# The Effect of Pre-wilting and Incorporation of Maize Meal on the Fermentation of Bana Grass Silage

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**ABSTRACT :** An experiment was conducted to investigate the effects of pre-wilting Bana grass (*Pennisetum purpureum* x *P. americanum*) herbage under sunny conditions for 0, 6, 18, 24, 32 and 48 h and ensiling it with maize meal. Four levels of maize meal (*viz*., 0, 5, 10 and 15% on fresh weight (Fw) basis) were tested. The experiment had a split-plot design. Wilting increased the concentration of water soluble carbohydrates (WSC) significantly ($p<0.001$) on a Fw basis, although there were no significant changes on DM basis. Unwilted grass contained 36.1 g·WSC·kg$^{-1}$·Fw (127.6 g·kg$^{-1}$·DM) and this increased to 64.1 g·WSC·kg$^{-1}$·Fw (116.7 g·kg$^{-1}$·DM) after 48 h of pre-wilting. Wilting also increased the DM content of herbage significantly ($p>0.001$) from 250 to 620 g·kg$^{-1}$, between 0 and 48 h respectively. The concentration of fermentation end-products decreased (except butyric acid) and pH increased when the period of wilting increased, indicating that fermentation was restricted. In particular, lactic acid content declined from 50.8 to 26.2 g·kg$^{-1}$·DM ($p<0.01$) and the residual WSC contents of silage increased from 2.7 with fresh herbage to 18.1 g·kg$^{-1}$·DM with 48 h of wilting ($p<0.001$). Rapid wilting for 24 h, to a DM of 450 g·kg$^{-1}$ was optimum since important increases in pH, residual WSC and DMD occurred at this level of wilting. Acetic acid, butyric acid and ammoniacal-N contents were lowest with 24 h of wilting. There were no significant interactions between length of wilting and the incorporation of maize meal. Wilting had a greater influence on fermentation than the incorporation of maize meal. Addition of maize meal facilitated fermentation by increasing forage DM content and reducing effluent production. In addition, the maize meal increased DMD. It was concluded that maize meal should generally be incorporated at a level of 5% on fresh weight basis. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 6 : 843-851)***

**Key Words** : Bana Grass, *Pennisetum purpureum* x *P. americanum* Hybrid, Silage, Pre-wilting, Additives, Maize Meal

## INTRODUCTION

Some smallholder dairy farmers in Natural Regions I and II of Zimbabwe cut and wilt Pennisetum forage before ensiling it, to avoid excessive spoilage of the silages (Manyawu et al., 1996). The farmers also incorporate maize meal as an additive at rates of 0.7 to 8.9 kg·m$^{-3}$. Maize meal is more often used than molasses because molasses is difficult to obtain in rural areas.

In scientific terms, little is known about the effects of pre-wilting on the fermentation of Pennisetums under sub-tropical conditions that prevail in Zimbabwe. In temperate regions, wilting grass herbage has produced contrasting results. Mayne and Gordon (1986) found the field losses associated with pre-wilting to be very large, even under ideal weather conditions. They concluded that it is better to ensile unwilted grass. A review by McDonald (1981) indicated that there is no change in the amount of fermentable sugar when ryegrass is wilted for 48 h. He suggested that WSC lost via respiration during wilting is replaced from polysaccharide hydrolysis. In contrast, Spoelstra and Hindle (1989) observed a net reduction in WSC content when temperate grasses were wilted for 48 h. Whilst, Petterson and Lindgren (1990) reported that wilting had the effect of increasing the concentration of WSC, on a fresh weight basis. Besides the effects on WSC, pre-wilting also reduces water activity in herbage, resulting in restricted fermentation. Therefore, silage made from pre-wilted tends to preserve at high pH (Catchpoole and Henzell, 1971).

In the tropics, Humphreys (1991) reported that pre-wilting increases the concentration of WSC in herbage, on a fresh weight basis. Catchpoole and Henzel (1971), Bates et al. (1989) and Humphreys (1991) agreed that pre-wilted tropical grasses produces stable silage, although the mechanism by which this is achieved is not clear. On the contrary, Spitaleri et al. (1995) did not find any advantage of pre-wilting hybrid Pennisetum. Therefore, there was a need to clarify the effects of pre-wilting Pennisetums under Zimbabwean conditions.

There was also a need to study the role played by maize meal in the biochemistry of tropical grass fermentation, and to establish its optimum rates of application. Since both wilting and application of maize meal were reported to reduce the water activity of plant cells (Catchpoole and Henzell, 1971), it was important to establish whether these two factors have an additive function on silage fermentation. Therefore, the current experiment was conducted to determine the effects of pre-wilting Pennisetum grass on its chemical composition and fermentation as silage, and to

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establish the optimum level of wilting and cereal incorporation.

## MATERIALS AND METHODS

The experiment was conducted in Zimbabwe, at Nyarungu Dairy Farmers' Training Centre. The centre is at an altitude of approximately 1,400 m above sea level. Its wet season normally lasts 7 months (November to May). The soils are mainly granitic sands that are usually associated with poor fertility. Soil pH was 5.1 ($CaCl_2$).

### Pasture agronomy

Bana grass was used to represent Pennisetums in this trial. The Bana grass was in its second year of production. It was dressed with single superphosphate (18.5% $P_2O_5$) and agricultural lime at the beginning of the wet season at rates of 200 kg·ha$^{-1}$ and 500 kg·ha$^{-1}$, respectively. It was top-dressed with 170 kg·ha$^{-1}$ of ammonium nitrate (34.5% N) in March of 1998, before it was left to re-grow for this experiment. The grass was harvested on 5 May 1998, when it was eight weeks old. It had last received rainfall at 6 weeks of regrowth.

### Experimental design and treatments

The experiment had a split-plot design. Wilting treatments were allocated to main plots and maize treatments were in the sub-plots. There were six pre-wilting treatments *viz.* 0, 6, 18, 24, 32 and 48 h and four application rates for maize meal, namely 0, 5, 10 and 15% on fresh weight basis. The 0, 6, 18, 24, 32 and 48 h wilting periods coincided with midday (day 1), evening (day 1), morning (day 2), midday (day 2), evening (day 2) and midday (day 3), respectively. The experiment had three treatment blocks. Differences in plant height were used as a blocking factor, since plant vigour seemed to be largely influenced by differences in soil texture.

### The laboratory silo

Laboratory silos were made from 20-litre plastic buckets. The buckets had fast-fit lids that were fitted with a rubber bung at the centre of the lid. The rubber bung had a bunsen valve to release fermentation gases. The bungs were fitted on to the lid with their wider side concealed on the underside of the lid and their narrower sides facing upwards. In-between the centre of the lid and its edges, a tiny hole (1.0 mm diameter) was drilled to fit a thermocouple tightly. The thermocouple was used to read temperatures at the centre of the silo. The silo was designed to carry up to 10 kg of fresh forage (equivalent to 500 kg·m$^{-3}$). At ensiling, the bucket lids were sealed with a double layer of air-tight duct tape to prevent air ingress.

### Silage preparation, storage and sampling procedures

Before cutting, the field was sub-divided into the different treatment plots using the randomisation procedure for a split-plot design described by Mead and Curnow (1987). On the day of harvesting, cutting commenced at midday to maximise the WSC contents of herbage. The grass was cut 10 cm above the ground. Forage from the '0' wilting treatments was immediately ground through a motorised silage chopper and herbage samples were collected to determine dry matter, crude protein, WSC contents and *in vitro* dry matter digestibility (IVDMD). Herbage samples from all subsequent wilting treatments where also subjected to the same nutritional analyses. A uniform amount of pre-determined weights of herbage that could fit into the silo at the end of each wilting interval were then compacted into pre-weighed silos, manually. During this process, maize meal was applied evenly in treatments that were supposed to receive maize.

Once full, the silos were sealed, weighed and stored in a warehouse for five months, until they were opened in October of 1998. During the entire storage period, the temperature of each silo was recorded once daily. On the sampling day of the silage, the silos were weighed and then opened in small batches to minimise the spoilage of silage samples before chemical analysis. Silage colour, spoilage and smell were recorded after removing the decomposed layers of silage at the top of the silo. The decomposed material was weighed and discarded, to provide an indication of losses from surface spoilage. A 20 g sample of the fresh, unspoilt silage was then dissolved in 200 ml distilled water to obtain liqiud samples (juice) to determine volatile fatty acids (VFA), pH and ethanol contents. The juice was separated from the ensiled material by filtering through a double layer of cheese cloth (Anon. 1972). In addition, a kilogramme of representative silage sample was collected to determine Toluene DM, WSC, CP, $NH_3$-N, starch, lactic acid contents and IVDMD and IVDOMD.

### Description of chemical analyses

The dry matter content of silage was determined by drying 200 g of a sample in a forced draught oven, at 80 °C, for 48 h. Crude protein content was determined as Kejldhal N×6.25. *In vitro* dry matter digestibility was estimated by the method of Tilley and Terry (1963). The ammoniacal-N content was determined using the method of Van Soest et al. (1965). Analytical methods that required modification, special equipment or non-standard procedure are described below.

*Water soluble carbohydrate* : The water soluble carbohydrate content was determined on fresh samples using the method of Allen (1989). However, the method was modified to cater for the fresh nature of the samples. In the modified procedure, fresh forage samples were chopped

into 1 to 2 cm pieces to obtain 50 g representative sub-samples for the analysis. Each sub-sample was chopped in a blender, with 750 ml of distilled water. The blended sample was filtered though a double layer of cheese cloth into a 2.0 l beaker. The residue was then washed with 500 ml of distilled water. Altogether, 1,250 ml of water was used per sample.

Thereafter, 50 ml of the filtrate was again filtered through a 41 and then 42 Whattman paper. A total of 3.0 ml of this filtrate was placed into a 50 ml volumetric flask, which was diluted to mark with distilled water. Out of the volumetric flask, 2 ml of filtrate was transferred to a 10 ml stoppered glass boiling tube, where it was mixed with 1.0 ml of anthrone reagent. The steps followed thereafter were similar to those described by Allen (1989)

*Starch* : Starch determination was based on the method of Allen (1989). In the modified method, 25 g of fresh forage sample were chopped in a blender with 250 ml of water for three minutes. Thereafter, 5 ml of the blended solution was measured into a 10 ml test tube and mixed with 0.25 g of fine sand. The mixture was then shaken vigorously to dislodge starch granules from the plant material. Subsequently, the test tube was placed in a boiling water bath for 5 minutes to gel the starch. Further steps followed in the analysis were similar to those detailed by Allen (1989).

*Lactic acid* : The lactic acid content of silage was determined by the method of Eldsden and Gibson (1954) using silage juice.

*VFA* : Volatile fatty acid contents of silage were determined by Gas Chromatography, using a Pye Unicam GVC Chromatograph. The chromatograph was set at a column temperature of 145°C and injector temperature was at 200°C. The standard VFA solution used to calibrate

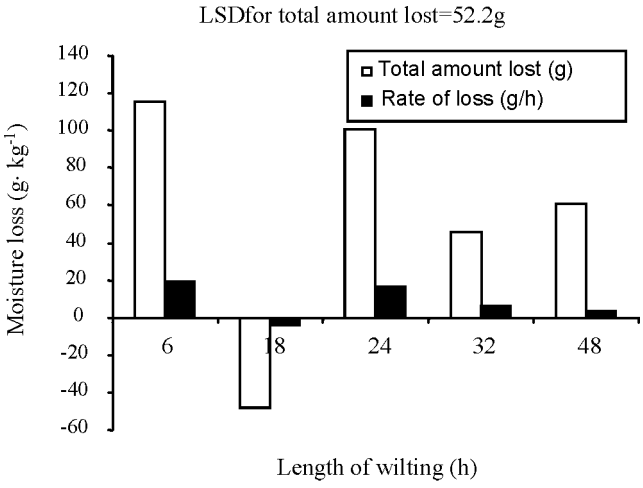


**Figure 1**. The rate of moisture loss in bana grass that was cut and left to wilt under sunny weather conditions

measurements on samples comprised acetic, butyric, propionic, i-butyric, n-butyric, i-valeric and n-valeric acids with concentrations of 0.1059, 0.993, 0.00475, 0.958, 0.0431 and 0.0940 g/100 ml respectively.

**Statistical analysis**

Data from this experiment was subjected to analysis of variance, using general linear models procedures (Proc GLM) of SAS (1996) statistical package (Statistical Analytical Institute Inc. Cary, North Carolina, USA), according to the following model:

$$Y_{ijkl}=\mu+b_i+W_j+(b\times W)_{ij}+ M_k+(M\times W)_{jk}+\varepsilon_{ijkl}$$

Where, Y=response variable (e.g. WSC concentration);
μ=general mean;
b=block effect;
W=wilting period;
(b×W)=main plot error term;
M=maize meal;
(M×W)=maize meal×wilting period interaction;
and ε = residual error.

Least squares means were used in treatment comparisons. Standard errors were calculated using the error mean square as an estimator of residual variance. Where appropriate, $LSD_{0.05}$ were used to compare least square means. Data on the wilting period could not be subjected to regression analysis because wilting period was treated as a non-continuous variable. Environmental conditions were different in each wilting period.

## RESULTS

The experimental plots were harvested between 10:00 and 12:00 h on May 5, 1998. By midday, shade temperature was 28.5°C. Later, ambient temperatures were 27, 11, 29, 25 and 29°C respectively, at 6, 18, 24, 32 and 48 h of wilting.

**Effect of pre-wilting on nutritive composition of herbage before ensilage**

To a large extent, herbage DM content and WSC content were affected by wilting. At the time of cutting, average DM content was 280 $g{\cdot}kg^{-1}$. It then increased rapidly to 401 $g{\cdot}kg^{-1}$ after the first 6 hours of wilting (Table 8.1). During early morning of the following day (18 h), mean dry matter content decreased to 353 $g{\cdot}kg^{-1}$ and then it increased significantly ($p<0.001$), reaching 561 $g{\cdot}kg^{-1}$ by mid-day of day 3. Thus, by the end of 48 hours, the DM content had almost doubled. The rate and amount of water losses are shown in Figure 1.

On fresh weight basis, WSC content followed the same trend as DM contents that increased with longer wilting, as

**Table 1.** The effect of wilting bana grass on its chemical composition

| Constituent | Wilting period (h) | | | | | | Mean | Signif-icance level | SE | C.V. (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 6 | 18 | 24 | 32 | 48 | | | | |
| Crude protein ($g \cdot kg^{-1}$ DM) | 130.8 | 125.9 | 131.9 | 123.8 | 117.2 | 125.1 | 125.8 | NS | 3.6 | 11.0 |
| *In vitro* Dry matter digestibility ($g \cdot kg^{-1}$ DM) | 669.3 | 656.8 | 676.0 | 654.7 | 645.3 | 634.5 | 656.1 | NS | 9.7 | 2.6 |
| Water soluble carbohydrate ($g \cdot kg^{-1}$ DM) | 127.6 | 101.8 | 110.8 | 131.4 | 112.3 | 115.8 | 116.7 | NS | 8.0 | 14.5 |
| Water soluble carbohydrate ($g \cdot kg^{-1}$ fresh) | 36.1 | 40.2 | 39.0 | 57.4 | 56.2 | 64.1 | 48.8 | *** | 2.1 | 15.1 |
| Starch content ($g \cdot kg^{-1}$ DM) | 38.8 | 36.5 | 34.2 | 34.0 | 38.2 | 29.4 | 35.2 | NS | 2.4 | 20.2 |
| Dry matter content ($g \cdot kg^{-1}$DM) | 285.0 | 401.0 | 353.0 | 454.0 | 500.0 | 561.0 | 426.0 | *** | 19.9 | 11.0 |

*** Refers to significant differences at $p<0.001$ and and NS refers to non-significant differences ($p>0.05$).

**Table 2.** Toluene dry matter contents (g DM $kg^{-1}$) of bana grass pre-wilted to different levels and supplied with graded levels of maize meal, as an additive

| Maize meal application rate (%) | Length of wilting (h) | | | | | | Mean | Significance level | SED |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 6 | 18 | 24 | 32 | 48 | | | |
| 0 | 273 | 320 | 353 | 433 | 496 | 562 | 406 | | |
| 5 | 333 | 353 | 380 | 481 | 545 | 629 | 454 | | |
| 10 | 313 | 427 | 380 | 518 | 518 | 565 | 454 | | |
| 15 | 327 | 427 | 393 | 561 | 521 | 623 | 475 | | |
| Mean | 317 | 382 | 377 | 498 | 520 | 595 | | *** | 23.9 |
| Significance level | All maize x wilting interactions = NS | | | | | | *** | | |
| SED | | | | | | | 13.4 | | |

Coefficient of variation=6.08%.

*** Refers to significant differences at $p<0.001$ and and NS refers to non-significant differences ($p>0.05$).

shown in Table 1. Significant increases in WSC content started to occur at 24 h. However, on a dry matter basis, WSC content tended to decline from 0 to 48 h of wilting, although reductions were not significant ($p>0.05$). Thus, wilting had the effect of concentrating WSC in the herbage on a fresh weight basis, even though there were no changes on dry matter basis. *In vitro* dry matter digestibility did not change significantly ($p>0.05$) between 0 and 48 h, nor did CP and starch contents.

Regarding the quality attributes measured during this phase of the experiment, there were no significant differences ($p>0.05$) observed in herbage from the subplots.

**Silage dry matter contents**

Both maize meal and pre-wilting increased silage dry matter content (Table 2). The toluene dry matter content of silage increased significantly ($p<0.001$) as the wilting period increased and as the amount of maize meal applied increased from 0 to 5%.

The increases in dry matter content beyond 5% level of maize meal application were non-significant. Significant increases in the dry matter content of silage occurred at 24 h and beyond.

There were no significant ($p>0.05$) interactions between wilting period and maize levels on the toluene dry matter content of silage. The application of maize meal affected the dry matter content of silage to the same extent in both wilted and unwilted grasses. Silage densities were also affected by changes in the dry matter content of the silage. The density of silage declined significantly ($p<0.001$) with longer wilting periods, from 540 $k \cdot gm^{-3}$ at 0 hrs to 330 $k \cdot gm^{-3}$ at 48 h. Between the maize treatments, the average density increased significantly ($p<0.001$) from 400 $k \cdot gm^{-3}$ without maize meal to 445 $kg \cdot m^{-3}$ with 15 % maize application. There were no significant interactions between wilting period and maize levels on bulk density.

**Residual sugars in silage**

Residual WSC contents differed significantly ($p<0.01$) between pre-wilting treatments (Table 3). They were lowest in non-wilted silage and highest in silage whose herbage had been pre-wilted for 48 h. Mean WSC contents were 8.92, 11.1, 14.0, 12.8, 26.1 and 31.8 $g \cdot kg^{-1}$DM at 0, 6, 18, 24, 32 and 48 h, respectively. The least significant difference ($LSD_{0.05}$) for treatment comparisons was 7.5 $g \cdot kg^{-1}$DM. The most significant changes in WSC content occurred in silage whose herbage was wilted for 24 h and beyond. There were no significant differences between the

**Table 3.** The effect of ensiling Bana grass pre-wilted to different levels, on the concentration of substrates and end-products of fermentation and the digestibility of silage

| Measured parameter | Length of pre-wilting (h) | | | | | | Mean | F-probability | SE |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 6 | 18 | 24 | 32 | 48 | | | |
| Residual WSC ($g \cdot kg^{-1}$ DM) | 2.7a | 4.1ab | 5.3b | 6.4b | 13.6c | 18.1d | 8.3 | p<0.001 | 0.69 |
| Silage pH | 3.9 | 4.4 | 4.1 | 4.4 | 4.5 | 4.7 | 4.3 | p<0.07 | 0.23 |
| Lactic acid ($g \cdot kg^{-1}$ DM) | 50.8a | 34.2bc | 38.3b | 34.1bc | 30.2cd | 26.2d | 35.6 | p<0.01 | 4.08 |
| Lactate:acetate ratio | 6.3a | 5.0abc | 5.0abc | 5.8a | 3.9bc | 3.8c | 5.0 | p<0.05 | 0.6 |
| Lactate: (acetate+butyrate ratio) | 4.9a | 3.7b | 3.3bc | 3.7b | 2.6cd | 2.4d | 3.5 | p<0.001 | 0.3 |
| Acetic acid ($g \cdot kg^{-1}$ DM) | 9.5 | 8.0 | 8.5 | 6.8 | 9.1 | 7.1 | 8.2 | p<0.39 | 2.5 |
| Butyric acid ($g \cdot kg^{-1}$ DM) | 1.8a | 2.2a | 3.7b | 3.0b | 3.7b | 3.7b | 3.0 | p<0.01 | 0.38 |
| Ammoniacal-N ($g \cdot kg^{-1}$ DM) | 2.3 | 1.4 | 1.7 | 1.2 | 1.6 | 1.4 | 1.6 | p<0.07 | 0.31 |
| $NH_3$-N as percentage of total available N. | 17.4a | 9.8b | 12.4c | 9.6b | 12.1c | 10.9bc | 12.1 | p<0.001 | 1.25 |
| *In vitro* dry matter digestibity ($g \cdot kg^{-1}$ DM) | 665 | 659 | 672 | 664 | 678 | 681 | 683 | p>0.45 | 8.3 |
| Improvement in DMD owing to pre-wilting & ensilage ($g \cdot kg^{-1}$ DM) | -4.0a | 2.6a | -3.7a | 6.5a | 33.0b | 45.2c | 12.8 | p<0.01 | 9.9 |

Values in the same row and followed by different letters are significantly different (p>0.05)

maize treatments and the mean WSC content was 17.4 $g \cdot kg^{-1}$. Similar trends were observed when the WSC content was expressed on a fresh weight basis. In this scenario, residual WSC increased significantly (p<0.001) from 0.9 $g \cdot kg^{-1}$Fw at 0 hrs of wilting, to 3.0 $g \cdot kg^{-1}$ at 48 h.

On the contrary, the starch content of silage tended to decline as the length of wilting increased, although the effects were non-significant (p>0.05). This observation was similar to the decline in starch content of herbage that occurred across all treatments before the pre-wilted grass was ensiled. However, the application of maize meal from 0, 5, 10 and 15% increased starch content significantly (p<0.001) from 12 to 43, 67 and 68 $g \cdot kg^{-1} \cdot$DM (s.e. 7.46), respectively. In spite of the significant differences observed in this analysis, a coefficient of variation (CV) of 67% in this experiment indicated that there were large sampling errors in the determination of starch contents of the silages.

**Silage pH**

There were no significant differences (p>0.05) in pH levels between the pre-wilting treatments and between the different levels of maize application. On average, pH was 4.3. However, pH tended to be lower in the non-wilted treatments (pH 3.9) compared to the wilted treatments (pH 4.4) at p<0.10.

**VFA and ammonia-N contents**

The mean acetic acid content of the silages was 8.1 $g \cdot kg^{-1} \cdot$DM. There were no significant differences in acetic acid content between the different pre-wilting treatments and the maize treatments. Significant differences (p<0.01) were observed in silage butyric acid contents at the different pre-wilting levels. The butyric acid contents increased significantly from 0 to 48 h of wilting. However, there were no differences in its content between the maize treatments. The average butyric acid content was 3.0 $g \cdot kg^{-1} \cdot$DM. Propionic and valeric acids appeared in minute quantities.

The $NH_3$-N content (expressed as a proportion of the total available N) differed significantly among the wilting treatments, although there were no consistent trends. The large $NH_3$-N values at '0' wilting accounted for most of the statistical differences, although there were some significant (p<0.05) differences between the 6 and 18 h (p<0.05) and between 18 and 24 h of wilting. When the ammoniacal-N was expressed as absolute values or as percentages of total available-N, there were no significant differences (p>0.05) in ammoniacal-N content between the maize treatments.

Evidence from the experiment suggests that the crude protein content of silage declined significantly (p<0.01) when pre-wilting was prolonged, from 8.9 $g \cdot kg^{-1}$ at 6 h to 8.2 $g \cdot kg^{-1}$ at 48 h. The application of maize meal did not result in any significant change in the crude protein content of silage.

All silages had white mould growing in the top layers. The levels of this surface spoilage were not significantly different (p>0.05) in all wilting time and maize application

treatments. Also, there were no significant interactions between maize and wilting treatments. On average, 15% of the silage was discarded due to spoilage. A large CV obtained in statistical analysis led to the conclusion that high levels of surface spoilage might have been caused by weaknesses in the design of silos and/or sampling error.

DM losses during fermentation were relatively small in all treatments (except the 6 h pre-wilting treatment) and they ranged between 2.0 and 4.4%. For unknown reasons, DM losses increased to 12.7% (s.d.=11.9) with 6 h of wilting. Addition of maize meal did not cause changes in dry matter loss.

## DISCUSSION

It is usually generalised that tropical forages do not have sufficient concentrations of WSC to sustain adequate silage fermentation, and that their fibrous nature presents difficulties in attaining adequate compaction. Results from this experiment demonstrated that Bana grass contains sufficient WSC and adequate silage density to sustain an acceptable fermentation without the excessive use of additives, even though it is a tropical grass. Other studies from tropical environments have also shown that Pennisetums contain adequate WSC concentrations to even sustain lactate fermentation. Tosi et al. (1983) obtained 170 g·WSC·kg$^{-1}$·DM in Napier grass that was eight weeks old. Without the use of additives. Woodard et al. (1991) produced lactate-dominated silage from Napier grass that contained 83.7 g·WSC·kg$^{-1}$·DM. However, there were indications from the current experiment that additional treatment of the forage will continue to be essential, to optimise fermentation and achieve high silage intake or performance by livestock.

Due to non-significant ($p>0.05$) interaction between the effects of pre-wilting and incorporation of maize meal in enhancing the fermentation of Bana grass silage, the two factors are discussed separately, in the following sections.

### Effects of wilting on the quality of forage before ensiling

The drying rate of forage was very fast in the initial period of wilting. By the end of the first 24 h, up to 76% of the total moisture lost over 48 hours had evaporated from the herbage. Moisture evaporated quickly at a rate of 19.2 g·kg$^{-1}$·h$^{-1}$ in the initial six hours of the wilting. If this drying rate had been sustained much longer, Bana grass forage would have attained 450 g·DM·kg$^{-1}$ in nine hours: not 24 h, as observed in the current experiment. It is obvious that low night temperatures and morning dew delayed the rate of drying.

Higher rates of moisture loss in Napier grass have been reported in Cuba by Rodriquez et al. (1989) who achieved losses of 20.5 g·kg$^{-1}$·h$^{-1}$ over 10 h. Lavezzo et al. (1988) in San Paulo observed a moisture loss of 10.9 g·kg$^{-1}$·h$^{-1}$ in Napier grass, over eight hours. These experiments showed that it is possible to wilt Pennisetums adequately within a day under sunny tropical or subtropical weather conditions. It will even be possible to attain a forage DM content of 350 g·kg$^{-1}$ (Woodard et al., 1991) to 400 g·kg$^{-1}$ (Rodriquez et al., 1989) which is considered to be optimum for fermentation and high DM recovery in Napier grass.

Evidence obtained in the current experiment supports the view that a DM content of about 450 g·kg$^{-1}$ is ideal for the fermentation of Pennisetum silage. In a study of 85 publications, Wright et al. (2000) observed that the rate of drying of forage during pre-wilting and the level of DM content finally attained at ensiling are the most important variables in determining the intake of pre-wilted silage by livestock. Therefore, silages produced in the present experiment would have supported high DM intake.

Although initial rates of moisture evaporation are high during wilting, Ruxton et al. (1975) argued that they are eventually checked by stomata closure. Ruxton et al. (1975) also indicated closure of the stomata is a gradual process. Results obtained in the current study with Bana grass indicated that farmers can take advantage of the delay in stomata closure by wilting grass rapidly. It is possible that the quick drying rates observed in the morning of day 2 (between 18 and 24 h) were exaggerated by the rapid evaporation of dew. However, between mid-day and the evening of day 2, moisture loss had reduced to 5.8 g·kg$^{-1}$·h$^{-1}$ and yet ambient temperatures were similar to those in day 1. This indicated that stomata had closed and that there was a high swath resistance.

In this experiment, wilting increased the concentration of WSC (g·kg$^{-1}$·Fw) in Bana grass forage. Similar observations were reported by Lavezzo et al. (1988) and Humphreys (1991), under tropical conditions. In addition, Petterson and Lindgren (1990) reported a similar observation under temperate conditions. As with DM content, the WSC content of Bana grass started to change significantly after wilting for 24 h. At 24 h, the concentration of WSC was 131.4 g·kg$^{-1}$·DM (or 54 g·kg$^{-1}$·Fw). This implies that the optimum level of wilting is about 450 g·kg$^{-1}$ in Bana grass and it corroborates the work of Rodriquez et al. (1989) who reported similar findings with Napier grass. It is possible that the rapid rate of drying restricted losses of WSC, as well CP and starch in Bana grass. However, experience has shown that it will be difficult to compact such high DM forage in a silo to achieve optimum densities of about 500 kg·Fw·m$^{-3}$.

Wilkinson (1983) suggested that WSC concentrations of 30 g·kg$^{-1}$·Fw are adequate to guarantee appropriate fermentation in tropical and temperate grasses, while Petterson and Lindgren (1990) suggested a concentration of 25 g·WSC·kg$^{-1}$·Fw. In the current study, the concentration of

57.4 g·WSC·kg$^{-1}$·Fw in Bana grass at 450 g·DM·kg$^{-1}$ exceeds these recommendations. Therefore, Bana grass at 450 g·DM·kg$^{-1}$ was suitable for ensilage. The quality of fermentation that ensued after wilting the grass for 24 h supports this inference.

**The effect of wilting on silage fermentation**

Although fermentation patterns were different, all silages in the current experiment achieved satisfactory preservation. The ability of Bana grass forage to form stable silages at widely different levels of chemical constitution made it difficult to compare the quality of silage from the different experimental treatments using conventional standards that are based on fermentation end-products. Therefore, other quality standards were incorporated in the comparison, as described later. Conventional standards were regarded as those described by Carpintero et al. (1969), Woolford (1984) and Holmes (1989), for temperate conditions.

Harrison et al. (1994) stated that silage pH below 4.0 can indicate that adequate fermentation ensued. Using both conventional standards and this guideline from Harrison et al. (1994), it was concluded that all Bana grass silages in this study were well preserved. All silages had lactate dominated fermentation. Research by Bates et al. (1989), Rodriquez et al. (1989), Woodard et al. (1991), Ruiz et al. (1992) and Spitaleri et al. (1995) has also shown that mature Napier grass silage is dominated by lactic acid. However, Rodriquez et al. (1989) observed that the lactic acid concentration of Napier grass silage decreased with length of pre-wilting: a trend that was also observed in the current study.

The lactate: acetate ratio and the lactate: acetate+ butyrate ratios decreased with length of wilting, mainly because lactate concentrations also decreased with wilting. Changes in butyrate concentrations had little effect on the lactate: acetate+butyrate ratio. Steen et al. (1998) and Wright et al. (2000) indicated that lactic acid concentration in silage is negatively related to DM intake by livestock. Therefore, the low lactic acid concentrations, high DM contents and high pH in pre-wilted silage of the present experiment would increase DM intake by livestock.

In general, pre-wilting lowered the proportion of $NH_3$-N in total available N (i.e. $NH_3$-N/Av. N.) of Bana grass silage and these findings were in agreement with Vilela and Wilkinson (1987). The $NH_3$-N/Av. N. values for Bana grass were lowest at 6 and 12 h of pre-wilting. An opposite trend was reported in temperate regions (Gordon et al., 1981; Wilkins, 1984; Spoelstra and Hindle, 1989; Dawson et al., 1999) and the differences can be explained by the faster wilting rate that occurs in the tropics. The high $NH_3$-N levels of unwilted silage in the current study were still within "acceptable limits". Catchpoole and Henzell (1971) acknowledged that stable silages with a ratio of $NH_3$-N /Av. N equivalent to 0.18 have been produced in the tropics.

Overall, the concentrations of fermentation end-products decreased as the wilting period increased, showing that wilting restricted fermentation. This observation was supported further by the increase in the level of residual WSC that occurred when the wilting period was prolonged. It was, therefore, not surprising that the pH increased with longer wilting time. However, the pH values obtained in all Bana grass silages were generally low. It is likely that relatively high WSC contents and low buffering capacity (Woodard et al., 1991; Spitaleri et al., 1995) in Bana grass gave rise to the low pH.

**The effect of incorporating maize on fermentation of Bana grass silage**

Smallholder farmers in Zimbabwe apply maize meal to silages as a substitute for molasses. Although maize meal and other cereals are mainly composed of starch, which is not readily utilized as a substrate during fermentation, Spomdly et al. (1986), Jones (1988) and Harrison et al. (1994) explained how cereals improve the preservation of silages. Cereals assist fermentation by acting as absorbents that reduce effluent production and reduce the likelihood of undesirable secondary fermentation which often leads to spoilage. They also improve the digestibility and feeding quality of the silage. Data from the current experiment supports these observations.

Evidence from the current experiment indicates that the incorporation of maize meal enhanced silage fermentation by absorbing excess moisture and controlling effluent production. It was surprising that the toluene DM content of silage did not increase substantially beyond the 5% incorporation of maize meal. This was probably due to the high DM content (280 g·kg$^{-1}$) of the Bana grass that was used in this experiment. It is likely that most of the excess moisture was absorbed at 5% cereal application, such that subsequent applications of the cereal had little effect.

Jones (1988) stated that the incorporation of cereals to herbage with more than adequate WSC contents will not show any added advantage. It is also possible that the levels of WSC in the current experiment were adequate, such that the incorporation of maize meal beyond 5% did not have any additional advantage.

In Taiwan, Hsu et al. (1990) compared 5 and 10% incorporation of maize meal in low DM Napier grass silage and concluded that 10% incorporation was better. However, even under their conditions, the optimum level may still be unknown since Hsu et al. (1990) only compared two levels of cereal incorporation. In temperate areas, the level of incorporation have tended to vary between 5% and 13% (Spondly et al., 1986; Jones, 1988). Therefore, under Zimbabwean conditions, the interaction between DM

content and maize levels needs further investigation, using forage of low DM content.

The incorporation of maize meal in this experiment increased silage density significantly, although there was no evidence that it assisted pre-wilted silages more than unwilted silages or vice-versa. The silage density of 540 $kgm^{-3}$ that was obtained in unwilted silage using laboratory silos is within the range of 400-550 $kg{\cdot}m^{-3}$, which was also observed by Woodard et al. (1991) on Napier grass. Catchpoole and Henzel (1971) also indicated that it is possible to produce silage of similar density in the tropics under field conditions, whereas Cruz (1984) reported low densities that averaged 383 $kg{\cdot}m^{-3}$. Whether or not such densities can be achieved under field conditions will depend on the stage of growth, leafiness, DM content of the original forage and the effectiveness of the method of consolidation.

The incorporation of maize meal in this study increased the starch content of the silage. This, in turn, enhanced the IVDMD of the silage. Apart from increasing silage DM content, IVDMD, silage density and reducing effluent production, there is little evidence that the addition of maize meal affected the levels of fermentation end-products or conversely, the fermentation patterns of Bana grass silage. This indicates that other additives should be used when one wants to improve silage preservation by changing the levels of fermentation end-products or manipulating fermentation pathways.

## CONCLUSION

This experiment showed that it is possible to wilt Bana grass rapidly under sunny conditions in Zimbabwe, to achieve a sufficiently high dry matter content that will ensure satisfactory silage fermentation and DM intake by livestock. The optimum level of pre-wilting Bana grass was about 450 $g{\cdot}kg^{-1}{\cdot}DM$. Pre-wilting enhanced silage preservation and nutritive value by reducing effluent production and increasing silage DM content, IVDMD and the concentration of WSC of forage on a fresh weight basis. By restricting fermentation and increasing the concentration of WSC, pre-wilting will enable Pennisetums that have sub-optimum concentrations of WSC to achieve stable preservation at high pH. Compared to the application of maize meal, pre-wilting would be more effective in the preservation of high DM Bana grass silage.

Although the incorporation of maize meal did not have significant additive or negative effects to pre-wilting, it improved preservation and nutritive value by acting as an absorbent, to reduce effluent production and by increasing DM content and IVDMD of silage. Application rates of maize meal should not exceed 5% on a fresh weight basis when used on forage of DM contents that are similar to those used in this experiment. However, the effects of higher levels of maize incorporation still need to be investigated on low DM silage. The experiment demonstrated that Bana grass is capable of producing sufficient WSC to sustain lactate-dominated silage fermentation at high levels of DM content.

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