Fermentation characteristics and chemical composition of silage made from different ratios of cattle manure and maize residues

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Fermentation characteristics and chemical composition of silage made from different ratios of cattle manure and maize residues were investigated. Manure (fresh) obtained from steers fed on a high concentrate diet was ensiled on a laboratory scale with maize residues in ratios of 50:50, 60:40, 70:30 and 80:20 for a period of 6 weeks. The ensiled mixtures were analysed for: *in vitro* dry matter digestibility, acid-detergent fibre, neutral-detergent fibre, crude protein, true protein, and water-soluble carbohydrates. Fermentation characteristics were determined by measuring: pH, lactic acid, acetic acid, butyric acid, and ammonia-nitrogen. Effective preservation with a favourable fermentation pattern was obtained which was little influenced by the ratio of manure to maize residues. The protein content of the silage showed a linear increase with an increasing ratio of manure to maize residues. A possible optimum ratio of 70:30 was found in respect of *in vitro* dry matter digestibility.
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Fermentasie-eienskappe en chemiese samestelling van kuilvoer gemaak van beesmis en mielie-oesreste in verskillende verhoudings, is ondersoek. Beesmis (vars) afkomstig van osse op 'n hoëkragvoer-rantsoen is op laboratorium-skaal met mielie-oesreste in verhoudings van 50:50, 60:40, 70:30 en 80:20 ingekuil vir 'n periode van 6 weke. Die ingekuilde mengsels is ontleed vir: *in vitro*-droëmateriaalverteerbaarheid, gedetergeerde suuronoplosbare vesel, gedetergeerde neutraalonoplosbare vesel, ruproteïen, ware proteïen en wateroplosbare koolhidrate. Fermentasie-eienskappe is bepaal deur die meting van pH, melksuur, asynsuur, bottersuur en ammoniak-stikstof. Doeltreffende preservering met 'n gunstige fermentasiepatroon wat min beïnvloed is deur die verhouding van mis tot mielie-oesreste, is verkry. Die proteïeninhoud van die kuilvoer het 'n lineêre toename getoon met 'n toename in die verhouding van mis tot mielie-oesreste. Die resultate ten opsigte van die *in vitro*-droëmateriaalverteerbaarheid dui op die bestaan van 'n moontlike optimum by die 70:30-inkuilingsverhouding.
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Introduction

When cattle are fed high concentrate diets as is done in feedlots, the faeces are rich in certain nutrients like crude protein, vitamins of the B-complex, and minerals (Anthony, 1974; Johnson, 1979). A crude protein content of 19% for faeces excreted by lactating Holstein cows fed a high concentrate diet was reported (Ward & Muscato, 1976; cited by Johnson, 1979). Feedlot manure had a calcium content of 1,9% and a phosphorous content of 0,5%. Manure obtained from cattle fed on high concentrate diets has been shown to be high in feeding value. Results obtained by Braman & Abe (1977) as cited by Johnson (1979) indicated an estimated digestibility of 77% for faeces from cattle fed an 80% concentrate ration. This value is corroborated by observations made by Snyman (unpublished results) who found an *in vitro* dry matter digestibility of 74% for faeces obtained from steers fed an 80% concentrate diet. The faeces were freeze-dried immediately after excretion. The length of time that manure is allowed to accumulate before collection can affect its chemical composition (Johnson, 1979).

The reuse of nutrients in manure was made possible by the discovery that it was readily consumed and used by cattle after it had been ensiled with ground hay in a ratio of 57 parts wet manure and 43 parts hay (Bandel & Anthony, 1969). The ensiled product had an acid fermentation with approximately the same characteristics as good silage. The pH stabilized at a value of approximately 4,3 – 4,5.

The use of manure, however, carries the risk of transmitting bacterial pathogens and parasitic nematodes between animals. Maturation of parasitic nematodes, however, was reported by Anthony (1974) to be inhibited by the ensiling process whilst bacterial pathogens were shown to be killed at a pH lower than 4,4 – 4,7 (Knight, McCaskey, Anthony & Walters, 1977).

In most experiments manure was ensiled with hay. In only a few experiments low quality roughages and especially maize residues were used for ensiling the manure. Cornman, Lamm, Webb & Fontenot (1981) indicated good fermentation when cattle waste was ensiled with rye straw whereas Lanari, Cesselli & Pinosa (1981) found that the quality of silage was very poor when ensiling cattle excreta with 40% maize stover. Ensiling cattle manure with maize residues, however, may be of importance in the Highveld Region as large quantities of each of these waste products are available in this region. According to the 1981 report of the Maize Board, 10,8 million tons of maize were produced in the Republic of South Africa during that season, most of it in the Highveld Region. Under normal circumstances this would mean that an equal amount of maize

residues were also produced. At the same time, commercial feedlots in this region have the capacity for finishing 75 000 cattle a year, thus producing a lot of manure. Recycling of this manure would not only mean an increase in production of food for human consumption, but also an alleviation of pollution in such feeding areas. Maize residues can be used as a cheap and easily available source of roughage in the vicinity of these feedlots for ensiling with manure. At the same time, the low crude protein and phosphorous content of maize residues will be supplemented by the relatively high content of these nutrients in manure, leading to improved use of the maize residues.

The object of this experiment was to determine on a laboratory scale whether maize residues could be ensiled successfully with manure obtained from cattle fed on a high-concentrate diet. The influence of the ratio of manure to maize residues on the fermentation characteristics, chemical composition and *in vitro* dry matter digestibility of the ensiled product were investigated.

Experimental procedures

Collection of manure

Manure was obtained from 18-months-old steers fed on high concentrate diets. The composition (dry matter basis) of the diet for Replication 1 consisted of maize meal, 73%; oil cake meal, 7%; and maize silage, 20%. The composition of the diet for Replication 2 consisted of maize cob meal, 95%, and a mixture of fishmeal and urea (9:1), 5%. Manure from these steers was collected freshly from a concrete floor. A representative sample of the manure was freeze-dried for analysis of chemical composition and *in vitro* dry matter digestibility (IVDMD).

Ensiling

The manure was thoroughly mixed by hand with maize residues (aerial portion of plant without grain) hammer-milled to pass a 6 mm screen, giving ratios of wet manure to maize residues of 50:50, 60:40, 70:30 and 80:20. From the mixture of each ratio, seven canned-fruit bottles (1 litre) were filled, compressed to expel as much of the air as possible and sealed using screw caps. The mixtures were ensiled at room temperature (*ca* 20°C) for a period of 6 weeks.

Chemical analysis

At the end of the ensiling period, part of the contents was freeze-dried. Another portion was extracted with water for 5 h after being stored at 6°C overnight. Extractions were performed by shaking 40 g of the 80:20, 70:30, 60:40 and 50:50 silage mixtures with 160, 180, 200 and 220 ml of water respectively. Two ml of a saturated solution of $HgCl_2$ were added to each 100 ml of water to eliminate bacterial activity. A third portion was dried at 105°C for a period of 24 h for DM determination. The following chemical analyses were done on the freeze-dried material: IVDMD according to the method of Tilley & Terry (1963) as modified by Engels & Van der Merwe (1967), acid-detergent fibre (Van Soest, 1963), neutral-detergent fibre (Van Soest & Wine, 1967), crude protein (Clare & Stevenson, 1964) using micro-Kjeldahl apparatus, true protein using the same method of N determination as for crude protein after precipitation of true protein by trichloroacetic acid (Agrawala, Duncan & Huffman, 1953), and water-soluble carbohydrates using the orcinol reaction (Shannon, 1972). Analyses made on the water extract were: pH, lactic acid according to the colorimetric method of Barker & Summerson (1941) as automated by Hochella & Weinhouse (1965), volatile fatty acids (Clancy, Wangsness & Baumgardt, 1977), and ammonia-nitrogen, using an ammonia-sensitive electrode (Orion ionalyzer).

Statistical analysis

Data were subjected to an analysis of variance (randomized complete block design) as described by Little & Hills (1975).

Results and Discussion

Chemical composition and IVDMD

The chemical composition and IVDMD of manure and maize residues used for ensiling in Replications 1 and 2 are shown in Table 1. It should be noted that, except for the crude protein content, a big difference existed in chemical composition and IVDMD between manure used for ensiling in Replication 1 and that used in Replication 2. This was probably due to the difference in diet that was offered to the animals providing the manure. There was also quite a difference in IVDMD between the two sources of maize residues.

Table 1 Chemical composition and *in vitro* dry matter digestibility of manure and maize residues used in Replications 1 and 2

	Replication 1		Replication 2	
Measurement (g/100 g DM)	Manure	Maize residues	Manure	Maize residues
In vitro dry matter digestibility	63,8	60,8	54,4	52,5
Acid-detergent fibre	16,7	47,7	27,8	48,9
Neutral-detergent fibre	49,6	81,4	64,0	84,9
Crude protein	14,2	3,5	12,7	7,3
Protein (true)	11,9	2,4	12,0	6,5
Water-soluble carbohydrates	4,6	5,9	3,5	5,5

The influence of increasing content of manure on the chemical composition and IVDMD of the ensiled mixture for Replications 1 and 2 is shown in Tables 2 and 3 respectively. The IVDMD of Replication 2 was significantly higher ($P < 0,05$) for the 70:30 ratio as compared to the 50:50 ratio. This trend was already apparent at the 60:40 ratio. The IVDMD of the 80:20 ratio, however, was significantly ($P < 0,01$) lower than the 70:30 ratio. A similar tendency with an optimum IVDMD at the 70:30 ratio was also observed in Replication 1. It is clear from this data that an increase in the content of manure up to an optimum ratio of 70:30, results in an increase in IVDMD. The increase in this experiment resulted mainly from the higher IVDMD of the manure compared to that of the maize residues. Similarly, one would also expect a decrease in IVDMD with an increasing content of manure in cases where the IVDMD of manure is lower than that of maize residues. Ratios higher than 70:30 will exert a negative influence on the IVDMD of the ensiled mixture. The difference in IVDMD between silages of Replication 1 and 2 can be attributed to the difference in IVDMD of the ensiling components (manure and maize residues) used (see Table 1). This clearly indicates that the feeding value of the ensiled product will be determined by the feeding value of the ensiling components.

The increase in IVDMD as the manure content increased was associated with a simultaneous decrease in ADF. A significant decrease in ADF was measured between the 50:50 and 60:40 ratios ($P < 0,01$) and between the 60:40 and 70:30

Table 2 Chemical composition and *in vitro* dry matter digestibility of silage made from different ratios of manure and maize residues during Replication 1

Measurement (g/100 g DM)	Ratio of wet manure to maize residues				Least significant difference[a]	
	50:50	60:40	70:30	80:20	$P < 0,01$	$P < 0,05$
In vitro dry matter digestibility	57,7[a]	58,8[a]	60,4[a]	57,7[a]	6,1	4,4
Acid-detergent fibre	40,4[a]	39,6[a]	35,8[b]	32,7[c]	2,3	1,7
Neutral-detergent fibre	70,4[a]	67,8[b]	62,7[c]	57,9[d]	2,2	1,6
Crude protein	5,57[a]	6,55[b]	7,94[c]	9,36[d]	0,36	0,26
Protein (true)	3,69[a]	4,41[b]	5,16[c]	6,23[d]	0,27	0,20
Water-soluble carbohydrates	3,39[a]	3,37[a]	3,37[a]	3,44[a]	0,16	0,12

[a,b,c,d] Least significant difference — values with common superscripts do not differ significantly ($P > 0,05$)

Table 3 Chemical composition and *in vitro* dry matter digestibility of silage made from different ratios of manure and maize residues during Replication 2

Measurement (g/100 g DM)	Ratio of wet manure to maize residues				Least significant difference[a]	
	50:50	60:40	70:30	80:20	$P < 0,01$	$P < 0,05$
In vitro dry matter digestibility	49,8[a]	51,8[a,b]	53,1[b]	49,2[a,c]	3,7	2,7
Acid-detergent fibre	42,7[a]	40,9[b]	38,8[c]	39,7[c]	1,4	1,0
Neutral-detergent fibre	75,5[a]	74,5[a]	71,5[b]	71,5[b]	3,3	2,4
Crude protein	4,87[a]	5,68[b]	6,75[c]	8,48[d]	0,55	0,40
Protein (true)	4,23[a]	5,27[b]	6,30[c]	7,49[d]	0,40	0,29
Water-soluble carbohydrates	2,89[a]	3,20[b]	3,50[c]	3,48[b,c]	0,41	0,29

[a,b,c,d] Least significant difference — values with common superscripts do not differ significantly ($P > 0,05$)

ratios ($P < 0,01$) of Replication 2. The same effect was measured in Replication 1 ($P < 0,01$ for 80:20 compared to 70:30 and for 70:30 compared to 60:40 and 50:50). The decrease in ADF content can be attributed to the lower content of ADF in manure in comparison to the maize residues. For the same reason, the NDF content also showed a decline with an increase in the ratio of manure to maize residues (Replication 2: $P < 0,05$ for 70:30 against 60:40 and $P < 0,01$ for 70:30 against 50:50; Replication 1: $P < 0,01$ for differences between all ratios). An increase in manure content thus results in a decreased fibre content.

A linear increase ($R^2 = 0,971$ for Replication 1 and 0,903 for Replication 2) in the crude protein content was found as the ratio of manure to maize residues was increased up to the 80:20 ratio ($P < 0,01$ for differences between all ratios of both replications). This was accompanied by a similar increase in the true protein content ($P < 0,01$ for differences between all ratios of both replications). In both cases the increase could be ascribed to the higher content of crude protein and true protein of the manure. A relatively high crude protein is characteristic of any manure, and is not dependent on the dietary intake as is the case with fibre and IVDMD. This is illustrated by the data presented in Table 1.

No differences in the content of water-soluble carbohydrates (WSC) were found between the different ratios of Replication 1 (Table 2). In Replication 2 (Table 3), however, a small increase ($P < 0,05$ for difference between ratios 50:50 and 60:40 and between ratios 60:40 and 70:30) was measured with an increasing manure content. Only a small decrease in the content of WSC seemed to occur as a result of fermentation. In both replications the initial contents of WSC (5,3 – 5,5% for the ratios of Replication 1 and 4,1 – 5,0% for the ratios of Replication 2) were lower than the value of 6 – 8% WSC necessary for successful fermentation (McCullough, 1977). It may be that undigested starch present in the manure component was hydrolyzed to fermentable sugars (Smith, 1971) and that this together with inoculation with massive numbers of acid-producing bacteria in the manure (Knight, *et al.*, 1977) lead to the highly successful preservation as will be seen under fermentation characteristics.

Fermentation characteristics

According to the values obtained for the parameters indicating extent and type of fermentation, excellent preservation was obtained for all ratios of manure to maize residues investigated. The values for the different parameters, viz. pH, lactic acid, acetic acid, butyric acid, ammonia-nitrogen, and dry matter content for Replications 1 and 2 are shown in Tables 4 and 5 respectively.

The pH values of all ratios for both replications varied between 3,96 and 4,14 which indeed show effective preservation

Table 4 Fermentation characteristics and dry matter content of silage made from different ratios of manure and maize residues during Replication 1

Measurement (g/100 g DM)	Ratio of wet manure to maize residues				Least significant difference[a]	
	50:50	60:40	70:30	80:20	$P < 0,01$	$P < 0,05$
pH	4,09[a]	4,00[b]	3,96[c]	3,90[d]	0,04	0,03
Lactic acid	6,31[a]	7,21[b]	8,52[c]	8,94[c]	0,84	0,61
Acetic acid	1,13[a]	1,42[a,b]	1,97[b,c]	2,18[c]	0,78	0,56
Butyric acid	0,150[a]	0,201[a]	0,283[a]	0,470[b]	0,191	0,138
Ammonia-nitrogen	0,037[a]	0,048[b]	0,061[c]	0,073[d]	0,006	0,004
Dry matter content	58,6	52,2	45,2	38,2	–	–

[a,b,c,d] Least significant difference — values with common superscripts do not differ significantly ($P > 0,05$)

Table 5 Fermentation characteristics and dry matter content of silage made from different ratios of manure and maize residues during Replication 2

Measurement (g/100 g DM)	Ratio of wet manure to maize residues				Least significant difference[a]	
	50:50	60:40	70:30	80:20	$P < 0,01$	$P < 0,05$
pH	4,14[a]	4,05[b]	3,98[c]	3,98[c]	0,05	0,04
Lactic acid	5,88[a]	6,59[a]	7,50[b]	8,91[c]	1,11	0,80
Acetic acid	1,37[a]	1,36[a,b]	1,23[b]	1,44[a,c]	0,194	0,140
Butyric acid	0,294[a]	0,262[a]	0,311[a]	0,424[b]	0,070	0,050
Ammonia-nitrogen	0,062[a]	0,072[b]	0,079[c]	0,108[d]	0,009	0,006
Dry matter content	59,6	52,9	46,3	40,2	–	–

[a,b,c,d] Least significant difference — values with common superscripts do not differ significantly ($P > 0,05$)

(Knight, *et al.*, 1977). An increase in the manure component caused a small but significant decrease in pH to a ratio of at least 70:30 (Replication 1: $P < 0,01$ for differences between all ratios. Replication 2: $P < 0,01$ for differences between ratios 50:50, 60:40 and 70:30).

The results indicate that the low pH values can be ascribed mainly to a lactic acid-type of fermentation. A relatively high lactic acid content which increased with an increase in manure content was found (Replication 1: $P < 0,01$ for differences between ratios 50:50, 60:40 and 70:30. Replication 2: $P < 0,05$ for differences between ratios 60:40 and 70:30 and $P < 0,01$ for differences between ratios 70:30 and 80:20). The increase in lactic acid, with a corresponding decrease in pH confirms the finding of Knight, *et al.* (1977), who ensiled mixtures containing 20, 40 and 60% manure. An increase in lactic acid content with increasing content of manure, varying between ratios of 30:70 and 70:30, was also demonstrated by Cornman, *et al.* (1981), who ensiled manure with rye straw.

As can be expected from a lactic acid type of fermentation, a relatively low content of acetic- and butyric acid was found. Again, an increase in the manure content resulted in only a small increase in the acetic acid content of Replication 1 with no overall effect on the acetic acid content of Replication 2 (Replication 1: $P < 0,01$ for differences between ratios 50:50 and 70:30 and between ratios 50:50 and 80:20, $P < 0,05$ between ratios 60:40 and 80:20). The butyric acid content of both replications showed no significant increase with an increase in manure content except at the 80:20 ratio (Replication 1: $P < 0,01$ for differences between ratio 80:20 and ratios 50:50 and 60:40; $P < 0,05$ between ratios 80:20 and 70:30. Replication 2: $P < 0,01$ for differences between ratio 80:20 and ratios 50:50, 60:40 and 70:30). This small increase in butyric acid at the 80:20 ratio is an indication of unfavourable fermentation, probably as a result of the higher content of moisture. This could partly explain the decrease in IVDMD found for the 80:20 ratio.

According to pH and pattern of acid production, excellent fermentation took place at all ratios investigated. This was corroborated by a low production of ammonia-nitrogen during both replications (Tables 4 and 5), resulting in a low ratio of ammonia-nitrogen to total nitrogen (4 – 8%). These results indicate that, except probably for ratios higher than 70 parts of wet manure and 30 parts of maize residue, the ratio of manure to maize residue should have little detrimental effect during ensiling on the chemical composition and IVDMD of the mixture.

In conclusion, this investigation indicated that maize residues ensile excellently with manure excreted by cattle fed on high concentrate diets and that the ratio of manure to maize residues within the limits of 50:50 and 80:20 has little influence on fermentation characteristics. Increasing the ratio of manure to maize residues increases the protein content linearly. An optimum ratio of 70 parts manure and 30 parts of maize residues was found with respect to *in vitro* dry matter digestibility.

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