0.0001
Regrowth length	2	15.878497	0.050
Plot within Pasture Type	4	7.958135	0.1923
Year x Pasture type	1	0.7850168	0.6943
Year x Regrowth length	2	2.112912	0.6591
Pasture type x Regrowth length	2	5.458676	0.3451
Error	58	5.029595	
R^2 0.92			
C.V. 5.77			

Appendix 10.7. ANOVA Table for CDOM content (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	0.9681921	0.6912
Pasture type	1	3150.851808	0.0001
Regrowth length	2	21.51218	0.0358
Plot within Pasture Type	4	17.656131	0.0298
Year x Pasture type	1	0.432514	0.7906
Year x Regrowth length	2	6.422186	0.3543
Pasture type x Regrowth length	2	19.35611	0.0491
Error	58	6.071434	
R^2 0.92			
C.V. 5.86			

Appendix 10.8. ANOVA Table for 48 hour degradability rate (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	17.900139	0.0037
Pasture type	1	99.170139	0.0001
Regrowth length	2	357.566806	0.0001
Plot within Pasture Type	4	2.1722222	0.3596
Year x Pasture type	1	4.253472	0.1455
Year x Regrowth length	2	4.026806	0.1365
Pasture type x Regrowth length	2	10.591806	0.0069
Error	58	1.953386	
R^2 0.89			
C.V. 2.74			

Appendix 10.9. ANOVA Table for the washing loss estimate ”a” (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	15.700085	0.0461
Pasture type	1	257.79513	0.0001
Regrowth length	2	86.76719	0.0001
Plot within Pasture Type	4	1.415983	0.8043
Year x Pasture type	1	0.31659	0.7668
Year x Regrowth length	2	6.918388	0.1633
Pasture type x Regrowth length	2	8.559921	0.1106
Error	22	3.512073	
R^2 0.86			
C.V. 10.03			

Appendix 10.10. ANOVA Table for the asymptote or potential degradability rate constant ”a+ b” (%) of pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	21.95547	0.0944
Pasture type	1	109.118916	0.0008
Regrowth length	2	137.63396	0.0001
Plot within Pasture Type	4	2.070693	0.8825
Year x Pasture type	1	11.307527	0.2229
Year x Regrowth length	2	6.119167	0.4404
Pasture type x Regrowth length	2	1.4203398	0.8221
Error	22	7.186974	
R^2 0.74			
C.V. 5.06			

Appendix 10.11. ANOVA Table for CP content of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	1.28403	0.03447
Pasture type	1	3.04336	0.0500
Regrowth length	2	1.99632211	0.0001
Plot within Pasture Type	4	0.168369	0.3297
Year x Pasture type	1	0.0971361	0.4100
Year x Regrowth length	2	0.330769	0.1139
Pasture type x Regrowth length	2	0.137689	0.0028
Error	22	0.137689	
R^2 0.91			
C.V. 2.67			

Appendix 10.12. ANOVA Table for CF content of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	99.5403202	0.0010
Pasture type	1	96.8584111	0.0001
Regrowth length	2	63.05632111	0.0001
Plot within Pasture Type	4	5.53857	0.1821
Year x Pasture type	1	0.1308034	0.8422
Year x Regrowth length	2	11.5221023	0.0453
Pasture type x Regrowth length	2	5.5456211	0.2024
Error	22	3.22528	
R^2 0.91			
C.V. 3.78			

Appendix 10.13. ANOVA Table for NDF content of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	90.7014113	1.09201
Pasture type	1	411.210942	0.0001
Regrowth length	2	78.552001	0.0001
Plot within Pasture Type	4	0.699711	0.9273
Year x Pasture type	1	1.89062	0.4541
Year x Regrowth length	2	5.82253	0.00736
Pasture type x Regrowth length	2	3.10944644	0.0010
Error	22	3.25467	
R^2 0.89			
C.V. 2.22			

Appendix 10.14. ANOVA Table for ELOS content of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	21.4133623	0.04201
Pasture type	1	1555.24823	0.0001
Regrowth length	2	30.517823	0.0001
Plot within Pasture Type	4	8.466627	0.0592
Year x Pasture type	1	9.2213362	0.1023
Year x Regrowth length	2	13.712682	0.1023
Pasture type x Regrowth length	2	23.7828111	0.0033
Error	22	3.17181	
R^2 0.92			
C.V. 6.02			

Appendix 10.15. ANOVA Table for CDOM content of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	3.06178	0.0412
Pasture type	1	1377.82621	0.0001
Regrowth length	2	3.2078412	0.0110
Plot within Pasture Type	4	0.1175211	0.0590
Year x Pasture type	1	0.089132	0.7619
Year x Regrowth length	2	0.007156231	0.0042
Pasture type x Regrowth length	2	0.0080763	0.0023
Error	22	1.22878	
R^2 0.89			
C.V. 5.98			

Appendix 10.16. ANOVA Table for 48 hour degradability rate of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	19.802483	0.00455
Pasture type	1	525.62461	0.0009
Regrowth length	2	129.575624	0.0001
Plot within Pasture Type	4	4.993333	0.0625
Year x Pasture type	1	0.0624823	0.9229
Year x Regrowth length	2	17.950782	0.0858
Pasture type x Regrowth length	2	6.5910765	0.0080
Error	22	6.52508	
R^2 0.90			
C.V. 2.77			

Appendix 10.17. ANOVA Table for the washing loss estimate ”a” of the hay (after baling)

Source of variation	df	Mean square	Pr > F
Year	1	3.7531654	0.0584
Pasture type	1	87.142164	0.0001
Regrowth length	2	244.463624	0.0001
Plot within Pasture Type	4	2.38047	0.0451
Year x Pasture type	1	0.90334	0.15263
Year x Regrowth length	2	1.9783112	0.1232
Pasture type x Regrowth length	2	24.86168231	0.0521
Error	22	0.064649	
R^2 0.90			
C.V. 9.98			

Appendix 10.18. ANOVA Table for the asymptote or potential degradability rate constant ”a+ b” of the hay (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	11.514162	0.1432
Pasture type	1	105.16452	0.0001
Regrowth length	2	19.74361	0.0100
Plot within Pasture Type	4	0.454116612	0.04521
Year x Pasture type	1	0.0200657	0.8611
Year x Regrowth length	2	1.2325093	0.1696
Pasture type x Regrowth length	2	2.9773	0.1213
Error	22	0.640017	
R^2 0.76			
C.V. 6.14			

Appendix 10.19. ANOVA Table for the crude protein yield (CP Yield) of the pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	2110.333889	0.0007
Pasture type	1	17440.8938889	0.0001
Regrowth length	2	18.3429167	0.8953
Plot within Pasture Type	4	58.836111	0.8393
Year x Pasture type	1	250.880000	0.2234
Year x Regrowth length	2	141.167638	0.4317
Pasture type x Regrowth length	2	9.4801389	0.9444
Error	58	165.60942	
R^2 0.68			
C.V. 12.03			

Appendix 20 ANOVA Table for the crude protein yield (ELOS Yield) of the pastures (at cutting)

Source of variation	df	Mean square	Pr > F
Year	1	50238.39528	0.0006
Pasture type	1	1844577.777778	0.0001
Regrowth length	2	117427.129514	0.0001
Plot within Pasture Type	4	2313.631857	0.6601
Year x Pasture type	1	12559.59882	0.0753
Year x Regrowth length	2	3260.11939	0.4315
Pasture type x Regrowth length	2	29716.054668	0.0011
Error	58	3818.4006	
R^2 0.92			
C.V. 7.84			

Appendix 10.21. ANOVA Table for CP content of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	0.396033	0.004
Pasture type	1	0.192533	0.0425
Plot within Pasture Type	4	0.202551	0.0025
Regrowth length	2	9.043837	0.0001
Week	2	1.1045814	0.0001
Year x week	2	0.104344	0.1065
Pasture type x Week	2	0.0430778	0.3914
Year x Pasture Type x Week	3	0.076922	0.1742
Error	90	0.045447	
R^2 0.92			
C.V. 2.80			

Appendix 10.22. ANOVA Table for CF content of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	107.720181	0.0001
Pasture type	1	263.703126	0.0001
Plot within Pasture Type	4	5.554784	0.0008
Regrowth length	2	306.046089	0.001
Week	2	2.0407843	0.1509
Year x week	2	7.656362	0.0012
Pasture type x Week	2	0.626223	0.555
Year x Pasture Type x Week	3	0.0237574	0.9954
Error	90	1.056787	
R^2 0.92			
C.V. 2.80			

Appendix 10.23. ANOVA Table for NDF content of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	16.054533	0.0078
Pasture type	1	882.3675	0.0001
Plot within Pasture Type	4	1.323699	0.6553
Regrowth length	2	369.45458	0.0001
Week	2	6.551906	0.0534
Year x week	2	0.880619	0.6669
Pasture type x Week	2	6.395175	0.0571
Year x Pasture Type x Week	3	4.382928	0.0571
Error	90	2.16400175	0.1160
R^2 0.90			
C.V. 2.04			

Appendix 10.24. ANOVA Table for ELOS content of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	35.23	0.0001
Pasture type	1	3438.49	0.0001
Plot within Pasture Type	4	3.3008222	0.0001
Regrowth length	2	143.6454321	0.0001
Week	2	16.7891243	0.0001
Year x week	2	1.452921	0.2217
Pasture type x Week	2	0.2892342	0.7492
Year x Pasture Type x Week	3	2.0784521	0.1085
Error	90	1.31812969	
R^2 0.93			
C.V. 6.59			

Appendix 10.25. ANOVA Table for CDOM content of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	6.020833	0.1181
Pasture type	1	4512.957959	0.0001
Plot within Pasture Type	4	11.11525	0.0020
Regrowth length	2	174.027112	0.0001
Week	2	6.913381	0.0626
Year x week	2	2.805833	0.3181
Pasture type x Week	2	27.1702259	0.0001
Year x Pasture Type x Week	3	0.5713519	0.8709
Error	90	2.41832586	
R^2 0.92			
C.V. 6.34			

Appendix 10.26. ANOVA Table for 48 hour degradability rate of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	56.188981	0.0211
Pasture type	1	210.84083	0.0001
Plot within Pasture Type	4	6.191852	0.6583
Regrowth length	2	407.155648	0.0001
Week	2	53.629259	0.0069
Year x week	2	2.113704	0.8131
Pasture type x Week	2	4.08444	0.6711
Year x Pasture Type x Week	3	1.923241	0.9039
Error	90	10.193989	
R^2 0.57			
C.V. 6.90			

Appendix 10.27. ANOVA Table for the washing loss estimate ”a” of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	12.696489	0.0035
Pasture type	1	167.876134	0.0001
Plot within Pasture Type	4	8.250189	0.0003
Regrowth length	2	615.844084	0.0001
Week	2	37.010489	0.0001
Year x week	2	9.6015954	0.0017
Pasture type x Week	2	3.046167	0.1209
Year x Pasture Type x Week	3	2.319397	0.1841
Error	90	1.4408079	
R^2 0.92			
C.V. 8.20			

Appendix 10.28. ANOVA Table for the asymptote or potential degradability rate constant ”a+ b” of the hay (during storage)

Source of variation	df	Mean square	Pr > F
Year	1	36.34280	0.0074
Pasture type	1	439.75449	0.0001
Plot within Pasture Type	4	9.971745	0.0931
Regrowth length	2	712.34982	0.0001
Week	2	46.005448	0.0002
Year x week	2	1.358893	0.7562
Pasture type x Week	2	2.652381	0.5808
Year x Pasture Type x Week	3	6.4124398	0.2719
Error	90	4.84758	
R^2 0.83			
C.V. 4.46			

Annex A. 29. Table of rainfall (mm) and humidity (% R.H.) in 1995

1995	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
mm Rain	0	0	54.9	60.1	287.8	147.5	271.8	319.4	326.3	195.3	26.4	0	1689.5
% Rel. Humidity	42.2	37.5	55.5	65.8	76.4	76.8	80.5	80.2	77.5	74.4	64.5	50	

Annex A. 30. Table of rainfall (mm) and humidity (% R.H.) in 1996.

1996	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
mm Rain	0	0	93.3	191.3	313.4	190.6	202.8	293.3	264.9	226.6	0	0	1776.2
% Rel. Humidity	41.8	41.2	58.9	71.9	72.2	80.7	81.2	81.5	79.3	76.2	60.7	49.8	

Annex A. 31. Table of rainfall (mm) and humidity (% R.H.) in 1997.

1997	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
mm Rain	0	0	32.3	296.6	261.6	157.3	275.3	249.9	209	127.4	12.1	0	1621.5
% Rel. Humidity	41.2	35.4	43.4	72.1	77.6	78.8	79.5	80.1	76.6	77.2	65.8	50.7	