Title: The production of high quality silage from adapted forage and legume crops for the maintenance of dairy cow productivity on smallholder farms through the dry season in the semi-arid region of Zimbabwe.

FINAL TECHNICAL REPORT

DFID Project No. R7010

M Titterton, B Maasdorp, O Mhere, B Mugweni and L Nyoni

Table of contents

Executive Summary

The project purpose was to determine the feasibility of producing and conserving sufficient biomass of high quality forage on a small holding to maintain good productivity in small holder dairy cows in the semi-arid region of Southern Africa during the dry season.

The research activities undertaken to achieve the project purpose were the following:

Forages adapted to the semi-arid environment were intercropped with adapted legumes using three planting regimes and two soil types, over three seasons. Biomass yield, nutrient quality of harvested forage and fermentation quality of the ensiled forage were measured. This trial was carried out on station and in participatory trials on farm.

Forage legume trees in place of annual legumes were used in another trial where tree leaf harvested from different species was mixed with chopped maize and ensiled. The silage was tested for nutrient and fermentation quality and fed to lactating cows with maize silage and protein concentrate as control.

Differing techniques were tested in developing low-cost ensiling technology which would ensure adequate fermentation of the forage without the use of costly machinery and which entailed minimal labour, especially for women.

Feeding trials were carried out to determine optimum feeding strategy with limited silage to cows during the dry season and into early lactation to ensure maximum productivity in lactation and fertility.

Outputs were the following:

- Forage sorghum and Pennisetums can be intercropped with lablab (dolichos bean) or cow pea to produce up to 8 tons dry matter per hectare on sandy soil under formal experimental conditions and up to 4 tons dry matter per hectare under farming conditions. This is an average yield over three seasons, which included a severe drought.

- With the inclusion of legume, the protein content of the harvested forage averages 11.5% crude protein with an ME value of 9.2MJ/kg dry matter

- The forage can be successfully ensiled in quantities of up to 15 kg in reject fertiliser bags or recycled garbage bags using a hand or petrol driven chopper with manual compression in the bags of the forage.

- Over two good seasons it was found that enough bags were produced on farm (ranging from 130 to 400 bags over forty farms) to feed two cows one bag a day each for the last two months of the dry season, i.e. two months before calving. This allowed the cows to calve in good condition (average body condition score 2.5) which was shown to be important for normal return to conception but had no significant effect on lactation yields in indigenous nor in cross bred cows. In the drought year, the equivalent of half a bag a day was fed over one month before calving and this allowed body condition maintenance of 1.75 BCS which kept the cows alive, while control cows on no supplement were emaciated or died.

Contribution of outputs to project goal was the following:

The outputs of the project have been achieved. The project showed that it is feasible for a small holder dairy farmer in the semi-arid region to produce and conserve high quality forage for dry season feeding of his dairy cows, thus making dairy production a potentially viable enterprise in this region. However, the project goal is to produce the high quality silage at low cost and this still presents challenges. Harvesting management requires further development, taking into account the need to harvest early to achieve maximum nutrient content and digestibility with wilting and locally available additives to produce the best possible silage quality against the constraint of other farming activities and labour. Feeding strategy also requires further investigation, especially in cross bred cows, to optimise both fertility and lactation yields. In the drier areas, where there is dam or borehole water, strategic flood irrigation could overcome problems with establishment of the forages and this, together with further selection of forage legume trees for inclusion of leaf material in silages, is recommended for future research. The major challenge may lie in production costs, as fertiliser prices increase rapidly with inflation. The system of producing bagged silage under central management on land provided by the community, where manure can replace fertiliser if the cattle are kept in a central dairy unit is worth investigating.

Background

It is recognised that production of milk for sale is an attractive option for smallholder farmers in the semi-arid regions of Southern Africa. (Food and Agricultural Organisation [FAO], 1996). Milk contributes to improving the livelihood of the household and is a more attractive incentive for investment of scarce financial resources than beef, which is a long term investment, 'destructive' and brings infrequent returns (Smith, Ndlovu and Mhere 1996, Chigaru, 1998 and 1999). In Zimbabwe, the need to generate improved livelihoods / more cash at the household level was emphasised by the 1991-92 drought (livestock numbers still not back to pre-drought levels) and the Economic Structural Adjustment Programme (ESAP) of the early 1990's. It has also been noted that in Africa as a whole, smallholder dairying generates a more regular income than any other rural enterprise and can lead to improved human nutrition and health, poverty alleviation and improvement of household food security (International Livestock Research Institute, 1997).

Many farmers in the low potential areas of Zimbabwe own cattle and milk them for their own consumption and sale. However, in the dry season, natural grazing and crop residues are inadequate to support lactation, making supplementary feed necessary to maintain milk production at this time. Prices of bought-in protein and energy-rich feeds are now beyond the reach of most smallholder milk producers. As a result, milk production has become seasonal rather than annual. If continuous milk production is to be ensured and sustained, then there is a need to produce, on-farm, high quality conserved forage from high yielding and ecologically adapted forage crops. Smallholder dairying, which is rapidly developing in the low potential areas of Zimbabwe needs to be backed by sustainable feed production and management interventions. Conserving the communal grazing is normally insufficient with no forage available for conservation. The farmers' own lands are too small to produce pasture grasses for grazing or production of hay, so they rely on communal rangelands to graze their stock. Even if forage were available, institutional constraints would probably exclude individuals from cutting forage for conservation. With limited land resources for forage production it is especially important to produce higher yielding and high quality forage.

Optimum nutrient quality of forage coincides with the rains, making silage the practical option for conservation. Silage is sealed from leaching, insect and rodent damage, which are problems in openly stored hay. Although cereal crops are easier to ensile, they are low in protein, while legume crops are difficult to ensile due to high buffering capacity and low levels of water-soluble carbohydrates. A possible solution is to intercrop cereals and legumes and then ensile the mixtures. In the smallholder sector, lack of skills in fodder production and conservation has been cited as one of the major factors contributing to failure and, or, lack of profitability of most livestock development programmes (Mupunga and Dube, 1990).

The Dairy Development Programme (DDP) established by the government in 1983, is probably the most important agency working with the small holder dairying sector and is assisting with the development of cooperatives. At present, the total number of small holder farmers registered with the DDP is over 2000, spread over 15 project sites (cooperatives) with the majority of those located in the high rainfall areas of the country. There is potential for thousands more to enter dairying, particularly in low rainfall areas, if the important constraint of inadequate high quality dry season feed can be overcome. This problem is of great concern to the DDP as current dairy projects are failing to supply milk in the dry season and their cows are becoming acyclic due to poor nutrition. It has also effectively prevented the DDP from bringing additional farmers into the programme and providing the support needed to develop viable dairy cooperatives. The DDP were very supportive of the project as they saw it providing a solution to the dry season feeding problem, particularly in the semi-arid region.

Maize silage is a major component of the winter forage available on most large-scale and to some extent, small-scale, dairy enterprises in Zimbabwe. However any factors such as moisture stress during the flowering and seed set stages severely affect grain content and lower maize quality. Maize silage alone has a low crude protein content of about 75 g/kg dry matter (DM) (Topps and Oliver, 1993). The persistent droughts experienced in the last twenty years have led to markedly reduced yields in some areas, (Central Statistical Office (CSO), Zimbabwe, 1992). It is no longer possible to rely on maize silage as the staple forage and bought in commercial dairy meals or protein supplements to provide protein requirements for dairy cows as they have become too expensive (Titterton, 1996).

High yielding forage crops such as Elephant grass (*Pennisetum purpureum*); hybrid *Pennisetum* (interspecific cross between elephant grass and pearl millet) and forage sorghum are adapted to local conditions and grow very well in low rainfall areas of Zimbabwe. Their potential as animal feed is recognised and most large and smallholder dairy farmers are now growing them (ICRISAT, 1992; Mhere, Ncube and Matshe, 1995, Gupta and Mhere, 1997). Cowpeas (Vigna *unguiculata*) and dolichos beans (*Lablab purpureus*), are adaptable and drought tolerant legumes which can be intercropped successfully with cereal forages (Matopos Research Station 1947-1958; Johnson, 1968; Skerman, 1988; ICRISAT, 1992; Maasdorp and Titterton 1997). Use of cowpeas and dolichos beans, as is that of other forage legumes is severely limited by availability of seed, (Sibanda 1995, Thornton and Odero, 1998).

Productivity of cowpeas and dolichos beans under intercropping situations and their ensiling characteristics as sole crops and as mixtures with forages need to be established in the semi-arid areas of Zimbabwe where growing conditions are different from the areas of Zimbabwe where most studies have been done. Legume tree forage, harvested from browse trees, which are also adapted to these conditions and are perennial, should be considered as an alternative protein source to that of annual legumes, for which, at times, seed is not easily available.

Silage making has become the traditionally accepted means of forage conservation for large-scale farms, where the machinery appropriate for harvesting and chopping forage, carting forage to the silo and compressing it before the silo is sealed, is available. The costs of machinery were the major limitation to small holders ensiling forage and this has to be overcome in the development of low-cost techniques for ensiling which do not involve expensive farm machinery

Project purpose

The purpose of the project was to address a number of management issues which needed to be resolved before it could be determined whether it was feasible to maintain productivity in small holder dairy cows with forage produced and conserved on a small plot in the small holding. Those issues were:

1. The majority of smallholder livestock owners in Africa have an average of 2 to 10 hectares in which they plant their own crops and vegetables. The land on which their livestock graze is communal, so that the smallholder's arable land for forage cropping is very limited since priority has to be given to growing food for the family on a small plot.. Pasture improvement or grazing schemes have rarely succeeded because communal areas by their definition inherently allow no one farmer to take responsibility for the pastures or the fencing. Thus the only possible source of good forage is the forage crop grown by the farmer on his own plot. The challenge therefore is to produce sufficient high quality forage from a small area of no more than 0.5 ha. to feed silage to an average of two cows for part or all of the dry season. The other option is to have land provided by the community for a forage centre under management.

2. Time of harvesting is a complex matter involving not only maximum yield, nutrient and fermentation quality but family labour (often a major constraint) and integration with other farm activities. It is a question of determining which "trade-offs" to make to achieve the best result in terms of the smallholder animal's needs over the dry season and of the return to the farmer of his investment.

3. Harvesting and chopping a crop to the ideal chop length is laborious and time consuming and hence specialised machinery is employed on the commercial farm to cut and chop the forage. The cost of such machinery is far beyond the resources of the smallholder and so the challenge here is to produce a satisfactorily chopped, compressed and sealed ensiled forage with appropriate and low-cost technology.

4. The silo for a commercial farm would normally be a bunker or pit in Zimbabwe, sufficient to store up to 100 tons of silage per bunker or pit and would require tractor compression. The challenge to the smallholder is to compress, seal and store silage of up to 5 tons without the benefit of a tractor. Small pits in which the silage has been compressed with water drums pulled by oxen have been tried and are still in use in some areas but generally it has been found that spoilage is very high due to poor compression and over exposure of the silage upon removal for daily feeding Drums have been used in other countries mainly in Asia but are scarce and expensive in many African countries

5. Even with a high yield of good quality forage, the quantity conserved would not be sufficient to feed dairy cows through both the dry season and during the rains, when the cow is lactating and may require higher levels of nutrition. Feeding strategy to maximise returns in the form of both milk yield and fertility from a limited amount of silage needs to be determined.

Our research was aimed at addressing all five of these constraints, using formal experimentation and on-farm participatory trials, bearing in mind that participatory research on-farm where there are one or two animals per farm and a wide range of soils and farmer attitudes and management practices inherently incorporates large variation and experimental error. However, the research is meaningful where anecdotal and observational evidence can help to explain the error.

Research activities

A. Formal experimentation

Yield and quality of intercropped forages and legume

i. Biomass yield and quality of sorghum / hybrid *Pennisetum* intercropped with legumes

Introduction

Hybrid *Pennisetums*, forage sorghum, dolichos beans and cowpeas are well adapted to low rainfall areas, such as those in Zimbabwe. Their forage production under mono cropping has been found to be adequate for maintenance purposes in most livestock production systems. Hybrid *Pennisetums* and forage sorghums have also found favour with small-scale dairy farmers as alternative crops to maize silage (Sibanda, 1993). Forage production patterns of hybrid *Pennisetums* have shown that over 50 - 60 % of the annual forage yields are produced during January and February, during which time there is production surplus to grazing requirements in most systems (Gupta and Mhere, 1997, Mhere, 1997). This allows for conservation of the excess for use in the dry season. This study examined the suitability of these four species for intercropping in three planting patterns at two sites with sandy and clay soils. The hybrid *Pennisetum* used in these comparisons was established during the 1995-96 season. Biomass production of the sole and intercrops were assessed during the 1996/97 and 1997/98 seasons.

Materials and Methods

Treatments

The forages tested were one hybrid Pennisetum cv SDPN-3; sweet stem forage sorghum cv Sugargraze; a dual purpose semi-trailing late maturing cowpea cv. TVX 1948 01F and dolichos bean cv Highworth). Density and inter row spacing for each cereal was constant across the three planting patterns. Three planting patterns resulting in different legume densities were used for the intercrops.

The treatments were:

i. Legume and cereal in the same row,

ii. One row of legume mid way between two cereal rows

iii. Two legume rows in between two cereal rows

Between row spacing for sorghum and hybrid Pennisetum was 0.75m and 1.5m respectively. Both legumes had an in-row spacing of 15 cm whilst that of sorghum and hybrid *Pennisetum* was 20cm and 100 cm respectively. Legume sole crop between row spacing was 0.5m. The two cereals were planted in all possible combinations with the two legumes and three planting patterns. The two grasses and two legumes were also grown as sole crops for comparison with the intercrops and to calculate the Land Equivalent Ratio (LER).

Target populations of component crops in each of the three planting patterns

Crop combination	Planting Pattern 1	Planting Pattern 2	Planting Pattern 3
Sole SDPN-3	7 000	7 000	7 000
Sole Sugargraze	70 000	70 000	70 000
Legume with SDPN-3	44 000	44 000	89 000
Legume with Sugargraze	89 000	89 000	178 000

Experimental design

The treatment combinations were arranged in a randomised complete block design with 3 replications at each site. Gross plot size was 6 x 5m^2. Gross plots for the hybrid Pennisetum treatments had four rows 1.5m apart and 5m long while Sugargraze plots had seven rows 0.75m apart and 5m long. Net plot was 3 x 4 m^2.

Experiment management and data collection

Land area used for the experiment was 76.5 x 28.5 m^2, i.e.2180.25 m^2, per site. The sites were ploughed and disced after the first effective rains in both seasons. Plots were marked and basal fertiliser applied using Single Super Phosphate (19 % P_20_5) at 300 kg/ha per site just before planting. Planting of sorghum and the two legumes was done by hand at both sites during mid and early December in the 1996-97 and 1997-98 seasons, respectively. The hybrid *Pennisetum* was established in December 1995 using root cuttings. This was done to enable it to be well established for comparison with the annual sorghum and legumes in the 1996-97 season.

During the 1996-97 and the 1997-98 seasons, all other crops except the hybrid Pennisetum (which is perennial) were replanted on the same plots. Top dressing using Ammonium Nitrate (34.5 % Nitrogen) was done in February during the two seasons on all cereals at a rate of 100kg / ha. Harvesting was done by hand when sorghum had reached the milk dough stage in mid March during both the 1996-97 and 1997/98 seasons, respectively. This was at 14-15 weeks after planting. Cowpea was at the hard dough stage whilst dolichos beans were at the grain filling stage. The hybrid *Pennisetum*, being photosensitive was still in the vegetative stages. All plots were harvested at the same. Fresh weights were recorded and samples taken for dry matter and laboratory analysis with the remainder of the fodder for being ensiled.

Other measurements recorded included the following:

i. Emergence percentage of both components

ii. Tiller numbers on cereal at the time of harvest.

iii. Stem thickness of cereals of harvest. (mm)

iv. Phenological observations

v. Stage of development of all crops at harvesting

vi. Nitrogen content of each component (Macro-Kjeldahl method).

vii. Modified Acid Detergent Fibre (Clancy and Wilson 1966; Goering and Van Soest, (1970).).

viii. Digestibility derived from the Modified Acid Detergent Fibre (Clancy and Wilson 1966).

ix. Disease and pest incidence.

x. Rainfall was measured at both sites whilst evaporation was determined at a site one kilometre away.

Statistical analysis
The 12 factorial intercrop treatment combinations (2 cereals; 2 legumes and 3 planting patterns) were subjected to analysis of variance (ANOVA) using STATISTIX for Windows (1998). The data from the two sites were statistically analysed separately during the two seasons. ANOVA for the combined sites was also carried out.

Data from the 4 sole crops were used to calculate Land Equivalent Ratios (LER).

The LER was calculated using the following formula developed by Willey and Osiru, (1972):

$$LER = \frac{\text{Yield of cereal in mixture}}{\text{Yield of cereal in pure stand}} + \frac{\text{Yield of legume in mixture}}{\text{Yield of legume in pure stand}}$$

Laboratory Analysis
After hand harvesting with sickles, whole plant samples were taken from the intercrops and sole crop treatments and chopped using an electric motor driven chaff cutter. Dry matter was then determined by oven drying the samples at 60 ^{0}C to a constant weight. The samples were milled to pass through a 1mm screen prior to determination of total nitrogen using the Macro-Kjeldahl process. Modified Acid detergent Fibre (MADF) was determined in dry samples as described by Goering and Van Soest, (1970). Dry Matter digestibility was derived from MADF using the formula:

DM digestibility (%) = 99.43-1.17 MADF (Clancy and Wilson, 1966; Linn and Martin, 1992)

Results

Weather Patterns during the 1995 - 96 to 1997- 98 seasons
The weather patterns during the 1995-96, 1996-97 and 1997-98 seasons at Matopos were all characterized by above normal rainfall (figure 2). In terms of rainfall recorded per season over a ten year period 1987-1997 at this site, the 1995-96, 1996-97 and 1997-98 are ranked second, third and fifth respectively after 1987-88 season (fig.1). These weather patterns created an environment which to some extent, inhibited the full expression of intercrop competition during the growing period which would have been the case had the seasons bee normal (ones characterized by low rainfall, severe competition for nutrients and water).

Plant growth and development

Emergence of sorghum, cow peas and dolichos beans was very good during the three seasons. Target plant populations for all components (table 2), were achieved . The hybrid Pennisetum (SDPN-3) established successfully during the 1995-96 season as weather conditions were very favorable. Early vegetative growth patterns of the sole and intercrops were similar at both sites four weeks after planting in all the three seasons. Differences in growth began showing during the sixth week which coincided with the heavy rains. Legume growth was impressive at the clay site during the 1995-96 season resulting in dry matter yields of up to 5 t/ha under intercropping and 10 t/ha in sole plots (table 5.1.1a). Dolichos beans climbed on sorghums in all three seasons but effects of that imparted negatively on biomass production during the 1996-97 and 1997-98 seasons. Failure to withstand pressure from climbing dolichos was compounded by excessive soil moisture during the 1996-97 season at the sandy site leading to reduced yields (table 5.1.1b).

Dry matter yield and quality of forage sorghum and hybrid *Pennisetum* intercropped with cow peas and dolichos beans grown under different planting patterns.

The weather patterns during the 1995/96 and 1996/97 seasons at Matopos were characterized by above normal rainfall (830 and 601 mm versus the long term average of 570 mm). At the time of harvesting (14-15 weeks after planting), the two species had 280 g/kg dry matter (DM) content. Sorghum was at the soft dough stage but still maintaining substantial green leaf material. Sorghum dry matter content increased from 200 to 400 g per kg at 8 and 19 weeks after planting respectively, at both sites. The hybrid *Pennisetum* increased from 200 to 350 g per kg at 8 and 19 WAP, respectively. The critical level of water soluble carbohydrates (WSC) in plant materials for silage below which successful fermentation is in the balance lies between 60 - 80 g/kg DM. The results of the profiles over the two seasons showed sufficient levels of WSC for successful fermentation in both cereals. Sorghum and hybrid *Pennisetum* WSC levels progressively increased from 80 -220 and 50 to 112 g/kg DM at 8 and 19 WAP. Water soluble carbohydrate levels were 120 and 80 g/kg DM at the time of harvesting of sorghum and hybrid *Pennisetum,* respectively. MADF content increased from 320 and 370 to 420 and 480 g/kg DM in sorghum and hybrid *Pennisetum* respectively. The hybrid *Pennisetum* had higher MADF content than sorghum at each sampling stage over the two seasons. Digestibility of sorghum declined from 630 to 500 g per kg DM whilst that of hybrid *Pennisetum* declined from 550 to 440 g per kg DM from 8 to 19 WAP. At both sites during the two seasons, dry matter yields differed significantly between cereals, legumes and their corresponding intercrops (table 511a). Cereal intercrop yields were generally higher at the clay than the sandy site. Legume yields were three times higher at the clay than the sandy site in the 1995/96 season and only 41 per cent more in the 1996/97 season. Sorghum intercrops with either legume had higher yields than with those of hybrid *Pennisetum* in the 1995/96 season but the hybrid *Pennisetum* had higher yields in the 1996/97 season. The sole plots had higher yields than the intercrops at both sites in 1995/96 season but differences in the 1996/97 seasons were marginal. Changing planting patterns caused significant differences in legume and cereal + legume yields at the clay site only ($P<0.001$ and $P=0.05$). During the 1996/97 season, differences were not as pronounced though there were significant differences for legume yields at both sites. Where the legume density of SDPN-3 + cow peas or dolichos beans at planting pattern 3 (PP3) and that of Sorghum + cow peas or dolichos beans at planting pattern 2 was the same (88 889 plants per ha.) yields comparable in the 1995/96 season. During the 1996/97 season, either legume intercropped with sorghum recorded higher yields than its counterpart with the hybrid *Pennisetum (*table 511b). Across all intercrops and planting patterns, mean legume contribution towards total dry matter yield was 44 and 21 in

1995/96, 14 and 19 in the 1996/97 seasons at the clay and sandy site, respectively.

Table 1. Characteristics and nutrient status of soils at the two sites before planting December 1995.

Soil type	Colour	Texture	pH	Nitrogen (ppm)[e]	Avail. P2O5	Exchangeable Cations			
						K2O.	Ca.	Mg.	Total
Clay									
1.	Brown	Mg/Scl[a]	6.3	30	57	0.3	9.26	5.91	15.5
2.	Brown	Mg/SCl	6.4	27	81	0.42	10.99	6.68	18.1
Sands									
1.	LY brown[c]	Mg/LS[b]	5.2	25	5	0.13	1.8	1.6	3.50
2.	LY Brown	Mg/LS	4.9	25	7	0.23	1.66	1.35	3.2

[a]. Medium grained sandy clay

[b]. Loamy sand

[c]. Light yellowish brown

[d]. parts per million

Table 2 Dry matter yield (t/ha) of cereal / legume intercrops: Forage sorghum (SG) and hybrid *Pennisetum* (PN-3) intercropped with cow peas (CP) or dolichos beans (DB) in different planting patterns (PP) under dry land conditions during 1995/96 season.

Treatment	CLAYS				SANDS			
	cereal	legume	Total yield	Leg. % of total	cereal	legume	Total Yield	Legume % of total
PN-3 + CP (PP1)[1]	2.6	3.6	6.2	42.5	2.9	2.0	4.9	40.3
PN-3 + CP (PP2)	2.6	2.1	4.7	43.8	3.7	1.4	5.1	26.9

PN-3 + CP (PP3)	2.3	3.4	5.7	59.8	3.0	1.2	4.2	28.6
SG + CP (PP1)	13.1	3.9	17.0	22.9	10.0	1.8	11.8	15.4
SG + CP (PP2)	12.5	3.6	16.1	22.5	11.1	1.8	12.9	14.0
SG + CP (PP3	11.9	4.9	16.8	29.3	11.6	1.3	12.9	10.3
PN-3 + DB (PP1)	3.2	6.4	9.6	66.5	3.7	1.4	5.1	25.7
PN-3 + DB (PP2)	2.7	3.2	5.9	55.1	3.7	1.7	5.4	30.4
PN-3 + DB (PP3)	3.1	6.5	9.6	67.6	4.2	1.2	5.4	22.3
SG + DB (PP1)	11.1	7.2	18.3	39.4	11.9	0.9	12.8	7.3
SG + DB (PP2)	12.1	5.5	17.6	31.1	10.4	1.7	12.1	14.0
SG + DB (PP3)	8.0	8.4	16.4	51.2	11.8	1.5	13.3	11.0
Mean	**7.1**	**4.9**	**12.0**	**44.3**	**7.3**	**1.5**	**8.8**	**20.5**
C.V %	**22.97**	**26.08**	**13.21**		**18.83**	**40.25**	**16.06**	
<u>Significance</u>[2]								
Cereals (PN-3, SG)	*******	*******	*******		*******	**ns**	*******	
Legumes (CP, DB)	**ns**	*******	*******		**ns**	**ns**	**ns**	
Planting patt. (PP1-3)		**ns**	*******	*****		**ns**	**ns**	**ns**
Interactions								
Cereals x Legumes	*****	**ns**	*****		**ns**	**ns**	**ns**	
Cereals x PP	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**	
Legumes x PP	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**	
Cereals x Leg x PP	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**	
CP (Cow peas)	10.65	-	10.65		5.97	-	5.97	
DB (dolichos beans)	10.09	-	10.09		2.99	-	2.99	
PN -3 (SDPN -3)	3.15	-	3.15		4.15	-	4.15	
SG (Sugargraze)	18.59	-	18.59		10.63	-	10.63	

----

[1]. Planting pattern

[2]. Significance: * P<0.05

** P<0.01

*** P<0.001,

ns = not significant

Table 3 Dry matter yield (t/ha) of cereal / legume intercrops: Forage sorghum (SG) and hybrid Pennisetum (PN-3) intercropped with cow peas (CP) or dolichos beans (DB) in different planting patterns (PP) under dry land conditions during 1996/97 season.

Treatment	CLAYS				SANDS			
	Cereal	Legume	Total yield	Leg. % of Total	Cereal	Legume	Total yield	Leg. % of total
PN-3 + CP (PP1)	7.6	0.3	7.9	3.1	10.1	0.2	10.3	1.8
PN-3 + CP (PP2)	10.2	1.3	10.5	2.6	8.8	0.3	9.1	5.5
PN-3 + CP (PP3)	12.2	0.4	12.6	3.3	9.7	0.1	9.8	1.4
SG + CP (PP1)[1]	9.4	0.8	10.2	4.3	7.7	0.5	8.2	5.9
SG + CP (PP2)	11.3	1.1	12.4	9.3	8.5	0.3	8.8	3.7
SG + CP (PP3)	7.4	1.2	8.6	11.1	9.7	0.4	10.1	4.6
PN-3 + DB (PP1)	10.8	0.8	11.6	7.1	5.1	0.6	5.7	11.2
PN-3 + DB (PP2)	10.1	1.3	11.4	9.7	5.8	0.6	6.4	8.5
PN-3 + DB (PP3)	10.2	1.4	11.6	17.0	3.4	1.9	5.3	35.6
SG + DB (PP1)	9.8	2.4	12.2	19.4	2.4	2.2	4.6	50.5
SG + DB (PP2)	7.2	5.1	12.3	40.9	2.8	2.5	5.3	48.0
SG + DB (PP3)	8.3	5.6	13.9	40.1	3.5	4.5	8.0	55.7

Mean	**9.5**	**1.7**	**11.2**	**14.0**	**6.5**	**1.2**	**7.6**	**19.4**
C.V %	**17.22**	**45.7**	**16.12**		**31.17**	**73.29**	**24.82**	
<u>Significance</u> [2]								
Cereals (PN-3, SG)	*	***	ns		ns	***	ns	
Legumes (CP, DB)	ns	***	**		***	***	***	
Plant patt. (PP1-3)	ns	**	ns		ns	*	ns	
<u>Interactions</u>								
Cereals x Legumes	ns	**	ns		ns	**	ns	
Cereals x PP	*	*	ns		ns	ns	ns	
Legumes x PP	*	ns	ns		ns	*	ns	
Cer. x Leg.x PP.	*	ns	*		ns	ns	ns	
<u>Sole Plots</u>								
CP (Cow peas)	3.45	-	3.45		2.16	-	2.16	
DB (dolichos beans)	4.94	-	4.94		4.72	-	4.72	
PN-3 (SDPN-3)	10.97	-	10.97		9.48	-	9.48	
SG (Sugargraze)	10.02	-	10.02		6.57	-	9.48	

[1]. Planting pattern

[2]. Significance: * P<0.05

** P<0.01

*** P<0.001,

ns = not significant

Table 4 Dry matter yield (t/ha) of cereal / legume intercrops: Forage sorghum (SG) and hybrid *Pennisetum* (PN-3) intercropped with cow peas (CP) or dolichos beans (DB) in different planting patterns (PP) under dry land conditions during 1997/98 season.

Treatment	CLAYS				SANDS			
	Cereal	Legume	Total yield	Leg. % of Total	Cereal	Legume	Total yield	Leg. % of total
PN-3 + CP (PP1)	11.0	0.2	11.2	1.8	6.4	1.1	7.5	14.7
PN-3 + CP (PP2)	6.1	0.4	6.5	6.2	5.7	0.9	6.6	13.6
PN-3 + CP (PP3)	8.3	0.3	8.6	3.5	6.2	0.9	7.1	12.7
SG + CP (PP1)[1]	11.0	1.2	12.2	9.8	5.8	1.5	7.3	20.5
SG + CP (PP2)	9.2	1.2	10.4	11.5	6.8	1.5	8.3	18.1
SG + CP (PP3)	9.5	1.3	10.8	12.0	4.5	2.8	7.3	38.4
PN-3 + DB (PP1)	8.6	0.2	8.8	2.3	5.0	0.6	5.6	10.7
PN-3 + DB (PP2)	8.8	0.1	9.0	1.1	5.6	0.5	6.1	8.2
PN-3 + DB (PP3)	8.3	0.3	8.6	3.5	6.7	0.6	7.2	8.3
SG + DB (PP1)	6.9	2.5	9.4	26.6	2.7	3.6	6.9	52.2
SG + DB (PP2)	7.6	2.6	10.2	25.5	3.7	3.0	6.7	44.8
SG + DB (PP3)	6.8	3.3	10.1	32.7	2.6	3.9	6.5	60.0
Mean	**8.5**	**1.1**	**9.6**		**5.1**	**1.7**	**6.9**	
C.V %	**18.48**	**33.27**	**15.75**		**17.99**	**29.62**	**12.65**	
Significance[2]								
Cereals (PN-3, SG)	**ns**	*******	******		*******	*******	**ns**	
Legumes (CP, DB)	*****	*******	**ns**		*******	*******	*******	
Plant patt. (PP1-3)	**ns**	**ns**	**ns**		**ns**	*****	**ns**	
Interactions								
Cereals x Legumes	******	*******	**ns**		*******	******	**ns**	
Cereals x PP	**ns**	**ns**	**ns**		******	*****	**ns**	

Legumes x PP	*****	**ns**	*****	**ns**	**ns**	**ns**
Cer. x Leg.x PP.	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
<u>Sole Plots</u>						
CP (Cow peas)	3.1	-	3.1	4.1	-	4.1
DB (dolichos beans)	6.6	-	6.6	5.3	-	5.3
PN-3 (SDPN-3)	10.3	-	10.3	7.1	-	7.1
SG (Sugargraze)	11.7	-	11.7	7.7	-	7.7

[1]. Planting pattern

[2]. Significance: * $P<0.05$

** $P<0.01$

*** $P<0.001$,

ns = not significant

Discussion

Many studies have been conducted with mixed crops, the question arises as to what criteria for success are used when interpreting the results. It could be argued that for intercropping to be successful:

- there should be no penalty in total forage DM yield when compared with the host crop grown alone (usually at a sowing rate higher than that used when sown with the legume).
- the CP content of the mixed forage should be significantly higher than that of the host crop when grown alone
- the ME content of the mixed crop should be at least maintained or increased when compared with that of the host crop when grown alone
- from a sustainability perspective, N fixation from intercropping should be at least be equal to cropping rotations where the legume is grown separately as a pure crop.

A limitation with many intercropping experiments with tropical forages, and also temperate forage crops, is that they have not included a range of plant populations for the grass and legume components. In these circumstances it is not possible to identify optimum (or "successful ") mixtures based on the above criteria In our trials plant populations were included in the trial and so interpretation of the success of intercropping has more validity. It is clear that total forage yield of intercropped forage and legume was lower than that of the total of the sole crops of forage and legume- this was consistent over three seasons. It could be concluded therefore that sole cropping is the better system. However, putting this in practice in the communal area small holding is severely constrained by land limitation and labour. Under these circumstances, it can be concluded that while lower, yields are good and most importantly, nutritional quality of the mixed crop is significantly improved over that of the forage crop alone. Notwithstanding that, clearly forage sorghum intercrops more successfully with legume (which is able to climb on the sorghum plant so gaining from more light) than does pennisetum and it may be considered strategic with pennisetums to either grow legume as a sole crop if there is land or use more frequent cutting strategy to provide light advantage to the legume, particularly to a well established stand of pennisetums. ..

ii. Nutrient Profiles in Growth and Development of Forages

Introduction

The maturing process of plants is a complex process that involves numerous changes in plant composition and structure. The composition in turn influences the fermentation process (Goering, Smith, Van Soest and Gordon, 1972). Time of harvesting is critical when ensiling summer forage crops as digestibility and crude protein decline rapidly with advancing maturity (Stobbs, 1975; Wheeler, 1984; Kaiser and Havilah, 1992). Harvesting time of silage crops such as maize and sorghum has been based on the stage of development of the floral components and grain filling. This is because the stage of growth at harvesting is one of the most important factors determining the quality / nutritive value of the resultant feed be it silage or hay (McDonald *et al*., 1987). In photosensitive forage crops such as elephant grass and hybrid *Pennisetum*, time after planting and plant height seem to be the only practicable way to determine stage of harvesting. Maize and forage sorghum for silage are usually harvested at soft dough and early flowering, respectively. This is because of the high proportion of total dry matter present as grain in maize. At soft dough stage of maize, compacting of the crop at ensiling is not difficult compared to the hard dough stage. Air pockets are likely to remain within the crop even with compaction, as long as the dry matter is higher than 400g/kg and at stages after the soft dough. Protein content is at desirable levels at early flowering in forage sorghum but declines thereafter (Stuart, 1993; Kaiser, 1993).

Assessment of the changes in the concentration of quality parameters is necessary in order to come up with a locally appropriate harvesting management that optimises quality and quantity of forage.

This is pertinent when consideration is made of forage crops such as elephant grass and hybrid *Pennisetum* that do not have well established recommendations for silage making in Zimbabwe. The objective of this study was to determine the optimum stage of harvesting forage sorghum and hybrid *Pennisetum* on the basis of nutrient concentrations determined during the different growth stages.

Materials and methods

Treatments

These consisted of two crops, hybrid *Pennisetum* (SDPN-3) and forage sorghum cv. Sugargraze, planted on two soil types (sandy and clay) in two growing seasons (1996/97 and 1997/98). Details of their management are described in Chapter 3. Plants sampled were derived from border rows of one replication of the study.

Design and data analysis

The data on the different quality parameters were plotted to determine if there were any trends in the changes over time. Changes in the concentrations of dry matter (DM), crude protein (CP), water soluble carbohydrates (WSC), modified acid detergent fibre (MADF) and organic matter digestibility (OMD) were graphically plotted for the two crops planted in two soil types during the 1996/97 and 1997/98 seasons using the Sigma Plot (1994) scientific graphing software. Where linear relationships were observed after plotting, regression analysis was carried out using the STATISTIX (1998) computer package.

Sample collection, processing and laboratory analysis
From eight weeks after planting (WAP) in both seasons, whole plant samples of hybrid *Pennisetum* and forage sorghum were collected once a week until 15 WAP.

During the collection of sorghum samples, 5 alternate plants (combined fresh weight of 1.5 kg) were taken from border rows with in-row spacing of 20cm.

For the hybrid Pennisetum, 5 tillers (one tiller per stubble) were cut from each of the plants on the border rows (combined fresh weight of 1.5 kg). The samples were collected from all the three intercrop treatments

After collection, the samples were chopped using a motorised chaff cutter and divided into two parts. The first part was dried at 60 ^{0}C to determine dry matter content (DM) whilst the second part was immediately frozen and later dried at 50 ^{0}C to a constant weight. The latter samples were milled to pass through a 1mm screen before being analysed for CP, WSC and MADF. Crude protein was determined by the Macro Kjeldahl method and the WSC content by a calorimetric method according to Dubois *et al*, (1956). The MADF was determined as described by Clancy and Wilson (1966) and Van Soest and Roberts (1970).

Results

Dry matter content
Profiles for 1996/97 and 1997/98 showed progressive increases in DM content of sorghum and hybrid *Pennisetum* at both sites (Figures 4.1 and 4.2). These increases in DM content in 1996/97 were linear with R^2 >0.95 at P<0.0001 for both crops (Tables 4.1 and 4.2). In 1997/98, the increases in DM content with age were also linear with R^2 >0.96 at probabilities of 0.01 to 0.02 except DM content of hybrid Pennisetum on sand which had P<0.16 (Tables 4.1 and 4.2).

There were site differences at harvesting with higher dry matter values being recorded at the sandy site. There were also species differences across all sampling times, sites and seasons with SDPN-3 generally recording lower dry matter values than sorghum (Figures 4.1 and 4.2). At the time of harvesting in both seasons (14 WAP), sorghum had a DM content of between 310-390 g/kg. At this time, it was at the soft dough stage but still maintaining substantial leaf material. The hybrid *Pennisetum* was still in the vegetative stage with a height of about 150 cm, with minimum leaf losses and with a dry matter content of between 275–320 g/kg (Figures 4.1 and 4.2). Differences between the two seasons showed that DM content of the two species were higher on both soils in 1997/98 than 1996/97 at harvesting.

Water Soluble Carbohydrates (WSC)
The WSC profiles for sorghum and hybrid *Pennisetum* during the 1996/97 and 1997/98 seasons showed considerable differences between the two cereals and soil type (Figures 4.3 and 4.4). The differences were not similar in patterns to those of DM content.

Sorghum had higher levels of WSC than the hybrid *Pennisetum* at all sampling times, soils and seasons.

In 1996/97 the relationships between WSC and age were quadratic for the *Pennisetum* with R^2 of about –0.20 and linear for sorghum with R^2 of 0.53 to 0.94 (Tables 4.1 and 4.2). In 1997/98 both *Pennisetum* and sorghum had WSC contents which were linear with R^2 (Tables 4.1 and 4.2).

At harvesting during 1996/97, levels of WSC content in both crops varied with soil and the patterns lacked consistency (Figures 4.3 and 4.4). The WSC content in hybrid *Pennisetum* in 1997/98 did not decline considerably as did the 1996/97 up to harvesting stage. At harvesting, the WSC was in the region of 85-90 g/kg DM for the hybrid *Pennisetum* whilst the sorghum had about 84-163 g/kg DM at both sites.

The WSC content of both cereals tended to be consistently higher at all sampling times in 1996/97 than the 1997/98 except for sorghum in 1997/98 at harvesting on both soils (Figures 4.3 and 4.4).

Table 5 Regression equations relating age of crop (weeks) to changes in the dry matter (DM), water soluble carbohydrates (WSC), crude protein (CP), modified acid detergent fibre (MADF) and digestible organic matter (DOM) of hybrid *Pennisetum* planted on two soil types, during 1996/97 and 1997/98.

a. Hybrid *Pennisetum*, clay

Year	Equation	Regression coefficient and Probability
1996/97	DM = 174.107 + 6.964 * Age	R^2 = 0.95, P< 0.000
1997/98	DM = -72.50 + 26.07 * Age	R^2= 0.97, P< 0.02
1996/97	WSC = 109.071 - 0.071 * Age	R^2 = -0.20, P< 0.02
1997/98	WSC = 6.607 + 6.32 * Age	R^2= 0.81, P< 0.647
1996/97	CP = 180.79 - 5.357 * Age	R^2 = 0.96, P<0.000
1997/98	CP = 226.071 - 8.643 * Age	R^2= 0.96, P< 0.000
1996/97	MADF = 278.214 + 8.50 * Age	R^2 = 0.94, P<0.000
1997/98	MADF = 130.107 + 22.107 * Age	R^2= 0.98, P< 0.000
1996/97	DOM = 669.286 – 10.000 * Age	R^2 = 0.93, P<0.0003
1997/98	DOM = 841.071 –25.786 * Age	R^2= 0.98, P< 0.000

b. Hybrid *Pennisetum*, sand		
1996/97	DM = 106.071 + 13.214 * Age	R^2 = 0.95, P< 0.001
1997/98	DM = -18.214 + 24.643 * Age	R^2= 0.99 P< 0.16
1996/97	WSC = 92.107 + 0.250 * Age	R^2 = -0.19, P< 0.001
1997/98	WSC = -11.50 +7.357 * Age	R^2= 0.90, P< 0.345
1996/97	CP = 165.071 – 4.643 * Age	R^2 = 0.99, P<0.000
1997/98	CP = 237.429 – 10.429 * Age	R^2 = 0.89, P< 0.000
1996/97	MADF = 287.929 + 6.50 * Age	R^2 = 0.95, P<0.000
1997/98	MADF = 160.89 +19.036 * Age	R^2= 0.96, P< 0.001
1996/97	DOM = 658.071 – 7.643 * Age	R^2 = 0.96, P<0.000
1997/98	DOM = 806.929 – 22.357 * Age	R^2= 0.96, P< 0.000

Table 6 Regression equations relating age of crop (weeks) to changes in the dry matter (DM), water soluble carbohydrates (WSC), crude protein (CP), modified acid detergent fibre (MADF) and digestible organic matter (DOM) of hybrid *Pennisetum* planted on two soil types, during 1996/97 and 1997/98.

a. Forage Sorghum, clay

Year	Equation	R^2 and Probability
1996/97	DM = 123.214 + 13.214 * Age	R^2 = 0.96, P< 0.000
1997/98	DM = -98.57 + 34.286 * Age	R^2 = 0.98, P< 0.01
1996/97	WSC = 182.429 - 3.286 * Age	R^2 = 0.53, P< 0.000
1997/98	WSC = -36.679 + 13.036 * Age	R^2 = 0.94, P< 0.06
1996/97	CP = 163.79 - 4.929 * Age	R^2 = 0.93, P< 0.000
1997/98	CP = 223.75 - 9.964 * Age	R^2 = 0.99, P< 0.000
1996/97	MADF = 294.32 + 8.75 * Age	R^2 = 0.92, P< .0000
1997/98	MADF = 207.86 + 16.43 * Age	R^2 = 0.97, P< 0.000
1996/97	DOM = 651.250 - 10.321 * Age	R^2 = 0.92, P< .0000

1997/98	DOM = 752.50 - 19.357 * Age	R^2 = 0.97, P< 0.000
b. Sorghum, sand		
1996/97	DM = 88.93 + 17.50 * Age	R^2 = 0.98, P< 0.000
1997/98	DM = -63.57 +32.143 * Age	R^2 = 0.99, P< 0.01
1996/97	WSC = 179.25 - 3.892 * Age	R^2 = 0.66, P< 0.000
1997/98	WSC = -48.107 + 15.036 * Age	R^2 = 0.828, P< 0.178
1996/97	CP = 146.214 - 3.643 * Age	R^2 = 0.79, P< 0.000
1997/98	CP = 211.679 - 10.607 * Age	R^2 = 0.89, P< 0.000
1996/97	MADF = 306.179 + 5.607 * Age	R^2 = 0.98, P< 0.000
1997/98	MADF = 271.32 + 8.034 * Age	R^2 = 0.91, P< 0.000
1996/97	DOM = 637.75 - 6.68 * Age	R^2 = 0.98, P< 0.000
1997/98	DOM = 677.57 - 9.429 * Age	R^2 = 0.91, P< 0.000

Crude Protein (CP)
In both soils and seasons and at all sampling times, hybrid *Pennisetum* had higher crude protein than sorghum (Figures 4.5 and 4.6). During the next season (1997/98), there were marked disparities between the species with the sorghum being ensiled 14 WAP at a CP content between 70 – 90 g/kg DM and the hybrid *Pennisetum* at a CP of 99-110 g/kg DM. Differences between the two soil types were also noted with the crops planted in clays recording higher protein levels.

Crude protein content of the two cereals progressively declined with advancing maturity and varying with soil type (Figure 4.5 and 4.6). The decline in CP content was linear with R^2 = 0.89 to 0.96 for the hybrid *Pennisetum* and 0.79-0.99 for sorghum in both seasons and on both soils (Table 4.1 and 4.2).

Differences between the two years showed clearer patterns with sorghum where in both soils, CP content tended to be lower in 1997/98 than 1996/97. Trends with the hybrid Pennisetum lacked consistency with CP being higher 1997/98 and lower in 1996/97 (Figures 4.5 and 4.6).

Fibre content

There was a sharp increase in fibre content of both cereals in both seasons with advancing maturity from an average of 330 and 348 g/kg DM at 8 WAP, to 416 and 406 g/kg DM at harvesting, for hybrid Pennisetum and sorghum respectively (Figure 4.7 and 4.8). There were considerable differences between the two cereals with the hybrid *Pennisetum* recording higher fibre content than the sorghum in both seasons at harvesting.

Soil differences were evident in both seasons with the two cereals planted in clays showing higher fibre content (Figure 4.7 and 4.8). The progressive increase in fibre content was linear with $R^2 > 0.91$ at $P<0.0001$ on both soils and in both seasons. Differences between the two seasons showed that at harvesting, the hybrid Pennisetum or sorghum grown on clay soil had higher fibre content than on sand (Figure 4.7 and 4.8).

Digestibility

Digestible organic matter content of sorghum and hybrid *Pennisetum* decreased in both seasons with advancing maturity from about 600 g/kg DM at 8 WAP to about 500 g/kg DM at harvesting (Figures 4.9 and 4.10). Although differences between the two species occurred, they were not consistent from the first to the second season. Either cereal planted on sand recorded higher digestibility at harvesting than on clay. At harvesting in 1996/97 digestibility was lower than in 1997/98. The decline in digestibility showed linear patterns with $R^2 > 0.91$ at $P<0.000$ (Table 4.1 and 4.2).

Discussion

Dry matter content of forage affects the course of silage fermentation by influencing the rate of fermentation and the numbers of bacteria found on the crop (Courtin and Spoelstra, 1990). The linear increase in dry matter content in both species was expected. The DM content of the hybrid *Pennisetum* at 14 WAP (275 –320 g/kg) fell within acceptable limits for tropical silages, whilst the sorghum DM of 310 -390 g/kg was higher than normally required for successful silage making (Mc Donald, 1981).

Sorghum DM content was higher due to presence of grain and dry lower leaves on stems. However, because of the high WSC content in the sorghum used in this study, pH of silage made from such biomass is expected to be lower than 4.0 and without effluent produced. The higher DM content of biomass from both cereals on sand than on clay was due to the drying of lower leaves of both cereals and wilting of sorghum caused by water logging.

The higher DM content of biomass in 1997/98 than in 1996/97 was due to the generally drier conditions at 12-14 WAP at both sites. A total of 88mm was recorded in March and April in 1996/97 compared to only 31mm during the same time in 1997/98. In both seasons, if the possibility of harvesting early was to be considered, DM content of the two cereals at 12 WAP was ideal and DM being high enough not to warrant any wilting as it ranged between 280-330 g/kg in sorghum and 240-280 in the hybrid *Pennisetum* at both sites. Wilting would certainly be required in forage with DM content which is lower than 200 g/kg, as a lot of effluent would be produced and more feed energy used in the fermentation process (McDonald, 1981 and Webster, 1993).

The increase in WSC content of sorghum in 1997/98 with age is consistent with patterns typical of sweet sorghum (Havilah and Kaiser, 1992, Stuart, 1993). The levels found in this study for the sweet sorghum (120–160g/kg DM are similar to findings by Cole et al. (1996) with the same sorghum variety (Sugargraze) at 14 WAP in Australia. Levels of WSC found in this study in both sorghum and hybrid *Pennisetum* fall within the acceptable limits for tropical forages. Wilkins (1981) and McDonald (1981) stated that at least 25 g/kg WSC in fresh weight of the crop is required for well-preserved silage to be made without additives. Levels of WSC in the *Pennisetum* agree with findings by Woodard *et al*., (1991) who also indicated that WSC levels increased with frequent cutting. This suggests that, under intercropping, harvesting of the hybrid *Pennisetum* more than once to achieve satisfactory yields of companion legumes as recommended in Chapter 3 could result in quality parameters such as WSC being enhanced.

In sweet sorghums, the juiciness slows the dry down and increases the harvest window (Havilah and Kaiser 1992). In this study this relative stability in WSC content was evident especially in 1996/97 on both soil types where the hybrid *Pennisetum* maintained WSC contents at higher than 90 g/kg DM between 8 and 13 weeks.

Similarly sorghum maintained a WSC content of about 140 g between 9 and 12 weeks. These findings are similar to those reported by Havilah and Kaiser (1992) where WSC content of sorghum showed relative stability over a period of six weeks between milk and hard dough stage. It is therefore reasonable to suggest that sweet sorghum offers flexibility in harvesting management in that the crop can be harvested later without considerable loss in WSC content or earlier with limited wilting if DM content is below 300g/kg.

The decline in CP content of both cereals with age was expected as found in other studies (Thomas and Thomas, 1983 and Stuart, 1993). This was caused by corresponding increases in indigestible fibre in the stems of the plants. Trends in CP content of the two species with age suggest that harvesting recommendations must be species specific. This is because, for sorghum at 14 WAP, the CP content had declined to levels that can only sustain livestock for maintenance purposes (70-90 g/kg DM) (Humphreys, 1991). That of the hybrid *Pennisetum* at 14 WAP (99-110 g/kg DM) was still lower than the 120 g/kg DM which was more than required for maintenance purposes but lower than required for growth and production (Topps and Oliver 1993).

Differences between soil types in both seasons were expected, as there are inherent differences between clay and sand soils in fertility as shown by low nitrogen (N), phosphorous (P) and potassium (K) content in the nutrient analysis done prior to planting. In addition there are differences in water holding capacity (higher on clay than sand) that would determine the degree of leaching nutrients. Biomass from the clay soil would therefore be higher in CP content than on sand. The site differences reported in this study are similar to those reported in the high rainfall areas of Zimbabwe (Moyo, 1996).

Seasonal differences in respect of CP content of the two species were caused by excessive leaching as a result of the heavy rains (238 mm) received in January of the 1997/98 season which also caused waterlogging at the sandy site.

The MADF and Digestibility patterns showed a clear inverse relationship, which was expected because as plants mature, accumulation of cell wall constituents and lignin takes place (Heath, Barnes and Metcalfe, 1985). The higher fibre content at harvesting in the hybrid *Pennisetum* than in sorghum reflects the *Pennisetum* its rapid growth compared to sorghum. The higher fibre content of both cereals on clay than on sand were due to better fertility and other growth factors on clay which resulted in better growth, taller plants resulting higher biomass production. It is established that faster growing crops have higher fibre content than slower growing species (Van Soest, 1970).

The decrease in digestibility of the two cereals with advancing maturity was as expected for such tropical forages. The higher digestibility on sand than on clay was explained by the fact that growth was slow on sand, so rate of accumulation of cell wall and lignin content was lower than on clay. In addition, the short-term stress caused by excessive moisture at the sand site in both seasons led to relatively poor growth of both cereals with more leafy fractions than stems at harvesting. Such periods of stress in plants have a tendency of causing a slow down or suspension of the ageing process, leading to lower cell wall and lignin content in the biomass (Wilson, 1984). Digestibility of stressed plants is usually higher than unstressed plants (Wilson, 1982). This implies that animal live weight gains could therefore be supported on such biomass as long as yields are sufficient for intake requirements.

Lack of consistency in the differences between species from 1996/97 to 1997/98 is explained by the fact that differences between rainfall amounts have variable effects on perennial (hybrid *Pennisetum*) and annual (sorghum) crop (ICRISAT, 1987).

In the hybrid *Pennisetum*, the differences between seasons were more evident than differences between soil types and yet with sorghum, it was the opposite. Unlike the hybrid *Pennisetum*, the sorghum crop failed to recover after the waterlogging. This result is suggestive of important interactions between species, soil and rainfall, which should be considered in selection of forage species and their management in different soil type.

From the point of view of nutritional quality and forage quantity, these results show the practical difficulties likely to be faced by farmers in deciding when to harvest these forages on different soil types and in different seasons. However, the differences between the two species in nitrogen and digestibility point to the need to manipulate the harvesting management. Crude protein content of the hybrid *Pennisetum* at 12 WAP ranged from 105-122g/kg DM compared to 99-110 at 14 WAP whilst DOM content ranged from 522-571 g/kg DM compared to 477-549 g/kg DM at 14 WAP in both soils. For sorghum, at 12 WAP, CP ranged from 80-109g/kg DM compared to 71-93 at 14 WAP whilst DOM content ranged from 520-569 g/kg DM at 12 WAP compared to 491-545 g/kg DM at 14 WAP in both soils. The CP and DOM content at 12 weeks are capable of supporting livestock production beyond maintenance purposes (Topps and Oliver 1993). Harvesting the fast growing *Pennisetum* two times (January and March) a season which would ensure better quality or, harvesting once but earlier e.g. at 12 weeks and wilt the forage to raise dry matter. After ensiling, the levels would be lower than at the stage of harvesting due to fermentation losses.

Overall, the overall increase in DM, WSC and fibre content and decrease in CP and digestibility of the sorghum and hybrid *Pennisetum* with advancing maturity reported here is typical of tropical grasses and agrees with earlier findings by Catchpoole (1951), Webster and Davies (1956), Minson (1961), Danely and Vetter (1973) and Stuart (1993). The ranges in the nutritional changes with time found in this study also agree with studies by Black and Ely (1980), Kaiser *et al.*, (1992) and Titterton *et al.*, 1997. These results showed that harvesting 12 weeks after planting in environments similar to the study sites might result in satisfactory forage quality for silage, which could meet the needs of most classes of livestock.

2. The use of low-cost technology and other interventions to produce high quality silage

i Harvesting, chopping and compressing silage.

Introduction

The objectives of this study were to examine ways of overcoming the major constraints to small holder farmers when ensiling forages, the use of high-cost machinery traditionally used in chopping and compressing forage on large-scale farms and unsuitable silos. Labour and gender issues were addressed as both are important in the small holder dairy farming system.

Materials and Methods.

Treatments
The treatments consisted of:

- Five forages (including two mixes): forage sorghum-dolichos bean; pennisetum-dolichos bean; forage sorghum; pennisetum; dolichos bean.
- Two particle sizes (length of chop):- coarse chop (mean 45 mm) from the use of large knives (pangas), fine chop (mean 18mm) from the use of a motor driven chaffer.
- Two methods of compression:- mechanical from the use of a manual tobacco press with a screw press driven down on a metal plate covering the bag followed by twisting the top of the bag for tying with twine; manual, with simply leaning on the bag accompanied by pushing out air pockets before twisting the top of the bag for tying with twine.
- Two types of silos: recycled plastic garbage bags large enough to carry 50 kg (90-100 micron thickness); fertiliser/maize bags large enough to carry 50 kg of fertiliser (+ 125 micron thickness. The bags were, however, filled to carry 15 kg of silage, the amount estimated to comprise the daily total required to supplement an indigenous milking cow grazing natural pasture.

Samples were taken of the crop material at the time of bagging and analysed for dry matter content. Once sealed, the bags were weighed. The bags were weighed again every seven days for the next four weeks and then at opening at the beginning of October, when the silage was 22 weeks old (six weighings in total). On opening, the bags were subjected to visual and sensory evaluation. They were then sampled for the following analysis:

<u>Fermentation quality.</u> : pH, dry matter loss, lactic acid content, volatile fatty acid content and NH_3:N ratio.

<u>Nutritional quality:</u> Crude protein (g/kg dry matter), acid detergent fibre (% dry matter), neutral detergent fibre (% dry matter), digestible organic matter

Three 500g samples per bag were taken for determination of dry matter, pH, Ammonia nitrogen (NH_3-N), total nitrogen (TN), modified acid detergent fibre (MADF) and Digestible Organic Matter (DOM). The silage from each bag was thoroughly mixed before getting the three 500g samples per bag. Four hundred grams from each of the three 500g samples were dried at 60 ^{0}C for 48 hrs and milled to pass through 1mm screen before determination of TN and MADF.

Silage pH

Of the three 100g samples left after drying the 400g for TN and MADF, 50 g of fresh silage were taken and used for determination of silage pH. The 50g silage was placed in a 500 ml beaker and 125ml of distilled water added. The mixture was shaken on a shaking machine for one hour before decanting the extract in a beaker. Electrodes from a pH meter (Orion type, readable to 0.05 pH units), were immediately inserted into the extract and recorded the pH reading after 30 seconds. Whilst the pH meter was being used, periodic checks that the correct pH reading was observed was done by way of placing the electrodes in one of the buffer solutions (pH 4 or 7).

Ammonia Nitrogen

A further 20 g of silage was transferred into a 250 ml bottle and 100ml of distilled water added. The bottles were shaken using a shaking machine as was done for pH. The contents of each bottle were filtered through a 150 or 180 mm Whatman No.1 filter paper and the filtrate used to determine NH_3-N as briefly described below. Using a pipette, 5ml of Ammonium-nitrogen standard solution was placed into a 100ml flask where 10 ml of the aliquot had been added. Six millilitres of magnesium hydroxide suspension was added to the same flask to make the aliquot of the extract alkaline before steam distillation to liberate ammonia into 5ml of boric acid solution. 35-40ml of the distillate collected in 5 minutes was titrated with 5mM Sulphuric acid.

Total nitrogen

Total nitrogen was determined by the Macro-Kjeldahl method on the dried silage samples. The process involved conversion of organic nitrogen in the samples to ammonia by digestion with concentrated sulphuric acid (H_2SO_4) and a catalyst - Selenium. Distillation of the digest with Sodium hydroxide (NaOH) followed to liberate ammonia, which was collected in a volume of boric acid. Total nitrogen was then determined by titration with standard H_2SO_4.

Modified Acid Detergent Fibre

This method is a modification of the conventional Acid Detergent Fibre determination. The modification involved increasing acid strength and prolonging the reflux to 2 hours. Apart from these two modifications, the rest of the procedures are as described by Goering and Van Soest (1970) This method was adopted on account of the ability to relate the determined fibre content empirically to digestibility, and also estimating the Metabolisable Energy (ME) of the feed being analysed.

Digestible Organic Matter (DOM)

The *in-vivo* and *in-vitro* methods of determining digestibility of feeds were not used on account of time and logistical constraints. Digestible Organic Matter was therefore derived from MADF described above using the relationship: *Digestibility = 99.43-1.17 (MADF)*

Experimental design

The experimental design was a 2 x 4 x 4 randomised design with four replicates. Descriptive statistics were carried out on the data. A Friedman two way non parametric analysis of variance was carried out on the general data. for mean ranking and for chi-squared approximation. Two-paired T-tests were carried out on paired samples to assess the effect of treatment and crop variety.

Results and discussion

With the exception of coarsely chopped, non-pressed lablab, all silage samples looked and smelt either reasonably good or very good, the latter being particularly so in the sugargraze (sorghum) silages. This was verified by the fact that the pH was below 5.0 and the dry matter loss was below 20% in all silages and that sugargraze silages ranked best in pH and dry matter loss.

There were differences in fermentation and nutritional quality of silages due to grass crop variety but none due to chop length, compression treatment or type of bag (Table 4).

Table 6. Fermentation quality of forage crops ensiled under differing conditions. (From Kipnis *et al*., 2001)

Crop material	Dry matter	pH	NH3:N	Lactic	Butyric	Acetic	Ethanol
All sorghum							
(FS)	9.36	3.7	6.07	5.63	0.05	2.04	2.12
All pennisetum							
(PS)	18.0	4.3	6.99	4.25	1.17	1.89	0.97
FS/DB	12.3	3.78	8.37	6.55	0.3	2.34	0.72
FS only	7.15	3.63	8.85	4.76	0.07	1.74	2.81
PS/DB	16.46	4.25	12.2	2.32	1.7	2.42	0.68
PS only	19.79	4.4	9.71	1.92	0.57	1.34	0.72
Making techniques (all materials)							
fine chopped	12.43	3.84	7.4	4.65	0.50	2.12	1.22
coarse chopped	15.31	4.20	9.7	4.62	0.72	1.8	1.6
tobacco press	15.04	4.05	7.5	4.18	0.5	1.74	1.38
hand -press	12.88	4.01	8.2	3.59	0.67	2.13	1.45
garbage bags	11.56	4.34	8.8	4.26	0.45	1.43	0.95
fertilizer bags	9.11	4.04	7.3	4.77	0.22	1.66	1.21

Therefore, on-farm silage can be made in non-permeable plastic bags with coarsely chopped crop material, which is compressed by hand if there is no mechanization available. Notwithstanding that, labour and time constraints led to the accepted use of the petrol-driven chopper on -farm. This type of chopper is available on hire to dairy farmers, whose cooperatives are members of the dairy development programme in Zimbabwe. Collaborative studies carried out in Israel (Ashbell, *et al*., 1999; Kipnis *et al*., 2001) suggested that success of ensilage, despite the lack of fine chopping and partial compression, is due to effective sealing of the bags, preventing the loss of effluent containing lactic and volatile fatty acids, compared with pit or bunker silages, where loss of effluent is high, necessitating fine chopping and effective compression.

The technology is found to be ideal for smallholder farmers as losses are minimal, compared with silage pits, which have been used in smallholder dairy farms in the higher rainfall areas, where silage losses amount to as much as 30% of the dry matter due to poor compression and exposure losses in the remainder during removal for feeding. The bag technology has also been found to benefit women and children, as the bags can easily be stored and carried to the cows for feeding, thus there is minimum labour in feeding compared with daily digging out from pits. The nutrient requirements of a cross-bred Tuli/Jersey cow producing 8 litres a day are met from 5 kg silage dry matter per day, which equates to one bag of 15 kg of air-fresh silage per day (Nyoni, *et al*., 2000).

The fertilizer bags, being thicker, could be used over two seasons. This makes their present cost (2002, Zim$9.00) equivalent, when used over two seasons, to the cheaper bags (present cost around Zim$4.50). When no longer usable, the bags can be used for the manufacturing of wax for floor polish, a traditional practice in most small holdings. Some losses (5%) in the cheaper bags were experienced due to poor packing of bags in the silage storeroom, a problem requiring attention

ii Optimum ratios of mixing legumes and cereals at ensiling and assessment of the commercial additive Sil-All on silage of these different mixtures.

Introduction

The basic principle of mixed crop silage is to ensile the crops in a particular ratio or ratios in order to get desirable fermentation patterns. These ratios should be based on either volume or mass of the crops being ensiled. Broadly, it is known that while "cereal" forages have adequate content of water soluble carbohydrates to ensile successfully, they are low in protein content and therefore inadequate in terms of nutritional balance as a feed. Protein-rich plants, especially legumes, on the other hand, have inadequate levels of water soluble carbohydrate to prevent buffering from their proteins and hence poor ensilage qualities. Mixing the two should provide both fermentation and nutritional qualities to ensure well-ensiled and nutritional feed.

There is inadequate information on the desirable or appropriate proportions of cereals and legumes that would result in good quality silage when mixed at ensiling. Determination of desirable ratio(s) of cereal / legume at ensiling is important because critical agronomic decisions such as the planting patterns and the right densities of intercrops to plant can be based on the ratios. Alternatively, an optimum range of ratios is required to fit what has been shown to be successfully produced agronomically. An experiment where cereals / legumes were mixed in all possible ratios was carried out to identify this optimum range of ratios of mix which could result in desirable fermentation patterns and silage quality. A preliminary study in which ratios from 90:10 to 10:90 cereal/legume, without replications was first carried out during the 1995/96 season (Appendix 1a). Results of this preliminary trial were used to narrow down the ratios from 9 to 6 (40:60 to 90:10) as described below.

Materials and Methods.

Treatments

These consisted of forage sorghum or hybrid *Pennisetum* mixed with either dolichos bean or cowpea. Six ratios of mix ranging from 40:60 to 90:10. The 2 cereals and 2 legumes were also ensiled as sole crops (controls). One set of the treatments was ensiled with an additive (Sil-All).

Experiment design and data analysis

The 2 cereals, 2 legumes and six ratios were replicated thrice, with or without the additive. The quality parameters measured in this experiment were plotted against the cereal: legume ratio for each species combination to see how quality was affected by legume content, and regression analysis done. Where no curvilinear relationships were found, appropriate transformations were performed on the data first.

Silage preparation and measurements

The crops used in this study were grown in large unreplicated plots (60m * 20m) at the clay site described in the agronomy trials, during the 1996/97 and 1997/98 seasons. At harvesting, cowpeas was at the soft dough stage whilst forage sorghum at late flowering to grain filling stage and the hybrid *Pennisetum* and dolichos bean were in the late vegetative stage. The crops were harvested using sickles and chopped using a motorised chaff cutter before ensiling. A graduated container was used to determine volumes of the different crops. Weights of each component with mixes of hybrid *Pennisetum* or sorghum and cowpeas or dolichos in all ratios were recorded. Polythene bags (50 kg, size 1016 x 960 mm, and 125 microns) were used as the laboratory silos. Anaerobic conditions were achieved by consolidating / pressing the fresh material in the bags with a manual tobacco press before sealing of the bags airtight. The bags were stored in a closed room that was made rat and ant proof and opened for sampling after 10 weeks.

Sampling, sample preparation and laboratory analysis

At the end of 10 weeks, three 500g samples per bag were taken for determination of dry matter, pH, Ammonia nitrogen (NH_3-N), total nitrogen (TN), modified acid detergent fibre (MADF) and Digestible Organic Matter (DOM). The silage from each bag was thoroughly mixed before getting the three 500g samples per bag. Four hundred grams from each of the three 500g samples were dried at 60 ^{0}C for 48 hrs and milled to pass through 1mm screen before determination of TN and MADF. The analysis of nutrient and fermentation quality was carried out described above in trial (i).

Statistical analysis

The quality parameters determined were plotted against the cereal / legume ratio for each species combination to see how quality is affected by proportion of legume followed by regression analysis.

Results

Table 7 Optimum ratio of cereal (C) to legume (L) in mixed crop silage made from hybrid *Pennisetum* (SDPN-3), forage sorghum (SG), cowpea (CP), and dolichos bean (DB), and effects of a commercial additive on silage quality of these different mixtures in the 1995/96 season.

		Without Sil-All additive				With Sil-All additive			
C : L Ratio	Treatment details	Dry Matter (g/kg DM)	pH	NH3.N % of Total N	Crude Protein (g/kg DM)	Dry Matter (g/kg DM)	pH	NH3.N % of Total N	Crude Protein (g/kg DM)
10 : 90	SDPN-3 + CP	390	4.3	5.9	155	350	4.4	9.2	153
10 : 90	SDPN-3 + DB	300	4.0	4.7	134	280	3.9	6.2	156
10 : 90	SG + CP	350	4.3	5.4	145	350	4.1	6.5	157
10 : 90	SG + DB	300	4.3	6.4	139	310	4.2	5.5	151
20 : 80	SDPN-3 + CP	320	4.4	6.4	133	320	4.2	9.8	143
20 : 80	SDPN-3 + DB	270	4.4	5.1	128	250	4.0	5.0	150
20 : 80	SG + CP	360	4.2	4.4	138	320	4.0	6.1	138
20 : 80	SG + DB	290	4.0	4.4	126	280	4.6	3.7	140
30 : 70	SDPN-3 + CP	340	4.3	6.0	139	300	4.2	6.0	167
30 : 70	SDPN-3 + DB	270	4.2	7.7	127	280	3.8	6.4	146
30 : 70	SG + CP	330	4.1	4.7	137	320	3.8	6.0	138
30 : 70	SG + DB	300	4.0	4.6	124	320	4.0	3.8	134
40 : 60	SDPN-3 + CP	320	3.9	7.4	131	330	3.9	7.1	147
40 : 60	SDPN-3 + DB	280	4.5	6.3	124	260	4.2	6.8	133
40 : 60	SDPN-3 + CP	320	4.2	4.3	114	320	4.0	4.1	130
40 : 60	SG + DB	310	3.9	4.2	116	310	3.7	3.2	127
50 : 50	SDPN-3 + CP	270	3.9	5.4	129	310	3.8	5.5	144
50 : 50	SDPN-3 + DB	280	4.0	5.6	114	250	3.9	4.5	129
50 : 50	SG + CP	340	4.0	4.5	118	320	3.9	4.0	126
50 : 50	SG + DB	310	4.0	4.7	111	320	4.0	4.2	127

60 : 40	SDPN-30 + CP	270	4.7	6.9	126	270	4.4	4.7	121
60 : 40	SDPN-3 + DB	260	4.2	4.5	110	250	3.9	4.2	123
60 : 40	SG + CP	330	3.9	4.1	113	320	3.7	3.7	127
60 : 40	SG + DB	310	4.1	4.8	109	320	3.9	3.4	123
70 : 30	SDPN-3 + CP	300	4.0	6.0	128	280	3.6	4.1	114
70 : 30	SDPN-3 + DB	310	4.0	3.3	113	260	3.2	3.7	110
70 : 30	SG + CP	320	3.9	3.5	120	320	3.2	3.9	119
70 : 30	SG + DB	330	3.9	3.8	105	320	3.3	3.5	120
80 : 20	SDPN-3 + CP	350	4.4	5.6	104	330	3.8	4.0	112
80 : 20	SDPN-3 + DB	280	4.0	4.0	107	260	3.9	3.9	109
80 : 20	SG + CP	320	4.0	4.5	96	330	3.9	3.1	105
80 : 20	SG + DB	330	4.3	3.1	95	350	3.9	2.8	111
90 : 10	SDPN-3 + CP	350	3.9	4.0	98	330	3.9	3.9	114
90 : 10	SDPN-3 + DB	270	3.9	4.6	100	260	3.7	3.7	97
90 : 10	SG + CP	310	4.0	3.4	92	330	3.8	3.2	110
90 : 10	SG + DB	330	4.0	3.3	89	340	3.9	2.8	103
100 %	SDPN-3	260	4.5	5.2	100	240	4.2	4.2	99
100 %	SG	320	4.2	6.5	89	300	3.3	5.5	85
100 %	CP	400	4.7	8.0	168	370	4.4	6.0	160
100 %	DB	300	4.8	8.7	146	280	4.3	6.7	138
Mean		**313**	**4.2**	**5.1**	**119**	**304**	**3.9**	**4.9**	**128**

Table 8 Optimum ratio of cereal (C) to legume (L) in mixed crop silage made from hybrid *Pennisetum* (SDPN-3), forage sorghum (SG), cowpea (CP), and dolichos bean (DB), and effects of a commercial additive on silage quality of these different mixtures in the 1996/97 season.

		Without Sil-All additive				With Sil-All additive			
C : L	**Treatment**	**Dry**	**pH**	**NH3.N**	**Crude**	**MADF**	**Dry**	**pH**	**NH3.N**
	Crude	**MADF**							

Ratio	details Protein (g/kg DM	Matter (g/kg DM)		% of Total N	Protein (g/kg DM)	(g/kg DM)	Matter (g/kg DM)		% Total	of (g/kg DM)
40 : 60	SDPN-3 + CP 336	243	4.2	4.1	147	366	281	3.7	6.2	162
40 : 6	SDPN-3 + DB 341	293	3.8	5.7	149	375	257	3.6	5.2	155
40 : 60	SG + CP 334	408	3.9	2.6	141	352	335	3.7	8.6	141
40 : 60	SG + DB 342	235	3.6	5.1	146	335	273	3.5	5.5	146
50 : 50	SDPN-3 + CP 339	269	3.9	4.5	137	373	319	3.8	4.3	147
50 : 50	SDPN-3 + DB 346	246	3.4	7.0	139	352	246	3.6	5.2	149
50 : 50	SG + CP 338	308	3.5	4.5	131	373	330	3.5	5.8	138
50 : 50	SG + DB 346	279	3.5	4.6	135	370	330	3.4	6.6	136
60 : 40	SDPN-30 + CP 343	239	4.2	5.5	133	366	272	3.8	7.5	138
60 : 40	SDPN-3 + DB 351	253	4.0	6.7	139	408	242	3.6	6.0	135
60 : 40	SG + CP 342	287	3.6	5.1	121	366	306	3.4	8.3	122
60 : 40	SG + DB 353	256	3.5	7.1	125	395	241	3.4	7.5	120
70 : 30	SDPN-3 + CP 350	242	4.4	8.2	122	352	250	3.7	6.2	134
70 : 30	SDPN-3 + DB 356	274	3.7	5.4	119	361	231	3.7	5.6	129
70 : 30	SG + CP 346	240	3.8	7.9	119	389	286	3.4	6.5	119
70 : 30	SG + DB 356	256	3.6	6.1	106	376	259	3.3	8.3	115
80 : 20	SDPN-3 + CP 355	250	4.1	7.4	101	402	263	5.0	5.2	128

80 : 20	SDPN-3 + DB 362	242	3.6	8.9	104	402	244	3.6	5.6	121
80 : 20	SG + CP 352	259	3.4	8.3	97	372	257	3.3	6.3	111
80 : 20	SG + DB 360	263	3.4	7.4	101	390	272	3.4	5.8	110
90 : 10	SDPN-3 + CP 361	314	4.5	6.1	108	333	216	3.7	4.5	123
90 : 10	SDPN-3 + DB 369	248	3.8	7.2	103	331	221	3.4	5.2	118
90 : 10	SG + CP 357	245	4.1	4.7	112	325	263	3.4	4.9	112
90 : 10	SG + DB 376	280	3.8	3.7	101	323	263	3.2	4.3	107
100 %	SDPN-3 389	240	3.7	4.5	108	409	244	3.4	3.5	118
100 %	SG 393	235	3.8	3.5	89	423	259	3.2	4.2	98
100 %	CP 318	288	3.9	6.2	148	308	373	4.2	9.5	167
100 %	DB 307	279	4.0	5.1	154	304	274	4.4	8.8	165

Mean

Discussion

Fermentation was good at all ratios in terms of pH and ammonia produced. The optimum range of ratio however in terms of nutrient quality lay between (forage :legume) 50:50 to 70:30 where there is an increase of between 12 and 25 % in protein content respectively.. This matched the ratio of forage legume in total dry matter yield of the inter-crops. on sand soils. Since sand soils are prevalent in the communal farming lands in the semi-arid areas, it can be concluded that given that yields reflect the same ratios on farm, optimum forage-legume ratio is achieved in the 1:1 or 1:2 planting pattern of intercropping forage with legume. The addition of Sil-All additive had no beneficial effect on fermentation at any ratio but for reasons not understood in this study, dry matter content, digestibility and protein content were improved.

iii A comparison of the effect of commercial additive (SilAll) with local or farm-produced additives on fermentation and nutritional quality of mixed crop silages.

Introduction

Apart from wilting farmers can also use silage additives to improve silage quality and reduce silage losses. Most of the chemical additives (the fermentation inhibitors - McDonald *et al., 1991*) are likely to be uneconomic in developing countries like Zimbabwe, but byproducts that provide a rich source of fermentable carbohydrates to stimulate the silage fermentation are likely to be more feasible The most successful additive in this category is molasses. It has been shown to improve the preservation of both temperate and tropical species (McDonald et al., 1991) including tropical forage crop legumes (Morris and Levitt, 1968) and tree legumes (Alli et al., 1984). Even with very low DM grass, molasses addition will improve silage preservation (Piltz et al., 1999). This is likely to be useful for early cut pennisetum, which occurs in January during the rains. With higher DM silages (> 30%) lactic acid inoculants have shown potential as silage additives (Wilkins, 1996) but their use in developing countries may be limited by the availability of adequate transport and refrigerated storage facilities. An alternative source (and likely to be more easily available than molasses) of fermentable carbohydrate is sweet sorghum, a sugar-cane like forage which is grown widely in this region. Their efficacy with tropical forages needed evaluation.

Materials and Methods.

Treatments

These consisted of hybrid *Pennisetum* or forage sorghum mixed with cow pea or dolichos bean. Mixed crop silage with no additives served as a control.

Experimental design and data analysis.

A randomised block design in a factorial structure was used. There were 3 replications, i.e. 3 bags of silage each made from material from a different replication. The data from this experiment were analysed as a 2*2*3 factorial using the statistical package, STATISTIX, (998). The data collected were initially analysed within each season and then across seasons.

Silage preparation and measurements

Ensiling of these crop mixtures was done immediately after harvesting of the agronomic experiment described in Chapter 3. Cereals and legumes were mixed in the ratio of 70:30 by volume. This ratio fell within the range that has been found to be optimum (60:40 - 70:30) in past research findings with other species/mixtures (Kaiser and Lesch, 1977; Ojeda and Diaz, 1990 and 1994; Titterton and Maasdorp 1997.

Maize meal, ground to pass through a 3 mm screen was added at 5 % by fresh weight of the crop mixtures and Sil-All at 20 ml Sil-All solution per 10 kg of biomass. The crop mixtures and the additives were thoroughly mixed. Measurements that were recorded on the silages included DM, pH, NH_3-N of Total Nitrogen (TN), Total nitrogen from where CP was derived, ADF, DOM (calculated from MADF), Metabolisable Energy (Mega-joules /kg DM) which was derived from DOM.

Sampling, sample preparation and laboratory analysis

This was carried out as described in the above two experiments.

Results

There were significant ($P < 0.05$ to $P < 0.001$) differences between additives for silage DM, pH, NH_3-N (% of TN), CP, MADF, DOM and ME during the 1996/97 and only DM and CP during the 1997/99 season (table 15 and 16). When combined over the two seasons, there were significant differences ($P<0.01$- $P<001$), between additives for all variables except for pH (table 17). In the two seasons, silage treatments where Sil-All was added had lower DM, CP, MADF, higher NH_3-N (% of TN), DOM and ME than the control and those where maize meal was added. Differences between cereals were significant ($P<0.01$-$P<0.001$) for DM, pH, NH_3-N and CP during the 1996/97 and for NH_3-N, CP and DOM during the 1997/98 season (table 15 and 16). Across the two seasons, significant differences ($P<0.001$) between cereals were recorded for DM, pH and CP (table 17). Over the two years differences between legumes were significant ($P<0.01$ – $P<0.001$) for DM, pH, MADF, DOM and ME (table 17). The DM content of the forage sorghum was generally higher than that of the hybrid *Pennisetum*. In both seasons, CP content of all cereal / legume combinations was significantly raised by addition of additives (tables 15 and 16). During the 1996/97 season, significant interactions between cereal and legume, cereal and additive, legume and additive as well cereal and legume and additives were recorded for pH and CP (table 15). However, during the 1997/98 season, only interactions between cereals and legumes were significant for DM (table 16). Over the two seasons, interactions between cereals and legumes were significant for DM and pH (table 17).

Table 15 Fermentation and quality of silage made from Sorghum (SG) and hybrid *Pennisetum* (PN-3) mixed with Cowpea (CP) or Dolichos bean (DB) as affected by additives during 1996/97 season.

Table 8 Optimum ratio of cereal (C) to legume (L) in mixed crop silage made from hybrid *Pennisetum* (SDPN-3), forage sorghum (SG), cowpea (CP), and dolichos bean (DB), and effects of a commercial additive on silage quality of these different mixtures in the 1997/98 season.

		Without Sil-All additive					With Sil-All additive				
C : L Ratio	Treatment details	Dry Matter (g/kg DM)	pH	NH3.N % of Total N	Crude Protein (g/kg DM)	MADF (g/kg DM)	Dry Matter	pH	NH3.N % of Total	Crude Protein (g/kg DM)	MADF (g/kg DM)
40 : 60	SDPN-3 + CP	320	4.2	9.1	155	404	350	4.2	10.1	148	407

40 : 6	SDPN-3 + DB 396	305	3.8	6.1	141	434	265	3.7	6.0	135
40 : 60	SG + CP 370	4.0	5.0	132	391	370	4.0	5.8	126	417
40 : 60	SG + DB 275	3.8	8.1	132	386	270	3.7	5.7	157	436
50 : 50	SDPN-3 + CP 404	320	4.1	9.4	143	411	350	4.4	9.3	127
50 : 50	SDPN-3 + DB 414	287	3.8	3.7	147	395	240	3.8	4.0	129
50 : 50	SG + CP 343	3.9	5.1	118	385	330	3.9	5.7	112	418
50 : 50	SG + DB 292	3.7	3.6	126	378	270	3.7	6.1	142	360
60 : 40	SDPN-30 + CP 401	330	4.1	9.4	128	370	305	3.9	6.7	115
60 : 40	SDPN-3 + DB 406	305	3.7	4.0	117	385	247	4.0	7.0	113
60 : 40	SG + CP 407	335	3.9	7.2	94	402	327	3.8	7.6	94
60 : 40	SG + DB 315	3.8	4.2	122	390	260	3.6	7.3	120	385
70 : 30	SDPN-3 + CP 425	335	3.9	6.0	121	417	282	3.7	8.3	104
70 : 30	SDPN-3 + DB 414	320	3.7	4.7	109	357	245	3.7	6.1	106
70 : 30	SG + CP 333	3.8	5.5	88	380	315	3.7	6.8	82	383
70 : 30	SG + DB 338	3.7	3.1	112	386	240	3.6	4.9	91	374
80 : 20	SDPN-3 + CP 414	336	3.8	7.4	105	409	250	3.6	8.9	94
80 : 20	SDPN-3 + DB 401	294	3.7	5.2	90	396	235	3.6	7.0	95
80 : 20	SG + CP 329	3.7	4.8	88	342	305	3.7	5.4	75	359
80 : 20	SG + DB 285	3.6	5.2	96	366	237	3.6	6.4	81	363
90 : 10	SDPN-3 + CP 410	332	3.5	7.4	91	424	260	3.7	6.4	87
90 : 10	SDPN-3 + DB 404	270	3.6	4.9	78	394	225	3.6	8.6	92
90 : 10	SG + CP 325	3.5	3.1	84	382	300	3.7	4.8	73	339
90 : 10	SG + DB 331	3.6	2.9	85	348	230	3.7	4.2	73	354
100 %	SDPN-3 292	3.6	5.1	104	434	245	3.6	3.9	90	403

100 %	SG	285	3.5	2.9	81	414	350	3.7	2.7	74	384
100 %	CP	415	4.7	10.6	160	464	430	4.3	11.0	146	346
100 %	DB	321	3.7	6.9	182	410	250	3.8	12.5	163	412
Mean		**319**	**3.8**	**5.6**	**127**	**395**	**285**	**3.8**	**6.8**	**109**	**387**
S.E +		**3.57**	**0.03**	**0.33**	**11.8**	**3.88**	**2.63**	**0.02**	**0.23**	**1.57**	**7.86**

Table 9. Fermentation and quality of silage made from Sorghum (SG) and hybrid *Pennisetum* (SDPN-3) mixed with Cow peas (CP) or Dolichos beans (DB) as affected by additives during 1995/96 season.

Crop mixture[1]	DM (g/kg)	pH	NH3.N % of Total N	Crude Protein (g/kg DM)	Ash (g / kg DM)	MADF	Digestibility
SDPN-3 + CP(control)	303	4.8	5.9	101	94	399	528
SDPN-3 + CP + maize[3]	330	4.5	5.3	114	87	375	556
SDPN-3 + CP + Sil All[4]	280	4.5	5.4	114	93	349	586
SDPN-3 + DB(control)	270	4.3	5.9	94	111	415	508

SDPN-3 + DB+ Maize		300	4.2	5.1	95	83	394	533
SDPN-3 + DB+ Sil All		277	4.3	5.1	89	91	383	546
SG + CP(control)	343	4.4	8.2	84	70	395	532	
SG + CP+ maize	363	4.2	6.6	86	57	368	564	
SG + CP+ Sil All	340	4.1	7.0	89	63	367	565	
SG + DB(control)	353	4.3	6.8	79	60	421	501	
SG + DB+ Maize	403	4.1	7.7	81	55	383	546	
SG + DB+ Sil All	290	4.2	8.6	84	84	383	546	
Mean	**321**	**4.3**	**6.5**	**92**	**79**	**386**	**543**	
S.E ±	**1.75**	**0.18**	**0.82**	**0.63**	**0.84**	**2.55**	**0.30**	
Significance[2]								
Cereals	***	ns	***	***	***	ns	ns	
Legumes	ns	ns	ns	**	ns	***	***	
Additive	***	ns	ns	ns	ns	***	***	

Cereals x Legumes; Cereals x additive; Legumes x additive and Cereals x Leg. x additive Interactions were not significant

[1]. Cereals were mixed with legumes in the ratio of 50:50 by volume.

[2]. Significance: * P<0.05

** P<0.01

*** P<0.001

ns not significant

3. Maize meal was added at 5 % of the biomass.

4. Sil-All (a commercial additive) was added at 20ml Sil-All solution per 10 kg of biomass.

f. Total Nitrogen

Table 10 Fermentation and quality of silage made from Sorghum (SG) and hybrid *Pennisetum* (SDPN-3) mixed with Cow peas (CP) or Dolichos beans (DB) as affected by additives during 1996/97 season.

Crop mixture[1]	DM (g/kg)	pH	NH3.N % of Total N	Crude Protein (g/kg DM)	MADF (g/kg DM)	Digestibility
SDPN-3 + CP(control)	245	4.1	4.1	118	404	522
SDPN-3 + CP + maize[3]	279	4.2	3.1	142	390	539
SDPN-3 + CP + Sil All[4]	241	4.1	4.3	132	369	563
SDPN-3 + DB(control)	209	3.7	3.9	113	405	520
SDPN-3 + DB+ Maize	261	3.8	3.2	139	389	539
SDPN-3 + DB+ Sil All	206	4.0	4.6	126	378	552
SG + CP(control)	247	3.4	4.6	104	384	545
SG + CP+ maize	307	3.5	3.9	117	362	571
SG + CP+ Sil All	271	3.7	4.7	121	353	581
SG + DB(control)	247	3.5	4.9	104	412	513
SG + DB+ Maize	277	3.6	4.4	107	379	551
SG + DB+ Sil All	252	3.8	5.0	122	378	552
Mean	**253**	**3.8**	**4.2**	**12.1**	**384**	**545**
S.E +	**2.28**	**0.11**	**0.24**	**0.42**	**3.35**	**0.39**
Significance[2]						
Cereals	***	**	***	***	**ns**	**ns**
Legumes	***	**ns**	**ns**	**ns**	**ns**	**ns**
Additive	***	*	***	***	***	***

Interactions

Cereals x Legumes	*******	*****	**ns**	**ns**		**ns**	**ns**	
Cereals x additive	*******	**ns**	**ns**	**ns**		**ns**	**ns**	
Legumes x additive	*****	**ns**	**ns**	*****		**ns**	**ns**	
Cer. x Leg. x additive		*******	**ns**	**ns**	**ns**		**ns**	**ns**

[1]. Cereals were mixed with legumes in the ratio of 50:50 by volume.

[2]. Significance: * P<0.05

** P<0.01

*** P<0.001

ns not significant

3. Maize meal was added at 5 % of the biomass.
4. Sil-All (a commercial additive) was added at 20ml Sil-All solution per 10 kg of biomass.

f. Total Nitrogen

Table 11 Fermentation and quality of silage made from Sorghum (SG) and hybrid *Pennisetum* (SDPN-3) mixed with Cow peas (CP) or Dolichos beans (DB) as affected by additives during the 1997-98 seasons.

Crop mixture[1]	Dry Matter (g/kg)	pH	NH3.N % of Total Nitrogen	Crude Protein (g/kg DM)	Ash	MADF (g/kg DM)	Digestibility
SDPN-3 + CP(control)	303	4.4	6.8	110	89	408	517
SDPN-3 + CP + maize[3]	360	4.0	6.9	132	85.6	404	521
SDPN-3 + CP + Sil All[4]	357	3.9	6.7	121	84.5	389	539
SDPN-3 + DB(control)	233	4.0	6.6	104	98.1	395	532
SDPN-3 + DB+ Maize	280	3.8	6.5	125	89.7	384	544
SDPN-3 + DB+ Sil All	247	3.7	6.6	120	96.9	374	557

SG + CP(control)	313	4.1	6.4	96		85.7	374	557
SG + CP+ maize	353	3.8	6.3	111		83.2	356	577
SG + CP+ Sil All	334	3.8	6.1	107		87.7	340	597
SG + DB(control)	283	4.0	6.3	92		72.9	402	524
SG + DB+ Maize	310	3.6	6.1	111		64.9	375	556
SG + DB+ Sil All	287	3.6	6.1	121		66.5	373	558
Mean	**306**	**3.9**	**6.5**	**113**		**83.7**	**381.2**	**548**
S.E + **7.01**	**5.5**	**0.04**	**0.05**	**1.26**		**4.28**	**5.99**	
Significance[2]								
Cereals	**ns**	**ns**	*******	*******		**ns**	**ns**	*******
Legumes	*******	*****	**ns**	**ns**		**ns**	**ns**	**ns**
Additive	******	**ns**	**ns**	*******		**ns**	**ns**	**ns**
Interactions	*****	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**
Cereals x Legumes	**ns**	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**
Cereals x additive	**ns**	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**
Legumes x additive	**ns**	**ns**	**ns**	**ns**		**ns**	**ns**	**ns**
Cer. x Leg. x additive **ns**		**ns**	**ns**	**ns**	**ns**		**ns**	**ns**

[1]. Cereals were mixed with legumes in the ratio of 50:50 by volume.

[2]. Significance: * P<0.05

** P<0.01

*** P<0.001

ns not significant

3. Maize meal was added at 5 % of the biomass.

4. Sil-All (a commercial additive) was added at 20ml Sil-All solution per 10 kg of biomass.

f. Total Nitrogen

Table 12 Fermentation and quality of silage made from hybrid *Pennisetum* (PN-3) mixed[1] with Cow peas (CP) or Dolichos beans (DB) as affected by different levels of maize meal (MM) and crushed sweet stem sorghum (SSS) additives during 1995/96 season.

Crops + additive mixture	Dry Matter (g/kg DM)	pH	NH3.N % of total N	Crude Protein (g/kg DM)	Ash (%)	MADF (g/kg DM)	Digestibility- (g/kg DM)
1. PN-3 + CP + 0 % MM	290	5.6	11	95	11.2	403	523
2. PN-3 + CP + 5 % MM	290	4.6	5	113	9.6	370	561
3. PN-3 + CP + 10 % MM	330	4.5	4	122	10.1	363	570
4. PN-3 + CP + 15 % MM	410	4.3	3	115	6.4	338	599
5. PN-3 + CP + 20 % MM	420	4.1	4	119	5.8	333	605
Mean	350	4.6	5	113	8.6	361	572
6. PN-3 + DB + 0 % MM	320	5.0	5	104	13.0	422	501
7. PN-3 + DB + 5 % MM	320	4.1	4	123	7.9	386	543
8. PN-3 + DB + 10 % MM	330	3.9	4	96	5.8	387	542
9. PN-3 + DB + 15 % MM	280	3.7	5	116	13.1	335	602
10. PN-3 + DB + 20 % MM	350	3.4	4	124	10.5	334	604
Mean	320	4.0	4	113	10.1	373	558

11. PN-3 + CP + 0 % SSG	300	5.0	5	91	7.5	424	498
12. PN-3 + CP + 5 % SSG	320	4.4	3	95	7.9	388	540
13. PN-3 + CP + 10 % SSG	330	4.2	3	115	8.6	392	536
14. PN-3 + CP + 15 % SSG	290	4.2	3	115	8.0	340	596
15. PN-3 + CP + 20 % SSG	340	4.1	4	126	7.9	355	579
Mean	320	4.4	4	108	7.9	380	550
16. PN-3 + DB + 0 % SSG	340	5.6	5	95	8.1	434	487
17. PN-3 + DB + 5 % SSG	270	4.3	4	85	9.3	402	524
18. PN-3 + DB + 10 % SSG	300	4.1	6	109	8.4	396	531
19. PN-3 + DB + 15 % SSG	280	4.1	11	117	14.3	356	578
20. PN-3 + DB + 20 % SSG	290	4.0	10	112	13.4	367	565
Mean	300	4.4	7	104	10.7	391	537

[1]. Cereal and Legumes were mixed in the ratio of 50:50 by volume.

Table 13 Quality parameters of silage made from hybrid *Pennisetum* (PN-3) mixed[1] with Cow peas (CP) or Dolichos beans (DB) as affected by different levels of maize meal (MM) and crushed sweet stem sorghum (SSS) as additives (ADDV) during 1996/97 season.

Crops + ADDV mixture	Dry Matter (g/kg DM)	pH	NH3.N % of total N	Crude Protein (g/kg DM)	MADF (g/kg DM)	Digestibility (g/kg DM)

1. PN-3 + CP + 0 % MM	215	4.7	9.9	99	401	541	
2. PN-3 + CP + 10 % MM	257	3.8	7.2	121	302	653	
3. PN-3 + CP + 20 % MM	256	3.5	6.9	127	310	644	
4. PN-3 + DB + 0 % MM	242	4.0	9.7	103	422	517	
5. PN-3 + DB + 10 % MM	262	3.7	7.6	124	386	558	
6. PN-3 + DB + 20 % MM	307	3.6	6.4	132	287	670	
7. PN-3 + CP + 0 % SSG	286	4.3	8.8	100	398	545	
8. PN-3 + CP + 10 % SSG	225	3.9	6.9	140	375	571	
9. PN-3 + CP + 20 % SSG	230	3.5	6.4	143	351	597	
10. PN-3 + DB + 0 % SSG	239	4.0	10.2	108	396	547	
11. PN-3 + DB + 10 % SSG	252	3.7	7.2	137	360	588	
12. PN-3 + DB + 20 % SSG	347	3.6	6.5	142	329	622	
Mean	**260**	**3.9**	**7.8**	**128**	**359**	**588**	
C.V %	**6.38**	**3.03**	**7.53**	**2.29**	**4.54**	**3.14**	
Significance							
PN- 3 + leg.	***	***	***	ns	ns	ns	
Additive type	ns	ns	ns	***	***	**	
Level of ADDV		***	***	***	***	***	***
Interactions							
PN-3+leg. x ADDV	ns	ns	**	ns	***	***	
PN-3+leg. x level of ADDV	***	***	***	***	***	***	
Additive x level of ADDV	***	ns	ns	***	***	***	
PN3-3 x ADDV x level of ADDV	***	ns	ns	ns	***	***	

[1]. Cereal and Legumes were mixed in the ratio of 50:50 by volume.

Table 14 Quality parameters of silage made from hybrid *Pennisetum* (PN-3) mixed[1] with Cow peas (CP) or Dolichos beans (DB) as affected by different levels of maize meal (MM) and crushed sweet stem sorghum (SSS) as additives (ADDV) during 1997/98 season.

Crops + ADDV mixture	Dry Matter (g/kg DM)	pH	NH3.N % of total N	Crude Protein (g/kg DM)	MADF (g/kg DM)	Digestibility (g/kg DM)
1. PN-3 + CP + 0 % MM	300	4.2	9.2	100.9	421	502
2. PN-3 + CP + 10 % MM	373	3.9	6.8	117.2	392	536
3. PN-3 + CP + 20 % MM	387	3.9	6.1	119.6	379	551
4. PN-3 + DB + 0 % MM	350	4.4	6.8	102.3	394	534
5. PN-3 + DB + 10 % MM	313	4.0	5.9	115.4	386	543
6. PN-3 + DB + 20 % MM	317	3.7	6.9	128.4	372	559
7. PN-3 + CP + 0 % SSG	240	4.3	6.1	108.5	397	530
8. PN-3 + CP + 10 % SSG	270	4.0	5.7	128.8	375	555
9. PN-3 + CP + 20 % SSG	337	3.9	7.2	129.9	375	555
10. PN-3 + DB + 0 % SSG	237	4.2	7.6	75.7	405	520
11. PN-3 + DB + 10 % SSG	253	4.1	6.3	141.6	387	541
12. PN-3 + DB + 20 % SSG	273	3.9	7.6	115.3	391	537
Mean	**304**	**4.0**	**6.9**	**115.3**	**390**	**538.5**
C.V %	**17.95**	**6.57**	**28.23**	**20.89**	**5.93**	**5.02**
S.E	**4.84**	**0.04**	**0.32**	**3.56**	**0.37**	**0.43**
Significance						
PN- 3 + leg.	*******	**ns**	**ns**	**ns**	**ns**	**ns**
Additive type	******	**ns**	**ns**	**ns**	**ns**	**ns**

Level of ADDV	***	***	ns	***	*	*
<u>Interactions</u>						
PN-3+leg. x ADDV	ns	ns	ns	ns	ns	ns
PN-3+leg. x level of ADDV	ns	ns	ns	ns	ns	ns
Additive x level of ADDV	**	ns	ns	ns	ns	ns
PN3-3 x ADDV x level of ADDV	ns	ns	ns	ns	ns	ns

[1]. Cereal and Legumes were mixed in the ratio of 50:50 by volume.

Discussions

All quality parameters were within acceptable standards for tropical forages (Catchpoole and Henzell, 1971) and agree with findings by Morris and Levitt, (1968), Titerton and Maasdorp, (1997). The significant differences between the effects of maize meal and Sil-All were attributed to their mode of action on the silage. Maize meal being an energy-yielding substrate and absorbent of effluent enhanced fermentation better than the Sil-All (liquid, microencapsulated lactic acid bacteria). The increase in silage DM due to addition of 5 % maize meal and the corresponding decrease due to addition of Sil-All were expected because of the solid and therefore absorptive and liquid nature of the two. These findings agree with work by Alberto <u>et al</u>. (1993) who used 8 % ground sorghum, Onselen and Lopez, (1988), Jingura, (1994) who used maize meal. In a study by Davies and Onwuka (1996), Napier grass + *Gliricidia sepium* + 4.5 % ground maize were ensiled in black polythene bags similar to those used in this study and found similar results. Improvement in nutritional content by the 5 % maize meal and Sil-All, and the presence of significant effect on fermentation quality was due to the storage of silage in small sealed silos where all effluent was retained thus eliminating the differences that would have resulted had the effluent been drained as in the case of pit silos.

Improvement in the crude protein content of the silage due to addition of the additives is not common because maize meal and Sil-All are both low protein additives, which would otherwise be expected to have diluted the total nitrogen of mixture. However, in this case the additives were effective in retaining the nitrogen content of the mixtures. The lower low pH and NH_3-N as % of total nitrogen found in this study therefore indicated the low proteolytic activity and subsequent lack of decline in the CP content due to additives. These findings do not agree with popular belief, e.g. findings by Mosely and Ramanathan (1988) or Jones (1988) who all reported an increase in the pH and NH_3-N as % of total nitrogen with the addition of additives. The CP content of all treatments was much higher than the threshold level of 70-80 g/kg DM (1.1 –1.3 Nitrogen) below which intake is reduced (Milford and Minson, 1965). Low NH_3-N (% of TN) found in this study are consistent with good quality silage (Coshima and McDonald 1978, Church 1991, Titterton and Maasdorp, 1997).

iv Forage tree legumes as an alternative source of protein to annual legumes for mixed crop silage.

Introduction

Multipurpose legume trees and shrubs are potentially a good source of high quality forage through the dry season. Several species have been screened and evaluated in Zimbabwe, including varieties of *Calliandra, Sesbania, Acacia, Glyricidia* and *Cajanus* (Dzowela et al., 1993; Maasdorp, 1993). There has been no formal evaluation of these species in the semi-arid areas of Zimbabwe where they may be more productive than annual forage tree legume crops. However, some tree legumes contain anti-nutritional compounds. Maasdorp *et al*. (1999) showed that *Calliandra* and *Acacia* supported poor milk production responses in dairy cows compared with *Leucaena* when fed in the dried form. *Calliandra* has a high tannin content and moderate levels of tannin have also been observed in a number of commonly used tropical forage legumes (Jackson *et al*., 1996). Tannins can reduce the digestibility of protein by protecting feed protein from microbial degradation (McNeill et al., 1998, 2000).

In addition, forage tree legume has the same disadvantage as a conserved forage as annual forage legumes- it lacks the fermentable carbohydrate required for successful ensilage. If ensiled with a cereal forage, however, it was thought that not only would the cereal provide the necessary carbohydrate in the same way as it has for annual forage legumes but the ensilage process itself my reduce the adverse effects of high tannin levels in tree legume species. There is evidence that drying and ensiling may reduce tannin activity (Norton and Ahn, 1998) while mimosine content of *Leucaena leucephela* decreased significantly due to ensilage (James and Gangadev, 1990)

Ideally, forage sorghum and pennisetum would have been the suitable “cereal” forage to ensile with forage tree legumes in this trial. However, the forage tree legume (FTL) material was only available at the University Farm where maize is grown for silage and where there were sufficient lactating cows for experimentation. If this proved successful it was thought that it provided potential for future research where screening of suitable forage legume trees in the semi-arid area for ensiling with suitable forages would be carried out.

Materials and Methods

Treatments

The FTLs used in this experiment were *Acacia boliviana* (Acacia) and *Leucaena leucocephala* (Leucaena). These legumes were established at the University of Zimbabwe’s Farm Teaching and Research Unit about eleven years ago. The material used came from coppices from 1999 harvests. Harvesting for the ensilage was done between the 5th and 10th of April, 2000 when the maize crop had reached the medium dough stage. About 25% of the legumes were at flowering stage. The coppices were cut at about 0.7 meters high. The leaves were stripped by hand from the branches and twigs.

Maize

A long season white maize variety, Z709, was used. The crop was planted on 26th November 1999 on a 3 ha plot at the University of Zimbabwe's Farm Teaching and Research Unit. The targeted plant population at planting was 70 000/ha. Four hundred kilograms of compound D basal fertilizer and three hundred kilograms of ammonium nitrate top dressing fertilizer were applied to the crop. Pre-emergence herbicides were used and the crop was hand weeded once. Harvesting was done by hand between the 5th and 9th of April, 2000. A motorised chuff cutter was used to chop the maize into pieces of +/- 15cm long.

Ensilage process

Ensilage was done in 50kg plastic bag silos. Five kilograms of freshly chopped maize was weighed using a dial scale and placed on a clean polythene paper spread on a flat floor. Similarly five kilograms of the respective freshly cut legume leaves was weighed and thoroughly hand mixed with the maize. The mixed forages were then packed in the plastic bags and compacted by hand to exclude as much air as possible and then tied by a string ensuring air-tightness. The material was left to incubate in a room for seven weeks before samples were taken for laboratory analyses. Ten kilograms of fresh chopped maize was also ensiled in plastic bag silos for the control. At the same time, maize from the same crop was ensiled in a bunker. This silage provided the basal diet for the trial animals.

Forage sampling

Two-kilogram samples were taken from each batch of the respective legume and chopped maize. All the batch samples were then thoroughly hand mixed before three two-kilogram samples were taken for laboratory analyses. Samples of freshly mixed maize-legume material were also taken. After a seven-week incubation period three bags of each of the respective silages were randomly selected, opened and thoroughly mixed before three two-kilogram samples were taken for laboratory analyses. Three one-kilogram samples of the lactating meal were also taken for laboratory analyses.

Sample preparation

Two of the three fresh two-kilogram samples of the respective silages were stored in sealed plastic bags in the freezer. One of the samples for each respective silage was immediately analysed for DM and the oven dried samples were then ground through a 1.5mm screen. The dried samples were stored in plastic sample bottles at room temperature until sub-samples for laboratory analysis were taken.

Laboratory analyses

The analyses were done on samples of fresh chopped maize, fresh Acacia, fresh Leucaena, fresh mixed maize-leucaena, fresh mixed maize-acacia, the mixed silages, bagged maize silage, bunker maize silage and the lactating meal. The parameters analysed on the fresh material and the silages included oven dry matter (DM), neutral detergent fibre (NDF), modified acid detergent fibre (MADF), crude protein (CP) and ash. All analyses were done in duplicate excerpt for the DM which was in quartet. DM in fresh forages and silages were determined in a forced air oven at 60 C for 48 hours. The DM of the lactating meal was determined by drying the feed in an oven at 105 C for 24 hours. CP content was determined by the Kjeldahl method as outlined in the University Of Zimbabwe Department Of Animal Science Nutritional Biochemistry Laboratory Manual (Mpofu et al, 2000). The NDF and MADF were assessed using the procedures outlined in the same manual. All analyses were done in duplicate. Energy in the forages was estimated from the MADF values according to the following formula:

*ME (MJ/kg) = 0.16D (where D is the estimated digestibility of the forage calculated from the MADF value from the formula; Digestibility (D) = 99.43 - 1.17*MADF).*

For the lactating meal 0.15D was used. (Linn and Martin, 1991)

For the fermentation characteristics the following parameters were also determined for silages: pH, ammonia nitrogen (NH_3-N), volatile fatty acids (VFAs) and lactic acid (LA). All the analyses on silage quality parameters were carried out using the procedures outlined in “The Analysis of Agricultural Materials” 3rd edition manual (1985) used by the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food in the United Kingdom.

The Flieg point system modified as outlined by Woodard (1991) was applied on the levels of organic acids in order to rank (index) the quality of the silages. This scoring system is based on the relative proportions of lactic acid (LA), acetic acid (AA) and butyric acid (BA) to the total sum of these acids contained in silage. More points are awarded to a silage when LA makes up a larger proportion of total organic acids. Fewer points are awarded to a silage when AA and BA make up the larger proportion of the total organic acids (Woodard et al 1991). A good silage has over 80 points whilst a medium quality silage would score between 60 and 79 points. Anything less than 60 points would be regarded unsatisfactory.

Statistical analysis

The data on parameters for fermentation characteristics and nutritive composition was analysed using the Statistical Analysis Systems Analysis of Variance procedures (1994) for a completely randomised design as represented by the model below. Tukeys method was used to separate means.

$$\mathbf{R} = \quad + \mathbf{T_i} + \quad_{\mathbf{ij}}$$

Where; **R** = response variable (e.g. dry matter, crude protein, pH etc)

= overall mean

$\mathbf{T_i}$ = treatment effect (i = 1, 2, 3) $_{\mathbf{ij}}$

= random error

Results

Silage fermentation characteristics

Silage fermentation quality was assessed by such parameters as dry matter (DM) content, pH, lactic acid (LA), VFAs and NH_3-N content. Table 1 shows the fermentation quality parameters of the three silages used in the experiment. The dry matter (DM) content of the silages is not significantly different (P>0.05). Bagged maize silage had the lowest pH followed by maize-acacia silage and bunker maize silage which had similar values and maize-leucaena silage had the highest pH value. The pH values were significantly different (P< 0.05). NH_3-Npercent in relation to the total nitrogen in the silage was not significantly different (P>0.05) as indicated in table 1.

Bagged maize silage had significantly higher LA concentration than the two mixed maize FTL silages depicted in table 1. The volatile fatty acids that could be identified by the GLC method were acetic acid (AA), propionic acid (PA), n- and iso-butyric acids (BA) and iso-valeric acid. AA and PA amounts did not vary significantly across the silages (p>0.05). The amount of acetic acid in the mixed maize-FTL silages was double that of the maize silage when expressed as a percentage of the total organic acids in the silage. The n- and iso-butyric acid levels across the silages varied significantly (P<0.05) with both being highest in the maize silage followed by that of the mixed maize-leucaena silage and that of the mixed maize-acacia silage respectively. Iso-valeric acid could not be detected in the maize silage but was in appreciable amounts in the mixed maize-FTL silages as shown in table 1.

Table 3.1: The Fermentation quality parameters of the silages

Silage Type	Bunker Maize Silage	Bagged Maize Silage	Maize--Leucaena Silage	Maize--Acacia Silage	Standard Error of Means
DM (g/kg)	309a	271a	276a	339a	12.3
pH	4.5b	3.7c	4.8a	4.5b	-
NH_3-N (g/kg DM)	9.59a	7.46a	10.09a	8.09a	0.8
Organic acids (g/kg DM)					
Lactic acid	nd	73.25 a (83.4)	33.30 b (67.3)	29.00 b (70.2)	6.1
Acetic acid	nd	9.56 a (10.9)	9.91 a (20.0)	7.76 a (18.8)	0.5
Propionic acid	nd	1.00 a (1.1)	0.99 a (2.0)	0.72 a (1.7)	0.1
iso-butyric	nd	3.10 a (3.5)	2.24 ab (4.5)	1.75 (4.2)	0.2

acid					
n-butyric acid	nd	0.96 a (1.1)	0.68 ab (1.4)	0.47 b (1.1)	0.1
iso-valeric acid	nd	-	2.34 a (4.7)	1.59 a (3.9)	0.4
Total organic acids	**-**	**87.87 (100)**	**49.46 (100)**	**41.29 (100)**	

Note:

nd = Not determined

All values are least square means except for total organic acids

Values with different superscripts across the rows are significantly different (P<0.05)

The values in brackets represent the proportion of the respective acid as a percentage of total organic acids

Table 3.2 Flieg score for the silage quality used in the experiment

Silage Type	**Score**	**Comment**
Bagged maize silage	83.3	Very good
Maize-Leucaena silage	67.3	Satisfactory
Maize-Acacia silage	70.2	Good

Note: Scores range from 1 to 100. The closer the score is to 100 the better the quality

Nutritional composition of the silages and the meal

The NDF content of the silages were not different but they were all significantly different from that of the meal (P < 0.05) as indicated in table 3. The NDF content of the bunker maize silage and that of the mixed maize-leucaena silage was just about the maximum recommended 65% (Titterton et al 1997). Bagged maize silage and mixed maize-acacia silage had similar MADF whilst on the other hand the bunker maize silage and the mixed maize-leucaena had higher but similar MADF which all differed from that of the lactating meal. The MADF values were used to calculate the digestibility estimates (called D values) of the silages and these are shown in table 3. The lactating meal had the highest D value of 90.7 as expected followed by the good quality bagged maize silage with 63.8, mixed maize-acacia silage (62.2), bunker maize silage (57.9) and the mixed maize-leucaena silage (57.6). The estimated D value of the bagged maize silage was significantly different from that of the maize-leucaena and the bunker maize silage (P<0.05) but similar to that of the maize-acacia silage. The maize-acacia silage was not significantly different from that of the bunker silage and the mixed maize-leucaena silage. The same trend was found with the estimated metabolizable energy values.

The CP content of maize- acacia was the highest (208,7g/kg DM) whilst the bunker silage had the lowest (65g/kg DM). The CP content of the lactating meal (196,9g/kg) was similar to that of mixed silages although maize-acacia (208,7g/kg) had a greater CP content which was significantly higher than that of maize-leucaena (176.0g/kg) silage (P<0.05) as indicated in table 3. The ash content was highest (P<0.05) in the mixed maize-leucaena silage (7.4%) followed by the bagged maize silage (6.6) and then the lactating meal with similar levels to those of the bunker silage and the mixed maize-acacia silage (5.6%).

Table 3.3 Nutritive composition of the mixed maize-FTL silages in relation to maize silage and lactating meal

Feed Type	**Bunker maize silage**	**Bagged maize silage**	**Maize--Leucaena silage**	**Maize--Acacia silage**	**Lactating meal**	**Standard Error of means**
DM (g/kg)	309^{a}	271^{a}	276^{a}	339^{a}	865♣	12.3
CP (g/kg)	65.0^{c}	71.2^{c}	176.0^{b}	208.7^{a}	196.9^{ab}	0.5
NDF (g/kg)	665.0^{a}	608.2^{a}	1658.4^{a}	602.6^{a}	420.0^{b}	17.5
MADF (g/kg)	353.5^{a}	304.4^{b}	357.4^{a}	318.6^{b}	98.9^{c}	4.4
ME (MJ/kg)	9.29^{c}	10.21^{b}	9.22^{c}	9.95^{bc}	13.01^{a}	0.1
Ash (g/kg)	5.6^{b}	6.6^{ab}	7.4^{a}	5.6^{b}	15.6^{b}	0.2
Digestibility (%)	57.9^{c}	63.8^{b}	57.6^{c}	62.2^{bc}	90.7^{a}	1.5

Note

Values with different superscripts across the rows are significantly different (P<0.05)

*The values were calculated using MADF.

The value was not included in the separation of the means.

Discussion

Silage fermentation quality

The quality of the mixed silages produced were of satisfactory quality as indicated by the DM within the recommended range of 21 – 32 % although this range is derived from the traditional crops such as maize and grasses. DM indicates the bulkiness and the subsequent feeding value of a feed. What is required in silages is a match between high DM (25% to 32%) and high nutrient content. In ruminant nutrition DM is important because it has a bearing on the rumen fill effect which is important in the voluntary feed intake which in turn influences the passage rates and overall digestibility of a feed.

pH values of less than 5 were achieved in these mixed silages and so were low NH_3–N, being <11% of total nitrogen in the silage as reported by Catchpoole & Henzell (1971) and by Titterton (1996). The pH values were similar to those found by Titterton et al (1999) where maize silage achieved 4.0, mixed maize-leucaena 4.6 and maize-acacia 4.7. The variation in the pH and the NH_3–N values could be explained by seasonal variation of the quality of the material and the harvesting and ensiling techniques followed in each case. McCullough (1978) cited by Woodard et al (1991) proposed a silage fermentation quality index to include pH less than 4.2, acetic acid 5 - 8 g/kg DM, LA 15 - 25g/kg DM, butyric acid of less than 1g/kg DM and less than 80g of ammoniacal nitrogen in relation to total nitrogen in silage. According to this criterion the quality of the bagged maize silage was good whilst those of the mixed maize-FTL were satisfactory. Lactic acid (LA) is produced by such lactic acid bacteria in the following genera, *Lactobacillus, Pediococcus, Leuconostoc, Streptococcus, Enterococcus and Lactococcus* whilst butyric acid is produced by Clostridium species (Stefanie et al 1999).

Another way of assessing silage quality is the Flieg point score indexing method was used in this study and the ranking followed that of the pH levels. Using this method confirmed that LA is the main organic acid produced during fermentation and that it has the ultimate effect on pH levels achieved. The indices obtained in this study by the various methods confirmed that good quality silages can be produced from mixed cereal and legume crops without any additives provided ensilage is done at the correct time. The correct time appears to be when the FTLs are at 25% flowering giving DM contents of between 30% and 40% DM and for maize at medium dough stage giving 25% and 30% DM. These stages would ensure good compaction to facilitate anaerobic conditions.

It is generally believed that leguminous forage material has high buffering capacity, which would result in relatively high pH values in silages made from such material. The pH values achieved in this study seem to suggest that when the legume (FTL) is mixed with maize that has high levels of fermentable carbohydrates the buffering effect is reduced and desirable pH levels are achieved. Hattori et al (1996) concluded that fermentation quality of silages was more dependent on WSC than on lactic acid buffering capacity of the material ensiled. Observations in this study confirm this assertion. These findings also confirm the technical feasibility of mixed maize-legume silages. The pH, LA, BA, NH_3-N, levels achieved in this experiment clearly indicate that there was little proteolytic decomposition and putrefaction even by temperate standards. The plastic bag silo technology may have contributed to the production of good quality silage because it seems to provide better anaerobic conditions. This can be confirmed by the fact that the amount of the NH_3-N expressed as a percentage of total nitrogen in silage, which gives a reflection of the extent to which the decomposition of nitrogenous compounds has taken place, is low (<11%). These findings of high Lactic acid, low pH and low NH_3-N may also suggest that some of the protein is actually used in the fermentation process since it is generally thought that there should be enough fermentable carbohydrates in the ensiling mixed cereal-legume material which were certainly not as high as in the maize silage. However, it must be remembered that a good fermentation process does not depend on the type and quality of the forage crop only, but also on harvesting and ensiling techniques (Stefanie et al 1999).

Good quality silage should also be aerobically stable. However this parameter was not assessed in this study but Kung et al (1998) reported that low pH and acidic acid content do not guarantee the aerobic stability of the silage. Aerobic stability was defined as the time required for the silage mass to increase by 2 C above the ambient temperature. Woolford (1975) identified propionic acid to have the greatest antimycotic activity and could be used to stabilise silages. Reports have been made on the use of propionic acid to stabilise silages at the rate of 1 to 2% of the DM (Stallings et al, 1981). The propionic acid levels obtained in maize silage in this study suggest that it could be more stable than the mixed silages. An aerobic stability analysis is necessary where pit silos than small plastic bag silos are used because small bags are opened and emptied once at feed.

Nutritional composition of the silages

The CP of the mixed silages (17 – 21%) is comparable to that of commercial dairy feeds and this gives them the advantage over the maize silage (6.8%). These findings are similar to what Titterton and Maasdorp (1999) found although the values in this study were slightly higher. However the efficiency of utilisation of the CP in the mixed silages is not guaranteed due to the perceived interference from the polyphenolic compounds. In view of the interference from the polyphenolic compounds, the feeding value of mixed silage can best be judged from the performance of animals in a practical feeding trial. CP content and the availability of the protein in any livestock feed is quite important in that it has a bearing on the supplementary requirements, if any, for this expensive nutrient.

The NDF levels of the mixed maize-FTLs are within the range for some forage silages in the tropics. For example, guinea ‘A’ grass silage in Sri-Lanka had 69.9-71.9 NDF (Panditharatne et al 1986), napier grass silage in Thailand had 64.2 - 70.2 NDF (Shinoda et al 1999). The MADF of forages and silages should be within the 22-50% range as suggested by Slater, (1991). The lower the MADF the higher the energy level in a forage or silage. The levels found in this study are within this range and this indicates that the mixed maize-FTL silages have a potential to replace the silage from traditional crops such as maize and sorghum if other factors are ideal. It is important to note though that the NDF and MADF levels are dependent on the maturity stage of any given forage since they are essentially indicating the levels of cell wall components mainly the cellulose, hemicellulose and lignin (for NDF) and cellulose and lignin (for MADF).

Similarly the DM and CP of a silage all depend on the type and stage of maturity of the crops at the time of ensiling in addition to the methodology of harvesting and technique of ensiling. It is generally known that feeds with high fibre content have low digestibility and hence are of poor quality. The MADF of the bagged maize silage and that of the mixed maize-acacia were similar and so were those of the bunker maize silage and that of the mixed maize-leucaena silage but they were all within the 22-50% range suggesting that the quality is acceptable. If NDF is considered, the picture is different, with all the four silages having similar content. In this regard MADF seems a better parameter to indicate the potential digestibility of a given silage than NDF. The MADF was used to calculate the estimated digestibility values (D value) for each silage. The digestibilities of all the silages are slightly higher than those reported in literature. The variation could be due to the differences in the stage of ensilage for the various crops, with better digestibilities being found in young forage material. After the laboratory work there is need to confirm the estimated feeding value (the D value) of the mixed silages through proper feeding trials.

The ash content of the mixed silages was comparable to that of the maize silage and the lactating meal which had commercial additions of minerals required by lactating dairy cows. Mixed maize-leucaena silage had a significantly higher level of the ash than the lactating meal and other silages used in this study. This suggests that there may be no need to add commercial mineral supplements if the mixed silages are used. However there is need to analyse the ash for the quantities of calcium, phosphorus, iron, magnesium and other minerals required by lactating cows in order to ascertain the sufficiency from the silages.

Conclusion

Mixed maize-FTL silage of good quality can be produced under tropical conditions. On the basis of high CP content, good fermentation characteristics and improved digestibility, mixed silages have the potential of eliminating the need for commercial feeds in low yielding (<10kg/day) dairy cows. Growing of multipurpose forage tree legumes should be encouraged in view of their important role in ruminant livestock nutrition. However in view of the limited research done so far on mixed cereal-FTL silages and the varied results obtained by the researchers more research on the quality and utilisation parameters of the silages is imperative before large scale uses of the silages is advocated. For example trials on nitrogen balance and in-vivo degradabilities of such silages need be done to complement the laboratory findings.

iv. The effect of ensilage on polyphenolic content and tannin action in mixed maize-FTL silages

Introduction

Ensilage is a conservation technology for forages meant to be fed to animals during times of low quantities of good quality roughage sources. A variety of crops can be ensiled and among them are forage tree legumes. These crops can be grown and ensiled as single crops or as mixed crops especially cereals mixed with legumes. For example Beever and Thorps (1996) reported that lucerne and maize are highly complementary feeds for high yielding dairy cows and that several countries including South Africa, and Argentina are exploiting the nutritional potential of legume forages. In Zimbabwe Titterton et al (1999) reported good quality mixed maize-forage tree legume silages both in terms of fermentation and nutritional composition with pH values between 4.1 and 4.7 and CP between 14% and 18.7%.

It is well known that legumes have appreciable amounts of crude protein but they have relatively high polyphenolic compounds and other antinutritional properties when compared to most grasses and cereals. Antinutritional factors have been defined by Makkar (1993) as substances which either by themselves, or through their metabolic products arising in the system, interfere with food utilisation and affect the health and production of animals. Polyphenolic compounds such as tannins are included in this definition of antinutritional factors. Tannin themselves can be defined as water-soluble polymeric phenolics that precipitate proteins (Haslam 1989 cited by Reed 1994). The tannins are found in two broad categories i.e. the hydrolysable tannins (HTs) and the condensed tannins (CTs) are the ones that interfere with protein and other macromolecules digestion in ruminants.

Mixing the maize and FTLs would result in a well fermented silage with high levels of CP whose utilisation is known to be hampered by CTs and other polyphenolic compounds present in the FTLs. This study sought to establish the effect of ensilage on phenolic and condensed tannin levels and action in mixed maize-FTL silages as an approach to tannin management. Two experiments were carried out in this study of which the first one involved the determination of the amounts of extractable CTs and precipitable phenolics as a percentage of total phenolics before and after ensiling. The second experiment was carried out in order to determine the effect of ensilage on tannins by way of in-vitro gas production. In the second experiment degradability was measured as loss of weight from the incubated samples. Wood and Plumb (1995) when they investigated the effect of polyethylene glycol (PEG) on phenolic compounds from fodder trees used this approach. The differences in the cumulative gas volumes in ensiled and un-ensiled material were taken as measures of the effects of ensilage on phenolic compounds in the present study.

iv-a. Experiment 1:Effect of ensilage on the amount of condensed tannins in mixed maize-FTL silages

Materials and methods

Samples of fresh pure FTLs, fresh mixed maize-FTLs, mixed maize-FTL silages, maize silage and the lactating meal were prepared as described in chapter 3 section 3.2.4. 70% aqueous acetone was used to extract tannins following the procedures outlined in the laboratory manual for the Food and Agriculture Organisation (FAO) and International Atomic Energy Agency (IAEA) by Makkar (1999). Three portions of 10ml 70% aqueous acetone each were used to extract CTs from 300mg of dried and milled sample. The butanol-HCL method was used for determination of the CTs as outlined by Porter et al (1986). A spectrophotometer was used to read off the absorbance of the samples at 550nm. The calculations of tannin concentrations were done according to the formula given below as presented by Porter et al (1986). A dilution factor of 3 was included in the calculations because the extraction was done using three portions of 70% aqueous acetone.

CTs in sample (% in dry matter) = (Abs550nm X 78.26 X Dilution factor)/(% dry matter)

Statistical Analysis

The data on the content of condensed tannins was analysed using the Statistical Analysis Systems Analysis of Variance procedures (1994) for completely randomised design as represented by the model below. Tukeys method was used to separate means.

$$\mathbf{R} = \mu + \mathbf{T_i} + E_{ij}$$

Where; **R** = response variable (condensed tannins) μ = overall mean

$\mathbf{T_i}$ = treatment effect (i = 1, 2, 3) E_{ij} = random error

Results

Table 4.1 indicates the tannin levels in fresh pure FTLs, fresh mixed maize-FTLs, silages of maize-FTLs as well as for the fresh and ensiled maize. Fresh leucaena had the highest significant level of CTs followed by fresh mixed maize-leucaena and mixed maize-leucaena silage, mixed maize-acacia silage, pure acacia, fresh mixed maize-acacia then fresh and ensiled maize with the least levels of CTs ($P<0.05$).

Discussion

The butanol-HCL method was used for the determination of CTs in this study because it is more specific than the Vallin HCL method, which is the other method widely used. The butanol HCL method measures CTs as well as simple flavonoids (Porter et al 1986). However this method may also be less reliable if there are pigments present in the sample that may interfere with absorbance readings. Magan (1988) cited by

Terrill et al (1994) indicated that the butanol-HCL and vallin-HCL methods are semi quantitative such that considerable variation can occur between assays. In this study the extractable CTS content of the pure acacia and leucaena are significantly different with leucaena having more than five times that of acacia. Fresh maize had the least amount of CTs. Significantly higher content of CTs were found in mixed maize-acacia silage than in fresh mixed maize-acacia as shown in table 4.1. This indicates that ensilage may have an effect to increase the extractable CTs in mixed maize-acacia silage.

Fresh mixed maize-leucaena and mixed maize-leucaena silage had similar levels of CTs ($P>0.05$). This suggests that ensilage has no effect on the level of extractable CTs in mixed maize-leucaena silage unlike mixed maize-acacia silage. There was no significant difference in the content of CTs between the fresh maize and maize silage. The difference in CTs content between the mixed maize-acacia material could indicate that there is some reaction during ensilage which result in the release of extractable CTs. If the fibre-bound CTs were also determined it would have given a clearer picture as to what happens to the total amount of CTs and phenolics. It is possible that the amount of fibre-bound CTs is reduced by ensilage such that more macromolecules locked in the fibre-bound CTs will be availed to rumen bacteria for digestion. The variation in the content of the CTs among the mixed forages under study could be due to the differences in the types and nature of CTs in the different plant species.

Table 4.1: Condensed tannin content of pure FTLs, un-ensiled and ensiled mixed maize-FTL silages and un-ensiled and ensiled maize

Sample	**Butanol-HCL CTs (g/kg DM)**
Fresh pure acacia	4.77[d]
Fresh mixed maize-acacia	2.93 [e]
Mixed maize-acacia silage	6.0 [c]
Fresh pure leucaena	26.93 [a]
Fresh mixed maize-leucaena	9.20 [b]
Mixed maize-leucaena silage	9.07 [b]
Fresh maize	0.97 [f]
Maize silage	1.37 [f]
Standard error of means	0.1

Note: Values with different superscript letters down the column are significantly different (P<0.0

Waghorn (1990) suggested that mixing forages of high CTs with those of low CTs could result in an overall low concentration of CTs and improve the nutritive value of the mixed forages. In the same light Jackson et al (1996) indicated that forages with low concentrations of CTs should improve the efficiency of nitrogen digestion whilst tropical forages with high levels of CTs should only be fed as supplements to dilute the concentration of CTs thereby preventing CTs from restricting voluntary feed intake. This suggestion supports the concept of mixed cereal-legume silages. Terril et al (1994) pointed out that CTs might be either beneficial or detrimental to the animal's nutrition depending on concentration in the forage, astringency and pH dependent protein binding characteristics. Similarly Waghorn et al (1990) consider that when CTs concentrations are above 6% of DM they have detrimental effects on intake and digestibility but when they are less than 4% of DM they could be beneficial to ruminant animals in that they provide protect protein which will be eventually be availed post ruminally. These findings support the concept of mixed silages as a way of managing tanniniferous forages to improve the efficiency of their utilisation.

Using the butanol-HCL method, Jackson et al (1996) found much higher contents of CTs in *Acacia boliviana* (24g/kg DM) and *Leucaena leucocephala* cv Cunningham (41.5g/kg DM). Ahn et al (1989) found 13.9g/kg DM in L leucocephala cv Cunningham whilst in *Acacia angustissma* (the closest to *A. boliviana*) no CTs were detected. Hove (2000) used the butanol-HCL method in A. angustissma and L. leucocephala cv Cunningham and found 18g/kg DM and 26g/kg DM CTs levels respectively. In this regard the levels of CTs found in this study are within the range reported elsewhere in literature. This also validates the values obtained in the fresh mixed forages and the silages.

CTs were detected in fresh and ensiled maize which are generally regarded as having none. These findings can be supported by the fact that different maize varieties may have different levels of tannins due to breeding efforts against pests and diseases that may actually increase the tannin content of the plants. This is because one of the primary roles of tannins is to act as a defence mechanism against pests and disease infection. In light of this it is advisable to carry out periodic analyses on the levels of tannins in new crop varieties that are intended for animal feeding.

Conclusion

Ensilage seems to have varied effects on the levels of extractable CTs in different forages. This suggests that there are different types of CTs in various plants and that these require different management approaches to deal with the tannins for improvement of ruminant nutrition. There is need to investigate the effect of ensilage on the levels of CTs in a number of the FTLs currently being grown by some farmers. Such investigations would include the different growth stages and the influence of the seasonal as well.

iv-b Experiment 2. Effect of ensilage on the level and action of phenolic compounds

Materials and methods

Samples of fresh pure FTLs, fresh mixed maize-FTLs, mixed maize-FTL silages, maize silage and the lactating meal were prepared as described in chapter 2 section 3.2.4. 50% aqueous methanol was used to extract the tannins because acetone interferes in the protein precipitation assay (Makkar 1999). Three portions of 10ml 50% aqueous methanol each were used to extract CTs from 300mg of dried and milled sample. The procedures described by Makkar et al (1988) were followed. A commercial standard, tannic acid, was used. Bovine serum albumin was used in the assay. Sample concentrations were determined by a spectrophotometer. A dilution factor of 3 was included in the calculations.

Statistical Analysis

The data on the content of condensed tannins was analysed using the Statistical Analysis Systems Analysis of Variance procedures (1994) for completely randomised design as represented by the model below. Tukeys method of comparison of means was used to separate the means.

$$\mathbf{R} = \quad + \mathbf{T_i} + \quad_{ij}$$

Where; **R** = response variable (e.g. total phenolics) = overall mean

$\mathbf{T_i}$ = treatment effect (i = 1, 2, ..8) $_{ij}$ = random error

Results

Mixed maize-acacia silage and pure leucaena had the highest significant total phenolic compound followed by pure acacia, fresh mixed maize-acacia and fresh maize-leucaena, mixed maize-leucaena silage, un-ensiled fresh maize and maize silage as shown in table 4.3. A similar trend occurred for the amount of protein precipitable phenolics. Pure leucaena and mixed maize-acacia silage had the greatest significant precipitable phenolics followed by pure acacia, fresh mixed maize-leucaena, maize-leucaena silage and fresh maize with fresh mixed maize-acacia and maize silage having the least ($P<0.05$). When the precipitable phenolics are expressed as a percentage of the total phenolics almost all phenolics in un-ensiled and ensiled maize precipitated proteins. Fresh mixed maize-leucaena and the silage had similar proportions of precipitable phenolics. Pure acacia, pure leucaena and mixed maize-acacia silage had similar proportions of precipitable phenolics ($P>0.05$). Fresh mixed maize acacia had the lowest levels of precipitable phenolics.

Discussion

There are several methods available for quantification of polyphenolic compounds. Most of these methods are not specific and do not distinguish low molecular weight phenolics (which generally do not adversely affect the nutritional quality) from polyphenolics of nutritional concern (Makkar 1989). Total phenolics were determined by the sodium dudecyl sulphate triethaloamine and ferric chloride reagent method as described by Makkar et al (1988). The principle behind this method is that phenolics are reducing agents thus their concentration give relative absorbance values in the spectrophotometer. Bovine serum albumin (BSA) was used for the quantification of the phenolics that precipitate proteins. The BSA method is based on the formation of tannin-protein complexes and it is highly sensitive and allows the determination of protein binding capacity of both HTs and PAs (Makkar et al 1993; Makkar 1999).

In this study pure leucaena and mixed maize-acacia silage had similar amounts of total and precipitable phenolics as well as the proportions of precipitable phenolics($P>0.05$). The significant differences of these parameters between ensiled and un-ensiled mixed maize-acacia forage where the un-ensiled mixture has the least precipitable phenolics suggest that there could be some reaction that takes place during the ensiling process. These reactions seem to release fibre or protein bound phenolics making them available for interaction with the BSA. It is also possible that the types of phenolic compounds in the acacia have exhibit high affinity for BSA than for plant protein under ensilage conditions. Naczk et al (1996) found the optimal pH for precipitation of BSA to be 4.0. However Silanikov et al (1996) concluded that both PEG binding and protein precipitation capacity (BSA) were useful in predicting the negative effects of tannins on ruminal degradation of the plant material.

Table 10 Total and protein precipitable phenolics in fresh and ensiled mixed maize-FTL forages.

Feed	Total phenolics (mg/mg leaf DM	precipitable phenolics (mg/mg leaf DM)	Protein precipitable phenolics (%)
Pure acacia	0.186^{b}	0.087^{b}	46.77^{c}
Fresh mixed maize-acacia	0.103^{c}	0.015^{e}	14.72^{d}
Mixed maize-acacia silage	0.218^{a}	0.101^{a}	46.55^{c}
Pure Leucaena	0.226^{a}	0.099^{a}	43.79^{c}
Fresh mixed maize-leucaena	0.113^{c}	0.068^{c}	59.97^{b}
Mixed maize-leucaena silage	0.071^{d}	0.043^{d}	60.79^{b}
Fresh maize	0.041^{e}	0.038^{d}	93.75^{a}
Maize silage	0.012^{f}	0.011^{e}	91.18^{a}
Standard error of means	0.002	0.001	1.45

These propositions could suggest that the use of polyethylene glycol (PEG) in mixed maize-acacia silage might result in improved utilisation of proteins since PEG has a high affinity for phenolic compounds. The low precipitable phenolic compounds in the fresh mixture of maize-acacia could just be due to the dilution effect of maize.

Maize silage had the least amount of total and precipitable phenolics that were significantly less than those of fresh maize ($P < 0.05$). This observation may indicate that ensilage has an effect on the level and action of phenolic compounds in maize silage. However the proportion of precipitable phenolics are the same suggesting that there could be some specific type of phenolic compounds that precipitate proteins in the maize variety used unlike in fresh and ensiled mixed maize-acacia. The same explanation could be advanced for the fresh and ensiled mixed maize-leucaena that also had similar proportions of precipitable phenolics. These observations seem to be supported by the fact that tannin-protein interactions are specific and depend on the chemical environment and the characteristics of both the tannin and the protein involved. The tannin-protein interactions are also influenced by the number and arrangement of the tannin phenolic groups available (Hove 2000). This could be the other likely explanation for the higher levels of precipitable phenolics in the mixed maize-acacia silage where interactions could have been enhanced by the low pH due to the presence of high levels of fermentable carbohydrates.

These findings, however, need to be interpreted with caution since the methods of estimating tannin and protein content in a tannin-protein complex fail to quantify protein binding capacity if the quantity of tannins in solution are low (Makkar et al 1993). Caution should be applied to these findings as well since sample preparation influence the concentration and extraction of phenolic compounds in addition to the stage of maturity of the plants and the environmental conditions such as soil fertility and moisture. The genetics and nutrition of the plants have been reported to influence the concentration of phenolics (Gerhenzon 1983) and Palo et al (1985) indicated that concentration of phenolic compounds may change across seasons and as plants mature or due to climatic stress (Jackson and Barry (1995).

It seems the use of proportions of the precipitable phenolics is a misleading parameter where the forage material has low concentrations of the phenolics such as indicated by the fresh and ensiled maize. It is better to use the actual concentrations when dealing with these forages of low total phenolic compounds to use the BSA method in conjunction with the PEG binding assay.

Conclusion

Ensilage has varied effects on the total and precipitable phenolics in mixed maize-FTL silages when determined by the BSA method. Ensilage of mixed maize-acacia forage resulted in an increase in total and precipitable phenolics. It seems there are specific types of phenolic compounds that are responsible for protein precipitation in different types of forages that are not affected by ensilage especially in maize and mixed maize-leucaena forages. Different management systems may be required for the different mixed maize-FTL silages due to the varied responses obtained in this study. The use of proportions of precipitable phenolics to the total phenolics as a nutritive evaluation parameter is not suitable for forages of low total phenolic compounds.

iv-c. Experiment 3: In-vitro gas production from fresh and ensiled forage material

Objective

To determine the effect of ensilage on tannin action using the Menke in-vitro gas production technique

Materials and methods

Samples of fresh pure FTLs, fresh mixed maize-FTLs, mixed maize-FTL silages, maize silage and the lactating meal were prepared as described in chapter 3 section 3.2.4. Procedures described by Menke and Steingass (1988) were followed. The rumen liquor was obtained from two steers 15 minutes before incubation started. The steers were on a Rhodes grass hay diet for the previous 24 hours. The 100ml syringes were pre-warmed at 40 C for 3 hours prior to the injection of the 30+/- 1.0ml of the rumen liquor-buffer mixture into the syringes. Incubation was carried out in a water bath at 39 C +/- 0.3. Each sample was run in triplicate and Rhodes grass hay was used as standard forage. The incubation period was 96 hours and gas volume readings were taken at the start (0), 3, 6, 12, 24, 48, 72 and 96 hours. When the gas volume exceeded the 90ml mark between 12 and 48 hours the gas was released and the piston moved back to the 30ml position.

Principle behind the in-vitro gas technique.

Anaerobic rumen microbes are responsible for the fermentation of forage material and in the process they degrade the material producing volatile fatty acids and nitrogen and gaseous products such as carbon dioxide. The sealed 100ml syringes mimic the anaerobic conditions of the rumen and the gas produced exerts pressure to the piston which then slides back such that the extend of gas production can be measured. Extend of gas production can be used to compare the fermentation activity of the microbes of various forage material under investigation. In this regard any substance which interferes with the activity by enhancing or inhibiting the microbes would be assessed through the extent of gas produced. Phenolic compounds are known to protect the protein in forages from microbial attack or prevent microbial attachment on to food particles for the microbial enzymes to act. The result is that there will be little degradation that avails little amounts of nitrogen for microbial protein synthesis. Lack of sufficient microbial protein synthesis would result in low populations of the microbes and hence less forage degradation and this is seen low gas volume production. In this regard forage degradation is correlated to the total gas volume produced.

Statistical analysis

The kinetics of gas production were obtained by fitting the data for gas production over a 96 hour period to the following non-linear exponential equation $P = a + b(1 - e^{-ct})$ (Orskov and McDonald 1979) where Presents gas production at time t, (a + b) the potential extend of gas production, c the rate of gas production and, a, b and c are constants in the exponential equation. In this st6udy a = 0 hence the shortened equation $b(1 - e^{-ct})$ was used. The fitted data was run using SAS (1994) procedures for non linear models (proc NLIN) and the mean values of b and c were subsequently analysed using SAS (1994) ANOVA general linear model procedures. Tukeys method of comparison of means was used for separation of means. The values of actual gas produced and dry matter loss over a 96 hour incubation duration were also analysed by SAS (1994) ANOVA general linear model procedures. A correlation analysis was made to assess the association among gas production, degradability, CTs, total phenolic compounds, precipitable phenolic and the rates of gas production.

Results

Table 4.4.1 indicates the data on actual total gas produced, potential total gas production, dry matter degradability and the rates of gas production over a 96-hour incubation duration.

Actual total and potential gas production

As expected fresh maize, maize silage and the lactating meal produced the largest volumes of gas and had the potential to produce the greatest gas volumes as well. There was no significant difference between fresh mixed un-ensiled and ensiled forages (i.e. FMA vs SMA; FML vs SML; and FMZ vs SMZ) in terms of actual gas production ($P>0.05$). However, significant differences occurred between the respective pure FTLs and the ensiled mixed maize-FTL forages (i.e. FA vs SMA; FL vs SML) ($P<0.05$). The potential total gas was similar for the fresh pure FTL vs the un-ensiled and ensiled mixed forages ($P>0.05$). FMA, SMA, FML and SML all can produce similar gas levels but may not exceed that of Rhodes grass hay.

Dry matter degradability

FMZ, SMZ and LM had the highest dry matter degradability (DMD) as expected ($P<0.05$). FL, FML, SML, FMA, BS and RH all had similar DMD that were second highest. FL, FML and SML DMD were similar while that of FMA was higher than that of FA yet SMA and FMA are similar.

Gas production rates

LM had the greatest significant gas production rate (P<0/05). A group of forages including FMA, SMA, SMZ, FML, FA, FL and BS had similar rates that were second highest. FMZ and RH had the least rate of gas production.

Correlation

Cumulative gas production and DMD were significantly positive correlated ($P<0.05$). Gas production and DMD were significantly negative correlated to total phenolics ($P<0.05$) and protein precipitable phenolics ($P<0.1$). CTs are not correlated to gas production and DMD.

Table 4.4.1 In-vitro gas production, dry matter degradability and rates of gas production of pure forage tree legumes, fresh mixed maize-FTLs, ensiled mixed maize-FTL forages, fresh and ensiled maize over a 96 hour incubation period.

Feed Actual total gas produced (ml)	Potential total gas produced (ml)	Dry matter degradability (%)	Rate of gas production (constant)
FMA	47.2[cde]	49.4 [b]	48.4 [bc]
SMA	42.9 [de]	42.3 [bc]	40.1 [cd]
FMZ	96.8[a]	101.8 [a]	77.9 [a]
SMZ	94.4 [a]	91.9 [a]	72.4 [a]
LM	100.6 [a]	97.9 [a]	85.6 [a]
FML	55.8 [cd]	56.7 [b]	55.1 [b]
SML	58.4 [c]	58.7 [b]	52.9 [bc]
FA	27.7 [f]	30.7 [c]	34.2 [d]
FL	39.2 [ef]	43.9 [bc]	44.8 [bcd]
RH	56 [cd]	98 [a]	51.8 [bc]
BS	76.5 [b]	86.1 [a]	56.9 [b]
Standard Error of means	**3.9**	**5.0**	**3.8**

FMA = fresh mixed maize-acacia

SMA = mixed maize-acacia silage

FMZ = fresh maize

SMZ = maize silage

LM = lactating meal

FML = fresh mixed maize-leucaena

SML= mixed maize-leucaena silage

FA = fresh *Acacia boliviana*

FL = fresh *Leucaena leucocephala*

RH = Rhodes grass hay

BS = bunker silage

Table 4.4.2Correlation (Pearson) coefficients of in-vitro gas production, dry matter degradability and phenolic levels

Total gas production	Dry matter degradability	Total condensed tannins	Total phenolics	Proteins precipitable phenolics (BSA)

Dry matter degradability	0.9836***			
Total condensed tannins	0.4655	0.3728		
Total phenolics		0.8641**	-0.8542**	0.6175
Proteins precipitable phenolics (BSA)	-0.6658	-0.6924*	0.5666	0.9063**
Rate of gas production	0.0171	-0.0383	0.0865	-0.0621 -0.1100

Discussion

The Menke in-vitro gas production technique was used to investigate the effect of ensilage on the action of phenolic compounds in mixed maize FTL silages in this study following the reports by Blummel and Orskov (1993) that it was more efficient than other laboratory techniques in predicting animal performance. Khazaal et al (1993b) reported that Menke in-vitro gas production technique was more efficient than the nylon bag technique for the determination of the nutritive value of feeds containing anti-nutritive factors. Simonetto et al (1997) used this technique to evaluate the efficiency of sodium and ammonium hydroxide treatment of soyabean. These reports confirm the suitability and relevance of the technique in the present study.

In this study total gas produced and DMD from pure FTLs and un-ensiled mixed forage was compared to that of mixed maize-FTL silages. No differences were found between the un-ensiled mixed forages and the mixed maize-FTL silages. The differences found between the pure FTLs and the mixed maize-FTL silages seem to reflect the dilution factor due to mixing. This indicates that ensilage does not improve rumen fermentation and dry matter digestibility of mixed maize-leucaena and maize-acacia forages. In other words ensilage does not seem to interfere with the status and action of phenolic compounds found in leucaena and acacia in low pH (<5) conditions. Probably the phenolic compound contents of the forages used in this study were too low or were largely composed of the inactive type (hydrolysable) to exert significant differences anyway. This is possible in view of the reports made by Hagerman et al (1992) and Wang et al (1994) pointing that reactivity of phenolic compounds with protein is probably a function of plant phenolic compound concentration, molecular weight and structure. The use of PEG (a strong tannin binding chemical) in conjunction with the in-vitro gas production technique could have assisted to determine whether the phenolic compounds present were in fact of the reactive type. In this research it was found that ensilage of mixed maize-acacia resulted in greater recovery (or detection of more amounts) of the phenolic compounds. Makkar and Becker (1996) reported that the inactivation of tannins in Acioa barteri (shrub) was pH dependent and that alkaline pH inactivates tannins hence its widespread use in the leather tanning industry. The opposite seems to have been confirmed true in this study that low pH does not inactivate phenolic compounds found in leucaena and acacia.

The correlation analysis indicated that the rate of gas production is not dependent on the amount of phenolic compounds present in the forages but the phenolic content of the forages has significant ($P < 0.05$) negative effects on the total gas produced. RH had the slowest rate of gas production but it is known to have very low concentration of phenolic compounds if any. *Leucaena leucocephala* and SMA had the highest levels of total phenolics but had the second highest rates of gas production (after LM) that were even higher than those of the fresh maize and Rhodes grass. Thus it is not surprising that ensilage was not found to be influenced by the phenolic content of the forage.

The significant negative correlation between gas production and total phenolic compound levels suggest that assays for phenolic compounds can provide useful indicators of the degree of inhibition of rumen bacteria by the phenolic compounds in FTLs. Protein precipitation and CTs are less accurate indicators of inhibition of the rumen microbes by the phenolic compounds. These findings also confirm the work done by Wood and Plumb (1995) when they worked with 12 Bolivian fodder trees. The correlation coefficient between DMD and CTs (= -0.85) is substantially higher than that found by McKey et al (1978) (R^2 = -0.49). In fact Wood and Plumb (1995) mentioned that varied correlation have been obtained by different researchers.

In this study a correlation coefficient ($R^2 = 0.91$) was found between total phenols and BSA protein precipitable phenolics (Sodium dudecyl sulphate triethaloamine -SDS TEA method). This coefficient is higher than findings made by Hove (2000) (R^2 = 0.91), between phenolic content of forages and BSA protein precipitation (radial diffusion method). In this regard it would appear that the methods used to determine the phenolic compounds have an effect on the coefficients obtained. This actually raises the question of whether there is a reliable and most suitable method for quantification of phenolic compounds in forages.

Conclusion

Ensilage was found to have no effect on the reactivity of the phenolic compounds present in the mixed maize-acacia and leucaena forages. More studies with forages of higher levels of phenolic compounds are advocated. The use of chemicals that strongly bind phenolic compounds such as PEG in conjunction with the in-vitro gas production technique could lead to better understanding of the effects of ensilage on tannin levels and reactivity in these forages. The negative correlation between DMD and total phenolic compound content of the forages indicated that phenolic assays could save as useful indicators to inhibition of the function of the rumen microbes.

Table 2 forage chemical composition, polyphenolic characteristics, production components (potential gas production '*b*' and fractional rate of gas capacity '*c*' .

Component	ac	cal	leu	rhodgrass	SED	*p*
SPAs (AU550 nm/gDM)	113^a	69^b	63^b	0.5^c	3.0	***
NDF-PAs (AU550nm/g DM)	24.7^b	29.2^a	17.3^c	0.37^d	0.74	***
PPC	11.2^a	9.6^b	7.2^c	nd	0.22	***

mm/gDM						
YPP	189[b]	232[a]	160[c]	7.0[d]	4.32	***
g/kgDM						
***b* (ml 300/mg air dry sample**	18.1[c]	29.4[b]	64.7[a]	69.5[a]	2.21	***
c (/hr)	0.027	0.029	0.027	0.007	0.001	***
***b* (ml 300/mg air dry sample**	18.15	29.45	64.75	69.52	2.21	***
c (/hr)	0.0275	0.0290	0.0271	0.0076	0.00173	***

DM=DRY MATTER

NDF= NEUTRAL DETERGENT FIBRE

ADF=ACID DETERGENT FIBRE

YPPs=YTTERBIUM-PRECIPITATED

POLYPHENOLS,

SPAs= SOLUBLE PROANTHOCYANIDINS

NDF-PAs= NEUTRAL DETERGENT FIBRE-BOUND

PROANTHOCYANIDINS

PPC= PROTEIN PRECIPITATING CAPACITY

AU=ABSORBANCE UNITS AT 550nm

Nd= NOT DETERMINED

OMD= ORGANIC MATTER DEGRADABILITY

b = POTENTIAL GAS PRODUCTION

c= FRACTIONAL RATE OF GAS PRODUCTION

Table 1. Ensilage and nutritional characteristics of pure maize and 50:50 maize-tree legume silages.

Silage type	pH	NH3:N%	CP%	OMD%
Maize	4.0	7.7	9.4	56.0
M+AC	4.7	12.0	18.7	44.8
M+CAL	4.1	11.6	14.0	37.5
M+GLY	4.2	8.5	15.5	59.1

M+LEU	4.6	12.8	17.2	49.3

pH OF <5 and NH3-N% < 15 acceptable for legume silages

3. Effect of feeding mixed crop silages on productivity in dairy cows.

i. Effect of mixed cereal-legume silages on milk production from lactating Holstein dairy cows

Introduction

In Zimbabwe there is a general shortage of natural grazing in winter resulting in high use of commercial feeds during this period. Panditharatne et al (1986) this highlighted this phenomenon of lack of all year round supply of good quality on-farm forages and indicated that it was one of the major limiting factors to improved milk yield in the tropics. In the smallholder dairy sector of Zimbabwe commercial feeds account for over 60% of the total production costs (ARDA, 1999). In this regard dairy producers would benefit if the amounts of commercial feeds were reduced in their feeding systems without a decline in yield and quality of milk.

Traditionally silage has been made from cereals and grasses. Legume silages have been produced elsewhere (Dunn, 1991; Beauchemin et al, 1993; Okine et al, 1993; Belibasakis et al, 1997). The cereal silages are rich in energy but low in protein, +/- 7% CP (.........1997) whilst the converse is true for legume silages (Catchpoole and Henzell, 1971). Titterton et al, (1997) found that the protein content of the maize silage could be improved significantly by ensiling it together with forage legumes at ratios ranging between 60 : 40 and 60 : 40 (maize:legume). Titterton et al, (1999) successfully ensiled mixed forage tree legumes with maize and the crude protein content of the mixed silages was reported to be comparable with that of commercial feeds, being 17.2% for maize-leucaena and 18.7% for maize-acacia silages.

Forage tree legumes (FTLs) are protein rich forages that have the potential to replace protein concentrate in commercial feeds in low yielding dairy cows. In addition FTLs have several advantages in that they provide fuel-wood, shade, live fences, fencing poles, improving soil fertility, protecting the soil from raindrop impact and erosion, livestock feed. The FTLs are also drought tolerant thus they can be grown in areas of marginal rainfall. However these forages contain high levels of anti-nutritional substances such as tannins and toxic chemicals (mimosine) that interfere with the digestion and utilisation of protein or digestion processes in ruminants. James and Gangadev (1990) reported that the mimosine content of *Leucaena leucocephala* decreased significantly due to ensilage. In light of these findings a hypothesis can be put forward that ensilage reduces the amount and effect of active tannins. The work by Titterton et al (1998) did not look into the effect of ensilage on the quantity and effect of the phenolic compounds, which have an influence on protein digestion in ruminants, nor did it look into the production responses on cows fed mixed silages.

The effect of partial substitution of the commercial meal and maize silage on dry matter intake, milk yield and milk quality was assessed. Economic implications of such substitution are discussed in terms of savings on costs of supplementary protein.

Objective

To assess the nutritive value of A. boliviana and L. leucocephala FTL-maize silages as partial substitutes for commercial dairy meal through a feeding trial using lactating Holstein dairy cows.

Materials and methods

Ration formulation

Individual animal rations were formulated to give an overall CP content of 13% (SD = 0.3) and energy concentration of 11.0MJ/kg (SD = 0.09). The forage analysis data obtained in chapter 3 were used in formulating rations. The bunker silage provided the basal diet for the experimental animals. Balancing was done using the lactating meal, which also provided the mineral requirements.

Animals and treatment allocation

Twelve animals with a mean of 610 +/- 71 kg live weight and all in mid-lactation (days in milk 166 SD = 27) were used in the study. The animals were arranged into four groups of three animals each according to parity. The three cows in each group were randomly allocated to one of the three treatment silages i.e. maize (control), maize-leucaena and maize-acacia. All the experimental animals were then randomly allocated to individual feeding troughs in the feeding shed.

Feeding system and measurements

The cows were given three meals per day at 06:00, 12:00 and 17:00 for a period of 21 days of which 14 days were for adaptation followed by seven days of data collection. Animals were allowed at least 2 hours feeding time after which the refusals were removed and weighed for each meal. The treatment silage (10 kg) was fed at 06:00 everyday. At 12:00 and 17:00 the cows were given 10 kg of the basal bunker silage. Whenever an animal left less than 5 kg of basal silage in any two consecutive meals the amount of the basal silage would be increased by 5 kg in the subsequent meals.

The apparent intake was calculated as the difference between the amount offered and the refusals for each meal. Apparent intake data during the three meals was expressed on dry matter (DM) basis and then added for the total daily dry matter intake. The animals were given access to water in-between meals every day. Daily milk yields were recorded during the morning and evening milking sessions. Milk sampling was done twice per week during morning and afternoon milking sessions. Twenty millilitre samples were collected into sample bottles with potassium dichromate preservative to prevent any spoilage before chemical analysis.

Laboratory analyses

The samples were analysed for butter fat (BF), lactose, protein, and total solids at the Dairy Services.

Statistical analysis

The DMI, milk yield and milk composition data was analysed using the general linear model (GLM) procedures of Statistical Analysis Systems (SAS) of 1994 for a completely randomized block design. The following statistical model was used:

$$\mathbf{R} = \quad + \mathbf{P_i} + \mathbf{T_j} + \quad_{ijk}$$

Where: **R** is the response variable (DMI, milk yield, protein butterfat, lactose and total solids)

is the overall mean

$\mathbf{P_i}$ is the effect due to parity (i = 1, 2, 3 or 4)

$\mathbf{T_j}$ is the treatment silage effect (j = 1, 2 or 3)

$_{ijk}$ is the random error

The differences among the means were assessed by Tukeys studentised range method.

Results

Dry matter intake

The dry matter intake levels of the silages and the lactating meal are shown in table 5.1. The cows given mixed maize-acacia and maize silage (control) had higher intake levels than those fed on the mixed maize-leucaena silage (P<0.05).

Milk yield and quality

The milk yields (table 5.1) was higher (P < 0.05) in cows fed on mixed maize-acacia and maize silages compared to animals on mixed maize-leucaena silage. However the milk composition in terms of BF, lactose, protein and total solids was not different (P>0.05) across the treatment diets.

Table 5.1: Dry matter intake, milk yield levels and milk composition from animals fed on mixed cereal-legume silages.

	Maize silage (control)	Maize-Leucaena silage	Maize-acacia silage	Standard error of means
DMI (kg/100kg live weight)	3.30[a]	3.11[b]	3.31[a]	-
Daily milk yield (kg)	17.02[a]	14.06[b]	15.7[a]	0.69
Butterfat (%)	3.59[a]	3.72[a]	3.57[a]	0.11
Protein (%)	3.36[a]	3.44[a]	3.45[a]	0.05
Lactose (%)	4.58[a]	4.57[a]	4.48[a]	0.04
Total solids (%)	12.47[a]	12.74[a]	12.48[a]	0.16

Note Values with different superscripts across the rows are significantly different at P<0.05 level

Discussion

Dry Matter Intake (DMI)

The potential of the mixed silages as a source of protein in dairy cattle feeding seems to have been confirmed by the DMI levels achieved where there was no significant difference between that of maize-acacia (3.31kg/100kg live weight) and the control was not significant ($P < 0.05$). DMI is an important parameter in assessing the nutritive value of a feed or forage. The CP content of a feed influences the DMI of that feed because it tends to improve the palatability. However the CP content alone is not responsible for high DMI because the energy content of the feed also plays an important role. (Seyd and Leaver, 1999). The nutrient demand for lactation may have had a bigger role in influencing DMI rather than the quality of the forage per-se.

It is also possible that the good silage resulting from the mixed FTLs and the maize may have reduced the effect of tannins and other anti-nutritional factors thereby equating the mixed silages to maize silage (control). (*The effect of ensilage on tannin levels and action will be reported in another experiment investigated by the same authors). From literature it is known that acacia contains more tannins than leucaena and this should have reflected by low DMI in maize-acacia. The different picture given by the DMI values seem to suggest that ensilage has an effect on tannin levels and or action of the respective tannins in FTLs.

Milk yield and quality

Milk yield and quality are influenced by stage of lactation, parity, animal size and the body condition at calving within the same breed. It is a fact that rations that stimulate high milk yield will depress BF% and boost TS. Good levels of feeding tend to stimulate high milk yields and lactose but depress BF, protein and minerals. Conversely under feeding results in high BF, protein and minerals and low milk yield and lactose (Slater, 1991). Following these guidelines it seems there was some level of under feeding in the maize-leucaena silage treatment. However, there is a possibility that the values of BF and lactose obtained in this treatment, which differed from those of the control and maize-leucaena silage, may be due to the illnesses of the animals in this treatment during the experiment. Mastitis and other infectious diseases reduce milk yields for the period of illnesses or for the lactation or lifetime production.

The marginal reduction in costs obtained when one uses the FTL silages may justify the use of these FTL silages especially the maize-acacia in this case. The advantages of the mixed silage are translated in terms of the savings on costs of commercial feeds. The substitution of commercial feeds by the FTLs would be ideal for as long as there are no hidden costs involved and as long as the ingredients of the commercial feeds are highly priced.

Conclusion

Mixed silages of good quality can be produced and used to replace commercial feed supplements without loss in milk yield or quality. However, there is need to ascertain the trend with low yielding dairy cows especially crossbreeds cows where there is potential to completely replace the commercial feeds with mixed FTLs and boost profits. It can safely be concluded that ensiled mixed maize-acacia can be used in dairy feeding rations at 30% substitution level of maize silage in order to cut down on the amount of commercial feeds used. There is need to translate the substitution rates in monetary terms in order to assess the economic impact of the mixed silages. Judging from the performance of the mixed silages in this experiment it is possible to recommend their use for feeding heifers and dry cows to replace the commercial feeds.

ii The effects of breed and prepartum supplementation with forage Sorghum bicolor-Lablab purpureus mixed silage on body condition and post partum milk production in dairy cows in a semi arid area of Zimbabwe.

Introduction

Animals grazing the poor dry season pasture lose weight (Topps, 1977). It is imperative that dry season supplementation be done for sustainable dairying. With almost inhibitory prices for commercial supplements, farmer grown and conserved feed is the cost effective way forward. For semi arid areas, sweet sorghum is a better alternative to maize being more drought tolerant hence higher yields (Havilah and Kaiser, 1992). However most smallholder farmers have no experience with feed conservation (Mupeta, 1999).

Besides feed, breed suitability is another problem. The predominant breed in the sector is the indigenous small hardy Sanga, namely the Mashona, Nkone and Tuli which are poor in milk production (Mupunga *et al*,. 1993). The most suitable breed for this sector is yet to defined, in fact according to Mutsvangwa *et al*., (1989), the most suitable is not known.

This study therefore seeks to asses the benefits of pre partum dry season supplementation as an option of strategic supplementation to improve dry season condition scores in cows and hence better milk production in the subsequent lactation for semi arid small holder dairying.

Materials and Methods.

Site description

The study was conducted at Matopos Research Station in Matebeleland South Province of Zimbabwe. It is a centre for semi arid country livestock production. The site lies 20^{o} ^{S} and 28 ^{o} E and is 1340m above sea level. The mean maximum temperatures in summer are around 30 ^{o} C and in the cool dry season around 20 ^{o} C. The area receives low to moderate annual rainfall (570mm), mainly during the rain season, which spans from November to March. The area also experiences periodic droughts. The vegetation in the area mainly savannah woodland with acacia trees and shrubs being the predominant tree species. The pasture quality and quantity varies seasonally, being very good and abundant in the rainy season but turning poor and scarce in the dry season. The animal depending on such lose weight (Topps, 1977). At the time of this study there was a drought with rainfall at 380mm which affected the yield and quality of the silage. The silage had CP of 9% as compared to 12% in intercropped silage in previous years (Mhere *et al.*, 1999).

Animals

A total of 40 primi-and multiparous cows in the last two months of pregnancy were selected from the station’s pregnant herd. Of these 20 were indigenous (10 Tuli & 10 Nkone) and the 20 Jersey crosses of the first two (10 Jersey x Nkone & 10 Jesery x

Tuli). At inception, cows were of mean body weight 363.4 ± 52 kg and body condition 2.5. The supplementation commenced around late August 1999 to November 1999 and data collection continued to July 2000. During the lactation period, suckled briefly in the morning before milking and were allowed to run with their dams after milking until separation in the evening in simulation of smallholder practice.

Treatments

Cows were stratified by breed and allocated to the four silage supplementation levels. The 4 breeds as mentioned above indigenous that is Nkone (N) and Tuli (T) and the crosses, JerseyxNkone (JN) and Jersey x Tuli (JT).

The 4 dietary treatments were as follows, treatment 1: unsupplemented (control) only natural grazing, Treatment 2: 3kgDM sweet sorghum-lablab silage/cow/day, Treatment 3: 6kg DM sweet sorghum-lablab silage/cow/day and treatment 4: Adlib sweet sorghum-lablab silage/cow/day. The first three groups were allowed a basal diet of grazing natural veld. The silage produced from intercropped sweet forage sorghum (sugargraze) and *Lablab purpureus* (Dolichos beans)made from the plastic bag silos using a technology developed by Titterton *et al.,* (1999) and the chemical composition is shown in table 1.

Table 1. Chemical composition of the sweet sorghum – lablab silage.

DM	CP	Ash	ADF	NDF	MADF	DOM	pH	ME	AN
			g/kg DM					MJ/kg DM	%
370	93.3	110	350.3	611	45.2	55.6	4.1	8.34	7.3

Measurements

Body condition scores: These were monitored during the two months of supplementation and through to 18 weeks post partum by scoring every week on. The five-point scale (1-emancieted and 5-obesse) according to Mulvany, (1981) was used. This was done throughout by the same two personnel. Scoring was carried out by palpation of the transverse vertebrae and tail head and was based on the amount of fleshing or fat in these two areas.

Lactational response:

Milking commenced 1-week post calving to allow colostrum dispensation to calves before. The cows were hand milked once in the morning and the daily yield for each cow recorded. Prior to milking calves were allowed momentary suckling to stimulate the milk let down response. Milking was done to dry off point, which was set as a consecutive daily yield of 0.5 kg for 5 days. The lactation length was measured as the number of days in milk from 7 days postpartum to drying off.

Statistical analysis:

One cow in the control group died before the end data collection so was excluded from analysis. Data on milk yields and lactation length were analysed using GLM procedure of SAS (SAS, 1994). The model used was:

$$Yijkl = \mu + Ti + Bi + (TB)\ ij + Pk + eijkl$$

Where Yijkl = milk yield, lactation length; μ = population mean; Ti = fixed effect of supplementation level (I=1, 2...4); Bj = fixed effect of breed (j=1.2..4); (TB)ij = supplementation level x breed interaction; Pk = fixed effect of parity (1and2); eijkl = random error.

Body condition score being discrete data were subjected to square root transformation according to Gomez and Gomez (1984) before the trends were analysed using the PROC MIXED procedure of SAS (SAS, 1994) for repeated measures analysis. The model used was :

$$Yijklmn = \mu + Ti + Bj + Pk + Wl + (TxB)ij + (TxW)il + (TxBxW)ijl + (BxW)jl + C(TxB)ijm + eijklmn$$

Where:

Yijklmn = response variable (body condition)

μ = population mean; Ti = fixed effect of level of supplementation (i = 1,2..4);Bj = fixed effect of breed (j = 1,2,..4); Pk = fixed effect of parity(k = 1,2); Wl = fixed effect of time (week) (l = 1,2 …..20 weeks); (TxB)ij = treatment x breed interaction; (TxW)il = treatment x time interaction; (TxBxW)ijl = treatment x breed x time interaction; (BxW)jl = breed x time interaction; C(TxB)ijm = random effect of m^{th} cow in the i^{th} treatment group and j^{th} breed, Eijklmn = random error.

Results:

Effect of prepartum supplementation on body condition scores

Figure 1 depicts the pattern in body condition scores across treatment groups from 1 week before calving to 18 weeks post partum. At calving, cows in the supplemented groups were significantly higher p<0.05) than the control group (unsupplemented). In all treatment groups, cows lost condition after calving into early lactation before beginning to gain gradually after 5 weeks post calving. Treatment 2 (3kg silage) cows had condition scores significantly higher (p<0.05)higher the unsupplemented) only up to the week 2 post partum after which the scores remain not significantly different (p>0.05) to the end of the monitoring period. The condition change from pre-feeding condition to calving condition was significantly different (p<0.05) between the treatment groups with the unsupplemented) losing the most and the adlib group gaining the most.

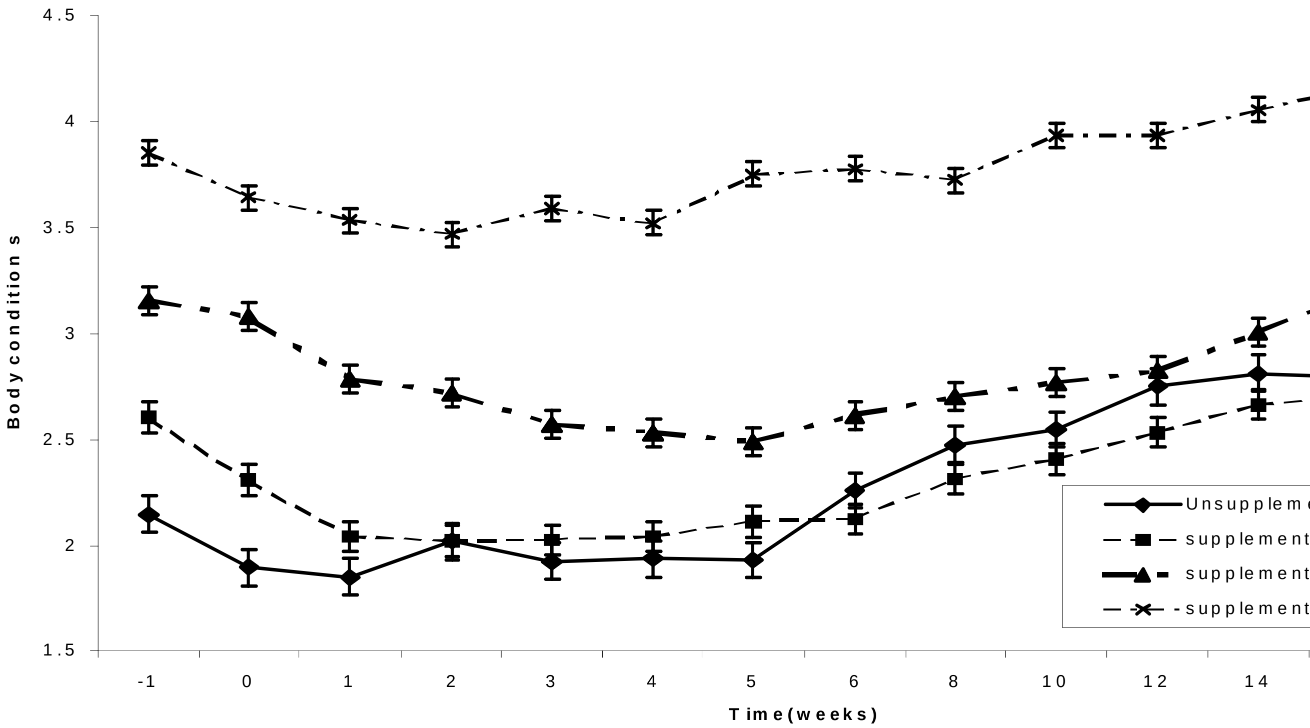

Figure 1. Changes in body condition scores in unsupplemented and supplemented cows.

Figure 2 shows the pattern in the body condition scores in the indigenous and cross breeds. The indigenous (Tuli and Nkone) had significantly higher conditions (p>0.05) than the crosses (Jersey x Nkone and Jersey x Tuli) from calving to the end of the monitoring period at 18 weeks post partum. Between the indigenous groups there were no significant differences (p>0.05) in the body condition scores except for week 1 and week 4 post calving. The Jersey Nkone and Jersey Tuli had similar conditions

($p>0.05$) except between week 2-8 post partum when the Jesery Nkone higher scores ($p<0.05$).

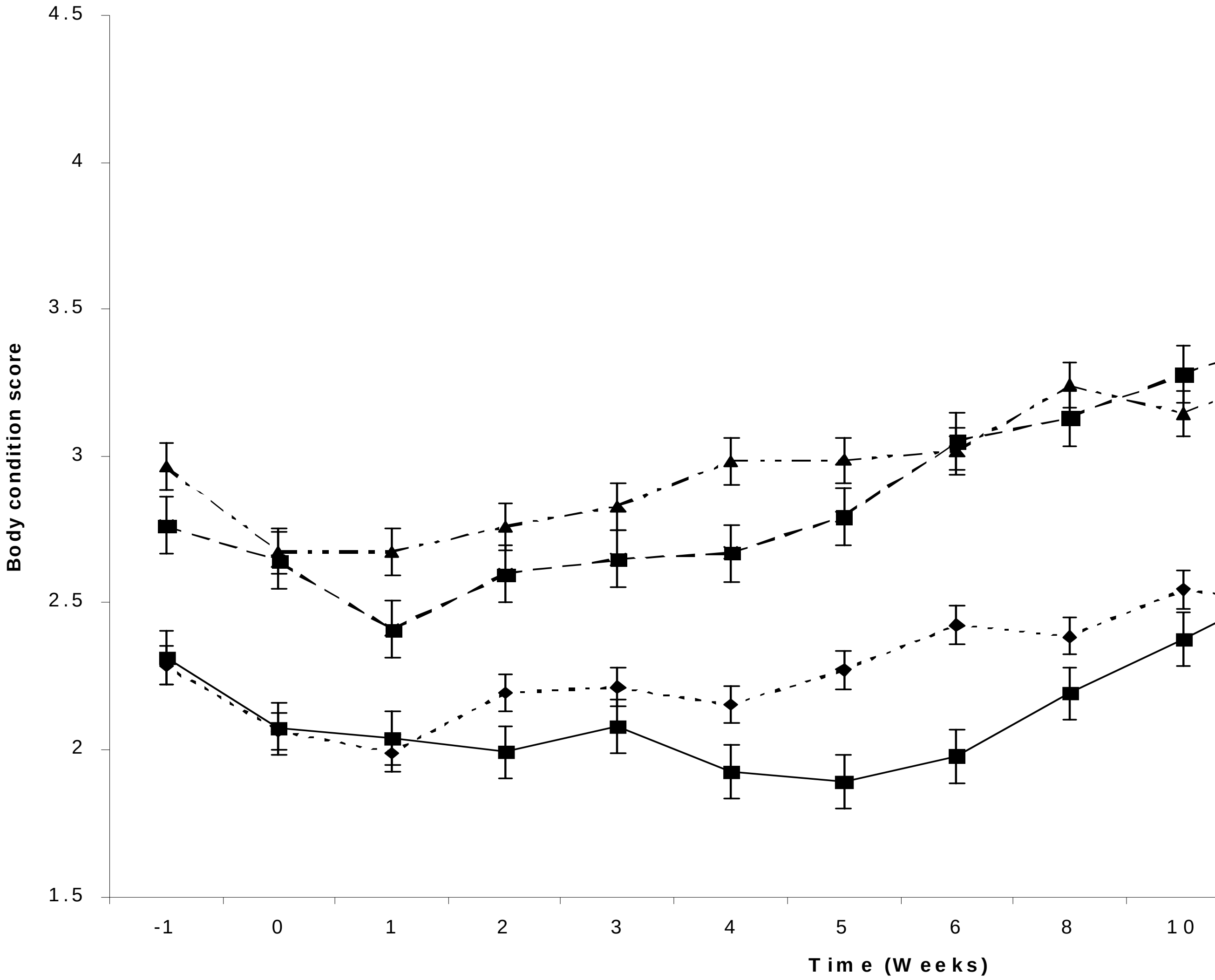

Figure 2. Changes in body condition scores in the indigenous (Nkone & Tuli) and cross bred cows (Jersey x Nkone and Jersey x Tuli) from 1 week prepartum to 18 weeks post partum.

Table 2. The body condition scores for the breeds different supplementation levels.

Breed	Control	3 kgDM silage	6kg silage	Adlib
JN	**2.05^{1a}±0.001**	**2.02^{1a}±0.0007**	**2.48^{1b} ±0.003**	**3.61^{12c} ±0.008**

JT	**1.95^{1a} ±0.001**	**1.94^{1a} 0.0008**	**2.3^{1b} ±0.003**	**3.39^{1c} ±0.009**
N	**2.56^{2a} ±0.008**	**2.69^{2a} ±0.006**	**3.2^{2b} ±0.002**	**4.3^{3c} ±0.009**
T	**2.59^{2a} ±0.0007**	**2.65^{2a} ±0.007**	**3.35^{2b} ±0.003**	**3.84^{2c} ±0.009**

Means with the same letter in a row are significantly different.

Means with same number in a column are significantly different

Effect of prepartum supplementation with silage on milk yield and lactation length

The crossbreeds had significantly higher daily milk yields, total lactation milk yields and longer lactation lengths ($p<0.05$) than the indigenous breeds. Between the two indigenous (Tuli and Nkone) breeds there were no significant differences ($p>0.05$) in terms of milk yields and lactation lengths. There were also no significant differences ($p>0.005$) between the Jersey x Tuli and Jersey x Nkone crosses in terms of milk yield and lactation length.

Table 3: Milk yield and lactation length in indigenous and crossbreds

	Breeds			
Parameter	**JN**	JT	N	T
Daily milk yield (kg)	2.82^{a} ±0.2	3.17^{a} ±0.18	1.12^{b}±0.19	1.25^{b}±0.19
Lactation yield (kg)	652^{a} ±46.8	760^{a} ±38.9	230^{b}±40	248^{b}49.4
Lactation length (days)	246.6^{a} ±11	241.8^{a} ±9	194.5^{b} ±9.7	194.5^{b} ±10

Ls means with the same superscript in a row are not significantly different ($p>0.05$)

Table 4. Milk yields and lactation lengths for breeds in the each supplementation level.

		Supplementation levels			
Parameter	Breed	Control	3kgDM silage	6kgDM silage	Adlib
	JN	$597.8^{1a}\pm 89.6$	$620.7^{1a} \pm 70$	$629.7^{1a} \pm 89.6$	$760^{1a} \pm 89.6$
Lactation yield(kg)	JT	$659.8^{1a} \pm 70$	$875.3^{2a} \pm 87$	$775^{1a} \pm 85$	$730.6^{1a} \pm 75$
	N	$233.6^{2a} \pm 85$	$311^{3a} \pm 70$	$212.8^{2a} \pm 70$	$163.8^{2a} \pm 89.6$
	T	$303.7^{2a} \pm 89.6$	$122.5^{3a} \pm 85$	$335^{2a} \pm 70$	$232^{2a} \pm 75$
	JN	$2.82^{1a} \pm 0.41$	$2.67^{1a} \pm 0.32$	$2.54^{1a} \pm 0.41$	$3.28^{1a} \pm 0.41$
Daily milk yield (kg)	JT	$2.68^{1a} \pm 0.32$	$3.68^{1a} \pm 0.41$	$3.15^{3a} \pm 0.39$	$3.17^{1a} \pm 0.35$
	N	$1.12^{2a} \pm 0.39$	$1.61^{2a} \pm 0.32$	$1.1^{2a} \pm 0.32$	$0.68^{2a} \pm 0.41$
	T	$1.37^{2a} \pm 0.41$	$0.75^{2a} \pm 0.39$	$1.6^{12a} \pm 0.32$	$1.33^{2a} \pm 0.30$
	JN	$237.3^{1a} \pm 21$	$237^{1a} \pm 16$	$250^{1a} \pm 22$	$262^{1a} \pm 22$
Lactation length	JT	$245.8^{1a} \pm 16$	$233^{1a} \pm 21$	$259^{1a} \pm 21$	$230.4^{1a} \pm 18$
	N	$216^{1a} \pm 20.5$	$191^{21a} \pm 17$	$203.5^{1a} \pm 17$	$167.9^{2a} \pm 22$
	T	$221.4^{1a} \pm 21.6$	$163.4^{2a} \pm 21$	$208.6^{1a} \pm 19$	$185^{2a} \pm 18$

For each parameter, means with same letter in each row are not significantly different and means with the same number in each column are not significantly different.

Discussion

By the time cows calved, those in the unsupplemented group had lost more condition than the supplemented groups. This confirms the findings of Topps, (1977) that cattle in tropics lose weight in the dry season due to the poor quality in the natural pastures, which have crude protein as low as 3%. The supplemented group (6kg and Adlib silage) gained condition by calving time. This shows at these supplementation levels, sweet sorghum-lablab silage was effective in curbing the dry season nutritional stress.

The indigenous had higher conditions than their crossbred counterparts, most probably due of an inherent ability to utilise lower quality feeds according to Hunter and Siebert (1990). Similarity between unsupplemented and supplemented cows in terms of milk production and lactation length could be an indication that a very good condition at calving does not give any lactational advantage for indigenous and crossbreeds. The poor milk yields could also have been due to poor grazing during the post calving period. It is well documented that high-producing cows must calve with adequate reserves for mobilisation to help meet energy and protein requirements of early lactation (Erb *et al.*, 1990). However poor milk producers such as indigenous cows and cross-breds may behave differently. Mupeta, (1999) in his study of Zimbabwean smallholder cows reports that Bos indicus give priority to maintenance of body condition than milk production. Jingura (2000) working with smallholder cows in Gokwe, Zimbabwe reported that cows were 'not milking 'off their backs'. Munyoro, (1997) and Khombe *et al.*, (1999) also state that the indigenous on a higher plane of nutrition do not produce more milk but tend to put on weight. In this study however, slight mobilisation occurred depicted by the drop in condition after especially in the unsupplemented cows and the 3kg-silage group. It could therefore be hypothesised that indigenous and crossbreed cows have a lower capability to mobilise reserves to thus benefit much from fat reserves at calving.

The milk yields obtained (1.12kg and 1.25 kg for indigenous, 2.82 and 3.17kg/day for crosses) in this study are slightly higher than those reported for the same breeds by Hamudikuwanda *et al.*, (2000) who found 0.7 kg and 2.47kg/ day for indigenous and cross breeds respectively. The 5.5kg/day for crossbreeds reported by Mupeta (1999) is higher. The lactation length of 194 days for the indigenous are slightly higher than 150 days reported by Mupunga *et al.*, 1992 and 180 days by Henson, (1990). The lactation length of 243 days in this study is comparable with the 250 days for the crossbreeds as reported by Mupeta 1999.

Conclusions

Cows supplemented at levels of at least 6kgDM silage per cow a day gained weight through the dry season shows sorghum-lablab silage is good enough for dry season supplementation in smallholder dairying. However the benefits of improved prepartum body conditions does not seem realisable gains in terms of lactational performance in the indigenous and crossbreeds according to this study however fertility may benefit, this will be reported in another paper . The effect of a combination of prepartum and also postpartum supplementation need to be assessed for smallholder dairy indigenous and crossbred cows. Use of cross-breds for smallholder dairying would be more profitable since they have higher milk yields and longer lactations than pure indigenous breeds.

iii The effects of breed and prepartum supplementation with forage *Sorghum bicolor-Lablab purpureus* mixed silage on trends in blood metabolites in cows in a semi arid area of Zimbabwe.

Introduction

Unsupplemented cows lose their body conditions in the4 dry season (Nyoni, 2000). Work by Garwe *et al*. (1999) reported that the Jersey x indigenous crosses tended to have poorer body condition scores than indigenous cows in the dry season. It is therefore, especially using affordable farm grown and conserved feeds such as sorghum-lablab silage. The conventional way of monitoring the nutritional status of animals has been the use of body condition scores and weighing. However blood levels of metabolites such as non-esterified fatty acids (NEFA), ketones and glucose have been reviewed as indicators of energy status of ruminant animals (Bowden, 1971; Natchomi *et al.* 1991). Therefore, where feed intake measurements are difficult to take such as for animals on range, these metabolites offer another avenue to assess the nutritional status in animals. Early lactation in high producing dairy cows is associated with elevated plasma levels of NEFA and depressed glucose levels. (Titterton, 1994). This is attributed to a high glucose demand by the mammary gland and hence mobilisation from depots of NEFA (Tivapasi, 1998; Rukkwamsuk, 1999). Elevated NEFA levels are indicative of an energy deficit. Richardson (1984) reported rising NEFA levels as dry matter intake declined below maintenance. Glucose on the other hand rose parallel with supplementation level (Natchomi, 1991; Chimonyo, 1998). There is however a breed effect on the plasma concentrations of these metabolites reported by Richardson (1984).

The objective of this study was to assess the response of plasma glucose and NEFA levels to prepartun supplementation and breed effect in smallholder cows. The usefulness of these metabolites in monitoring the nutritional status of cows shall be discussed.

Materials and Methods

These are as stated before

Blood sampling

Blood samples were collected weekly during the morning before feeding by jugular vein puncture. The blood samples were used for the assay glucose and non-esterified fatty acids (NEFA). During blood collection, 10 ml of the blood sample from each cow was collected in a test tube containing sodium fluoride to arrest glycolysis. Another sample of 10 ml was collected in a plain test tube and allowed to clot and the serum obtained was used for the analysis of NEFA content. Both samples were centrifuged at 1000 x g for 15 minutes and the resultant plasma and serum were stored at –20^{o}C for later analysis.

Laboratory analysis

Determination of glucose concentration

The concentration of plasma glucose was determined using the ACE^{TM} ®Clinical Chemistry kit (Sigma Company, Amsterdam, Netherlands). In this assay, the enzyme glucose hexokinase was used to catalyse the oxidation of glucose in the presence of nicotinamide adenine dinucleotide (NAD) and adenosine trisphophate (ATP) to give gluconate 6-phosphate and reduced NAD (NADH). The total amount of NADH formed was proportional to the initial amount of glucose present. Therefore absorbance of the NADH and gluconate 6-phosphate was then bichromatically measured at 340 nm wavelength.

Determination of non esterified fatty acid (NEFA) concentration

The concentration of NEFA in the blood was determined by the high performance liquid chromatography method (HPLC). In the determination, 1ml of blood plasma was mixed with 1 ml of a chloroform/methanol (50:50) mixture in a test tube and thereafter 50 µl of concentrated hydrochloric acid was added. In addition about 100 µl of acetonitrile was added and the mixture was centrifuged for 5 times at 1000 x g. After centrifugation, 15µl of the supernatant was injected into the HPLC system equipped with an ultraviolet detector (Pye Unicam PU 4020 detector, South African Scientific Products, Johannesburg, South Africa) using a flow of 0.8 ml per minute. The fatty acid concentrations were then determined by UV absorption at 254 nm wavelength.

Statistical analyses

One cow in the control (unsupplemented) group died and consequently the data from this cow was excluded from the analysis. The effects of breed and supplementation level on plasma NEFA and glucose concentrations was determined by the PROC MIXED procedure of SAS (SAS, 1994) for repeated measures.

The model used was:

$$Y_{ijklmn} = \mu + T_i + B_j + P_k + W_l + (TxB)_{ij} + (TxW)_{il} + (BxW)_{jl} + C(TxB)_{ijm} + (TxBxW)_{ijl} + e_{ijklmn}$$

Where: Y_{ijklmn} = response variable (body condition, NEFA and glucose)

μ = population mean

T_i = fixed effect of level of supplementation (i = 1, 2, 3, 4)

B_j = fixed effect of breed (j = 1, 2)

P_k = fixed effect of parity (k = 1, 2)

W_l = fixed effect of time (l = 1, 2 …..20 weeks)

$(TxB)_{ij}$ = treatment x breed interaction

$(TxW)_{il}$ = treatment x time interaction

$(BxW)_{jl}$ = breed x time interaction

$C(TxB)_{ijm}$ = random effect of m^{th} cow in the i^{th} treatment group and j^{th} breed

$(TxBxW)_{ijl}$ = treatment x breed x time interaction, and

e_{ijklmn} = random error

A pearson correlation was carried out to determine the association between plasma NEFA and glucose concentrations. The NEFA concentrations were regressed against supplementation level using the PRO REG of SAS (SAS 1994).

Result

The interaction between breed and supplementation level was highly significant ($P < 0.001$). Among the crossbred cows, there was no difference ($P > 0.05$) in blood glucose levels across all supplementation levels (Table 2), however among the indigenous cows, plasma glucose concentrations increased linearly with increasing supplementation level. Within the indigenous cows, those fed the supplement had the highest ($P < 0.001$) glucose levels compared to the 0 kg, 3 kg and 6 kg supplementation levels. Cows in the 3 kg and 6 kg supplementations had similar ($P > 0.05$) but higher glucose levels than unsupplemented. Pre and postpartum plasma glucose levels in the cows in all the treatment groups declined during the first week after parturition. The levels then rose again thereafter. During lactation, the indigenous cows in each treatment had relatively higher ($P < 0.001$) plasma glucose levels compared to crossbreds in the treatment.

Table 2. Effect of breed and prepartum supplementation level on mean plasma glucose concentrations (mmol/litre)

	Silage supplementation level (kg DM)			
Breed	**0**	**3**	**6**	**Ad lib**
Crossbred	$3.65^{ad} \pm 0.053$	$3.66^{ad} \pm 0.04$	$3.6^{ad} \pm 0.045$	$3.68^{ad} \pm 0.046$
Indigenous	$3.79^{ae} \pm 0.058$	$4.01^{be} \pm 0.042$	$3.94^{be} \pm 0.037$	$4.3^{ce} \pm 0.045$

$^{a-c}$LS means with different letters within a row are different ($P < 0.05$)

$^{d-e}$LS means with different letters within a column are different ($P < 0.05$)

Effects of breed and prepartum supplementation on plasma NEFA concentrations

Crossbred cows had significantly higher ($P < 0.001$) mean plasma NEFA levels than indigenous cows (0.45 ± 0.04 mmol/l and 0.32 ± 0.05 mmol/l respectively). The NEFA levels were not significantly affected ($P > 0.05$) by supplementation level and there was no interaction ($P > 0.05$) between breed and supplementation level.

However, in both breeds there was a tendency ($P > 0.05$) for the NEFA concentrations to decline as the pre partum supplementation level increased in both breeds (Fig. 3). At calving, there was a sharp rise in the plasma concentration on NEFA in all cows (see Fig 4). The rise reached a peak about one week after parturition. Thereafter there was a gradual decline in the NEFA levels although the levels in the crossbreds cows remained significantly higher ($P < 0.001$) than those indigenous cows. By the end of the period of blood collection (18 weeks postpartum) the crossbreds still had higher ($P < 0.001$) mean NEFA levels than the indigenous cows.

Plasma NEFA and glucose concentrations were significantly ($P < 0.001$) negatively correlated ($r= -0.32$).

Discussion

Plasma glucose concentrations

The linear increase in plasma glucose concentrations with increasing supplementation level observed in indigenous cows agrees with the reports by Richardson (1984) and Natchomi *et al* (1991) that plasma glucose concentrations increased with energy intake. However in the work by Natchomi *et al* (1991) the cows were supplemented in early lactation. Chimonyo (1998) also reported higher plasma glucose levels in supplemented Mashona cows compared to the unsupplemented animals. The lower of glucose levels observed in crossbreds compared to the indigenous cows is in line with the breed differences reported by Richardson (1984) that indigenous cattle had higher plasma glucose concentrations as compared to the exotic breeds. These differences could also be attributed to milk yield differences in these breeds. At the onset of lactation, there is a high glucose requirement for lactose production (Tivapasi, 1998). Therefore crossbred cows, which produce more milk than the indigenous cows, have a higher demand of glucose. This is the cause of lower plasma glucose levels in the crossbreds in this study. The indigenous cows produced less than 2 kg of milk per day where as the crossbreds produced 3 kg per day (see paper A). Therefore, the crossbreds had a higher demand for glucose to use in lactose synthesis. It is likely that the crossbred cows were more nutritionally stressed and experienced a lower energy balance than the indigenous cows.

The sharp drop in plasma glucose concentrations experienced by all cows in this study immediately after calving experienced by all cows confirms the report by Tivapasi (1998) that cows experienced a drop in plasma glucose at one week post calving due to the lactation demand for glucose.

Plasma NEFA concentrations

The concentration of Plasma NEFA levels was not affected by supplementation level and this is in agreement the findings of Sahlu *et al.* (1995) who reported insensitivity of plasma NEFA levels to prepartum dietary energy and crude protein intake. Richardson (1984) reported that plasma NEFA concentrations increased as DM intake declined below maintenance. This trend was observed in the current study where plasma NEFA levels decreased as the level of supplementation increased. The increased NEFA levels were an indication of low energy balance and fatty acid release from adipose tissue (Richards *et al*., 1989). Therefore in early lactation greater mobilsation of fat occurred in crossbreds than indigenous cows. According to Reid *et al.* (1986) plasma NEFA levels begin to rise before calving reaching a maximum at one week postpartum before they decline. The decrease in plasma NEFA concentrations in both breeds with time after calving indicated a recovery from low energy balance as milk yield decreased and appetite improved in the cows.

Herdt (1988) reported that hypoglycemia caused an increase in NEFA levels, which seems to confirm the findings in this study in where the rise in NEFA plasma concentration occurred as decrease in plasma glucose levels decreased. The observed negative correlation between plasma NEFA and glucose was also reported by Teleni and Hogan (1989). This observation is supported by the findings of Rukkwamsuk (1999) that the fall in glucose leads to a decrease in insulin to glucagon ratio which means that lipolysis occurs and causes a rise in NEFA concentrations.

It is concluded that there is a strong breed effect on blood metabolite concentrations, these metabolites also showed a pattern determined by feeding level therefore could be used to monitor nutritional status in cows.

iv The effects of breed and prepartum supplementation with forage *Sorghum bicolor-Lablab purpureus* mixed silage on body condition, milk production and resumption of ovulation in dairy cows in a semi arid area of Zimbabwe.

Introduction

According to Topps (1977), animals depending on the poor dry season natural pasture lose body condition scores and liveweight. A survey by Hamudikuwanda *et al.* (2000) in Matebeleland revealed calving intervals of up to 3 years, the major cause being poor nutrition. In fact long calving intervals are a feature of cow infertility in the smallholder and communal areas (Mukasa-Mugerwa, 1989: Chimonyo, 1998). It is therefore imperative that dry season supplementation should be practised if acceptable levels of production are to be attained and sustained. With almost inhibitory prices for commercial feed supply, farm grown and conserved feeds could be the cost effective way forward.

According to Titterton *et al*. (1999), sweet sorghum intercropped with *Lablab purpureus* (dolicos beans) is recommended for mixed silages, because of high yields in semi arid areas as well as good ensiling properties. Titterton *et al*. (1999) reported that in the Matopos area of Zimbabwe, forage sorghum intercropped with dolichos beans (*Lablab purpureus*) could give yields of up to 7 tonnes DM/ha with annual rainfall of less than 600 mm, and that good quality silage could be made (CP around 120g/kg of DM).

Besides nutritional constraints, smallholder dairying faces problems of breed suitability. The predominant breed in this sector is the indigenous, small, hardy Sanga type of cattle, namely the Mashona, Nkone and Tuli, which are poor milk producers (Mupunga and Dube, 1993). The produce daily milk yields of less than 2 kg per day (Nyoni, 2000). In Matebeleland, smallholder dairying and the involvement of DDP are recent. Milk production is from indigenous Nkone and Tuli cows however in some projects crossbreds of Tuli or Nkone and Jersey sourced from Matopos Research Station, have been introduced (Hamudikuwanda *et al*., 2000).

Poor body condition scores at calving compromise milk yields and fertility (van der Merwe, 1995). Trials by Garwe *et al*. (1999) found that crossbred cows tended to have poorer body conditions in the dry season relative to the indigenous.

This study therefore sought to evaluate body condition scores, milk production and postpartum resumption of ovulation of indigenous and crossbred cows, receiving prepartum supplementation consisting of farm grown and conserved legume-grass silage during the dry season.

Materials and Methods

Study site

The study was carried out at Matopos Research Station in Zimbabwe. The site lies 20^{o}S and 28^{o}E and is 1340 m above sea level. The mean annual rainfall received in the area is 570 mm. The rain season spans from November to March. The area also experiences periodic droughts. The mean maximum temperature in summer is around 30^{o}C, and in winter the mean temperature is 20^{o}C. The vegetation in the area is mainly Savannah woodland with Acacia trees and shrubs being the predominant tree species. The predominant grass is the Hyparrhenia species. The natural pasture is of good quality and quantity in summer but declines in quality and in quantity in the dry season.

Animals

In late August 1999, 40 cows in their last two months of pregnancy were randomly selected from a herd at Matopos Research Station. Of these, 20 were indigenous cows (Tuli and Nkone) and the other 20 were crossbreds (Jersey x Nkone and Jersey x Tuli F1). Cows were pooled as indigenous and crossbreds. The cows were of mean body-weight of 363 ± 52 kg and body condition score 2.5 ± 0.25 at the beginning of the experiment in August 1999. The supplementation ran from August 1999 to November 1999.

Experimental treatments

The experimental design was a 2 x 4 (breed x diet) factorial treatment. The cows were allocated such that each breed (indigenous or crossbred) was represented in each supplementation level. The supplement was silage made from intercropped sweet forage sorghum and *Lablab purpureus* (dolichos beans). It was made in plastic bag silos using a low cost method developed by Titterton *et al.* (1999). The chemical composition of the mixed silage is shown in Table 1. The cows were fed the silage in individual stalls in the afternoon after grazing and were allowed an adaptation period of two weeks before data collection commenced.

The supplementation levels of the silage in kg DM were as follows: Level 1 (0 kg group) in this group, the cows were not given any supplement at all but were allowed to graze natural veld. Level 2 (3 kg group): the cows were offered 3 kg (DM) silage per cow per day above a basal diet of natural veld grazing. Level 3 (6 kg group): the cows were given a daily supplement of 6 kg (DM) silage above a basal diet of natural veld grazing. Level 4. *Ad lib.* group: Cows in this group were fed on silage on an *ad lib*. basis.

Table 1. The chemical composition of sweet sorghum-lablab mixed silage

			g/kg DM						
DM	**CP**	**Ash**	**ADF**	**NDF**	**MADF**	**DOM**	**Ammonia N**	**pH**	**ME (MJ/kg)**
370	93.3	110	350.3	611	452	556	7.3%	4.1	8.34

Measurements

Body condition

The experimental animals were body condition scored using the 5 point scale as described by Mulvany (1981). The areas assessed were at the tail head and loin area. The animals were scored once every week during the experimental period.

Milk yields

After calving the cows were allowed to suckle their calves so that they obtained colostrums. After about a week, the cows were hand milked once a day after allowing brief suckling by the calf. Milking was done in the in the morning before the cows went to graze. The cows were milked until the dry off point, which was set as a consecutive daily yield of 0.5 kg for 5 days. The lactation length was measured as the number of days in milk.

Milk samples for progesterone assays
Milk samples were collected three times weekly from each cow into 1.5 ml plastic tubes containing a table of potassium dichromate preservative for progesterone analysis. The samples were then stored at 4^o C pending analysis.

Laboratory analysis

Determination of milk progesterone concentration
Progesterone concentration in the milk samples was analysed using the Self-Coating Milk Progesterone RIA kit (Animal Production Unit, FAO/IAEA Agriculture Laboratory, Agency's Laboratories, Seibersdorf, Austria). The intra and inter assay coefficients of variation were 9.3% and 10.4%, respectively.

Determination of postpartum resumption of ovarian activity.
Progesterone profiles were plotted using the three times weekly progesterone concentrations. The number of days from calving to the first ovulation was determined from the profiles as days from parturition to reach a first rise to progesterone values of equal or greater than 2 ng/ml from a postpartum basal level.

Statistical analyses

One cow in the control (unsupplemented) group died and thus data from the cow was excluded from the analysis. The effects of breed and supplementation level on the body condition scores were determined using the PROC MIXED procedure of SAS (SAS, 1994) for repeated measures. Body condition scores were subjected to square root transformations as described by Gomez and Gomez (1984) before statistical analysis.

The model used was:

$$Y_{ijklmn} = \mu + T_i + B_j + P_k + W_l + (TxB)_{ij} + (TxW)_{il} + (BxW)_{jl} + C(TxB)_{ijm} + (TxBxW)_{ijl} + e_{ijklmn}$$

Where:

Y_{ijklmn} = response variable (body condition score)

μ = population mean

T_i = fixed effect of level of supplementation (i = 1, 2, 3, 4)

B_j = fixed effect of breed (j = 1, 2)

P_k = fixed effect of parity (k = 1, 2)

W_l = fixed effect of time (l = 1, 2 …..20 weeks)

$(TxB)_{ij}$ = treatment x breed interaction

$(TxW)_{il}$ = treatment x time interaction

$(BxW)_{jl}$ = breed x time interaction

$C(TxB)_{ijm}$ = random effect of m^{th} cow in the i^{th} treatment group and j^{th} breed

$(TxBxW)_{ijl}$ = treatment x breed x time interaction, and

e_{ijklmn} = random error

The effects of breed and supplementation level on daily milk yields and lactation length were determined using the GLM Procedures of Statistical Analysis Systems (SAS) (1994).

The model was:

$$Y_{ijkl} = \mu + T_i + B_j + (TB)_{ij} + P_k + e_{ijkl}$$

Where:

Y_{ijkl} = response variable (Average daily milk yield and lactation length)

μ = population mean

T_i = fixed effect of level of supplementation (i = 1,2….4)

B_j = fixed effect of breed (j = 1, 2)

$(TB)_{ij}$ = supplementation level x breed interaction

P_k = fixed effect of parity (k = 1 (primiparous), 2 multiparous)

e_{ijkl} = random error

The number of cows resuming ovarian activity by stipulated days postpartum (60–140) among the treatments were analysed by Chi-square test using the PROC FREQ procedure of SAS (SAS, 1994).

Results

Effects of prepartum supplementation on body condition score

There was a significant ($P < 0.001$) interaction between breed and supplementation level on body condition scores.

There was a higher response ($P < 0.001$) of body condition to supplementation in the indigenous than crossbreeds. Across breeds, the unsupplemented cows and the 3 kg group lost body condition in the 2 months prepartum compared to the 6 kg and adlib groups, which gained body condition (Table 2). All cows lost body condition after calving before regaining it around 4-5 weeks post calving. Within each supplementation, level indigenous cows had higher body condition scores than crossbreds. The greatest loss being in the crossbreeds ($P < 0.05$) on 0 and 3kg supplementation levels with the least drop ($P < 0.05$) in the indigenous on 6 kg and *ad lib*.

Daily milk yield and lactation length

The Jersey x indigenous crosses had significantly higher ($P < 0.001$) daily milk yields and longer lactation length than the breeds (Table 3). Prepartum supplementation did not affect ($P > 0.05$) daily milk yields and lactation length. There also was no interaction between breed and supplementation on the milk production parameters.

.Table 2. Effect of prepartum supplementation with forage sorghum-lablab silage on body condition score change cows between August and November.

	Supplementation level (kg DM)			
	0 kg	**3kg**	**6kg**	**Adlib**
Body condition change	-0.91[a]±0.18	-0.05 [b]±0.16	0.25 [c]±0.17	0.69 [d]±0.2

Means with the same letter in a row are not significantly different ($P>0.05$)

Effects of breed and prepartum supplementation on postpartum resumption of ovarian cyclicity

There was no difference ($P > 0.05$) between the indigenous and crossbred cows in terms of percentages resuming ovarian cyclicity (Table 4). In both breeds, less than 50% of the cows had resumed ovarian cyclicity by day 100 postpartum. Prepartum supplementation, positively enhanced onset of ovarian activity as depicted in Table 5. The unsupplemented cows did not resume ovarian cyclicity at all until after day 100 postpartum as compared to 50% ($P < 0.01$) of the supplemented. After 140 days postpartum the unsupplemented still had a lower ($P < 0.05$) proportion of cows that had resumed ovulation as compared to the supplemented (83%

and 44% respectively). Table 6 shows the proportions of cows resuming ovarian activity postpartum for the different supplementation levels. By day 80 postpartum there were similar ($P > 0.05$) proportions of cows resuming ovulation in the 0 kg, 3 kg and 6 kg levels but the ad lib fed cows had a higher ($P < 0.01$) percentage of cows having resumed ovulation than the three groups.

Discussion

The unsupplemented cows both indigenous and crossbreds lost body condition between August and October. The possible cause of this loss was poor nutrition due to the decline in the nutritive value and quantity of the natural pastures available (Chimonyo, 1998). The cows which were fed the 3 kg silage supplement experienced only a slight loss in body condition which means that this supplementation managed to help maintain the body condition in the dry season. These findings confirms the findings of Topps (1977) that cattle lose body condition during the dry season because of poor natural pastures that

Table 3. LS means for Daily milk yield and lactation lengths in the indigenous and crossbred cows

	Breed	
Parameter	**Indigenous**	**Crossbred**
Milk yield (kg/day)	1.26[a] ± 0.14	3.00[b] ± 0.15
Lactation length (days)	195[a] ± 6.6	244[b] ± 6.6

LS means with different letters within a row are different ($P < 0.05$)

Table 4. Influence of breed on percentage of cows exhibiting first ovulation postpartum

Days postpartum	Indigenous	Crossbreds	Significance level
60	5	0	NS
80	15	26	NS
100	40	37	NS
120	65	58	NS
140	70	79	NS

NS = difference within a row not significant ($P > 0.05$)

Table 5. Percentage of cows (across breeds) starting to cycle postpartum in unsupplemented vs supplemented groups

Days postpartum	Unsupplemented	Supplemented	Significance level
60	0	3	NS

80	0	27	NS
100	0	50	0.007
120	22	73	0.006
140	44	83	0.019

NS= difference within row not significant ($P > 0.05$)

Table 6. Percentage of cows exhibiting first ovulation postpartum in cows on different prepartum supplementation levels

Days postpartum	0	3	6	Adlib
60	0 [a]	0 [a]	0 [a]	10 [a]
80	0 [a]	10 [a]	10 [a]	60 [b]
100	0 [a]	20 [ab]	60 [b]	70 [b]
120	22 [a]	60 [ab]	70 [b]	90 [b]
140	44 [a]	80 [ab]	80 [ab]	90 [b]

Percentages with different superscripts within a row are different ($P < 0.05$) have crude protein as low as 2%. The cows offered the silage supplement of 6 kg and *ad lib.* gained body condition during the pre-calving dry season. This shows that at these supplementation levels, sorghum-lablab silage provides enough nutrients to offset the effects of dry season poor pastures which resulted in good body condition of cows at calving. It is likely that supplementation at these levels during the prepartum period reduced the use of body reserves for foetal growth during the last trimester of pregnancy as reported by Echevarria and Dela-Torre (1996). After calving, all cows gained body condition. This occurred at the beginning of rain season when the pasture was plentiful and of good nutritional value (Chimonyo, 2000).

Generally, in each treatment, the indigenous cows had higher body condition scores relative to the crossbreds. This observation, was also reported by Garwe *et al*. (1999), who carried out similar studies at Matopos. It appears that the crossbred cows, due to their higher milk yield suffered lactational stress such that they had to mobilise their body reserves to support milk production. On the other the low producing indigenous cows mobilised less body reserves. It is also possible that indigenous cows had a better utilisation of low quality feeds which promoted better body condition scores as compared to the crossbreds. Hunter and Siebert (1985) reported that indigenous cows were better at utilising low quality feeds than their exotic counterparts.

According to Rukkwamsuk (1999) cows experience a drop in body condition after calving due to mobilisation of body reserves to support milk production in early lactation. This view explains the observed loss of body condition which occurred in both the indigenous and crossbred cows after parturition. However, the cows fed the silage supplement of 6 kg and *ad libitum* the least indicating that very little mobilisation of body reserves occurred in early lactation. Therefore prepartum supplementation at feeding levels above 6 kg of mixed silage improved body condition of the cows before and after calving.

Despite the good body condition observed at calving in the cows fed the silage supplementation at 6 kg and *ad. lib* groups, there was no corresponding advantage in terms of milk yield and lactation lengths compared to the unsupplemented cows. Mupeta (2000) also reported similar findings that indigenous and crossbred cows had a limited ability to mobiles body reserves to support milk production.

The Jersey x indigenous crosses produced more milk than the indigenous cows. Their daily milk yields were almost twice as much as the yield obtained from the indigenous cows. The relatively low yields could be attributed to the fact that the cows were milked hand milked once a day. Frequency of milking increases the daily yields. The daily milk yields of 1.26 ± 0.14 kg from the indigenous cows and 3.0 ± 0.15 kg from the crossbreds are comparable to yields reported by Garwe *et al*. (1999), of 0.71 kg and 2.47 kg for the indigenous and crossbred cows, respectively. A lactation length of 195 ± 6.6 days for the indigenous cows reported in this study is comparable to the 150 days of lactation reported by Mupunga and Dube (1993) and 180 days observed by Henson (1992). The lactation length of 244 days recorded in crossbreds was comparable with a lactation length of 250 days reported by Hamudikuwanda (2000) for the Jersey x indigenous crosses.

In this study resumption of ovulation postpartum was influenced by breed. This is in contrast to the findings of Garwe *et al*. (1999) and Hamudikuwanda *et al*. (2000) that crosses of the Jersey with the indigenous breed cows resumed postpartum ovarian cyclicity earlier than indigenous cows. The unsupplemented did not resume ovarian activity until after 100 days postpartum as compared to the supplemented, the latter started cycling within 60 days postpartum thus indicating that prepartum supplementation enhanced resumption of ovarian activity. The present study showed that the natural grazing available in the dry season at Matopos was not adequate to support reproduction. This means that without prepartum supplementation the chances of achieving the ideal 365 days calving interval would be slim. To achieve this interval, cows must resume ovulation early and become pregnant by 80 to 85 days after calving (Perera, 1999).

The findings of this study agree with those of Peters and Ball (1995) that an increase in energy supply in pregnant beef cows accelerated return to ovarian cyclicity postpartum. The cows fed the prepartum silage supplement in excess of 3 kg/ cow /day cows had better body condition scores as compared to the unsupplemented, so it could be inferred that the body condition at calving influenced the postpartum reproductive performance of the cows. According to van der Merwe and Stewart (1995) and Peters and Ball (1995), cows calving in a poor body condition undergo prolonged periods before the onset of ovarian activity. This means the prepartum unsupplemented cows most likely had lower energy balance than the prepartum supplemented, and hence took longer to recover and start ovarian cycles.

Conclusion

This study showed that across breeds, prepartum supplementation with sorghum-lablab silage did not improve milk production. Crossbred cows were better as compared to indigenous cows in terms of milk production. The silage supplement in excess of 3 kg DM/day/cow was nutritionally adequate to prevent body condition loss in the dry season. This allowed the cows to calve in good body conditions thereby enhancing postpartum resumption of ovulation.

B. On-farm participatory experimentation and development.

Materials and methods.

Informal Diagnostic Survey

This was carried out in the Gulathi area during the winter months of the 1998/99 season with the objective of understanding the different crop-livestock systems, constraints and potentials in an informal, intensive way combining field observations, discussions and interviews with farmers. A number of farmers in the community had been in contact with the station since the 1995/96 season.

Among the major constraints, lack of adequate grazing land, dry season feed shortages and soil fertility featured prominently. However, Matopos Research Station had over the years been involved in forage production, conservation and utilization research activities, which could contribute towards alleviating these identified constraints.

On-farm study (1) Forage yields and silage quality of hybrid pennisetum or sorghum intercropped with cow pea or dolichos bean under limed and unlimed soil conditions in the Gulathi communal lands.

Treatments

These consisted of two cereals (Sorghum and hybrid Pennisetum), two legumes (cow pea) or dolichos bean intercropped in alternate rows. Two villages that differed by degree of water logging (wet W or dry D) were selected for the study. All forages were planted with and without agricultural lime application. A factorial arrangement of treatments in a split –split plot design which had one replication per farm in the 1998/99 season and 2 replications per farm in the 1999/2000 season. Data from the first season and second season was subjected to analysis of variance (ANOVA). The study was researcher-managed and farmer implemented (RMFI) whose scope was limited to verifying productivity of the identified system of forage production.

Results

Forage yields

Considerable differences between the wet and dry areas were recorded with the wet areas producing more forage in both seasons (Tables 1 and 2). In the second season, crop growth was very impressive. However, after January 2000, waterlogging caused lodging of the sorghums which were swamped by the dolichos bean. Higher cereal and legume forage yields were recorded during the second season. (Table 2) than often recorded in on-station trials (Mhere et al., 2000). Both legumes grew well and contributed about 30% of the combined yields in both wet and dry areas. Legume yields averaged over all treatments were 5.0 tons /ha. Ensiling mixtures with that amount of legume has resulted in good quality silage on station (Titterton et al., 2000).

Effects of lime application

No significant effects of lime on forage yields were recorded during the first year. In the second season, limed plots gave higher yields than unlimed, this being more consistent in the wet areas. Adding lime did not seem to affect both the legume yields and the contribution of legumes towards combined dry matter.

and farmer-implemented forage production for silage using sorghum and hybrid pennisetum intercropped with cow pea and dolichos bean in alternate rows during the 1998/99 and 1999/2000 seasons.

Materials and Methods

In the two areas, used in the first on-farm study, and concurrent with it, a farmer managed study, to assess biomass production of the 4 crop combinations used in the first trial, was conducted on large plot areas ranging from 0.15 to 0.4 ha, in two seasons (1998/99 and 1999/2000) Thirty farmers took part. All plots were limed at 550 kg/ha and dressed, at planting, with 200 kg/ha of a compound fertilizer supplying 8N:14P_2O and K_2O.

Biomass from each of the four intercrops was harvested by hand, weighed to determine yields, sampled for further analysis with the rest being ensiled in strong polythene bags with a capacity of 50kg. Air exclusion was done by hand pressing and then sealed airtight by strings. The bags were stored in storerooms that were rat proof. During the first year hand operated chaff cutters were used and diesel operated cutters in the second season.

Results

The silage from the farmers' fields had protein levels of 95-105 kg/kg DM; dry matter of 400/kg pH of 4.2-4.8, NH3-N% of total N of 9-11%; ash 110-130 g/kg, ADF 380-410 g/kg and NDF of 510-610 g/kg.

During the second season (1999/2000), 63 tons of silage were ensiled in 4771 bags. Each farmer made an average of 1.75 tons of silage in 132 bags, range 90- 400 bags) Average weight of each bag was 14 kg. As in trial 1, the wet areas recorded higher yields in both seasons. There were positive changes in the land planted to these forage crops which in a way revealed the impact the technology had on the farmers.

On-farm study (3): The preliminary feeding of indigenous cows using mixed crop silage.

During the first year, 62 pregnant cows from 25 farms were fed with silage made by the farmers. The other farmers did not have pregnant cows and used the silage for draught animals and goats. The preceding rainy season was characterized by low rainfall in both areas (Table 3).

The concerns of the farmers to feed other animals, in addition to those that were pregnant, were accepted. The decision to feed all animal was based on the need to ensure survival of the herd, due to lack of grazing because of poor rains. The projects then monitored one or two pregnant cows per farm for 1.5 to 2 months, during which the cows were fed 4 kg silage a day. This was considered to be a supplement on account of its good quality. Body weights and conditions scores were taken every 14 days.

Preliminary results

Fed animals maintained body condition, with some gaining weight. Conception, re-conception and milk yields of the fed animals were monitored during the 1998/99 season. The number of bags of silage available determined the length of the feeding period. The availability of silage in a drought year encouraged farmers to increase the area of land, management and yields of these forage crops during the 1999/2000 season.

Discussion

The differences in productivity among the treatments in the first year (1998/99) were largely due to very low rainfall and delayed planting. These differences were not just confined to the experimental plots but were evident in the other 30 farms, resulting in double the yield in the wet. compared with the dry area, demonstrating the overriding effect of sol moisture on plant growth. In the second season, differences in productivity among the six farms were attributed to individual farmer management, soil and factors other than rainfall.

The content of legumes in the intercrop biomass was similar to that recorded at Matopos on sandy soils. similar to those of Gulathi (Mhere et al). The results showed that it was possible to intercrop cereals and legumes for silage within the smallholder sector. Ensiling mixtures where the legume content is about 30% of the biomass resulted in good quality silage in on station trials (Titterton et al., 2000)

Effects of lime application were not evident during the first year due to very low rainfall and delayed planting. Although it is not a widespread practice in small holder systems of Zimbabwe, lime applications does create favourable growing environments for most crops by neutralizing the hydrogen ions, that when in high concentration, cause soil acidity. The second season showed some improvements in forage yields due to liming.

Although results of the feeding carried out in the first season were preliminary, the maintenance of body condition and weight are indications that animal can be sustained during harsh dry seasons. Post calving performance would be expected to be much better than that of unsupplemented cows.

Dissemination

1998/1999 season

Towards the end of silage feeding during the first year, the projects organized a “Farmer to Station” visit where the Gulathi farmers viewed the on-station feeding and discussed in detail their views, feelings, comparisons of the four feeding treatments.

The on-farm work at Gulathi during the 1998-1999 season was very useful as a first year when farmers tested the intercropping agronomy and silage technology. Consultative meetings discussed the impact of the project activities from 1997/98 to 1998/99 seasons, which have led to wider awareness within the community and beyond.

Many enquiries on how to either join, get involved with, or start a similar project in the East, South and South –West of Gulathi have been received and those making enquiries seem to be conversant with what is taking place at Gulathi. These activities have raised awareness and changed the general perception towards dairy production by other stakeholders in Matabeleland (Mhere in press)’

The National Dairy Development Programme (DDP) together with an NGO (Africa Now) has taken up the project for further funding and development. This has allowed the construction of a milk collection centre (MCC), employment of a resident project officer and purchase of improved animals and other activities.

Linkages among the main collaborators (Matopos Research Station, AGRITEX, Veterinary Department, University of Zimbabwe and the Department of Environmental Health) have been strengthened considerably.

1999/2000 season

Farmer training and information dissemination workshop 15th April 2000
A farmer –led workshop was held to extend findings, share experience and build interaction and communication techniques of information exchange from farmer-to- farmer. Five groups were represented and a total of 75 participants attended.

Farmer to farmer visits
Gulathi farmers hosted farmer groups from Wenlock (Gwanda), Irisvale, Esigodini and Natisa.

Farmer to station
A field day jointly organized by the project and the National Association of Dairy Farmers was attended by 26 producers on 28 April, 2000.

New initiatives
Four new projects were initiated within the Matobo district influenced by the project at Gulathi. These are Gulathi (Lukadzi x 2), Vulindlela Ward (Lushumbi), Dema Ward (Natisa). In addition 3 wards in the Gwanda district are mobilizing to initiate similar ventures.

Strengthening the linkages
Among the original collaborators, Agritex, Veterinary Department, Department of Health and the District Council and DDP continue to be involved. New linkages have been established with three NGO's: Masiye raining camp in Silozwi, ENDA Zimbabwe in the Dema and Vulindlela Wards and Ethandweni children's home in the Whitewaters/Natisa area.

The overwhelming response by different communities to the farmer-centred strategies used in our project showed the relevance of the project. It also showed the compatibility of the technology with the individual farmer problems, with local ecological, socio-cultural and economic conditions of these communities who view milk production as a vehicle for change. Dissemination activities attempted in this project shoed the importance of farmer involvement in the whole process. It also showed that open communication and strong multidisciplinary teams are essential for appropriate technology development and testing.

References

1986/87, Annual Report of the Agronomy Institute, Department of Research and Specialist Services, Ministry of Agriculture, Zimbabwe

Abate Tedla and Jutzi, S. 1985 Results of cereal forage legume intercropping trial on smallholder farms in Ethiopian Highlands. *Highlands Program Report. ILCA, Addis Ababa, Ethiopia.*

Abate, A., Dzowela, B.H. and Kategile, J.A. (1992). In: J A Kategile and Mubi (eds), Future of Livestock Industries in East and Southern Africa, pp. 165-172.

Adu-Gyamfi and Ito O, 1997 Nitrogen management in sorghum pigeon pea Intercrop. In Rupela, O.P., Johansen, C., and Herridge, D.F. (eds.) 1997. Extending nitrogen fixation research to farmers' fields: Proceedings of an International workshop on Managing Legume Nitrogen Fixation in the Cropping Systems of Asia, 20-24 August 1996, ICRISAT Asia Center, India. ISBN 92-9066-378-2

AGRITEX, 1993 Sorghum: in The Farm Management Handbook, part 1 : Crops.

Akinbamijo O O, Bennison J J, Romney D L, Wassink G J, Jaitner J, D J Clifford and Dempfle L (1997) An evaluation of food intake, digestive physiology and live weight changes in Ndama and Gobra zebu bulls following experimental Trypanosoma Congolese infection. British Society of Animal Science.

Alberto, G., Portella, J.S., and Oliveira, O.L.P de. 1993.Effect of addition of ground sorghum grain and of wilting on elephant grass. Grasslands and Forage Abstracts, vol. 65 (11), November 1995.

Annual Report, ILCA, Addis Ababa, Ethiopia. pp.

ARDA Dairy Development Program annual report – 1999 Ministry of Agriculture and rural resettlement.

Balibasakis N G, Progia E and Papaioannou A (1997) Comparison of maize and alfalfa silages on milk production, milk composition and blood components of dairy cows. Veterinarni-Medicina 42 –8 239- 242.

Bareeba, F.B. 1992.Forage Conservation and Utilization. Nomadic Peoples, 31: 91-96.

Beauchemin K A, Farr B I, Rode L M and Schalje G B (1994) Effects of Alfalfa Silage Chop length and Supplementary Long Hay on Chewing and Milk Production of Dairy Cows. Journal of Dairy Science 77 1326-1339.

Bhagat, R.K., Prasad, N.K. and Singh, A.P. 1992 Nitrogen levels and spacing of hybrid Napier intercropped with legumes. Journal of Research, Birsa Agric. University 4 (1): 67-69

Black, J.R., Ely, L.O., McCullough and Sudweeks, E.M, 1980.Effects of stage of maturity and silage additives upon yield of gross and digestible energy in sorghum silage. Journal of Animal Science, 50 (4): 617-624

Bolsen, K.K. and Heidker, J.I. 1985.Silage Additives, USA. Chalcombe Publications, Marlow

Bottom, Marlow, Bucks, UK.

Bowden, D. M. (1971). Non-esterified fatty acids and ketone bodies in the blood as indictors of nutritional status in ruminants. Can. J. Anim. Sci. 51:1-13.

Breirem, K. and Ulvesli, O. 1960 Ensiling Methods. Herbage Abstracts, 30 (1) : 1-9

Castle, M.E and Watson, J.N. 1982 Silage and milk production: comparison between unwilted and wilted grass silages made with differences additives. Grass and Forage Science, 37: 235-241. Catchpoole, V.R. 1951

Catchpoole V R and Henzell E F (1971) Silage and silage making from tropical herbage species

Catchpoole, V.R and Henzell, E.F. 1971.Silage and silage –making from tropical herbage species. Herbage Abstracts 41(3): 213-221

Cattle food resources and their use in the communal lands Zimbabwe Society for Animal Production (ZSAP), 1993 pp 37-42.

Central Statistical Office 1992

Charmely, E. and Veira, D.M. 1990a.Inhibition of proteolysis in alfalfa silages using heat at harvest. Effects on digestion in the rument, voluntary intake and animal performance. Journal of Animal Science. 68, 2042-2051

Chigaru, P. 1998.Dairying, a powerful tool for rural progress. The Financial Gazette, Zimbabwe. May 21 1998, pp 27

Chimonyo, M. (1998). The effect of work and nutrition on reproductive performance in Mashona cows in a semi-arid smallholder area of Zimbabwe. MSc. Thesis. University of Zimbabwe. Harare.

Chimonyo, M. (1998). The effect of work and nutrition on reproductive performance in Mashona cows in a semi-arid smallholder area of Zimbabwe. MSc. Thesis. University of Zimbabwe. Harare.

Chimonyo, M., Kusina, N., Hamudikuwanda, H., Nyoni., O., and Ncube. I. (2000). Effects of dietary supplementation and work stress on ovarian activity in non-lactating Mashona cows in a smallholder farming area of Zimbabwe. Animal Science70: 317-323.

Church, D.C. 1991.Livestock feeds and feeding. pp 80-94 Prentice Hall, Englewood Cliffs, New Jersey.

Clancy, M.J and Wilson, R.K. 1966.Development and application of a new chemical method for predicting the digestibility and intake of herbage samples. Proceedings of the 10th International Grassland Congress. (Helsinki, Finland), pp. 445-453

Clatworthy, J.N. (1985) Pasture research in Zimbabwe (1964 - 1984). In: Kategile J.A (ed), Proceedings of the IDRC/SADCC workshop on Pasture Improvement Research in Eastern and Southern Africa, Harare, Zimbabwe,17-21 September, 1984 pp. 25-58.

Coshima M. and McDonald P, 1978.A review of the change in nitrogenous compounds of herbage during ensilage. Journal of Science, Food and Agriculture, 29: 497-505.

Courtin, M.G. and Spoelstra, S.F. 1990. A simulation model of microbiological and chemical changes accompanying the initial stage of aerobic deterioration of silage. Grass and Forage Science. 45, p 153-165

Crowder, L.V and Chheda, H.R. 1982 Tropical Grassland Husbandry. Longman. London and New York.

Dairy Development Programme, 1999. A report given at the Annual Smallholder Dairy Producer of the Year (1999) at Rusitu, Chipinge on July 30 1999. Zimbabwe

Danely, M.M. and Vetter, R.L. 1973 Changes in carbohydrate and nitrogen fractions and digestibility of forages: Maturity and ensiling. Journal of Animal Science, 37: 994-998

Davies AT and Onwuka, CFI, 1996 Conservation of forage for dry season feeding in the humid zone of Nigeria. In: Sustainable Feed Production and Utilisation for Smallholder livestock Enterprises in Sub-Saharan Africa. Proceedings of the Second African Feed Resources Network (AFRINET), Harare, Zimbabwe, 6-10 December 1993.

DDP (Dairy Development Programme), (1999). A report given at the Annual Smallholder Dairy Producer of the Year at Rusitu, Chipinge on July 30 1999. Zimbabwe.

DDP (Dairy Development Programme), (1999). A report given at the Annual Smallholder Dairy Producer of the Year at Rusitu, Chipinge on July 30 1999. Zimbabwe.

Department of Research and Specialist services (DR & SS, 1987

Deriaz, R.E. 1961. Routine analysis of Carbohydrates and Lignin in herbage. Journal of the Science of Food and Agriculture, 12: 152-160

Dube D.M.J 1995. The role of high quality dry season forage from mixed crop silage in the smallholder dairy sector of Zimbabwe: Dairy Development Programme perspective. Paper presented at the Rockefeller-funded mixed crop silage workshop. University of Zimbabwe August 1995.

Dube, D. M. J. 1995. The role of high quality dry season forage from mixed crop silage in the smallholder dairy sector of Zimbabwe: A Dairy Development Programme perspective. In: Proceedings of a workshop on Forage conservation for dry season feeding of livestock in Sub-Saharan Africa, August 1995.University of Zimbabwe, Harare. Zimbabwe.

Dunn N (1991) Danes change to pea silage Special report Farmer’s weekly.

Echevarria, L., and Dela Torre, M. (1996). Feed supplementation for improving reproduction efficiency of crossbred Zebu cattle in the Peruvian Tropics. Proceedings of a meeting held in Brazil on Development of feed supplementation strategies for improving ruminant productivity on smallholder farms in Latin America through radioimmunoassay techniques. Sept 27-Oct 1, 1993. IAEA, Vienna, Austria.

Enyi B.A.C. 1973. Effects of intercropping maize or sorghum with cowpea, pigeon peas or beans. Experimental Agriculture, 9: 83-90.

Erb, H. N., Smith, R D., Sniffen, C. J., Chase, L. E. and Cooper, M. D. 1990. Relationship of changes in condition score to health in Holsteins. J Dairy Sci 73: 3132-3140.

FAO (Food and Agriculture Organisation). (1994). Farming systems development. A participatory approach to helping small-scale farmers. Rome, Italy.

FAO (Food and Agriculture Organisation). (1994). Farming Systems Development. A participatory approach to helping small-scale farmers. Rome, Italy.

Feishcher JE and Tackie, AM 1996 Studies on the productivity of ensilage of ‘wild sorghum‘(Sorghum arundinaceum) for dry season ruminant feeding. In: Ndikumana J. and de Leeuw P. 1996. Sustainable Feed Production and Utilisation for Smallholder livestock Enterprises in Sub-Saharan Africa. Proceedings of the Second African Feed Resources Network (AFRINET), Harare, Zimbabwe, 6-10 December 1993.

Fisher, N.M. 1977 Studies in mixed cropping. 1. Seasonal differences in relative productivity of crop mixtures and pure stands in the Kenyan highlands. Experimental Agriculture, 13: 177-184

Food and Agriculture Organisation, 1994. Farming Systems Development. A participatory approach to helping small-scale farmers. Rome.

Francis, C.A. Prager, M., and Tejada, G. 1982a. Effects of relative planting dates in bean (Phaseolus vulgare) and maize intercropping patterns. Field Crop Research, 5: 45-54

Francis, C.A. Prager, M., and Tejada, G. 1982b Effects of relative planting dates in bean (Phaseolus vulgare) and maize. Field Crop Research, 5: 63-68

Garwe, E., Ball, P. J. H., Hamudikuwanda, H., and Mutisi, C. (1999). Reproductive performance of crossbred cattle developed for milk production in the semi arid tropics and the effect of feed supplementation. Proceedings of the second DFID workshop on livestock production programme projects in Zimbabwe held at Ingwe Lodge, Matobo, Zimbabwe. 22-23 February 1999.

Garwe, E., Ball, P. J. H., Hamudikuwanda, H., and Mutisi, C. (1999). Reproductive performance of crossbred cattle developed for milk production in the semi arid tropics and the effect of feed supplementation. Proceedings of the second DFID workshop on livestock production programme projects in Zimbabwe held at Ingwe Lodge, Matobo, Zimbabwe. 22-23 February 1999.

Gawall and Sampath, 1989 Effect of plant density on the dry matter and protein yield of subabul (Leucaena), hybrid Napier, guinea grass and their intercrops. Indian Journal of Dairy Science, 42(3): 449-451

Gildenhuys, P.J. 1950. A new fodder grass. A promising cross between Babala and Napier fodder. Farming in South Africa, June 1950, pp. 189-191

Gill, A.S. and Tripathi, S.N. 1991 Intercropping Leucaena with particular reference to hybrid Napier varieties in: Range Management and Agroforestry 12 (2): 201-205.

Gill, A.S. and Tripathi, S.N. and Gangwar, K.S. 1990 Effect of stand geometry on productivity of hybrid Napier – subabul association under agroforestry system. Indian Journal of Agronomy 35(4): 434-437

Goering, H.K. and Van-Soest, P.J. 1970. Forage fibre Analysis (Apparatus, Reagents, Procedures and some applications). Agricultural handbook 379, Department of Agriculture, Washington D.C, USA,

Goering, H.K., Smith, L.W., Van-Soest, P.J. and Gordon, C.H. 1972 Digestibility of fibrous materials ensiled with sodium chlorite. Journal of Dairy Science, 56: 233-237

Gomez, K. A and Gomez, A. A. 1984. Statistical procedures for Agricultural Research. 2nd edition. John Wiley and Sons. New York. USA.

Gomez, K. A., and Gomez, A. A. (1984). Statistical procedures for Agricultural Research. 2nd edition. John Wiley and Sons. New York. USA.

Gupta, S.C. and Mhere, O. 1997 Identification of superior Pearl millet by Napier hybrids and Napiers in Zimbabwe. African Crop Science Journal, 5(3): 229-237

Haigh, P.M and Parker, J.W.G 1985 Effect of silage additives and wilting on silage fermentation, digestibility and intake, and on liveweight change of young cattle. Grass and Forage Science, 40: 429-436.

Hamudikuwanda, H., Munyoro, E., Mutisi, C., Ball, P., and Moyo, S. (2000). Smallholder dairy production and research in the Matabeleland provinces of Zimbabwe. A paper presented at the UZ/RVAU/DANIDA- ERECA Project review workshop held in Harare, Zimbabwe form 10-13 January, 2000.

Hamudikuwanda, H., Munyoro, E., Mutisi, C., Ball, P and Moyo, S. 2000 Smallholder dairy production and research in the Matabeleland provinces of Zimbabwe. A paper presented at the UZ/RVAU/DANIDA- ERECA Project review workshop held in Harare, Zimbabwe form 10-13 January, 2000.

Haque, I and Jutzi, S., 1984 Nitrogen fixation by forage legumes in Sub Saharan Africa: Potential and limitations. International Livestock Centre for Africa (ILCA) bulletin (Ethiopia) No. 20 pp 2-13

Haque, I. 1989.

Harrison, H., Kincaid, R.L., Loney, K.A., Riley, R.E. and Cronrath, J. 1994 Fermentation and nutritive value of maize and Lucerne forage ensiled with added rolled barley. In: Symposium on utilisation of grass silage, Journal of dairy Science, 77:3209-3235

Havilah, E., and Kaiser. A.G (1992). Sorghums for silage: a review. Proc. 2nd August. Sorghum conference. February 4th–6th 1992, Gatton. p 338-54.

Havilah, E.J. and Kaiser, A.G., 1992 Sorghums for silage: A review. In proceedings: Second Australian sorghum conference, Gatton, Queensland, 4-6 February, 1992, pp

Heath, M.E., Barnes, F.R. and Metcalfe D.S., 1985 Maize and Sorghum silages In: Forages. The science of grassland agriculture. 4th Edition. Iowa State University Press, Ames, Iowa, USA. p 527-536

Henderson, A.R. 1991 Biochemistry of forage conservation. In: Pahlow, G and Honig, H (editors), Proceedings of a Conference on Forage conservation towards 2000. January 23-25, Braunschweig, Germany. Pp 37-47.

Henson, B. R. (1992). Dairy farmers and rural Zimbabwe. In eds. Brokken, R. F and Seyoum, S. 1992. Proceedings of Dairy marketing in sub-Saharan Africa symposium. p 279-292. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Henson, B. R. (1992). Dairy farmers and rural Zimbabwe. In eds. Brokken, R. F and Seyoum, S. 1992. Proceedings of Dairy marketing in sub-Saharan Africa symposium. p 279-292. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Henson, B. R. 1992. Dairy farmers and rural Zimbabwe. In: Proceedings of Dairy marketing in sub-Saharan Africa symposium. Pages 279-292. Eds. Brokken, R. F and Seyoum, S. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Herdt, T. H. (1988). Fatty liver in dairy cows. In ed. Herdt, T. H. 1988. Metabolic diseases of ruminant livestock. The Vet. Clinics of North America. p 269-287. B. Saunders Co., London, UK.

Hulugalle, N.R. and Lal, R., 1986 Soil water balance of intercropped maize and cowpea grown in a tropical hydromorphic soil in Western Nigeria. Agronomy Journal. 77:86-90

Humphreys L.R 1980. A guide to better pastures for the tropics and sub-tropics.

Humphreys L.R 1987. Tropical pastures and fodder crops. Intermediate Tropical Agriculture Series. pp. 82

ICRISAT (International Crop Research Institute for the Semi-Arid Tropics). 1992. ICRISAT, Annual Report 1992. pp. 50-51.

Ifenkwe, O.P., Odurukwe, S.O., Okwonkwo, J.C. and Nwokocha, H.N., 1989 Effects of maize and potato populations on tuber and grain yields, net income and land equivalent ratios in potato/maize intercropping. Tropical Agriculture (Trinidad), 66:329-333

ILCA (International Livestock Centre for Africa). 1989

ILCA, Annual Report 1988, Addis Ababa, Ethiopia. pp. 15-16

International Livestock Centre for Africa (ILCA), 1994. Improving livestock production in Africa: Evolution of ILCA’s programme 1974-1994. ILCA, Addis Ababa, Ethiopia. pp 102-103.

James C S and Gangadevi P (1990) The influence of ensiling and nutrient content of leucaena leucocephala. Journal of Veterinary and Animal Sciences 21 2 1 – 8.

Jarridge, R., Dermaquilly, C., and Dulphy, J.P. 1982 Forage Conservation. In: Hacker, J.B. (editor). Nutritional limits to animal production from pastures. Farnham Royal, U.K: Commonwealth Agricultural Bureaux.

Jingura, R. M. 2000. Fodder production and use of farm-grown foods in the smallholder dairy sector: A participatory approach to designing feeding systems in Gokwe South District, Zimbabwe. Ph.D. Thesis. University of Zimbabwe.

Johnson, D.T, 1968 The Cowpea in the African areas of Rhodesia Bulletin no. 2548, Rhodesia Agricultural journal, 65: 61-64

Kaiser, A.G. 1984. The influence of silage fermentation on animal production. In: Kempton, T., Kaiser, A.G. and Trigg, T., (editors): Silage in the 80's. Proceedings of a national workshop, Armidale, New South Wales, August 1984. pp 106-135

Kaiser, A.G., Havilah, E.J., Chopping, G.D. and Walker, R.G. 1993. Northern dairy feeding base 2001. 4. Feeding systems during winter and spring. Tropical Grasslands, 27: 180-211.

Kaiser, H.W and Lesch, S.F 1977. A comparison of maize and maize-legume mixtures for silage production in the Natal Midlands. Agroplantae, 9: 1-6.

Kawamoto, Y., Masuda, Y. and Goto, I. 1988.Sorghum-legume mixed cropping for high yields of high quality forage. Agricultural Research quarterly 22(2): 114-120

Kennan T.C.D 1950. Preliminary report on a comparison of several heavy yielding perennial grasses for the production of ensilage. Rhodesia Agricultural Journal vol. 47 (6): 531 - 543.

Kennan T.C.D 1952. The Improved west African Napier fodders. Rhodesia Agricultural Journal, 49(4):221 228.

Khombe, T., Mhlanga, F. N and Makuza, S 1999. Evaluation of indigenous livestock Khombe, T., Mhlanga, F. N and Makuza, S 1999. Evaluation of indigenous livestock genotypes in Zimbabwe. Department of Animal Science, University of Zimbabwe. Mhere, O. Titterton, M and Maarsdorp, B.V. 1999.

Kusekwa, M.L., Kyamanywa, R.S., and Ngowi, M.D. 1992. Fitting forage legumes into the cropping systems of semi-arid Tanzania. In Stares, J.E.S.;

Lamming, G. E., and Bulman, D. C. (1976). The use of milk progesterone radioimmunoassay in the diagnosis and treatment of sub fertility in dairy cows. British Vet. Journal. 132: 507.

Landsberg, J.J. 1964. Spacings for sorghum grain production Rhodesian Journal of Agricultural Research, 2 (1): 23-30

Lima, A.F and Lopes, L.H.O 1981 Plant population and spatial arrangement study on the Intercropping of Maize and Beans (Phaseolus vulgaris L) in Northeast Brazil. In: ICRISAT (International Crop Research Institute for the Semi-Arid Tropics). 1981. Proceedings of the International Workshop on Intercropping, 10-13 January 1979, Hyderabad, India. pp. 50-51.

Lindgren Sven, Bromander, A and Pettersson, K. 1988 Evaluation of Silage additives using scale model silos. Swedish journal of agricultural research. 18: 41-49

Livestock and Sustainable Nutrient cycling in mixed farming systems of sub-Sahara Africa. Vol. 2. Technical Papers. Proceedings of an international Conference held in Addis Ababa, Ethiopia, 293-304 Nov. 1993. ILCA.

Louisiana State University Agricultural Center, Louisiana Agricultural Experiment Station, Southeast Research Station, Franklinton, LA 70438, USA.

M Titterton (1996) The importance of high quality conserved forages for dairy cattle in the dry season. Farming World Magazine.

M. Ahmed, M., Rohrbach, D.D., Gono, L.T., Mazhangara, E.P., Mugwira, L., Masendeke, D.D.

and Alibaba, S. 1997. Soil fertility management in communal areas of Zimbabwe: Current practices, constraints, and opportunities for change. Results of a diagnostic survey. Southern and Eastern Africa Region Working Paper no. 6. P. O. Box 776 Bulawayo, Zimbabwe: International Crops Research Institute for the Semi Arid Tropics (ICRISAT) Southern and Eastern Africa Region

Maasdorp, B.V and Titterton, M. 1997. Nutritional improvement of maize silage for dairying: mixed crop silages from sole and intercropped legumes and a long season variety of maize. 1. Biomass yield and nutritive value. Animal Feed Science Technology, 69: 241-261

Machaya, A. C. (1994). some factors affecting smallholder dairy production in Zimbabwe. Journal of the Zimbabwean Society for Animal Production VI: 61-67.

Maiti, S.; Sahu, B.B.; Pal, S. and Chatterjee, B.N. 1988. Effect of Phosphate manuring on intercropping of hybrid Pennisetum Environment and Ecology 6(2): 422-427.

Mariga, I.K. 1990. Effect of cowpea planting date and density on the performance of maize-cowpea intercrop. Zimbabwe Journal of Agricultural Research 28: 125-131

McCormick, M.E., Morris, D.R., Ackerson, B.A and Blouin, D.C 1995 Ratoon cropping forage sorghum for silage: yield, fermentation and nutrition. Agronomy Journal, 1995, 87(5): 952-957.

McDonald, P and Edwards R.A .1976 The influence of conservation methods on digestion and utilisation of forages by ruminants. Proceedings of the nutrition Society, 35: 201-211

McDonald, P. 1981. The biochemistry of silage. New York: John Wiley and Sons.

McDonald, P. 1987. Animal Nutrition. ELBS / Longman. pp. 407-415.

McKersie, B.D. and Buchanan-Smith, J. 1980 Changes in levels of proteolytic enzymes in ensiled alfalfa forage. Canadian Journal of Plant Science, 61: 53-59

Mhere, O. 1997 Dry matter yield, quality and persistence of Elephant grass / Napier fodder and hybrid Pennisetum as affected by plant density. Annual Reports, 1996-97, Division of Livestock and Pastures, Department of Research and Specialist Services, Ministry of Agriculture, Zimbabwe.

Mhere, O., Ncube, S. and Matshe, F. 1994 Dry matter yield, quality and persistence of Elephant grass / Napier fodder and hybrid Pennisetum as affected by irrigation in two soil types. Annual Reports, 1993-94 and 1994-95, Division of Livestock and Pastures, Department of Research and Specialist Services, Ministry of Agriculture, Zimbabwe.

Mhere, O., Ncube, S. and Matshe, F., 1995 Dry matter yield, quality and persistence of Elephant grass / Napier fodder and hybrid Pennisetum as affected by irrigation in two soil types. Annual Reports, 1993-94, Division of Livestock and Pastures, Department of Research and Specialist Services, Ministry of Agriculture, Zimbabwe.

Michelena, J.B. and Molina, A. 1990.The effect of time of sun exposure of King grass (hybrid Pennisetum) on silage quality. Cuban Journal of Agricultural Science, vol. 24 (2): pp 219-224.

Milford R., and Minson D.J., 1965. Intake of tropical pasture species. Proceedings of the 9th International Grassland Congress, Sao Paulo, Brazil pp 815-828.

Morris, D.R., and McCormick, M.E. 1994 Ensiling properties of sweet sorghum. Communications in Soil and Plant Analysis (1994), 25: 15-16.

Morris, J.G. and Levitt, (1968) The intake and digestibility of silages made from dolichos lablab alone and with sorghum c.v. Sugardrip. Proceedings of the Australian Society of Animal Production, 7: 78-85.

Mosley, G. and Ramanathan, V. 1989 The effects of dry feed additives on the nutritional value of silage. Grass and Forage Science, 44: 391-397.

Mugwira, L.M., Mukurumbira., Butai, P.C. and Mandiringa, O.T. 1992 Soils of the small scale-scale farming areas of Zimbabwe and their management. In: Small scale Agriculture in Zimbabwe. Editors: E.E. Whingwiri, K. Mashingaidze, and M. Rukuni, Book Two. Field Crop Production. Rockwood Publishers, Harare, Zimbabwe. Pp 7-21.

Mukasa-Mugerwa, E. (1989). A review of reproductive performance of female Bos indicus (Zebu) cattle. ILCA Monograph 6. ILCA, Addis Ababa, Ethopia.

Mulbach, P.R.F (1999) Additives to improve the silage making process with tropical forages. In: L. 'tMannetje (editor), Proceedings of the FAO Electronic Conference on tropical silage, 1 September – 15 December 1999. p 151-164

Muldoon, D.K. 1985. Summer forages under irrigation. 2. Forage composition Australian Journal of Experimental Agriculture, Vol 25 (2) 1985, pp 402-410.

Muldoon, D.K. and Pearson, C.J. 1979 The hybrid between Pennisetum glaucum and Pennisetum purpureum. Herbage Abstracts, 49(5): May 1979.

Mulvaney, 1981. Dairy condition scoring. Handout No.4468. Nat 1. Inst. Res. Dairying, Shinfield, Reading, UK.

Mulvany, P. M. (1981). Dairy cow condition scoring. British Society of Animal Production 4:349-352.

Munyoro, E. 1997. Post partum ovarian activity in indigenous versus crossbred cows developed for milk production in semi arid regions and the effect of postpartum feed supplementation. Doctor of Philosophy Thesis (unpublished). University of Zimbabwe.

Mupeta, B. (2000). Studies on milk production: The potential of sunflower residue as a source of protein for moderate milk yield in crossbred (Bos taurus x Bos indicus) cows in the smallholder dairy sector in Zimbabwe. PhD Thesis. University of Zimbabwe, Harare, Zimbabwe.

Mupeta, B. 1999. Studies on milk production: The potential of sunflower residue as a source of protein for moderate milk yield in crossbred (Bos taurus x Bos indicus) cows in the smallholder dairy sector in Zimbabwe. PhD Thesis (Unpublished). University of Zimbabwe.

Mupunga E.G and Dube D.M.J 1992. Smallholder dairy development in resettled and communal areas in Zimbabwe, In: Future of Livestock Industries in East and Southern Africa edited by J A Kategile and S. Mubi. pp.165- 172.

Mupunga, E. G. and Dube, D. M. J. 1993. Smallholder dairy development programme in resettled and communal areas in Zimbabwe. In: Proceedings of Future of livestock industries in

East and Southern Africa workshop, July 1992, held at Kadoma Ranch Hotel, Zimbabwe. Pages 165-176. Eds. Kategile, J. A. and Mubi, S. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Mupunga, E. G., and Dube, D. M. J. (1993). Smallholder dairy development programme in resettled and communal areas in Zimbabwe. In eds. Kategile, J. A., and Mubi, S. 1992. Future of livestock industries in East and Southern Africa. p 89-94. Proceedings of a workshop held at Kadoma Ranch Hotel, Zimbabwe, July 20-23. 1992, ILCA, Addis Ababa, Ethopia.

Muriethi, JG and Thorpe 1996 Effects of herbaceous legume intercropping and mulching on the productivity of Napier grass (Pennisetum purpureum) and total forage yield in coastal lowland Kenya. In: Ndikumana J. and de Leeuw P. 1996. Sustainable Feed Production and Utilisation for Smallholder livestock Enterprises in Sub-Saharan Africa. Proceedings of the Second African Feed Resources Network (AFRINET), Harare, Zimbabwe, 6-10 December 1993.

Murwira, H.K., Swift, M.J. and Frost, P.G.H. 1995 Manure as a key resource in sustainable agriculture. In: Powell, J.M., Fernandez - Revera, S., Williams, T.O. and Renard, C. (eds). 1995.

Nachtomi, E., Halevi, V., Brucketnal, I., and Amir, S. (1991). Energy–protein intake and its effect on blood metabolites of high producing dairy cows. Can. J. Anim. Sci. 71: 401-407.

Natarajan, M. and Shumba, E.M. 1990 Intercropping research in Zimbabwe: Current status and outlook for the future. In: Waddington, S.R., Palmer, A.F.E, and Edje, O.T. (editors), 1990. Research methods for cereal /legume intercropping: proceedings of a Workshop on Research Methods for Cereal / Legume intercropping in Eastern and Southern Africa. Mexico, D.F.: CIMMYT.

Natarajan, M. and Willey, R.W. 1980a Sorghum –pigeon pea intercropping and the effects of population density. 1. growth and Yield. Journal of Agricultural Science, Cambridge, 95:51-58

Natarajan, M. and Willey, R.W. 1985 Effect of row arrangement on light interception and yield in sorghum-pigeon pea intercropping. Journal of Agricultural Science, Cambridge, 104: 263-270.

Nnadi, L.A. and Haque, I. 1988 Forage Legumes in African crop-livestock production systems. ILCA Bulletin (Ethiopia), No. 30. 1988, pp10-19.

Noller, G.H. and Thomas, J.W. 1985. Forages: The Science of Grassland Agriculture. Iowa State University Press 1985.

Noorudin, Roy, L.N. 1975. Investigation on silage making. Digestibility and nutritive value of Giant Napier silage. Indian Veterinary Journal, 52 : 34-37.

Norton, B.W. 1982. Differences between species in forage quality. In: Hacker, J.B. (Editor), Nutritional Limits to Animal production from Pastures. Farnham Royal: Commonwealth Agricultural Bureaux. Pp 89-110.

Ntare, B.R. and Williams, J.H., 1992. Response of cowpea cultivars to planting pattern and date of sowing in intercrops with pearl millet in Niger. Experimental Agriculture, 28:41-48

Nyoni, L. (2000). The effects of breed and prepartum supplementation with Sorghum-Lablab silage on production and metabolic profiles in cows in a semi-arid area of Zimbabwe. pp 33. MSc. Thesis. University of Zimbabwe. Harare. Zimbabwe.

Ofori, F,. and Stern, W.R., 1987c: Cereal Legume Intercropping systems. Advances in Agronomy 41: 41-90

Ojeda F. and Diaz, D. 1994b. Study of different proportions of sorghum and Lablab purpureus ensiled with and without preservatives. Grasslands and Forage Science Abstracts vol. 64 (12): 526.

Ojeda F., Jacome, I. and Diaz, D. 1994a. Effect of different proportions of Lablab purpureus c.v Rongai on the fermentation quality of three tropical grasses. 1. Evaluation without preservatives. Grasslands and Forage Science Abstracts vol. 64 (12): 525-526.

Ojeda, F., and Diaz, D., 1990 Mixtures of grasses and legumes for improving the nutritive value of tropical silages. 1. Utilisation of dolichos (Lablab purpureus).Pastos y Forrajes 13: 189. (Summary in English)

Okine E K , Khorasan G R, and Kennelly J J (1994) Effects of cereal grain silages versus alfalfa silage on chewing activity and reticular motility in early lactation cows. Journal of Dairy science 77 1315 - 1325

Onselen, V.J. van; Lopez, J. 1 988. Effect of addition of carbohydrate sources and of a commercial enzymatic product on the chemical and nutritional composition of elephant grass (Pennisetum purpureum) silage. (Pt) Revista da Sociedade Brasileira de Zootecnia 17(5): 421-427. (Summary: English).

Osiru, D.S.O. Willey, R.W. 1972 Studies on mixtures of dwarf sorghum and beans (Phaseolus vulgare) with particular reference to plant population. Journal of Agricultural science, Cambridge, 71: 531-540

Otieno, K., Onim, J.F.M. and Mathuva, M.N. 1990. A gunny bag technique for making silage by smallholder farmers.

Pahlow, G. 1991 Role of microflora in forage conservation. In: Pahlow, G and Honig, H (editors), Proceedings of a Conference on Forage conservation towards 2000. January 23-25, Braunschweig, Germany. Pp 26-36.

Panditharane, S., Allen, V.G., Fontenot, J.P. and Jayasuriya, M.C.N 1986. Ensiling characteristics of tropical grasses as influential by stage of growth, additives and chopping length. Journal of Animal Science, 63(1): 197-207.

Pandtharatne S, Allen V G, Fontenot J P and Jayasuria M C N (1986) Ensiling characteristics of tropical grasses as influenced by stage of growth, additives and chopping length.

PANESA/ARNAB 1990. Utilization of research results on forage and agricultural by-product materials as animal feed resources in Africa, Proceedings of the first joint workshop held in Lilongwe, Malawi. 5-9 December 1988 pp. 664-685.

Paul C.L. 1990 Intercropping with sorghum, In: Sorghum Agronomy, ICRISAT 1990, LASIP / ICRISAT, Mexico Agronomy Programme, pp 183-211.

Perera, O. (1999). Management of reproduction. In eds. Falvey, L., and Chantalakhana, C. 1999. Small-holder dairying in the tropics. International Livestock Research Institute, Nairobi, Kenya.

Peters, A.R., and Ball, P. J. H. (1995). Reproduction in cattle. 2nd edition. Blakewell Science ltd., London, UK.

Quarterly Digest, September 1992

Reid, I.M., Roberts, C.J., Treacher, R. J., and Williams, L. A. (1986). Effect of body condition at calving on tissue mobilization, development of fatty liver and blood chemistry of dairy cows. British Society of Animal Production 43: 7-15.

Richards, M.W., Weterman, R. P., and Schoeman, H. M. (1989). Nutritional anoestrus in beef cows: Concentrations of glucose and non-esterified fatty acids in plasma and insulin in serum. Journal of Animal Sci. 67: 2354-2362.

Richardson, F.D. (1984). The use of biochemical parameters to monitor the nutritional status of ruminants: The concentration of blood metabolites in relation to protein and energy intakes, breed and time of sampling in growing cattle. Zimbabwe Journal of Agric. Research 22:15-34.

Rodriguez J.A, Poppe, S., Meier, H. 1989. The influence of wilting on the quality of tropical grass silage in Cuba. 1. King grass (Pennisetum purpureum x Pennisetum glacaum). Archives of Animal Nutrition, 39 (8/9): 775-783.

Rukkwamsuk, T. (1999). Negative energy balance in postparturient dairy cows: Consequences and adaptations. PhD Thesis, Utrecht University, Netherlands.

Rukkwamsuk, T. (1999). Negative energy balance in postparturient dairy cows: Consequences and adaptations. PhD Thesis, Utrecht University, Netherlands.

Rukkwamsuk, T. 1999. Negative energy balance in Postparturient dairy cows: Consequences and Adaptations. PhD Thesis. Utrecht University, Netherlands.

Sahlu, T., Hart, S. P., Le-Trong, T., Jia, Z., Dawson, L., Gipson, T and The, H. (1995). Influence of prepartum protein and energy concentrations for dairy goats during pregnancy and early lactation. J. Dairy Sci. 78: 378-387.

Said, A.N.; and Kategile J.A. The Complementarity of feed resources for animal Production in Africa. ILCA, 1991 pp. 215-222.

Saleem, M.A.M 1982. Annual Report, International Livestock Centre for Africa, (ILCA) Addis Ababa, Ethiopia. pp.9

Saleem, M.A.M 1995. Mixed farming systems in Sub-Saharan Africa. In: Wilson, R.T., Ethui, S. and Mack, S. (eds). 1995. Livestock Development Strategies for Low Income Countries. Proceedings of the joint FAO/ILRI Roundtable on Livestock Development Strategies for Low Income Countries, ILRI, Addis Ababa, Ethiopia, 27 Feb - 2 March 1995.

SAS (Statistical Analysis Systems). (1994). SAS Guide for personal computers. Statistical Analysis Systems Institute, North California, USA.

SAS (Statistical Analysis Systems). (1994). SAS Guide for personal computers. Statistical Analysis Systems Institute, North California, USA.

Scoones, I. and Toulmin, C. 1995. Socio-economic dimensions of nutrient cycling in agropastoral systems in dryland Africa, in Powell, J.M., Fernandez - Revera, S., Williams, T.O. and Renard, C. (eds). 1995. Livestock and Sustainable Nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol. 2. Technical Papers. Proceedings of an international Conference held in Addis Ababa, Ethiopia, 22-26 Nov. 1993. ILCA.

Seale, D.R., Henderson, A.R., Petterson, K.O. and Lowe, J.F. 1986. The effect of addition of sugar and innoculation with two commercial inoculants on the fermentation of lucerne silage in lab silos. Grasslands and Forage Science, 41(1): 61-70.

Sekine J. and Ashida, Y. 1987 A note on the dry matter concentration in forages on water consumption of yearling steers. Animal Production, 45: 527-529

Shackel, K.A. and Hall, A.E. 1984.Effect of intercropping on the water relations of sorghum and cowpea. Field Crops Research 8: 381-387

Shetty, SVR., Ntare, BR., Batiano, A. and Renard, C. 1995 Millet and cowpea in mixed farming systems of the Sahel: a review of strategies for increased productivity and sustainability. In: Powell, J.M., Fernandez - Revera, S., Williams, T.O. and Renard, C. (eds). 1995. Livestock and Sustainable Nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol. 2. Technical Papers. Proceedings of an international Conference held in Addis Ababa, Ethiopia, 293-304 Nov. 1993. ILCA.

Sibanda, S., Jingura J.M., and Topps, J.H. 1997 The effect of level of inclusion of the legume Desmodium uncinatum and the use of molasses or ground maize as additives on the chemical composition of grass-and maize-legume silages. Animal feed Science Technology, 68: 295-305 Sibanda, S. 1995

Singh, S.P., Gautam, R.C. and Anjaneyulu, V.R. 1981. Adding a competition-free period to the intercrop: 'A new concept'. In: ICRISAT. Proceedings of the International workshop on Intercropping, 10-13 January 1979, Hyderabad, India. pp. 25 - 29.

Singh, V., 1987 Promising intercropping systems for increasing forage production. Indian Farming, 37 (5): 31

Skerman, P.J. 1988 Tropical Forage legumes. 2nd Edition, Food and Agricultural Organization (FAO), Plant production and Protection Series, number 2.

Slater K. (1991) Cropping for the dairy farm Farming press 11th Edition

Smith, D., 1973 The non-structural carbohydrates. In: Butler, G.W and Bailey, R.W. (editors) Chemistry and biochemistry of herbage. 3 : 106-155, London: Academic Press Inc.,

Smith, T and Ncube, S. 1996 The role of water in cattle production In: University of Zimbabwe, ZIMWESI Workshop: Water for Agriculture-Current practices and future prospects, 11-13th March, 1996.

Smith, T., Ndlovu, K. and Mhere, O. 1996. Smallholder milk production in a semi arid of Zimbabwe from crossbred Jersey cattle and forage based on Pennisetum hybrids. A progress report. Proceedings of an All Africa Conference on Animal Production, Pretoria, South Africa, April 1996.

Sorghum silage investigations progress report. Department of Agriculture, university of

Queensland.

Spitaleri, R.F., Sollenberger, L.E., Staples, C.R. and Schank, S.C. 1995. Harvest management effects on ensiling characteristics and silage nutritive value of seeded Pennisetum hexaploids. Grasslands and Forage Abstracts, 65, p 11.November 1995.

Statistical Analysis Systems (SAS) Institute. 1994. SAS Guide for personal computers.

Stobbs, T.H. 1975 A comparison of Zulu sorghum, bulrush millet and white Panicum in terms of yield, forage quality and milk production. Australian Journal of Experimental Agriculture and Animal Husbandry, 15: 211-218

Stoop, W.A.,1986. Agronomic management of cereal/cowpea cropping systems for major toposequence land types in the West African savannah. Field Crops research, 14 p. 301-319

Stuart, P.N 1993. The Forage Book. Pacific Seeds, Toowoomba, Australia.

Sunday Mail. (2000). Need to resuscitate dairy industry. In: The Sunday Mail of October 29, 2000, Zimbabwe.

Syed J S and Leaver J D (1999) Influence of milk production level of cow and protein content of supplement on the selection of maize and grass silages by dairy cattle given a choice of forages.

Tarawali, G. and Saleem, M.A.M, 1995 In Powell, J.M.; Fernandez-Rivera, S.; Williams, T.O and Renard, C. (eds). Livestock and Sustainable Nutrient Cycling in mixed farming systems of Sub Saharan Africa. Vol. 2. Technical papers. Proceedings of an International Conference held in Addis Ababa, Ethiopia, 22-26 Nov. 1993 (ILCA).

Teleni, E ., and Hogan, J. P. (1989). Nutrition of draught animals: Draught animals in rural development. ACIAR Proceedings. No 27: 118. James Cook University, Townsville, Australia.

Terao, T., Watanabe, I., Matsunga, R., Hakoyama. and Singh, B.B. 1997. Agro-physiological constraints in intercropped cowpea: an analysis In: Singh, B.B., Mohan Raj, Dashiell, K.E. and Jackai, L.E.N. (editors) Advances in Cowpea Research, Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Centre for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria. Pp 129-140.

The analysis of agricultural materials (1985) A manual of the analytical methods used by the agricultural development and advisory services Third Edition

Thomas C, and Thomas, P.C., 1985 Factors affecting the nutritive value of silage. In: Recent advances in Animal Nutrition, 1985, Haresign, W and Cole P.J.A (eds) London Butterworths, pp 223-256.

Thomas C, Wilkinson, JM and Taylor, JC, (1975) The utilisation of maize silage for intensive beef production. 1. The effect of level and source of supplementary nitrogen on the utilisation of maize silage by cattle of different ages. Journal of Agricultural Science, 84: 353-364

Thompson, J.G. and Purves, W.D. 1978 A guide to soils of Zimbabwe. Zimbabwe Agricultural Journal Technical Handbook No. 3.

Thornton PK and Odero AN (eds). 1998. Benefits of integrating cereals and forage legumes with crossbred dairy technology: In: Compendium of ILRI Research Impact and Adoption, 1975-1998. ILRI Impact assessment Series 1. ILRI (International Livestock Research Institute), Nairobi, Kenya.134 pp

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

Titterton M and Maasdorp B V (1997) Nutritional improvement of the maize silage for dairying: mixed crop silages from sole and intercropped legumes and a long season variety of maize. 2 Ensilage. Animal Feed Science technology.

Titterton, M (1994). The interaction between energy balance, hepatic metabolism and return to cyclicity in dairy cows in early lactation: A review and report on recent studies. Journal of the Zimbabwe Society for Animal Production VI: 3-14.

Titterton, M and Bareeba, F.B (1999) Grass and legume silages in the in the tropics In: L.'t Mannetje (editor). Proceedings of the FAO Electronic Conference on tropical silage, 1 September – 15 December 1999. p 43-50

Titterton, M. (1992). The relationship of body condition and aspects of reproductive performance pre and postpartum in Zimbabwean Dairy cows. D Phil Thesis. University of Zimbabwe, Harare, Zimbabwe.

Titterton, M. 1996. The importance of high quality conserved forages for dairy cattle in the dry season. Farming World magazine, November 1996, pp 39-45.

Titterton, M., Ashbell, G., Kipnis, T. Zeitzmann, Z., Mhere, O and Maasdorp, B. V. 1999. Low-cost technology of conserving forages for small holder dairy farmers. In Proc. FAO-ZSAP workshop. October. Harare.

Titterton, M., Bareeba, F. B. (1999). Grass and legume silages in the tropics. FAO electronic conference on tropical silages, September 1999. http://www. fao.org.ag./aga/AGA2.

Titterton. M, Maasdorp, B., and Mhere, O. Nyoni, L. (1999). Forage production and conservation for dry season feeding of dairy cows in the semi-arid region of Zimbabwe. 1999. Proceedings of the second DFID workshop on livestock production programme projects in Zimbabwe held at Ingwe Lodge, Matobo, Zimbabwe, 22-23 February 1999.

Tivapasi, M.T. (1998). Assessment of the health and nutritional status of Zimbabwean rural cattle by clinical pathology. Ph D Thesis, University of Zimbabwe, Harare, Zimbabwe.

Tjandraatmadja, M., Mac Rae, I.C. and Norton, B.W. 1993 Effect of inclusion of tropical tree legumes, Gliricidia sepium and Leuccaena leucocephala on the nutritive value of silages prepared from tropical silages. Journal of Agricultural Science, Cambridge, 120: 397- 406

Tjandraatmadja, M., Norton, B.W. and Mac Rae, I.C. 1994 Ensilage of tropical grasses mixed with legumes and molasses. World journal of Microbiology and Biotechnology, 10: 82-87

Topps, J. H. (1977). The relationship between reproduction and under nutrition in beef cattle. World Review of Animal Production X111: 43-49.

Topps, J. H. 1977. The relationship between reproduction and undernutrition in beef cattle.

World Review of Animal Production X111: 43-49.

Topps, J.H. and Oliver J. 1993 Animal foods of Central Africa, Zimbabwe Agricultural Journal, pp 106-124

Tothill, J.C. 1986 The role of legumes in farming systems of sub-Saharan Africa, (keynote address). In: Haque, I. Jutzi, S and Neate, P.J.H (eds) 1986. Potential of forage legumes in farming systems of sub-Saharan Africa. Proceedings of a workshop held at ILCA, Addis Ababa, Ethiopia, 16-19 September 1985.

Tothill, J.C. and Mott, J.J. 1985 Ecology and management of the world's savannas. Australian Academy of Sciences, Canberra, Australia and CABI, Farnham Royal, UK, 384 pp.

Trenbath, B.R., 1976. Plant interactions in mixed communities. In: Multiple Cropping, ASA Publication No. 27, Wisconsin, USA: American Society of Agronomy. pp129-171

Uchida, S. and Kitumura, Y. 1987. Silage making from tropical pasture plants grown in South West Islands of Japan. 1. Effects of various treatments at ensiling on quality of Rhodes grass and Napier grass silage. Journal of Japanese Society of Grasslands Science, 32 (4): 369-374.

University of Botswana and Swaziland 1976. A comparison of Napier, Banagrass, Babala and maize for silage. Annual Reports of the Agriculture Research Division 1975-76, pp. 52-54

University of Botswana and Swaziland 1977. A comparison of Napier, Banagrass, Babala and maize for silage. Annual Reports of the Agriculture Research Division 1976-77, pp. 170

University of Illinois and USDA 1946. Grass and legume silage for dairy cattle. Extension Service in Agriculture and Home Economics. Circular 605

van der Merwe, B. J., and Stewart, P.G. (1995). Condition scoring in dairy cows. In eds. Dugmore, T. J. 1995. Dairying in Kwa-Zulu Natal, KwaZulu-Natal Dept. of Agric., South Africa.

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

Van Soest, P.J. 1982. Nutritional ecology of the ruminant. pp 139-151. O & B Books Inc., Corvallis OR.

Vilela, D. and Wilkinson, J.M. 1987. The effect of wilting and of addition of urea on the fermentation and in vitro digestibility of ensiled elephant grass. Revista da Sociedade brasileira de Zootecnia, 16 (6): 550-562 (Abstract in English).

Walters J.A.T 1916. Napier's fodder or Elephant grass (Pennisetum purpureum). Rhodesia Agriculture Journal. vol. 15: 833-836.

Ward, H.K., Richardson, F.D., Denny, R.P and Dye, P.J 1979 Matopos Research Station, `a perspective’ Rhodesian Agricultural Journal, vol.76: 5-18

Webster, A.J.F., 1993. Understanding the dairy cow. Blackwell Scientific Publications. Oxford. p 119.

Webster, J. and Daves, F. 1956 The composition of sorghum forages at various stages of maturity and effects of weathering. Oklahoma A&M Exp. Station, Bulletin B-484.

Weiss, W.P. and Conrad, H.R. 1986. Digestibility of heat damaged alfalfa. Journal of Dairy Science. 69, 2658-2670

Wheeler, J.L and Mulchay, C. 1989 Consequences of animal production of cyanogenesis in sorghum forage and hay a review. Tropical Grasslands, 23: 193-202

Wheeler, J.L., Hamilton, B.A. and Hedges, D.A. 1984 Effects of sodium fertilizer, cultivar, temperature and growth stage on the mineral content and nutritive value of sorghum forage. Australian Journal of Experimental Agriculture and Animal Husbandry, 24:565-570.

Wilkins, R.J. 1981. The nutritive value of silage. In: Haresign, W. and Cole, D.J.A. (editors) Recent developments in ruminant nutrition. Pp268-282 , Butterworths

Wilkinson, J.M, Wilson, R.F and Barry T.N, 1976.Factors affecting the nutritive value of silage Outlook on Agriculture, 9: 3-8

Wilkinson, M.K.1990. Silage UK, 6th edition, Chalcombe Publications, Marlow Bottom, Marlow Bucks, UK.

Willey, R.W. 1979. A scientific approach to Intercropping Research. In: ICRISAT1981. Proceedings of the International workshop on intercropping, 10-13 January 1979, Hyderabad, India. pp 4-14.

Willey, R.W. 1979. Intercropping: Its Importance and Research Needs. Part 2 Agronomy and Research Approaches. Field Crop Abstracts, vol. 32 No.2, February 1979.

Willey, R.W. 1985. Evaluation and presentation of intercropping advantages. Experimental Agriculture, 21: 119-133.

Willey, R.W. and Osiru, D.S.O. 1972 Studies on mixtures of maize and beans (Phaseolus vulgaris) with particular reference to plant population. Journal of Agricultural Science, Cambridge, 79: 517-529

Williamson, G. and Payne, W.J.A 1978.An Introduction to Animal Husbandry in the Tropics. 3rd Edition Longman, London and New York 1978.

Wilson, R.J 1982 Environmental and nutritional factors affecting herbage quality. In: J.B Hacker (editor). Nutritional Limits to animal production from pastures. CAB: Farnham Royal, UK. p 111-131.

Wilson, R.J 1984 Effects of water stress on herbage digestibility. Australian Journal of Agricultural Research, Vol. 34 (1) p 377-390

Woodard, KR., 1990. Biomass yield and silage characteristics as affected by harvest frequency and genotype. Dissertation Abstracts international, B, Sciences and Engineering 51(3): 1052B

Woodard, KR., Prine, GM. and Bates, DB. 1991. Silage characteristics of elephant grass as affected by harvest frequency and genotype. Agronomy Journal, 83(3): 547-551

Woolford, M.K. 1984 The Silage Fermentation. Microbiological Series, 14, Marcel Decker, Inc., New York and Basel.

Wright Stevenson & Company (Australia) Pvt. Ltd. pp. 27-28.