Introduction to the conference on silage making in the tropics

L.'t Mannetje

Department of Agronomy, Agricultural University, Wageningen, The Netherlands. E-mail: ltmannet@bos.nl

1. Introduction

Forage, crop residues and by-products products are usually consumed fresh by domestic animals. However, it is possible to conserve them for use during future periods of feed shortages. Conservation can be achieved by sun drying (hay), artificial drying (meal), and addition of acids or fermentation (silage).

Hay making is difficult in tropical regions because at the time when the forage is of acceptable quality (early in the wet season) to conserve it, the weather is likely to be too unreliable for sun drying. Artificial drying is expensive and facilities are not widely available. Addition of acids may be beyond the resources of small holders and can be dangerous. Remains fermentation by silage making, which can be done of fresh or, preferably, wilted material.

Silage is forage, crop residues or agricultural and industrial by-products preserved by acids, either added or produced by natural fermentation. Fresh forage is harvested, or crop residues and by-products are collected, the material may be chopped or conditioned, additives may be added, and it is then stored in the absence of air so that facultative anaerobic bacteria, present on the forage, or added as inoculants, can rapidly convert soluble carbohydrates into acids. The quality of the ensiled product depends on the feeding value of the material ensiled and on the fermentation products present: the types of acids and the amount of ammonia. The resulting pH of a well-ensiled product becomes so low that all life processes come to a halt and the material will be preserved so long as it remains in airtight storage.

There are three important considerations to take into account before embarking on a silage making program:

- Is there a need for silage making?
- If so: Are there enough good quality forages or other products available to ensile?
- If so: Can the conditions for good silage making be met?

2. Is there a need for ensiled forage?

Silage making is practised widely in intensive animal production systems in temperate regions, mainly for two reasons. Firstly, because during the winter period there is no high quality feed available in the fields and secondly in order to feed high quality conserved supplements (e.g. maize) at any time of the year to complement grass to improve milk production and/or nitrogen utilization.

Whether silage making is recommendable in the tropics depends on the type of farm system and on the climate. For a start, feed conservation is generally only a proposition for intensive farm systems, such as milk production for a liquid milk market. Secondly, in humid and sub-humid climates with green forage available year-round, forage conservation is generally not profitable. If the quality of forage from permanent sources (pastures, road-sides) is inadequate, it is nearly always possible to grow a fodder crop (Saleem 1985) or harvest stockpiled forage (Andrade *et al.* 1998) or use fodder banks (Milera *et al.* 1994, Peters *et al.* 1994).

Materials to be ensiled can be grasses, legumes, fodder crops (sorghum, maize), crop residues or by-products. The storage period, after which the silage is fed, depends on the purpose of the silage making. If silage is made of forage or a fodder crop of exceptional quality that is only available at a certain time of the year, it will most likely be used in a matter of months. It may also be used for an annual recurrence of periods of shortage or for unseasonal droughts that occur every number of years. Silage can also be a standard feed supply in feedlot systems.

3. Is there enough good quality forage to ensile?

Only excess forage, crop residues or by-products for which there is no other economic use should be ensiled. In other words, if rainfall is unreliable, farmers will not know until late in the growing season that there will be excess forage. This points to a conflict between availability of forage to ensile and its quality. The quality is high early in the growing season, but the farmer cannot take the risk to preserve forage if he is not sure there will be excess. Once he can be sure of that, the quality is too low to make it worthwhile to conserve it. To overcome this problem it is possible to grow a fodder crop to be harvested, or crop residues and by-products or other waste materials to be collected for silage making.

4. Can the conditions for good silage making be met?

Silage making is useful only if the ensiled product is of good quality, i.e. well preserved and of high digestibility and protein concentration. The main prerequisites for ensilable forage are that it should be harvested at a young stage of growth from a feeding value point of view and that it should contain enough sugars for fermentation. The material to be ensiled should be easily compactable and covered to exclude air. If the material is of adequate quality, but lacking in sugars, molasses or another source of sugar may be added. Chopping before ensiling will also help to compact the material. Tropical grasses (C_4) are inherently low in soluble carbohydrates, with the exception of maize and *Sorghum* species. To ensure good quality silage it may be better to grow a crop of maize or sorghum for silage than to ensile tropical grass. Problems with silage can also arise when it is being fed out due to spoilage caused by moulds that grow particularly fast at high temperatures, common in the tropics. Therefore, silage pits or heaps for smallholders should be small, so that they can be fed out in a very short time (1 or 2 days). Poorly made silage can cause health problems in animals and man.

Catchpoole and Henzell (1971) wrote an early review, which clearly sets the scene for silage making from tropical forages.

5. The conference

The aim of the conference is to review the potential of silage making for livestock production in the tropics with special reference to smallholders.

There will be main papers and posters to cover the main issues of silage making under these conditions. The first main paper will deal with the theory of silage making, the fermentation processes, and what problems will be encountered to meet the requirements for good silage making. This will be followed by other main papers and posters on silage making in large and small scale animal production systems, of grass-legume mixtures, of cereals and fodder crops, of agricultural by-products and industrial, non-agricultural, residues, of harvesting and ensiling techniques, on the use of additives to improve the silage making process of tropical forages and case studies.

There will be ample opportunity for discussion.

6. References

Andrade, I.F., Atkinson, L.G., Sollenberger, L.E., Ruegsegger, G.J., Misley, P. and Kalmbacher, R.S. (1998). Stockpiling herbaceous tropical legumes for dry season feed in Jamaica. *Tropical Grasslands* **32**, 166-172.

Catchpoole, V.R. and Henzell, E.F. (1971). Silage and silage-making from tropical herbage species. *Herbage Abstracts 41*, 213 - 21.

Peters, M., Tarawali, S.A. and Alkamper, J. (1994). Evaluation of tropical pasture legumes for fodder banks in subhumid Nigeria. 1. Accessions of *Centrosema brasilianum, C. pascuorum, Chamaecrista rotundifolia* and *Stylosanthes hamata*. *Tropical Grasslands* 28: 65-73.

Saleem, M.A.M. (1985). Effect of sowing time on the grain yield and fodder potential of sorghum undersown with stylo in the subhumid zone of Nigeria. *Tropical Agriculture* **62**, 151-153.

The Future of Silage Making in the Tropics

L.'t Mannetje

E-mail: ltmannet@bos.nl

1. Introduction

Over a period of 3 months (September till early December 1999) the participation in this Electronic Conference on silage Making in the Tropics has been good and sustained. There were 355 participants from 68 countries, 148 of whom were from Latin America, but only a limited number of contributions came from there**.** Nine invited main papers were supported by 25 submitted posters and several comments have given a reasonable and sometimes lively discussion. It was an eye-opener to me and probably to many other participants in this conference to what extent silage making in the tropics has been advocated and tried. But a question remains: to what extent is silage production being adopted by small farmers? At this stage we cannot gauge how many small holders are actually practising silage making.

2. Adoption by small farmers

The contents of the papers and the posters show that silage making is generally known by scientists in the tropics, but that actual small holder silage making activity is low, except in Malaysia (Chin and Idris) and China (Li Dajue and Song Guangwei). The reasons for non-adoption of this technology were presented for Pakistan (Hassan Raza), India (Rangnekar) and Thailand (Nakamanee).

The main reasons mentioned were:

- lack of know-how
- lack of finance
- silage making was considered cumbersome and labour intensive
- benefits were not commensurate with effort and time
- animals have a low genetic potential for production and cost and trouble of silage making did not provide adequate returns
- lack of farm planning
- lack of available feedstuffs of good quality

It was also mentioned that farmers might be prepared to buy ready made silage, which indicates willingness to feed it, but lack of time to prepare it.

It is clear that it is necessary to have trained extension staff and in order to involve farmers in any pilot projects of silage making from an early start. Only a participatory approach will lead to adoption of new technology that fits in with their system of farming and availability of funds and labour. If farmers would like to feed silage but cannot adopt the technology it may then be necessary to modify it in close cooperation with the farmers to suit their needs and resources.

3. Materials to ensile

Anything that has feeding value can be ensiled. What actually is ensiled depends on availability and quality, but only good quality material should be ensiled to ensure that costs will be reimbursed. Materials mentioned in this conference include:

- grasses
- legumes (herbaceous and edible material of woody species)
- fodder crops
- crop residues
- oil palm fronds
- tomato pomace
- poultry litter

4. Methods of silage making

For large farms the temperate approach of mechanised methods and the use of large silos is also applied in Australia (Cowan) the Philippines (Montemayor *et al*.) and Cuba (Ojeda). Small farms use plastic bags, containers or small bale wrapping.

5. Additives

Although a large range of additives is available, there is little evidence of its use on small farms in the tropics. If anything, molasses is used on low-sugar containing materials.

6. Conclusions

Silage making is possible and can solve nutritional problems on small as well as larger farms, but as with many innovations to overcome animal production constraints in developing countries, socio-economic problems prevent general adoption. The main exception is Malaysia, where silage making has become part of a scheme of small scale milk production and collection, providing a regular income to farmers. This may be a lesson in its self: ***Technology of any kind will only be adopted if it can be part of production systems that generate income .***

This conference has been useful because it has brought together and made available the knowledge and shown the constraints concerning silage making in the tropics.

7. Acknowledgements

The readiness of authors for a quick turn-around of edited papers and posters has made it possible to adhere to the time schedule. I thank them for their cooperation and enthusiasm.

Special thanks to Héctor Osorio, who has given excellent assistance in technical editing and preparing the material for distribution by e-mail and posting on the Website.

8. References

Chin, F. Y and Idris, A.B., Silage making activities of the Department of Veterinary Services Malaysia, Poster 2p2

Cowan, Tom, Use of ensiled forages in large-scale animal production systems in the tropics, Paper 3.

Lin Dajue and Song Guangwei, Sweet Sorghum-a fine forage crop for the Beijing region, China, Poster 7P3.

Montemayor, J. M., Enad, R.A. and Galarrita, F.U. The use of silage in a year-round feeding system: The case in Sarangani Agricultural Company, Inc., cattle operation in the Southern Philippines, Poster 3P1

Rangnekar, D.V., Some observations on non adoption of silage making in central and western India , Discussion 2D1

Syed Hassan Raza, Basic reasons of failure of silage production in Pakistan, Poster 2P3

Additives to Improve the Silage Making Process of Tropical Forages

Paulo R . F. Mühlbach

Departamento de Zootecnia , Faculdade de Agronomia,
Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil.
E-mail : muhlbach@orion.ufrgs.br

1. Introduction

This contribution focuses on the ensilage of forages produced in tropical and sub-tropical climates.

The low dry matter (DM) and water soluble carbohydrate (WSC) content of tropical (C_4) grasses results in poor fermentation of freshly cut material and depending on climatic conditions wilting must be extended without having a positive effect on fermentation patterns, whilst increasing ammonia-N (Table 1). Use of certain additives may be an alternative to wilting, particularly with thick-stemmed , erect fodder crop grasses (*Pennisetum*, *Panicum*, etc.) that produce a large mass of plant material where pre-conditioning and handling is difficult to mechanise and labour-consuming. Tropical forage grasses (*Cynodon* , *Brachiaria*, *Digitaria*, *Setaria*, *Chloris*, etc.) can be wilted more easily but, when done so excessively, affecting compression in the silo and thus fermentation quality (Catchpoole and Henzell 1971). Even under controlled wilting conditions additives are being recommended to improve fermentation and nutritive value of conventional as well as round bale silages (Bates *et al*. 1989, Staples 1995).

In farm situations silage making often faces drawbacks which compromise the basic principles of silage making, especially where technology is limiting such as with smallholders in the tropics and subtropics (Bayer and Waters-Bayer, 1998). Additive can never be a substitute for good ensiling management. For example, additives will not make up for the negative effects on fermentation quality of a tropical forages caused by practices such as the use of low quality oxygen-permeable plastic covers and extended storage under temperatures in excess of 30ºC (Tjandraatmadja *et al.* 1991).

It should also be emphasised that the efficacy of any additive will ultimately be assessed by animal performance and by DM recovery from the silo which are parameters not commonly determined . Most of the experiments are restricted to measurements of traditional fermentation patterns under controlled laboratory conditions where even untreated silages made from thick-stemmed *Pennisetum* species may show acceptable preservation (Woodard *et al.* 1991, Spitaleri *et al.* 1995). On the other hand, bad fermentation products such as biogenic amines which cause intake depression in ruminants (Phuntsok *et al.* 1998) are not detected by conventional silage analysis. It has been suggested that the current parameters used to predict silage fermentation and quality may need some re-evaluation (Jones 1995).

2. Biological additives

Inoculants and enzyme preparations are regarded as natural products which are safe to handle, non-corrosive to machinery, do not cause environmental problems and their usage has expanded remarkably in the last decades. Perhaps no other area of silage management has received as much attention among both researchers and livestock producers as bacterial inoculants

(Bolsen 1999). There are many commercial products with variable efficacy available. However, dosage and method of application are decisive for effectiveness.

Inoculants

Based on a survey of inoculant studies, Muck (1993) concluded that inoculants are most successful in alfalfa and temperate grass silages and that with corn silage their success has been limited. However, Bolsen (1999) emphatically recommended that bacterial inoculants should be applied to every load of forage ensiled, based on results from over 200 laboratory-scale studies and from 28 farm-scale trials where this type of additive consistently improved fermentation efficiency, dry matter recovery, food efficiency, and liveweight gain per ton of crop ensiled in corn and forage sorghum silages.

Table 1. Effects of wilting on fermentation of tropical fodders (Part 1).

	Forage		
	Dry matter (%)	**Water soluble carbohydrates (% of fresh material)**	**True protein (% of crude protein)**
Elephant grass*			
120 days growth , unwilted	19,7	2,17	88,0[a]
Wilted for 50 h	26,6	3,00	62,0[b]
Millet*			
45 days regrowth , unwilted	16,0	2,70	82,1[a]
Wilted for 48 h	31,0	4,24	58,5[b]
78% Millet+ 22% Cowpea, unwilted[+]	20,8	1,40	78,6[a]
Wilted for 26 h	46,2	3,19	71,6[b]
60% Eleph.grass+40% Cassava tops[++]	20,5	1,62	84,7[a]
Wilted for 20 h	26,5	2,81	76,1[b]

Table 1. Effects of wilting on fermentation of tropical fodders (Part 2).

	Silage				
	Ammonia N (% of total N)	**pH**	**Total acids (% of dry matter)**	**Butyric acid (% of total acids)**	**Lactic acid (% of total acids)**
Elephant grass*					
120 days growth, unwilted	$9{,}4^{b}$	4,4	5,9	2,4	66,6
Wilted for 50 h	$14{,}8^{a}$	4,5	5,1	4,1	41,7
Millet*					
45 days regrowth, unwilted	$6{,}2^{b}$	4,0	$7{,}4^{a}$	0,9	78,6
Wilted for 48 h	$10{,}3^{a}$	4,2	$4{,}5^{b}$	2,0	60,6
78% Millet+ 22% Cowpea, unwilted +	8,9	$3{,}64^{b}$	$7{,}5^{a}$	0,3	72,7
Wilted for 26 h	7,5	$3{,}85^{a}$	$6{,}5^{b}$	0,3	71,3
60% Eleph.grass+40% Cassava tops,++	$9{,}5^{b}$	3,8	$8{,}9^{a}$	2,1	83,4
Wilted for 20 h	$11{,}7^{a}$	3,9	$7{,}3^{b}$	2,2	79,5

[ab]Means within column differ, $P< 0{,}05$

* Pinheiro Machado and Mühlbach, 1986.

[+]Figueiredo and Mühlbach, 1984.

[++]Zanotelli and Mühlbach, 1989.

Enzymes

The addition of enzyme preparations either alone or combined with inoculants is proposed as a strategy to increase available substrate to improve lactic acid fermentation in silage and/or to increase nutritive value of forage. With silages of temperate forages produced in subtropical conditions an inoculant/enzyme mixture (Sill-All®) improved fermentation quality of unwilted forage oats (*Avena strigosa*) (Berto and Mühlbach 1997) and reduced NDF contents of both unwilted and wilted alfafa (Rangrab *et al.* 1996). The complex interactions occurring with the addition of both products is not completely understood and earlier results indicate varying degrees of success

(Jaster 1994) . The first products were based on complexes containing ill-defined amounts of various enzymes from crude fermentations of fungi and results were inconsistent due to variable application rates, plant species, plant maturity , and DM content of the materials (Muck 1993).

Similarly, results have also been conflicting in experiments where enzymes were added to corn silage with no clear effects on fermentation characteristics, despite a decrease of ADF, NDF, and hemicellulose contents (Sheperd and Kung 1996). Positive results with cellulase in combination with organic acid have been reported with the ensilage of temperate grass forages (Nadeau *et al.* 1996).

More recently, newer enzyme preparations have prompted a renewed interest in the potential of these products also as feed additives for ruminants , enhancing forage digestion and milk production (Yang *et al.* 1999, Schingoethe *et al.* 1999).

Results with tropical forages

If different types of additive suit different crops (Wilkinson 1998) one should not expect that the effects achieved with biological additives on the ensilage of temperate forages will also be realised with tropical species, where fibre contents are generally much higher and more lignified. It stands to reason to consider that the constraints imposed by structural, anatomical and chemical characteristics which are peculiar to tropical forages and which impair nutritive value, i.e. intake and fermentation in the rumen (Wilson 1994; 1997), may also affect harvesting, wilting, chopping, and compressing the original material in the silo as well as influence the direction of fermentation.

Whilst literature on the use of biological additives for temperate forages is relatively abundant the information with tropical species is scarce. The data reviewed with this kind of additive is presented according to the type of tropical forage tested.

a) Sorghum spp.

Forage sorghum (*Sorghum bicolor* L.) is a fodder crop with a sweet juicy pith having types with finer, more numerous and more leafy stems (Bogdan 1977). Of the tropical forages it is one of the best suited for ensiling.

When harvested at the soft dough stage (29 % DM) it can have about 14 % WSC and 50 % NDF in DM and after a 30 days fermentation period the silage can still present 10 % WSC in DM. To such forage a mixture of *Lactobacillus plantarum* and *Streptococcus faecium* (Pioneer brand® 1129) was added at 1.1 x 10^5 CFU per gram of fresh forage in a microsilo trial. Inoculation reduced silage pH but did not affect concentration or *in vitro* digestibility of NDF or ADF, neither did it prevent aerobic deterioration (Sanderson 1993).

Froetschel *et al.* (1995) ensiled either untreated or inoculated forage sorghum harvested at the milk stage (61.5 % NDF) in 900-kg concrete tower silos. Silage lactic, acetic and total volatile fatty acids were increased 9.2 to 15.3 % and DM recovery was increased 7.1 % with inoculation.The level of response was considered cost effective in a 1.7 to l return for investment based on average prices for silage and inoculant. In a feeding trial with steers inoculation did not influence digestibility of DM or fibre components of silages and silage-based rations.

A sorghum-sudangrass hybrid was harvested at 90 days of growth (26 % DM) in Puerto Rico and ensiled in laboratory silos either untreated or inoculated with 10^6 CFU of *Lactobacillus plantarum* mixed or not with a multi-enzyme complex containing arabinase, cellulase, ß-glucanase, hemicellulase and xylanase, applied at 0.1 % of fresh material. The addition of inoculant either alone or in mixture with the enzyme complex improved silage quality as evidenced by lower pH and a greater population of lactic acid bacteria (Rodriguez *et al.* 1994 a). However, additives did not reduce aerobic deterioration of forage sorghum ensiled in a tropical environment (Rodriguez *et al.* 1994 b).

Similar results with the ensilage of *Sorghum bicolor* were obtained more recently by Cai *et al.* (1999), where selected strains of either *Lactobacillus casei* FG 1 or *Lactobacillus plantarum* FG 10 isolated from corn and *Panicum maximum* were used at 10^5 CFU per gram of fresh matter. Both inoculants effectively improved fermentation decreasing contents of volatile fatty acids and ammonia N and reducing gas production and DM loss as compared to the control silage. Again, the LAB-treated sorghum silages which contained relatively high concentrations of residual WSC and lactic acid suffered a faster aerobic deterioration than the control silage.

Johnson grass (*Sorghum halepense*) is a rhizomatous perennial, aggressive forage which can be established from seed for pasture and fodder (Mannetje and Jones 1992). This forage was harvested at 45 (22,6 % DM) and 110 days of regrowth (43,8 % DM), chopped into 2.5 cm pieces, and ensiled in laboratory silos either untreated or treated with a mixture of *Lactobacillus plantarum* at a rate of 10^6 CFU per gram of fresh material plus 0.1 % of a multi-enzyme complex with arabinase, cellulase, ß-glucanase, hemicellulase and xylanase (Rodriguez *et al.* 1998).

For both stages of regrowth, Johnson grass treated with microbial inoculant plus enzymes had lower pH and higher populations of lactic acid bacteria and higher lactic acid contents than untreated silages. Silage additives also decreased butyric acid content in grass ensiled at 45 days regrowth and ethanol content in the more mature forage. However , the authors also conclude that the resulting silage did not meet the criteria to be considered as good quality silage, suggesting for more research to evaluate other sources of addditives as well as the rates of additives used.

b) *Pennisetum* spp.

Elephant or Napier grass (*Pennisetum purpureum*) has thick erect stems 2-6 m tall, with 30-120 cm long leaves and has been introduced to practically all tropical countries being widely grown for fodder and less often for grazing (Mannetje and Jones 1992). Van Onselen and López (1988) reported on a trial from 1981 with the use of a commercial enzymatic product (sucrase and cellulase) added to elephant grass from a 105 days regrowth (19,4 % DM) at a rate of 0.1 % of fresh forage plus 0.9 % corn meal. When compared to a control treatment with 7 % corn meal the enzymatic product showed higher pH and ammonia-N values and a lower lactic acid content resulting in a silage of bad quality.

A 60 days regrowth of elephant grass (14 % DM, 70 % FDN in DM) was ensiled in 200-liter plastic containers testing the effects of two commercial products with bacteria and enzymes (Bio-Silo ® and Bio-Silo P.U. soluble®, Katec Kaiowa Ltda., Brazil). The product Bio-Silo was added at 0.1 % of forage fresh matter plus 0.9 % of corn meal and Bio-Silo P.U. was diluted in water and also added at 0.1 % , according to the manufacturer's recommendations. No effects of additive use were detected neither on silage composition and pH and ammonia-N values nor on nutrient intake and digestibility coefficients measured with sheep (Henrique and Bose 1992).

Tamada *et al.* (1999) conducted experiments in different latitudes in Japan with different harvest dates of Napier grass and two silage storage temperatures to test the effects of a mixture of cellulases (*Acremonium cellulolyticus* and *Trichoderma viride*) mixed or not with a commercial inoculum (*Lactobacillus casei*, 10^8 CFU/ kg wilted forage) and of a preparation of fermented green juice extracted from macerated Napier grass mixed or not with the cellulases, as compared to a control. All treatments were applied to wilted Napier grass (averaging 22.7 % DM and 4.6 % WSC in DM) ensiled in 0.9-liter bottles; in two experiments, 40 g of glucose/kg wilted forage was included to each treatment with additive. Improved fermentations with lower pH values and ammonia contents and increased lactic acid over control only were obtained when sufficient fermentable substrate was secured by adding the cellulases or glucose.

Kikuyu grass (*Pennisetum clandestinum*) is a creeping perennial with strong, thick stolons which requires fertile soil, can be associated with white clover and is not well adapted to high temperatures (Mannetje and Jones 1992). De Figueiredo and Marais (1993) used wilted kikuyu grass (30 % DM, 3.2 % WSC in DM) treated with inoculant alone (*Lactobacillus acidophilus* + *Lactobacillus bulgaricus* at 5 x 10^4/ g grass ensiled) or in combination with two different enzyme preparations (either from *Trichoderma reesei* or from *Aspergillus*). The best fermentation with lower pH and ammonia-N and higher lactic acid in micro-silos of polythene bags was obtained with the combination of inoculant plus the enzyme from *T. reesei* . In a second experiment the authors used the same forage unwilted (19.2 % DM, 3.7%

WSC) without or with an inoculant (*Lactobacillus plantarum* strain MTD/1) alone and in combination with molasses meal (5 or 10 % on a DM basis) at ensiling. The only significant effect as compared to untreated silage was a pH decrease with the inoculant combined to the 10% molasses level.

Pearl millet (*Pennisetum americanum*) – A late summer crop of pearl millet grain hybrid (HGM-100) at the soft dough stage of grain maturity (18.9 % DM, 60.2 % NDF in DM) was unwilted, treated with inoculant (Pioneer 1174®) and stored in a concrete stave silo. The resulting silage was poorly preserved, with a predominantly acetic fermentation (4.23 % acetic acid in DM) and the need to add a low level of readily available carbohydrates was indicated (Utley *et al*. 1995).

c) Other genera

Bermudagrass (*Cynodon dactylon*) is a stoloniferous and rhizomatous perennial, growing in the tropical, subtropical and warm temperate regions, with cultivars that tolerate frosts (Mannetje and Jones 1992). Wilted bermudagrass conserved as round bale silage is being used in the southeastern United States as an alternative to hay making and some of the first tests with a combination of enzymes containig cellulase and an inoculant showed potential to improve fermentation and dry matter recovery (Bates *et al*. 1989).

A thorough study by Umaña *et al*. (1991) was conducted with Tifton 81 bermudagrass which was harvested at the late jointing stage of growth and ensiled either unwilted (32.4 % DM, 2.85 % WSC in DM) or wilted (44.1 % DM, 4.14 % WSC in DM). Both materials were chopped and either left untreated or a) with dried sugar cane molasses at 5 % of forage DM added, b) inoculated with a mixture of *Lactobacillus plantarum* and *Streptococcus faecium* (1174 Pioneer ® at $3x10^5$ CFU/g DM), c) prepared with a combination of the inoculant treatment plus the dried sugar cane molasses, all treatments being packed by hand in 19-liter plastic containers. According to the authors, all unwilted silages went through a less than satisfactory fermentation, whilst the application of molasses and inoculant to wilted bermudagrass had an additive effect and produced stable silages having the lowest pH, lowest concentration of ammonia, and greatest lactic acid concentration and *in vitro* organic matter digestibility. Hence, according to the Cooperative Extension Service from the University of Florida adding a bacterial inoculant and molasses to wilted bermudagrass is more beneficial than adding just molasses or inoculant alone (Staples 1995).

Rhodesgrass (*Chloris gayana*) is a stoloniferous creeping or occasionally tufted perennial that thrives under a wide range of tropical and subtropical temperatures (Mannetje and Jones 1992). Ridla and Ushida (1998) used a first growth of rhodesgrass harvested at the heading stage (21.8 % DM, 5% WSC and 66.4 % NDF in DM) ensiled in 2-liter vinyl bottle silos. An inoculant with *Lactobacillus casei* was added at 10^5 CFU/ g fresh sample either alone or combined with increasing levels of cellulases (A - *Acremonium cellulolyticus* and/or M - *Trichoderma viride*). The combined treatment of inoculant plus enzymes showed lower pH values and higher lactic acid contents with increasing amount of cellulase addition. All combined treatments reduced NDF, ADF and *in vitro* DM digestibility of silages compared with the untreated silage, probably meaning that enzymes hydrolyzed especially the more digestible components of plant cell wall. The combinations inoculant plus cellulase A were the most effective. A parallel test with fermentation temperatures suggested that samples incubated at 40℃ resulted in better silages than those at 20 or 30º C. It is also concluded that the absence of effect in the inoculant treatment was due to the low WSC available in rhodesgrass. These same treatments were also applied to italian ryegrass harvested at the heading stage (21.7% DM, 7.2% WSC and 59.2% NDF in DM) and the results on NDF and ADF disappearances of the inoculant and enzyme mixtures as compared to those with rhodesgrass suggest that the cell wall components in rhodesgrass silages were more resistant to degradation by the cellulases (Ridla and Ushida 1999 b). In general , within the various treatments regarding fermentation products and chemical composition, ryegrass produced better silages than rhodesgrass (Ridla and Ushida 1999 a).

Weeping lovegrass (*Eragrostis curvula*) is a densely tufted perennial, stems slender to robust, 30-120 cm high, drought-resistant (Bogdan 1977). A six weeks growth of this forage (37.8 % DM, < 2 % WSC, 79.2 % NDF) was ensiled unwilted, but treated with an inoculant/enzyme mixture (Sill-All® with *L. plantarum*, *S. faecium* and *Pediococcus acidilactici* at 10^6 CFU/ g fresh material) resulting in a silage with lower pH, ammonia-N, butyric and acetic acid content and a higher lactic acid content compared to the control silage (Meeske 1998).

3. Feed ingredients and by-products as additives

The incorporation of easily fermentable feed ingredients such as sugar or molasses to low DM sugar-limited tropical forages is a way to improve silage fermentation. Feed-grade products such as grains in general and processed by-products such as corn or sorghum meal, rice bran, cassava meal , citrus pulp, etc. can also be used as additives partly to provide fermentable substrate but also to direct the course of fermentation by absorbing excessive moisture. To optimize their effectiveness by avoiding effluent losses they have to be used in relatively high rates (aiming a DM content > 25 % of the mixture) and adequately mixed with the chopped forage, which demands extra labour and/or appropriate equipment. This type of additive may be of seasonal and local supply and cost effectiveness should also consider the improvement achieved in nutritive value.

Molasses

Cane molasses (75 % DM) has been widely used added up to 10 % w/w to provide fast fermentable carbohydrate for the ensilage of tropical herbages. Due to its viscosity it is difficult to apply and should be diluted preferably with a reduced volume of warm water to minimize seepage losses. When applied to tropical grasses molasses should be used in relatively high concentrations (4 to 5%) and with crops of very low DM content, a considerable proportion of the additive may be lost in the effluent during the first days of ensilage (Henderson, 1993).

However, according to Woolford (1984) the provision of extraneous sugar alone is not sufficient to permit the lactic acid bacteria to compete with other components of the silage microflora and thus ensure preservation. So, under high moisture conditions molasses can also induce a clostridial spoilage especially with forages contaminated with soil.

Sugarcane molasses added at the rate of 3 % (w/w, fresh basis) to Napier grass (12.9 % DM, 6.6% WSC) produced silages of reasonably good fermentation quality , reducing , however, the nutrient recovery from the silo, as compared to formic acid treated silage (Boin 1975) . The same molasses dosis also resulted in increased *in vitro* DM digestibility coefficients of Napier grass ensiled at 51, 96 and 121 days of vegetative growth (Silveira *et al.* 1973).

Dwarf elephant grass (cv.Mott) cut at 72 days regrowth (14.4 % DM, 7.1% WSC) with a high buffering capacity was treated with 4 % molasses and ensiled in 4 kg polythene bags with the resulting silage having lower pH and ammonia-N than the control silage (Tosi *et al.* 1995).

Four levels (0, 4, 8, and 12%) of dried molasses (97 % DM) were applied to chopped bermudagrass (32.4 % DM, 70.2 % NDF) pre-treated with 1174 Pioneer ® silage inoculant (1.7 l/t of forage) and packed in 19-liter plastic containers. The increasing molasses levels lowered pH, ADF, and NDF percentages and increased *in vitro* DM digestibilities in bermudagrass silages (Nayigihugu *et al.*, 1995).

Guinea grass with 4 weeks (18.6 % DM) and 8 weeks (26.5 % DM) of growth was ensiled untreated or with 4 % molasses in 400 g laboratory silos. The pH varied from 4.4 to 5.4 and from 4.0 to 4.7 and ammonia-N ranged from 23.5 to 35.3 and from 15 to 39, respectively, for untreated and molasses treated silages (Esperance *et al.* 1985).

Tjandraatmadja *et al.* (1994) tested the effects of 4% and 8% molasses added at the ensilage of *Panicum maximum* cv.Hamil, pangola grass *(Digitaria decumbens)* and setaria *(Setaria sphacelata* cv. Kazungula) harvested at 4, 8 and 12 weeks of growth. The results from a laboratory trial with 500 g-vacuum sealed silo bags kept in a dark, temperature controlled room led to the conclusion that 4 % (w/w) molasses should be sufficient to achieve effective preservation. Pangola grass which had a highly significant different chemical composition prior to ensiling , with lower NDF and lignin content presented a dominant homo-fermentative lactic acid bacteria population in silage which was fairly well preserved even without molasses.

Starch sources

It is controversial to what extent starch is an available substrate for lactic acid bacteria (Woolford, 1984) . Jones (1988) recovered 100 and 90 % of starch from barley and oats, respectively, added at the ensilage of ryegrass, attributing an improved fermentation to the substrate available from 3 – 4 % of soluble carbohydrates or from fractions such as ß-glucan contained in the cereals and not to a hydrolysis of starch.

The effects of adding molasses (5 % w/w) or ground maize (5% and 10 % w/w) to star grass (*Cynodon nlemfluensis*) mixed or not with four levels (0, 15, 30, 45 % w/w) of legume (*Desmodium uncinatum*) were studied in a laboratory trial by Sibanda *et al.* (1997). In general, both additives improved fermentation up to the level of 30 % of legume inclusion, however, molasses addition resulted in lower levels of volatile N and higher lactic acid content compared to the control and both ground maize treatments .

A first growth of Napier grass was hand-harvested under rainy conditions (8.6 % DM, 67.6 % NDF), chopped to 3 cm, treated with 4 % molasses and/or 15 % defatted rice bran (2.0 % crude fat) on the fresh grass basis and ensiled in plastic bags. DM contents of silages were 13.4 %, 20.1 % and 22.5 % and spoilage losses were 5,6%, 0.3 % and 3.0 % for treatments with molasses, rice bran and their mixture, respectively. Treatment with plain rice bran had the highest content of acetic (6.7 % of DM) and propionic (1.4 %of DM) acids and ammonia-N but the lowest content of lactic acid. The authors (Yokota *et al.* 1998) concluded that the combination molasses/rice bran can improve the fermentation quality and enhance the utilization of the silage by goats, more than each additive as a single treatment.

Cassava (*Manihot esculenta*) tuber meal (72.1 % WSC) and coconut (*Cocos nucifera*) oil meal (17.6 % WSC) were both added (5 % wet basis) to Guinea – A (*Panicum maximum*) with 17.7 % DM and 6.3 % WSC and to NB-21 (*Pennisetum purpureum* x *Pennisetum americanum*) with 16.3 % DM and 9.9 % WSC forages, chopped (1.5 cm) and ensiled in 2 kg laboratory silos. Both additives improved fermentation as compared to untreated silages of both forages, with greater effects in silages with cassava tuber meal (Panditharatne *et al.* 1986).

Elephant grass was harvested at 75 days growth (19.4 % DM, 72 % NDF) and ensiled in 300 kg asbestos/cement containers either unwilted or wilted (29.6 % DM) both materials with or without 8 % ground sorghum grain (w/w). Wilting was achieved by exposing crushed forage stems three hours in windrow after harvesting with a mower/conditioner (New Holland) . Sorghum addition to both wilted and unwilted silage increased DM contents, reduced ethanol and acetic acid contents and increased intake of digestible energy as measured in sheep (Alberto *et al.* 1993).

Silages of elephant grass cv. Guaçu were obtained adding 0, 8, 16 and 24 % (w/w) either of ground ear corn with husks, wheat bran or “sacharin” (urea treated sugar cane, with 12.6 % crude protein, 17.5 % crude fibre in DM) to unwilted forage (12.40 % DM, 10.4 % WSC) harvested with a precision chopper (3 mm chopp lenght) and packed into 200 l plastic containers with a layer of ground hay at the bottom to absorb effluent (Andrade and

Lavezzo 1998a). Ground ear corn was more effective to increase DM content and to restrict lactic acid production while reducing ammonia-N which reached 31.3 % and 36.2% for “sacharin” and wheat bran treatments, respectively (Andrade and Lavezzo 1998b).

The fermentation pattern of wilted elephant grass cv. Taiwan-A146 silage (8 hour wilting, 26.6 % DM, 6.74 % WSC) did not differ from silages made of unwilted grass (23.5 % DM, 7.2% WSC) prepared with a cassava starch by-product added at 2, 4, 8 or 12 % (w/w). According to the authors (Ferrari Jr. *et al.* 1999) the relatively low lactic acid levels demonstrate that the substrate was not available to lactic acid bacteria.

Citrus pulp

Fresh citrus peels have been added at the ensilage of Napier grass with levels up to 50% improving fermentation quality as measured by low pH values and low butyric acid content and adequate lactic acid production (Faria *et al.*1972). Citrus peels may contain 50 % WSC in DM but the low DM content (14 – 21%) and intensive initial fermentation lead to high seepage losses causing a serious pollution problem (Ashbell 1992).

Dried citrus pulp added at the ensilage to low DM forages may increase its weight by 145 % by absorbing excessive moisture thus preserving nutrients which otherwise would be lost by effluent and uncontrolled fermentation (Vilela, 1998). The DM, WSC and fermentation acids content of elephant grass silage was increased whilst pH was reduced with the use 0, 5, 10, 15, and 20% of dried citrus pulp (Faria *et al.* 1972). Levels up to 30% of dried ground citrus pulp were added to a 75 days regrowth of elephant grass resulting in silages with a corresponding linear increase of DM content (y= 0.49x + 24.0), a pH in a range from 3.49 to 3.68 and a linear decrease of ammonia-N (Evangelista *et al.* 1996).

4. Formic acid and/or formaldehyde treatments

Commercial formic acid (85%) has been extensively used for the ensilage of unwilted temperate grasses but is gradually being substituted by biological additives, certainly because it is unsafe in handling and application and corrosive to equipment. Information about the use of such additives on tropical forages is limited to research data and no literature was found reporting farm-scale adoption.

Earlier studies by Boin (1975) with the production of young, high-protein, low WSC and DM elephant grass have shown that a 0.8 % rate of formic acid is needed for a reasonably good silage fermentation , while Vilela (1984) found no effectiveness based on silage composition when applying formic acid at various rates to unwilted or wilted elephant grass. On the other hand 0.5% formic acid treated elephant grass had not only an improved fermentation but also higher intake and digestibility as compared to the untreated control (Silveira *et al.* 1980).

King grass (*Pennisetum purpureum* x *Pennisetum typhoides*) silage treated with formic acid (3.5 l/t) showed better fermentation quality than benzoic acid treated and untreated silages (Ojeda and Cáceres 1984). In a review by Ojeda (1993) on the use of mineral or organic acids as well as of antimicrobials it is concluded that for the ensilage of tropical forages kind of additive and aplication rate need to be determined specifically according to the type of forage.

Formalin (35-40% formaldehyde solution) has also been used as a silage preservative, especially aiming at reduced protein degradation in the silo and thus increasing undegradable protein in the rumen of silage-fed animals. Formaldehyde restricts considerably fermentation of silage; 0.8% formalin (w/w fresh basis) almost sterilizes the ensiled mass of elephant grass and reduces digestibility of silage (Boin 1975). A dosis of 0.5% formalin (w/w) applied to a mixture of elephant grass with cassava tops (20.3% DM, 8.5 % WSC) reduced ammonia-N and increased precipitable protein in silage, however without suppressing a clostridial fermentation (Zanotelli and Mühlbach 198). Studies with a 70% formalin plus 26% formic acid plus 4% water mixture applied 0.2 % (w/w) to elephant grass (13% DM) aiming at a rate of 4 g formaldehyde/100 g crude protein in forage resulted in poor fermentation quality and impairment of nutritive value of silages produced (Lavezzo 1993). Accurate formaldehyde rates necessary to improve fermentation in the silo as well as to obtain a protein protection effect in the rumen are difficult to achieve especially under farm-scale conditions (Mühlbach and Kaufmann 1979).

5. Other additives

Salt – The addition of 1% sodium chloride to a mixture of wilted elephant grass and cassava tops (28% DM, 9.5% WSC) was not effective to improve fermentation of silage as compared to the unwilted control (Zanotelli and Mühlbach 1989).

NPN additives – Such additives as particularly urea when added to high dry matter, low buffering forages (maize or sorghum grain) increase crude protein content and are claimed to improve aerobic stability of silage at feedout. In a review by Lavezzo (1993) on the use of urea as a silage additive for elephant grass it was concluded that with low DM forage and in the absence of additives rich in WSC such type of product should not be recommended when aiming an improvement of fermentation. Generally, pH value, ammonia-N and acetic and butyric acid contents are increased. Singh *et al.* (1996) registered the highest pH values and ammonia-N levels associated to higher anaerobic proteolytic bacterial populations in *Sorghum bicolor* silages (34 % DM) made with 0.5 % urea. Other NPN sources as ammonium sulfate and biuret, either alone or associated with urea, calcium carbonate or starch sources have also been tested on their effects on silage fermentation, digestibility and intake. The results as rewieved by Vilela (1984) do not favour their use as silage additives either. According to Bolsen (1999), NPN always acts as a buffer during fermentation, requiring extra lactic acid to be produced to lower the pH enough for preservation, thus increasing DM loss.

Poultry litter – This waste product cannot be considered as a typical ensilage additive but has been mixed with easily fermentable forages as a way to increase crude protein content and to eliminate potential pathogens in litter through fermentation (Al-Rokayan *et al.* 1998; Rasool *et al.* 1998; Fontenot and Jurubescu 1980). It can also be used to increase DM content of the ensilage of elephant grass (Lavezzo 1993). It may present high protein together with a high ash content, which increases buffering capacity and may negatively affect fermentation. Almeida *et al.* (1986) ensiled elephant grass (20.3 % DM, 7.9 % WSC) together with 15 % sugarcane and 5 % broiler litter producing a silage of good fermentation quality; however the mixture with solely 10% litter produced silages with very high butyric acid content (2.36% of DM) and ammonia-N.

6. Conclusions and recommendations

Biological additives– when applied to higher quality tropical forages more suitable to ensilage, such as forage sorghum, fermentation is improved and in silo losses are reduced , however, silages are more liable to aerobic deterioration demanding a good feed-out management particularly with large silos.

With good quality (early growth stage) tropical pasture forages, which lends itself to fast wilting, both treatments wilting and biological additive (inoculant alone or in combination with an effectively proven enzyme mixture) can be recommended. Products so far tested, particularly with the ensilage of the thick-stemmed *Pennisetum* species, do not show consistent positive results regarding fermentation characteristics of silages. More field-scale research is needed to test additive effect on nutrient recovery with silage stored in small well-sealed plastic silos as might be realisable with smallholders. Biological additives are generally available as powders or granules which need to be applied mixed with water to allow a proper mixing with the forage. Sprinkling homogeneously with a watering can could be an alternative under smallholder conditions to spraying with a metered liquid sprayer.

High quality feeds and by-products – are so far the best option as additives for the hard-to-ensile forages such as the thick-stemmed *Pennisetum* and *Panicum* species. They may be relatively expensive, but cost-effectiveness should always consider the improvement in nutritive value of the ensiled forage. Molasses would be more adequate for wilted or higher DM (>25%) materials, while starch sources could be used alone but also combined with molasses for the ensilage of low DM, unwilted forages. Locally available and cost-effective absorbents such as dried citrus pulp can also be a good alternative.

Additives with restricted use - Formic acid can improve fermentation but most probably will not be cost-effective and realisable under smallholder conditions. More tests would be needed with other acids to determine dosage according to the type of forage. Formalin could be cheaper but results with the ensilage of tropical forages are inconsistent. NPN products are not the choice additives for low DM, low WSC forages; they could be used with wilted forage, preferably in combination with a readily fermentable substrate such as molasses.

7. References

Alberto, G. ; Portela, J.S. ; De Oliveira, O. L. P. (1993). Efeito da adição de grão de sorgo moído e do murchamento sobre a qualidade da silagem de capim-elefante (Pennisetum purpureum Schum.). Revista da Sociedade Brasileira de Zootecnia 22 (01), 01-11.

Almeida, E. X. de; Pinto, J.C.; Pérez, J.R.O.; Rocha, G.P. (1986). Cama de frango e cana-de-açúcar na qualidade da silagem de Pennisetum purpureum Schum. cv. Cameroon. Rev. Soc. Bras. de Zootecnia, 15 (3) 193-199.

Al-Rokayan, S.A.; Naseer, Z.; Chaudry, S.M. (1998). Nutritional quality and digestibility of sorghum-broiler litter silages . Animal Feed Science and Technology 75, 65-73.

Andrade, J. B.de and Lavezzo, W. (1998a). Aditivos na ensilagem do capim-elefante. I. Composição bromatológica das forragens e das respectivas silagens. Pesq. Agropec. Brasil. 33(11) 1859-72.

Andrade, J.B. de and Lavezzo, W. (1998b). Aditivos na ensilagem do capim-elefante.II. Qualidade das silagens amostradas por dois métodos. Pesq. Agropec. Brasil. 33(11) 1873-82.

Ashbell, G. (1992). Conservation of citrus peels by ensiling for ruminant feed. In: Anais do Simpósio Utilização de Sub-produtos Agroindustriais e Resíduos de Colheita na Alimentação de Ruminantes (A. G. da Silva, et al. eds.) São Carlos, SP. p. 189-190.

Bates, D.B.; Kunkle, W.E.; Dawson, T.E. et al. (1989) Round bale silage- a forage harvesting alternative. In: 38th Annual Florida Beef Cattle Short Course Proceedings, May 3-5; Gainesville, Fl., Univ. of Florida, 65p.

Bayer, W. and Waters-Bayer, A. (1998). Forage Husbandry MacMillan Education Ltd. 198 p.

Berto, J.L. and Mühlbach, P.R.F. (1997). Silagem de aveia preta no estádio vegetativo, submetida à ação de inoculantes e ao efeito do emurchecimento. Rev. Bras. Zootec.26 (4), 651-58.

Boin, C. (1975). Elephant (Napier) grass silage production effect of additives on chemical composition, nutritive value and animal performance. Ph. D. Thesis, Cornell University, 215p.

Bolsen, K.K. (1999). Silage management in North America in the 1990s. In: Biotechnology in the Feed Industry, Proc. of the 15th. Annual Symposium (T.P. Lyons and K.A. Jacques, eds.), Nottingham Univ. Press, p.233-244.

Cai, Y.; Benno, Y.; Ogawa, M.; Kumai, S. (1999). Effect of applying lactic acid bacteria isolated from forage crops on fermentation characteristics and aerobic deterioration of silage. Journal of Dairy Science 82, 520-26.

Catchpoole, V.R. and Henzell, E.F. (1971). Silage and silage-making from tropical herbage species. Herbage Abstracts 41 (3) 213-21.

De Figueiredo, M. and Marais, J. P. (1994). The effect of bacterial inoculants on kikuyu silage quality. Journal of Agricultural Science, Cambridge 122, 53-60.

Esperance, M.; Ojeda, F.; Cáceres, O. (1985). Estudio sobre la conservacion de la guinea likoni (Panicum maximum Jacq.) como ensilaje. Pastos y Forrajes 8, 127-41.

Evangelista, A. R.; Silva, L.V.; Correia. L.F.A. et al. (1996). Efeito de diferentes níveis de polpa cítrica, como aditivo seco, na ensilagem de capim Napier (Pennisetum purpureum Schum.). Anais da 33ª Reunião Anual da Soc. Bras. de Zootecnia, Fortaleza,21-26 de julho,p.354-355.

Faria, V.P. de; Tosi, H.; Godoy, C.R.M. (1972). Polpa de laranja fresca e seca como aditivo para ensilagem do capim elefante Napier. O Solo , 64(1) 41-47.

Ferrari Jr. E.; Lavezzo, W.; Vieira, M. P.; Lenut, A.L. (1999). Silagem de capim –elefante (Pennisetum purpureum, Schum.) emurchecido ou acrescido de farelo de mandioca. I. Qualidade. Anais da 36ª Reunião Anual da Soc. Bras. de Zootecnia, Porto Alegre, 26-30 de julho, CD-Rom 4p.

Figueiredo, L.A. and Mühlbach. P.R.F. (1984). Efeito do emurchecimento na composição dos produtos da fermentação de silagens de milheto e de milheto consorciado com feijão miúdo. Anais da 21ª Reunião Anual da Soc. Bras. de Zootecnia, Belo Horizonte, 16-20 de julho, p.383.

Fontenot, J.P. and Jurubescu, V. (1980). Processing of animal waste by feeding to ruminants. In: Digestive Physiology and Metabolism in Ruminants.(Ruckebush, Y. and Thivend, P. eds.) AVI Publ. Co. Inc. p.641-662.

Froetschel, M. A.; Nichols, S.W.; Ely, L.O.; Amos, H.E. (1995). Effect of silage inoculant on the fermentation and digestibility of tropical corn and sorghum silages. 1995 Annual Report / Inoculants for Warm-season Silages. Animal and Dairy Science Department, CAES, UGA, pp.203-211.

Henderson, N. (1993). Silage additives. Animal Feed Science and Technology 45, 35-56.

Henrique, W. and Bose, M.L.V. (1992). Efeito de aditivos enzimo-bacterianos sobre a qualidade da silagem de capim-elefante (Pennisetum purpureum. Schum.) Rev.Soc. Bras. Zoot. 21(03) 429-438.

Jaster, E.D. (1994). Complex interactions from inoculants, enzymes explored. Feedstuffs, Dec. 19, 1994.

Jones, D.J.H. (1988) The effect of cereal incorporation on the fermentation of spring- and autumn-cut silages in laboratory silos. Grass and Forage Science 43, 167-72.

Jones, R. (1995). Role of biological additives in crop conservation. In: Biotechnology in the Feed Industry, Proc. of the 11th Annual Symposium (T.P. Lyons and K.A. Jacques, eds.), Nottingham Univ. Press, 627 p.

Lavezzo, W. (1993). Ensilagem do capim elefante. In: Anais do 10º Simpósio sobre Manejo da Pastagem (A.M Peixoto, et al. eds.) , FEALQ, Piracicaba, Brasil, 329 p.

Lavezzo, W.; Lavezzo, O.E.N.M.; Silveira, A.C. (1984). Efeitos do emurchecimento, formol e ácido fórmico sobre o consumo e digestibilidade de silagens de capim-elefante (Pennisetum purpureum, Schum.) Rev. Soc. Bras. Zoot. 13(4) 501-08.

Mannetje, L.'t and Jones, R.M. (1992) (Eds). Plant resources of South East Asia. 4. Forages. PUDOC, Wageningen, The Netherlands, 300 pp.

Meeske, R. (1998). The effect of an inoculant on the preservation of a tropical grass (Eragrostis curvula) and lucerne (Medicago sativa) in South Africa. In: Biotechnology in the Feed Industry, Proc. of the 14th Annual Symposium (T.P. Lyons, and K.A. Jacques, eds.), Nottingham Univ. Press, p.145-155.

Muck, R.E. (1993). The role of silage additives in making high quality silage. In:Silage production from seed to animal. Proceedings ofthe National Silage Production Conference, Syracuse, New York, Febr. 23-25 1993,NRAES, Ithaka, p. 106-116.

Mühlbach, P.R.F. and Kaufmann, W. (1979). Eiweiss-Verfuegbarkeit von Formaldehyd-behandelter Grassilage beim Wiederkaeuer. Das wirtschaftseigene Futter 25(2/3) 115-132.

Nayigihugu, V.; Kellogg, D.W.; Johnson, Z.B.; Scott, M.; Anschutz, K.S. (1995). Effects of adding levels of molasses on composition of bermudagrass (Cynodon dactylon) silage. Journal of Animal Science 73, Suppl.1, p.200

Nadeau, E.M.G.; Buxton, D.R.; Lindgren, E.; Lingvall, P. (1996). Kinetics of cell-wall digestion of orchardgrass and alfalfa silages treated with cellulase and formic acid. Journal of Dairy Science 79, 2207-16.

Ojeda, F. and Cáceres, O. (1984). Efecto de los aditivos quimicos sobre el consumo y la digestibilidade de los ensilajes de king grass. Pastos y Forrajes, 7, 409-419.

Ojeda, F. (1993). Conservantes quimicos en la preservacion de ensilajes tropicales.Pastos y Forrajes, 16, 193-200.

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

Pinheiro Machado Fº, L.C. and Mühlbach, P.R.F. (1986). Efeito do emurchecimento na qualidade das silagens de capim elefante cv. Cameron (Pennisetum purpureum Schumach.) e de milheto (Pennisetum americanum (L.) Leeke), avaliadas quimicamente. Rev.Soc. Bras. Zoot. 15(3) 224-33.

Phuntsok, T.; Froetschel, M.A.; Amos, H.E.; Zheng, M.; Huang, Y.W. (1998). Biogenic amines in silage, apparent postruminal passage, and the relationship between biogenic amines and digestive function and intake by steers. Journal of Dairy Science, 81, 2193-203.

Rangrab, L.H.; Berto, J.L.; Mühlbach, P.R.F; Silva, A.L.B.da ; Lima, V.S. de. (1996). Silagem de alfafa (Medicago sativa) no estádio de início de florescimento submetida a ação de aditivos biológicos e ao efeito de emurchecimento. Anais da 33ª Reunião Anual da Soc. Bras. de Zoot., Fortaleza, 21-26 Julho, Vol.2. p. 365-67.

Rasool, S.; Sial, M.A.; ul-Haq, A.; Jamil, A. Chemical changes during ensiling of sudax fodder with broiler litter. Animal Feed Science and Technology 72, 347-354.

Ridla, U. and Ushida, S. (1998). Effects of combined treatment of lactic acid bacteria and cell wall degrading enzymes on fermentation and composition of Rhodesgrass (Chloris gayana Kunth.) silage. Asian-Australasian Journal of Animal Sciences 11(5) 522-29.

Ridla, U. and Ushida, S. (1999 a). Comparative study on the effects of combined treatments of lactic acid bacteria and cellulases on the fermentation characteristic and chemical composition of Rhodesgrass (Chloris gayana Kunth.) and italian ryegrass (Lolium multiflorum Lam.) silages. Asian-Australasian Journal of Animal Sciences 12 (4) 525-30.

Ridla, U. and Ushida, S. (1999 b). Comparative study on the effects of combined treatments of lactic acid bacteria and cellulases on the cell wall compositions and the digestibility of Rhodesgrass (Chloris gayana Kunth.) and italian ryegrass (Lolium multiflorum Lam.) silages. Asian-Australasian Journal of Animal Sciences 12 (4) 531-536.

Rodriguez, A.A.; Rust, S.R.; Yokoyama, M.T.; Riquelme, E.O. (1994 a) Microbial inoculant and enzymes in forage sorghum ensiled under temperate and tropical environments. I. Microbial sucession. Journal of Animal Science 72, Suppl. 1 / Journal of Dairy Science 77, Suppl. 1, p. 301

Rodriguez, A.A.; Rust, S.R.; Yokoyama, M.T.; Riquelme, E.O. (1994 b) Microbial inoculant and enzymes in forage sorghum ensiled under temperate and tropical environments. II. Aerobic stability. Journal of Animal Science 72, Suppl. 1 / Journal of Dairy Science 77, Suppl. 1, p. 301

Rodriguez, A.A.; Rust, S.R.; Yokoyama, M.T. (1998). Fermentation characteristics of Johnson grass ensiled at two regrowth periods with silage additives. Trop. Agric. (Trinidad) 75(4) 457-61.

Sanderson, M.A. (1993). Aerobic stability and in vitro fiber digestibility of microbially inoculated corn and sorghum silages. Journal of Animal Science 71, 505-14.

Sheperd, A. C. and Kung, L.(1996). Effects of an enzyme additive on composition of corn silage ensiled at various stages of maturity.Journal of Dairy Science, 79, 1767-73.

Schingoethe, D.J.; Stegeman, G.A.; Treacher, R.J. (1999). Response of lactating dairy cows to a cellulase and xylanase enzyme mixture applied to forages at the time feeding. Journal of Dairy Science, 82, 996-1003.

Sibanda, S.; Jingura, J.M.; 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 and Technology, 68, 295-305.

Silveira, A. C.; Tosi, H.; de Faria, V.P.; Spers, A. (1973). Efeito de diferentes tratamentos na digestibilidade in vitro de silagens de capim Napier. Rev. Soc. Bras. Zoot. 2 (2) 217-26.

Silveira, A. C.; Lavezzo, W.; Silveira Fº.,S. et al. (1980). Consumo de silagens de capim-elefante (Pennisetum purpureum, Schum.) submetida a diferentes tratamentos. Rev. Soc. Bras.Zoot., 9 (2) 306-320

Singh, A. ; Edward, J.C.; Mor, S.; Singh, K. (1996). Effect of inoculation of lactic acid and additives on ensiling M.P. chari (Sorghum bicolor). Indian Journal of Animal Sciences 66 (11) 1159-1165.

Spitaleri, R.F.; Sollenberger, L.E.; Staples, C.R.; Schank, S.C. (1995). Harvest management effects on ensiling characteristics and silage nutritive value of seeded Pennisetum hexaploid hybrids.Postharvest Biology and Technology 5,353-62.

Staples, C.R. (1995). Bermudagrass: growing, storing, and feeding for dairy animals. Circular 1140, Florida Coop. Extension Service, Inst. of Food and Agricultural Sci., Univ. of Florida.

Tamada, J.; Yokota, H.; Ohshima, M.; Tamaki, M. (1999). Effect of additives, storage temperature and regional difference of ensiling on the fermentation quality of Napier grass (Pennisetum purpureum Schum.) silage. Asian-Australasian Journal of Animal Sciences 12 (1) 28-35.

Tosi, H.; Rodrigues, L.R.de A.; Jobim, C.C. et al. (1995). Ensilagem do capim-elefante cv. Mott sob diferentes tratamentos . Rev. Soc. Bras. Zoot. 24 (5) 909-16.

Tjandraatmadja, M.; Norton, B.W.; Mac Rae, I.C. (1991). Fermentation patterns of forage sorghum ensiled under different environmental conditions. World Journal of Microbiology & Biotechnology 7, 206-18.

Tjandraatmadja, M.; Norton, B.W.; Mac Rae, I.C. (1994). Ensilage characteristics of three tropical grasses as influenced by stage of growth and addition of molasses. World Journal of Microbiology & Biotechnology 10, 74-81.

Umaña, R.; Staples, C.R.; Bates, D.B.; Wilcox, C.J.; Mahanna, W.C. (1991) Effects of amicrobial inoculant and (or) sugarcane molasses on the fermentation, aerobic stability, and digestibility of bermudagrass ensiled at two moisture contents. Journal of Animal Science, 69, 4588-4601.

Utley, P.R.; Gates, R.N.; Hanna, W.W.; Johnson, J.C. (1995) "HGM-100" pearl millet silage for growing beef heifers.1995 Annual Report/ Pearl millet silage for beef heifers. Animal and Dairy Science Department. CAES,UGA, pp.115-120.

Van Onselen, V.J. and López, J. (1988) Efeito da adição de fontes de carboidratos e de um produto enzimático comercial na composição quiímico-bromatológica da silagem de capim-elefante (Pennisetum purpureum Schum.). Rev. Soc. Bras. Zoot.17 (5) 421-27.

Vilela, D. (1984). Aditivos na ensilagem. Coronel Pacheco, MG: EMBRAPA-CNPGL, Circular Técnica 21, 32p.

Vilela, D. (1998). Aditivos para silagem de plantas de clima tropical. In: Simpósio sobre aditivos na produção de ruminantes e não-ruminantes. Anais dos Simpósios, XXXV Reunião da SBZ, (Wechsler, F.S., ed.), p. 73-108.

Wilkinson, J.M. (1998) Aditives for ensiled temperate forage crops. In: Simpósio sobre aditivos na produção de ruminantes e não-ruminantes. Anais dos Simpósios, XXXV Reunião da SBZ, (Wechsler, F.S., ed.), p.53-72.

Wilson, J.R. (1994). Cell wall characteristics in relation to forage digestion by ruminants. Journal of Agricultural Science, Cambridge 122: 173-182.

Wilson, J.R. (1997). Structural and anatomical traits of forages influencing their nutritive value for ruminants. In: International Symposium on Animal Production under Grazing. Viçosa, MG, Nov. 04-06 1997, p. 173-208.

Woodard, K.R.; Prine, G.M.; Bates, D.B. (1991). Silage characteristics of elephantgrass as affected by harvest frequency and genotype. Agronomy Journal 83, 547-51.

Woolford, M. (1984). The Silage Fermentation . Marcel Dekker, Inc. , 350 p.

Yang, W.Z.; Beauchemin, K.A.; Rode, L.M. (1999). Effects of an enzyme feed additive on extent of digestion and milk production of lactating dairy cows. Journal of Dairy Science 82, 391-403.

Yokota, H.; Fujii, Y.; Ohshima, M. (1998). Nutritional quality of Napier grass (Pennisetum purpureum Schum.) silage supplemented with molasses and rice bran by goats. Asian-Australasian Journal of Animal Sciences, 11 (6) 697-701.

Zanotelli, F. O. and Mühlbach, P.R.F. (1989). Efeitos de diferentes tratamentos nas características fermentativas de silagens da mistura de capim-elefante e parte aérea da mandioca. Rev. Soc. Bras. Zoot. 18 (6) 491-99.

Harvesting and Ensiling Techniques

Dr. Félix Ojeda García

Estación Experimental de Pastos y Forrajes “Indio Hatuey”
Central España Republicana
Apartado Postal: 44280
Matanzas, Cuba.
E-mail: ihatuey@atenas.inf.cu

1. Introduction

The principal objective of forage conservation is to supply nourishment that guarantees the productive function of livestock during periods of scarcity.

Only a few studies have been made and even less published, illustrating how small farmers may produce good silage under tropical conditions with minimum resources. In this paper different options for the preparation of silage will be examined, based on its principles and differentiating the implicit characteristics of small and large farmers.

Many of the ideas and concepts presented are not only the fruit of research, they are a summary of years of experience in silage production on different scales.

Even though an effort has been made to cover a wide range of situations and to generalize, without going into detail, it is a fact that each region and farming system has its characteristics, and the aim of this paper is not to supply rigid recipes.

2. Production of silage

The production process of silage may be divided in four stages:

1. Forage harvesting
2. Transport to the silo
3. Compaction
4. Sealing (air-tightness).

The execution of these stages has a big impact on the success or failure of the fermentation and the quality of the silage.

The first management decision to take when planning to make silage is on the amount of silage required, which depends on the following factors:

- Number and type of livestock receiving silage.
- Length of the feeding period
- Percentage silage of the full ration
- Material resources available (equipment, labour, financial means, technical assistance, etc.).

This is illustrated by the following example:

An adult bovine, consuming 50% of the ration in the form of silage would receive 5 kg of (DM) per day. For a feeding period of 180 days, 900 kg of DM/animal would be required, that is, 3.6 t of fresh forage, containing 25% DM. Considering 15% silage loss 540 kg of fresh forage should be added, to arrive at a total of 4.14 t per head. This is equivalent to 2.3 m^3 of silo capacity per animal, assuming a density of 0.6 t/m^3.

Using the same assumptions for a goat, the requirement would be 108 kg of DM silage at a rate of 0.6 kg per day, an amount of 497 kg fresh forage per animal would need to be ensiled, equivalent to a volume of 0.83 m^3 of silo capacity per animal.

This calculation can also be carried out in reverse, taking into account the resources available on the farm and the foreseen area to be conserved.

Irrespective of the amount of silage to be made the following principles for good silage apply:

1. The material to be conserved must have a high nutritive value.
2. The forage must not be contaminated with soil.
3. The forage should be chopped into pieces no longer than 2 cm to facilitate good compaction and reduce air retention.
4. It is necessary to expel the maximum amount of air within the forage before closing the silo, to avoid its re-entry and prevent water penetration.
5. The accumulation of the forage and sealing should be done in the shortest possible time.
6. During the feeding of the silage, the area exposed to air should be as small as possible and the time between opening and finishing the silo as short as possible.

Although the total silo capacity on a farm depends on the number and type of animals and the period of silage feeding, it is recommended not to have all the silage required in only one silo, to keep losses at a minimum. The best system is to create silos that can be emptied over short periods, so the actual silo size depends on the amount of silage per animal and the number of animals to be fed. The best strategy is to make silage at different times of the year and to feed it after approximately 60 to 70 days of conservation. This way the silage would have optimum fermentation and least chance of aerobic deterioration. However, the time of silage making also depends on the growing conditions and the availability of forage to be ensiled.

2. Silo type

There are many different types of silo: permanent or temporary structures that may be vertical or horizontal. However, all kinds of receptacles can be used, such as barrels of steel or plastic, concrete water pipes of 2 m diameter and height, 2 mm thick plastic packing bags, such as those used for fertilisers.

On large farms, which are highly mechanised, silos with a capacity of 100 m^3 or more will normally be filled and emptied mechanically. This increases efficiency and reduces labour cost. However, on small farms with only a few animals receptacles with a capacity of up to 200 l that are filled manually make very effective silos. In all cases the material must be packed tightly and kept under anaerobic conditions. Bags must be tied at the top. These should then be piled under a cover, forming a pyramid.

For permanent silo sites it is recommended that they have hard, impenetrable floors.

2.1 Vertical silos

The vertical silos may be made of wood, concrete, zinc, steel or plastic and should be cylindrical to facilitate compaction. Vertical silos are ideal for conservation, because of the high pressure accumulating inside as the forage is being added. This prevents the silage to be exposed to air during the periods of conservation and of feeding. However, the forage to be ensiled this way should have at least 30% DM, in order to prevent the formation of effluents and, at the same time, take advantage of its maximum capacity.

2.2 Horizontal silos

Horizontal silos are the most commonly used and may be a trench or made on the surface. Surface silos can be with or without walls. They are popular because they are easily adapted to the specific conditions of a farm. However, with horizontal silos it is more difficult to ensure adequate air-tightness.

2.2.1 Trench silos

These silos are usually wedge-shaped excavations in the ground, to facilitate the entrance and exit of trailers during silage making and feeding. However, when their capacity is less than 2 m^3 they may be in the shape of a rectangular. The main disadvantage of trench silos is that the interior walls must be clad to avoid soil contamination and care must be taken to eliminate surface runoff from penetrating the silo.

2.2.2 Surface silos

2.2.2.1 Silos without walls.

Silos without walls are the simplest because they do not require permanent construction. However, they are the most subject to damage of the covering material, which interferes with the necessary anaerobic conditions.

In Cuba, large silos containing 500 t or more were developed, which were not covered with polyethylene sheets. Air-tightness was achieved only in the centre as the outside forage decomposed. This led to heavy losses of over 25%.

For larger farms there are so-called vacuum silos, which consist of two plastic sheets. The forage is deposited on a sheet put on the ground and covered by the other, to a height that will allow joining the borders of both sheets. The silo is sealed by a rubber tube system. Through a corner of the package vacuum is applied, which seals it once all the air has been extracted. This process is repeated on the third day after closing the silo, in order to extract the gasses formed during the initial fermentation, as well as a portion of the humidity produced by respiration and possible effluents.

Another variation of silos without walls is the so-called “sausage”. This consists of a polyethylene tube, closed on one end and fitted with a circular steel band at the other. A press is used to push the forage into the plastic tube, leaving a “sausage” of about 2 m in diameter and a length proportional to the volume of forage entered.

The same concept is used when high density round, cylindrical or rectangular bales are prepared by special machinery. These can be wrapped in polyethylene and placed one upon the other under a cover.

Polyethylene-wrapped silos have a common problem, thatthe wrapping may be destroyed by animals, allowing air to enter, which leads to spoilage of the silage. Forage to be wrapped should have a minimum of 25% DM to take full advantage of volume reduction and to prevent loss of nutritive value as well as to foster optimal fermentation.

2.2.2.2 Silos with walls

The most commonly used silos have 2, 3 or 4 walls. In the latter case one must be mobile. Ideally, they should be covered with polyethylene and placed under a roof. The cheapest method is to build two lateral walls at rectangles against an existing wall.

In general, walled silos are less critical on the forage's DM content, because drainage systems for effluent can be incorporated, including a slightly sloping floor

3. Forage collection

3.1 Type of forage

In the tropics, grasses have been, by tradition and for practical reasons, the main forage used for conservation. However, recently herbaceous and woody legumes have become an important part in livestock feeding. In spite of their importance, too few studies have been carried out to determine the best way to incorporate them into silages. Particularly in the case of woody protein banks there are problems with mechanised pruning. When preparing silage of grasses and legumes together, the mixing should be done before loading the silo. The optimum grass:legume mixture is about 70:30. The best way to obtain proper mixing of the two components is to simultaneously introduce them into the chopper. If the forage is to be wilted, it is recommended to first cut the grass and then the legume because the latter generally dries more rapidly.

3.2 Pre-treatment

The principal treatments after cutting prior to conservation of forages are, in order of importance: *chopping*, *wilting* and *conditioning*. Chopping is necessary to obtain good compaction to exclude air in order to promote a rapid initiation of the microbiological processes and to take optimum advantage of silo capacity. Chopping is done with specialised equipment. This may be a stationary chopper used when the forage is entered into the silo, or a pick-up trailer that chops the forage when it is collected in the field.

Chopping to between 2-4 cm lengths has the additional benefit of ease of ingestion, regurgitation and posterior rumination.

Wilting forage before ensiling has many advantages. When DM levels are between 30 and 35%, effluents will not be produced, the development of undesirable microorganisms will be reduced, better fermentation will be promoted and intake increased. Anti-nutritional metabolites (e.g. tannins and alkaloids) in certain forages (e.g. herbaceous and woody legumes and cassava leaves) will be eliminated or reduced. However, these species tend to loose their leaves during handling when dehydrated to over 40% DM. The field-drying time required to reach an optimum DM content depends on the species and on the weather conditions. The time may vary between 4 and 24 hours depending on the thickness of the stems.

Drying time can be reduced when a mower-conditioner is used, which crushes the stems. Crushing cuts the fibres and compresses the forage so that cellular juices will be extracted. Tedding the cut forage immediately after cutting and one more time afterwards will reduce drying time. The shorter the field drying time the lower will be the risk of rain damage.

3.3 Cutting systems for small farms

The simplest cutting system is to cut forage with machetes, scythes or similar equipment. Manual cutting has a low productivity. Erect forage can be cut at a rate varying between 0.5 to 0.8 t/person/hr. With prostrate species the rate of cutting is lower. It is not possible to give a general estimate of time required to prune shrubs and trees because it depends on the density of the edible material and the density of the plants. However, one could accept an estimate of 0.8 t/person/hour.

In addition to the time required to cut the material there is also the time needed to carry it to the silo and to chop it before entering it into the silo.

The importance of making estimates of man-hours required to cut, carry and chop a certain amount of forage is that it will determine the size of the silos and the number of people necessary to do the work in order to start and finish a silo within one day.

3.4 Cutting systems for large farms

Silage making on a large scale is a complex process. It requires the co-ordination to cut the largest possible volume of forage, in the least possible time.

Factors as: the power of the tractors, type of forage harvesters, quantity and capacity of trailers, condition of machinery, distance between forage area and silo, as well as, pre-treatments and the use of additives, are deciding factors in organising the production process.

3.4.1 Harvesting machines

Harvesting machines can be self-propelled or tractor-pulled. There are three types of cutting machines classified according to their cutting mechanism, i.e. by:

- *impact.* These tractor-drawn machines have a group of knives mounted on a rotor blade that cut the forage by impact and sends it to a chopper that cuts the material in lengths of 6 to 10 cm. The disadvantage of these machines is their low productivity, 8-10 t/hour. Additionally, soil is sucked in to the forage due to the circular movement of the rotor. They are not very effective for thick-stemmed species as the forage is cut at ground level, facilitating the attack of insects and fungi in the re-growth.
- *rotating knives.* These tractor-drawn machines have the advantage of being very productive and not to affect the re-growth, producing clean cuts without harming the stalks. The size of the pieces is also superior (2-4 cm). They are not suitable for uneven terrain because of a greater chance of breakages.
- *plate shears* are fitted in. the most modern self-propelled machines with a large cutting capacity (15-20 t/hour). The cutting system protects the re-growth. The machines are more efficient, because they can cut large areas in a short time. However, they require the land to be flat and free of obstacles. The chopping size can be adjusted to between 0,5 to 2 cm.

3.4.2 Pick-up trailers

Pick-up trailers must have a mechanism that can raise the forage off the ground, chop it and send it towards the collection bin with a capacity of 8 m^3 or more. The unloading mechanism can be lateral, at the back or with a moving floor. Trailers with a lateral unloading system are practical for silos that are more than 6 m wide because they allow for rapid unloading.

In the case of wilted silage it is important to have large trailers, since forage density decreases linearly with increasing DM content.

3.4.3 Methods of compaction

The method of compaction depends on the silo dimensions. In vertical silos of 2 t or less, compaction can be achieved by a person walking over the successive layers of forage.

In horizontal silos, less than 4 m wide, compaction may be done by animals or people walking over the material. Larger silos require wheel or caterpillar tractors. The minimum width for mechanical compaction is 4 m. The tractor wheels or caterpillar must always pass over the inner border of the trail left during the previous passage, in order to guarantee homogeneous compaction. Mud or water accumulation around the silos must be avoided to prevent contamination of the forage.

3.4.4 Equipment for distribution of additives

Different implements are used for the application of additives, depending on the type of additive and whether it is added during chopping or after the material has been deposited in the silo. With large amounts of silage, the best way to distribute the additives is directly at the forage elevation system associated with the pick-up trailer taking advantage of the turbulence it creates. This will guarantee an efficient homogenisation of the additive.

The simplest equipment for manual application of liquid additives in the silo consists of a container fitted with a small-diameter T-shaped pipe with holes or a bag if the additive is solid.

It is also possible to add additives during silo filling by using a pressurised sprayer or a small centrifugal fertiliser-spreader, if the silo has walls.

4. Organisation of the silage-making process

The golden rules that guarantee an efficient production process are:

1. The available silo capacity must be adequate for the amount of material to be ensiled.
2. The rate of silo filling should be in accordance with the compaction capacity.
3. The whole process should be completed in as short a time as possible, ideally in one day, maximum three days.
4. Absolute air-tightness must be obtained.

In order to understand the development of the silage production process and procedures to be employed, some typical examples are given below.

4.1 Small farms

The characteristic of small-scale silage production is that the only specialised machinery used is a stationary chopper. Manpower and animal force replace the machine-energy. To prepare 2 t of silage per day, two people, one animal traction cart and a stationary chopper powered by electricity or by a tractor, are required.

The routine work for silage production could be as follows:

Manual forage cutting:	3 hours
Loading the forage:	1 hour
Transporting the forage (2 km round trip):	1 hour
Forage chopping:	1 hour
Silage preparation:	3 hours
Air-tight closing:	1 hour
Total time required:	10 hours

If the forage is to be wilted, the cutting is done the previous day, preferably in the afternoon to guarantee the highest possible water-soluble carbohydrate content, or in the morning depending on the expected drying time required.

It is important to only cut as much forage that can be transported during a day's work in order to minimise the respiration loss and development of aerobic micro-organisms.

Polyethylene covering for air-tightness does not necessarily need to be in one piece, sheets form previous packaging may be used as long as there is sufficient overlap and so long as the entire silo is covered. Weights required to place on top of the polyethylene may be old tires filled with concrete, bags of sand or earth, etc. The use of grills constructed with steel or wooden bars covering the top of the silos, on which additional weights are placed, has also been effective.

4.1.1 Vertical silos and barrels (3 to 6 m ^{3})

Once the receptacle has been completely covered with polyethylene on the inside, it is filled with successive layers of forage, no thicker than 20cm, additives being added to each layer. It is not recommended to use forage with less than 25% DM. Compaction is achieved by a person walking in a circle, starting at the sides going towards the centre.

The silos should be filled until a small dome is formed on top, immediately followed by covering with polyethylene and weights being placed on top. Steel or plastic barrels should be placed up side down. The barrels may be placed together under a roof or covered with lose plates or polyethylene.

4.1.2 Horizontal silos

A small horizontal silo (2 m high, 1 m wide) is best made under a roof, compacted by a person or animal.

Ideally, there should be 4 walls in a rectangular shape. In silos with openings at both ends, loading should start from the centre of the silo, trying to gain height, avoiding unnecessary scatter of forage towards the ends, because even if covered with polyethylene, conservation will not take place in heights below 40 cm. If silos are in the open, care should be taken that rain or runoff water cannot penetrate the silo.

The main problem with small-scale silos is to know when adequate compaction has been obtained. In well-chopped forages, placed in shallow layers, adequate compaction is obtained when the loose green material under the person's foot or animal's hoof does not exceed 2 cm.

With wilted forages, adequate expelling of air can be expected only if the particles are less than 2 cm long, For longer pieces it is recommended to add a final layer (10-15 cm) of fresh green forage to weigh down the material before closing.

4.1.3 Plastic bags

Plastic bags are ideal for small farms. Loading and compaction are done by hand taking care not to damage the sides. If a perforation should occur, it may be sealed with an adhesive plastic tape

4.2 Large farms

It is essential to have the following equipment available:

- A forage-harvester (with a tractor if it is not self-propelled)
- A tractor for compaction (except for vertical silos)
- One tractor for each pick-up trailer (minimum two).

The quantity of forage, which can be deposited in a silo per day of work, will depend on the minimum compaction time required. In accordance with past experience these are: 15t for forage chopped longer than 6 cm, 10 t for wilted and 5 t forunwilted forage chopped to 2 cm or less. This means that during a 12 hr working day, an average of 48 t can be entered into a silo when the pieces are long, 72 t if wilted and 144 t if the forage is green.

Because of the natural fragility of polyethylene, covers may only be used once. However, in order to lower costs, traders usually accept the residues of each year to recycle the plastic and grant discounts on the newly purchased.

5. Conclusions

It is better to prepare a smaller amount of good silage than large volumes of low quality, which will have to be discarded as non-consumable or be of low nutritive value.

Unfortunately, the processes involved in silage making are as yet not completely understood. Among the most difficult issues still to be solved are:

- the incorporation of legumes in large-scale silages
- when it is most convenient to use additives with respect to pre-drying technology;
- to analyse energy balances, to make the most of the material and human resources involved in conservation.

Another limitation in the production of silage, is the lack of knowledge of silage-making principles by the people and specialists involved in livestock farming. Nowadays, in sustainable livestock production, which is less dependent on external inputs, silage production has an important role to play.

Literature consulted

Bosma, A.H. and ´t Hart, C. 1980. The physical properties of ensiled grass and maize. In: Forage Conservation in the 80´s (C. Thomas, Ed). Occasional Symposium No 11. British Grassland Society, Hurley, 1980.

Corrot, L. Delajoud, J, Morel D´ Arleux, F. and Tillie. M. 1989. Volume-Densité des Ensilages. I.T.E.B. INRA. France. P 150.

Demarquilly, C and Gouet, Ph 1988. Les methodes modernes d´ensilage. Biofutur. Juin 1988. pp 98-101.

Dulphy, J.P. 1980. The intake of conserved forage- In: Forage Conservation in the 80´s (C. Thomas, Ed). Occasional Symposium No 11 British Grassland Society, Hurley, 1980.

Esperance, M. 1986. Algunas características fermentativas y valor nutritivo de los ensilajes fabricado en la región occidental de Cuba. Pastos y Forrajes 9:3 p 271.

Esperance, M. and Ojeda, F:1997. Conservación de forrajes. Pastos y Forrajes 20.1 p 45.

Fischer, L.J. ; Robertson, J. A and Savoie, P 1985. Grass, legume and cereal silages for ruminants. Minister of Supply and Service Canada. Publication 1786/E pp. 25.

Galloy, A. and Gillet, 1981. La conservatión de fourrages en silo. Revue de l´Agriculture 34, 729.

Iglesias, J. M Pereira E. and Fernández E. 1991. Utilización de cultivos temporales conservados en forma de ensilaje en sistema de secado para la producción de leche. Pastos y Forrajers 14, 165.

Iglesias, J. M. Reyes, F, Ojeda, F, Delgado, R. and Rivero, L.1992. Valor nutritivo de un ensilaje de maiz y dolichos. Pastos y Forrajes 15, 71.

McDonald, P. 1981. The biochemistry of silage. Chichester. Ed. John Wiley and Son.

McGechan, M.B. 1990. Operational research study of forage conservation systems for cool, humid upland climates. Part1; description of model. Journal of Agricultural Engineering Research 45, 117.

McGechan, M.B. 1990.Operational research study of forage conservation systems for cool, humid upland climates. Part 2 Comparison of hay silage systems. Journal of Agricultural Engineering Research 46,129.

Ojeda, F, and Cáceres, O, 1981. Efecto del troceado, adición de 4 % de miel y el presecado sobre el consumo y digestibilidad de la hierba Guinea Likoni. Pastos y Forrajes 4, 373.

Ojeda, F. and Cáceres, O. 1982. Efecto del troceado y adición de 4 % de miel y el presecado sobre el consumo y degestibilidad del ensilaje de Pangola (Digitaria decumbens, Stent). Pastos y Forrajes 5, 87.

Ojeda, F. Cáceres, O and Esperance, M 1991 Conservación de Forrajes . Pueblo y Educación. La Habana. p 80.

Ojeda, F. and Díaz, D.1991. Ensilaje de gramínias y leguminosas para la producción de leche. I. Panicum maximum cv. Likoni y Lablab purpureus cv. Rongai. Pastos y Forrajes. 14, 175.

Ojeda, F., Esperance, M and Díaz, D 1990. Mezcla de graminias y leguminosas para mejorar el valor nutritivo de los ensilajes tropicales. Utilización del dolichos (Lablab purpureus). Pastos y Forrajes 13, 189.

Ojeda, F., Luis , Lissette and, Ruz, F 1993. Evaluación de 3 ensilajes para la producción de leche. Pastos y Forrajes . 16, 81.

Parker, B. W. 1974 New techniques in silage conservation . New Zealand Journal of Agriculture. Sept. 1974, p 56.

Trencht, R. E and Gebremedhin, K. G. 1989. Effects of forage species, chop length, moisture content and harvest number on tower silo capacity and wall load. . Journal of Agricultural Engineering Research 44, 205.

Pletinckx, A and Oestges. O. 1998. Essais de sechage de fourrages en grange avec apport solaire. Revue de l´Agriculture No 5 41, 1183.

Rodríguez, J.A; Poppe, S and Meier, Hanna. 1989 . The influence of wilting on the quality of tropical grass silage in Cuba. 1- Kinggrass (Pennisetum purpureum x Pennisetum typhoides). Archives of Animal Nutrition 39, 775.

Rodríguez, J. A ; Poppe, S and Meier, Hanna. 1989. The influence of wilting on the quality of tropical grass silage in Cuba. 2 Guinea likoni (Panicum maximum var. likoni) Archives of Animal Nutrition 39, 785.

Silvia, J. 1998. Prioducção e utilizaçao de silagen de milho e sorgo Circular Técnica No. 47. Centro Nacional de Pesquisa de Gado de Leite Area de Difusão e Tranferencia de Tecnologías. ADT, Juiz de Foras. M.L. 1998 p 34.

Wylie P.B. 1975. Silage in Queensland. Queensland. Agricultural Journal. November- December 1975. p. 1.

Silage from tropical cereals and forage crops

G. Ashbell and Z.G.Weinberg

Forage Preservation and By-Products Research Unit,
Agricultural Research Organization (ARO).
The Volcani Center, Bet Dagan 50250 Israel
E-mail: gashbell@netvision.net.il

1. Introduction

The preservation of forages by ensiling has been a well known technology for many years and is popular in North America and Europe. This technology requires high investment in facilities, accurate timing in the several stages of the ensiling process, and better understanding of the whole process than hay making demands. In addition to these demands, silage making and management in tropical conditions needs special attention and care with regard to the following points:

- Maturation – depends on the climatic conditions. In warm areas, the lengths of maturation stages might be shorter and changes are faster than in a temperate climate. In such cases, it is more difficult to control the correct stage for harvesting, and this is especially crucial with cereal crops in the latest stages of maturity.

- DM content – the correct DM content in the plant before ensiling is an important factor for the fermentation success. Unexpected weather (dry, wet or hot) can damage the crop and increase losses.

- Aerobic stability – rapid deterioration of silage, especially during the feeding-out phase is a real problem in a hot climate: it reduces quality and results in losses. High temperatures enhance mold and yeast activities all year round; therefore, special attention should be taken in silage making to eliminate air penetration into the bunker (fine chopping, good compaction and sealing). The feeding-out of the silage should be done in such a way as to avoid destruction of the structure of the face and to leave it smooth. Aerobic stability should become a routine test in hot areas Ashbell *et al.* (1991).

This paper will discuss silage making of three main cereal-fodder crops in the tropics, viz.sorghum, maize and wheat.

2. Sorghum (Sorghum bicolor L. Moench)

2.1 Introduction

Sorghum was cultivated in Egypt as early as 2000 B.C. Usually it is grown in areas with inadequate rainfall for satisfactory maize cropping. Several qualities in which it differs from maize (an alternative forage crop) have made this a summer crop worldwide. The sorghum plant is not fastidious in moisture and irrigation requirements and it can be sustained on 300 mm of water (rain or irrigation), or grow on dry land relying on winter rain. Its demand for fertilizers is modest too. Sorghum can grow in a relatively saline environment (soil and water). In a hot and long summer it can re-grow during the same summer after cutting. Of course, yield is affected by growth conditions.

Poisoning by hydrocyanic acid occurs mainly through grazing of young sorghum. Therefore it is recommended to graze sorghum only when the plants are taller then 60 cm.

There are many varieties of sorghum; most of them were developed to provide grain for human and animal consumption.

2.2 Whole plant sorghum – qualities and ensiling

In the last few decades forage sorghum has become progressively more popular. Genetic work has been done to improve and adjust the sorghum qualities for forage too, and get a "whole plant sorghum forage". Much work on sorghum silage has been done in the USA (Dickerson 1986; Smith 1986; Dost 1989,).

Sorghum is a seasonal crop; the only way to preserve the whole plant for cattle feeding is by ensiling. Several characteristics of the plant have to be taken into account to succeed with the ensiling technology and to obtain high quality silage:

2.2.1 Digestibility: poorly digestible parts of the plant reduce its total nutritional value. Most of these parts are connected with the cell wall structure, especially lignin, which is dominant in the stem. Therefore, reducing the proportion of stem in the plant will increase its digestibility. i.e., in practice shorter hybrids are preferable.

2.3 Important properties determining the value of sorghum silage.

2.3.1 High energy. From a cereal crop we can expect mainly energy supply, and less protein. Water-soluble carbohydrates (WSC), structural carbohydrates and starch are the main energy resources in cereal crops. Starch is mainly accumulated in the grain, the amount of which greatly affects the total energy content. The higher the proportion of grain in the plant, the more the total energy. The positive effect of the presence of starch is especially important for dairy cows. Therefore, we are looking for a high-grain sorghum hybrid.

2.3.2 Dry matter content. Ensiling technology requires at least 30% of DM in the forage. With less than 30% of DM undesirable fermentation takes place and results in effluent, which creates an environmental pollution problem and increases losses. Such wet material encourages the activity of clostridial bacteria, enhances the production of butyric acid, increases losses, and reduces silage quality. Most of the water content in the sorghum plant is in the stem, therefore, wilting should be avoided because the stem will spoil before drying. A solution is needed that will enable us to harvest directly a whole sorghum plant that contains at least 30% dry. In the later stages of maturation (milk and dough), the grains are the driest part of the plant. High yield of grains, harvested between the milk and dough maturation stages will increase the total DM content to a level suitable to avoid effluent and clostridia fermentation. In this stage of maturity the DM content of the grain is around 50%. In other words, to increase the DM content of whole-crop sorghum for silage, the recommended maturation stage for harvesting is between the milk and dough stages. Harvesting at the late-dough maturity or later will increase the undigested amount of the grains and reduce the nutritional value. Processing the grain in the silage will increase its digestibility. Such a solution should be applied only if it is economic. A close ratio between the grain and the rest of the plant (stem and leaves) will help to reach the goal of increasing the DM content. Reducing the moisture content or an excessive WSC in forage sorghum hybrid for silage can be done by mixing it with a grain sorghum hybrid while ensiling (Ashbell *et al.* 1999)

Table 1 gives the changes in whole plant forage sorghum during maturation, and the resulting silages. DM increased, whilst WSC and NDF (neutral detergent fiber) contents decreased mainly between the milk and dough stages; this is attributed to the grain filling with starch; *in vivo* DMD (dry matter digestibility) was not affected by stage of maturity; pH of the silages prepared from sorghum harvested at the dough stage were highest; however, all silages were stable upon aerobic exposure; acetic acid and ethanol were found in all silages at 10-20 g kg^{-1} (data are from Ashbell *et al*. 1999, unpublished results).

Table 1 Changes in sorghum composition during maturation (g kg^{-1})

Maturation stage	DM	WSC	NDF	DMD	Silage pH	Lactic acid
Flowering	274±1	120±21	512±7	604±11	3.7±0.3	58±12
Milk	288±8	149±20	489±1	607±9	3.9±0.2	45±12
Dough	340±14	69±10	425±3	617±8	4.2±0.1	30±10

2.3.3 Lodging. Sorghum plants are susceptible to lodging. Harvesting lodged plants is complicated, takes more time and field losses are higher. Tall sorghum plants usually do not have heavy heads, but have a strong and a thick stem; both of these are negative factors. Therefore, short hybrids will be more lodging resistant, and are preferable.

Two negative components can be found in sorghum plants, and it is important to be aware of them:

2.3.4 Tannins. The grains of some hybrids may contain tanniins that have a negative effect on the digestibility rate of the protein in the diet. Large amounts of tannins are mainly found in "bird-resistant hybrids".

In places where sorghum grains are used for human consumption, it is possible to ensile the vegetative parts of the plant, the stem and leaves for feeding animals. In this case the sorghum is dual-purpose. Some hybrids of sorghum can “stay young” even in the late maturation stages, and retain fair digestibility.

Adding lactic acid bacteria inoculant during ensiling sorghum improved the fermentation process, but reduced the aerobic stability of the silage (Meeske *et al.* 1993). The decision to use additives, especially bacteria has to be decided after performing experiment under the particular conditions.

3. Maize (*Zea mays* L.)

Maize, a summer forage crop, originated in Mexico or Central America, but today it is a worldwide crop for grain, and it is a perfect crop for silage. Requirements for water and temperature are relative high, and often it is an irrigated crop.

Much scientific research has been done on maize for silage, from the agronomic, ensiling and nutritional points of view. Harvesting at the correct maturation stage is a very important factor, especially in tropical areas where vegetation and maturation processes are rapid. The maturation stage for harvesting is between the milk and dough stages. This requires opening the cob, inspecting the grain, and determining the ratio between the solid (starch) part and the “milk” part inside the grain. When each of the two components reaches 50% is the time to start harvesting, and it should end when 75% of the grain is in the solid form. At that stage it is expected to reach maximum total harvesting yield. An earlier harvest will cause potential loss, and a later harvest will increase field losses and reduce the digestibility of the grains.

In a hot climate, the correct maturation stage for harvesting can be reached after around 115 days of growth. In places with a long summer it is possible to obtain two harvests in the same year, one in summer and one in autumn. There is a big difference in the quality and the yield between crops in the two harvesting seasons.

The first maize crop has better climatic conditions for growth, and can complete a cycle of the vegetation period. While the days are getting shorter and cooler towards the end of the growth period of the second crop, the yield is lower, and the plant does not have the correct conditions to produce a mature cob. When harvesting the first maize crop, grains form the dominant energy source: almost 50% of the total nutritional value, mainly starch, (which is important for dairy cows) comes from the grains. Grains strongly affect the total DM content by increasing it, and bring the total DM of the whole maize plant to suitable moisture content for ensiling. To increase the yield and improve the quality of the second harvesting of the maize, it is recommended to sow more densely (according to conditions), and to wilt if possible. Ashbell and Lisker (1988) studied the aerobic deterioration of maize silage stored in commercial bunker silos in Israel (su-btropical climate). Losses in dry matter were between 4-7.5% in well sealed sites, and up to 36% at locations where air penetrated (upper layer and along the walls).

4. Wheat (Triticum L.)

4.1 Agronomic considerations

Wheat has been grown since the beginning of civilization, mainly for its grains.

Nowadays, in some areas whole-crop wheat is used as a forage crop, which is preserved either as hay or as silage. Whole-crop wheat provides both digestible fibres and energy (9.0 MJ kg^{-1} DM) and its nutritional value may approach that of maize silage, so that it can serve as an excellent forage for high-lactating cows or beef cattle (Adamson and Reeve 1992). There are numerous varieties and cultivars that have been adapted for different climates and soils. In tropical and sub-tropical climates only spring wheat is grown, which is sown just before the rainy season. Wheat for silage is harvested at the milk-dough ripening stage with a DM content of 30-35%. DM yields of whole-crop wheat for silage are around 10 t ha^{-1}, depending on cultivar and on growing conditions.

The advantage of growing wheat for silage in tropical and subtropical climates is that the early harvesting enables the farmer to grow an additional summer crop such as maize, potatoes, peanuts, etc. This system, referred to as 'double-cropping', has the advantages of more efficient utilization of soil, water and fertilizers, and of crop rotation (Ashbell and Sklan1985). In Israel, with a sub-tropical climate, this system even enables farmers to squeeze in a third crop of autumn maize for silage; this is irrigated with treated sewage water and is harvested after 80 days of growth, before the cob develops.

Spring wheat cultivars can be early and late maturing, with a 2-3-week difference between them in the time needed to reach adequate ripening. Advantages attributed to late-maturing cultivars used for silage in sub-tropical climates include:

- a longer growth period in semi-arid areas facilitates more efficient use of moisture remaining in the soil from late rains, so that they provide higher yields at a given stage of maturity;

- the time window available for silage making is extended, relieving some of the logistical pressure on the operating system ;

- the harvest period of the late-maturing cultivars offers a greater possibility of avoiding rainfall during silage making.

It is possible to grow wheat along with annual legumes such as vetch, peas and sulla (*Hedysarum coronarium*) and to ensile them together. The advantages attributed to such systems are

- the wheat may alleviate the lodging problem of the legumes;

- improved soil ecology and reduced incidence of plant disease;

- improved silage quality and reduced preservation losses of the legumes.

The latter advantage arises from the fact that the carbohydrate-rich cereals are complementary to the moist, protein-rich legumes, with regard to ensiling properties, aerobic stability of the silage and nutritional aspects. For example, Ashbell *et al.* (1997) found that the best combination was obtained when the silages were prepared from wheat and vetch at 3:1 (wet-weight basis), with 31% DM in the mixture. The problems that might be associated with such systems include growth domination of one type over the other, problems with using herbicides, and that the cereal and the legume may not reach optimal maturity for harvest at the same time.

4.2 Changes during maturation

Changes that occur in the whole-wheat plant during maturation are very rapid in warm climates, and the intervals between the various maturation stages are short. These changes affect DM yields, chemical composition, ensiling characteristics and nutritional value. During the short period between flowering and the soft dough stages the wheat plant undergoes remarkable changes; although there is a certain variability in composition among years and among cultivars, some tendencies are apparent (Table 2): DM content increases with advancing maturity, whereas crude protein decreases, mainly between the flowering and milk-dough ripening stages; starch accumulates in the grains while soluble carbohydrates decrease; fibre contents (both NDF and ADF, expressed as percentages of DM) peak at the flowering stage. The latter affects the nutritional value of this forage. Based on these facts, and considering yields, ensiling characteristics and nutritional properties, we believe that it is optimal to harvest wheat for silage at the milk ripening stage (Ashbell *et al.* 1997; Weinberg *et al.* 1991).

Table 2 Changes in wheat composition during maturation (g kg^{-1})

Maturation stage	DM	WSC	Ash	Crude protein	NDF	ADF	ADL
Shooting	170-190	-	108	133	562	360	57
Flowering	200-246	62-110	81-111	96-132	585-640	366-405	59-90
Milk	279-388	51-136	62-110	77-104	510-598	251-408	49-108
Dough	355-466	30-32	57-91	81-90	481-509	239-278	57-67

ADF, acid detergent fiber;ADL, acid detergent lignin.

4.3 Ensiling of wheat

Although yields are somewhat lower at the milk ripening stage, as compared with the dough ripening stage, it is preferable to harvest at the earlier stage because the wheat at the dough stage may be too dry and its fibres less digestible. On the other hand, wheat at flowering is too moist and requires prolonged wilting, and its ensiling properties are inferior.

Before ensiling, the wheat is usually subjected to a short wilting period in order to reach a DM content of 33-38%. It is difficult to control the DM content of the wheat at harvest because of the rapid changes mentioned above. In addition, in subtropical climates, the wheat for silage is harvested in spring when the weather is unstable and changes rapidly from cool to hot and dry. This affects maturation and drying rates during wilting.

Compaction of the chopped wheat in the silo is affected by its DM content and chopping length: the drier it is the more elastic it is and, therefore, more difficult to compact. Because wheat stems are hollow, removal of air demands more intensive compaction. Therefore, a drier crop requires a shorter chopping length. The recommended chopping length in Israel is 10 mm; however, excessively short pieces are not desirable because they are more costly to produce, and they may escape quickly from the rumen, and lose their function as roughage for ruminants.

Ensiling rates of wheat in subtropical climates are variable and depend on DM content, carbohydrate availability and development of adequate lactic acid bacteria in the silage. There are not many data on microbiological dynamics during ensiling of wheat in warm climates. Weinberg *et al.* (1987) found that the number of lactobacilli in the fresh crop varied between 10^2 and 10^6 colony-forming units (CFU) per gram. After 2 days of ensiling in mini-silos the numbers increased to 10^8-10^9 CFU g^{-1} in all cases.

Ashbell and Kashanchi (1987) and Ashbell and Weinberg (1992) studied DM losses in commercial wheat bunker silos in Israel. In the center of the silo DM losses ranged from 3 to 16%, near the walls from 10 to 22%, and under the cover from 14 to 27%. The shoulders of the bunker (where the walls and plastic sheeting meet) are the most susceptible parts of the silage to air penetration, and their DM losses ranged from 54 to 76%.

The aerobic stability of wheat silage is variable. In warm climates detrimental microorganisms (yeasts, molds) proliferate more rapidly, resulting in enhanced aerobic spoilage. In general, many factors may affect aerobic stability, including the presence of weeds, the management of the silage in storage (compaction and sealing), composition of the silage, additives, and the method and rate of feeding-out. In bunker silos in a warm climates it is important to refresh the face frequently by feeding-out 30-40 cm every day, in order to minimize its exposure to air. Aerobic deterioration of wheat silage is associated with increased numbers of yeasts and molds, heating and, consequently, DM losses. The roles of DM content, residual soluble carbohydrates and lactic acid in destabilization of the silage is not clear as yet. As in other silages, volatile fatty acids (such as acetic, propionic and butyric) produced during the ensiling fermentation inhibit yeasts and molds.

Molds are of concern in wheat silages because of the risk of mycotoxins. Several mycotoxins at various levels have been detected in wheat silage in Israel; there are not yet enough data to correlate their presence with disease incidence in cattle.

4.4 Additives

Both chemical and biological additives have been tried in wheat silage. A sulfur-based chemical, which inhibits yeasts and molds, is applied commercially in Israel; reduced losses and improved aerobic stability are attributed to it. On some farms, coarse sodium chloride is applied to the top layer (at 3-4 kg m^{-2}) of the bunkers for the preservation of this susceptible part of the silage. Anhydrous ammonia has also been tried on corn, wheat and sorghum silages, it improvrd aerobic stability, increased the NPN content, but it is hazardous to use, and therfore, not used in practice (Ashbell and Weinberg 1993).

Bacterial inoculants comprising homofermentative lactic acid bacteria were not found suitable for wheat silage in Israel: silages treated with such inoculants tended to deteriorate faster than the respective controls, and to enhance yeast and mold development (Weinberg *et al.* 1993). It was hypothesized that not enough volatile fatty acids, which inhibit yeasts and molds, were present in such silages. Inclusion of special bacterial strains alleviated this problem. Heterofermentative *L. buchneri* are being tried in several research laboratories and results are promising (e.g, Weinberg *et al.* 1999).

Cell-wall-degrading enzymes (cellulases, hemicellulases and pectinases) have also been tried. The expected benefits to be derived from such enzymes are the release of fermentable sugars and improved rumen digestibility. The enzymes have been found to reduce fibre content and to increase fibre digestibility only in silages made from moist wheat at the flowering stage, but not in those from drier more mature wheat (Weinberg *et al.* 1993 ; Weinberg *et al.* 1995).

4.5 Nutritional properties

The nutritional value of wheat for silage is strongly affected by the stage of maturity at harvest, because that affects yields, the ratio between grains and the vegetative plant parts, and DM and cell-wall contents and quality. In Israel wheat silage forms the main roughage in the rations for high lactating cows and, therefore, its quality is of the utmost importance, it forms approximately one third of the ration, and is fed at about 7 kg DM per cow per day.

Ashbell *et al*. (1997) compared the ensiling properties and rumen degradability of wheat silage from early- and late-maturing cultivars, at four stages of maturity: shooting, flowering, milk and dough. Although NDF degradability at the young wheat silage (shooting and flowering) was higher than at the milk or dough stages, yields of degradable DM and NDF (in terms of t ha^{-1}, increased as the wheat matured. Ben-Ghedalia *et al*. (1995) found *in vitro* organic matter digestibility of 69.2 and 70.5% and NDF digestibility of 63.3 and 56.3%, at the flowering and soft-dough ripening stages, respectively, of whole-plant wheat.

4.6 Research needs

Wheat cultivars that are used for silage making, were mainly developed for increased grain yields, and are actually dual-purpose types. Research should focus on development of cultivars intended solely for ensiling. Such cultivars should be adapted to specific climate and soil conditions, with higher yields and improved quality. Another possibility involves plants with intrinsic antimycotic properties, the silage of which should be more stable under aerobic exposure.

Development of more suitable inoculants for wheat silage in warm climate warrants research. The requirements of such inoculants should include crop specificity, improved ensiling fermentation with reduced losses, improved aerobic stability, and a probiotic effect on the animal performance (Weinberg and Muck 1996). Genetic engineering might also play a role in the development of ideal inoculants.

5. References

Adamson, A.H. and Reeve, A. 1992. Nutritional evaluation of whole-crop wheat. P. 85-96. In; B.A. Stark and J.M. Wilkinson (eds.) *Whole-Crop Cereals.* Chalcombe Publications , Aberystwyth, UK.

Ashbell, G. and Kashantchi, Y. 1987. In silo losses from wheat ensiled in bunker silos in subtropical climate. *J. Sci. Food Agric.* **40,** 95-103.

Ashbell, G. and Lisker, N. 1988. Aerobic deterioration in maize silage stored in bunker silo under farm condition in subtropical climate. *J. Sci. Food Agric.* **45**, 307-315.

Ashbell, G. and Sklan, D.1985. Winter wheat for silage: a double-cropping system for use in subtropical climate. *Feedstuffs* **57**, 18-19.

Ashbell, G. and Weinberg, Z.G. 1992 Top silage losses in horizontal silos. *Can. Agric. Eng.* **34**, 171-175.

Ashbell, G. and Weinberg, Z.G. 1993. The effect of applying ammonia on maize wheat, and sorghum upon ensiling. *Can. Agric. Engin.* **35**, 113-117.

Ashbell, G., Weinberg, Z.G., Azrieli, A., Hen, Y. and Horev, B. 1991. A simple system to determine the aerobic determination of silages. *Can. Agric. Engin.* **33**, 391-395.

Ashbell, G**.,** Weinberg, Z.G., Bruckental, I. Tabori, K. and Sharet, N. 1997. Wheat silage: the effect of cultivar and stage of maturity on yield and degradability *in situ. J. Agric. Food Chem.* **45**, 709-712.

Ashbell, G., Weinberg, Z.G., Bolsen, K.K., Hen, Y. and Azrieli, A. 1999. The silage characteristics of two varieties of forage sorghum mixed in different proportions at two stages of maturity. *African J. Range Forage Sci.* ***15,*** 69-72.

Ashbell, G., Weinberg, Z.G. and Hen, Y. 1997. Interactions between wheat and vetch during co-ensiling. *Meshek Habakar Vehachalav* **272**, 20-22 (in Hebrew).

Ben-Ghedalia, D., Kabala, A. and Miron, J. 1995. Composition and in vitro digestibility of carbohydrates of wheat plants harvested at bloom and soft dough stages. *J. Sci. Food Agric.* **68**, 111-116.

Dickerson, J., T., 1986.Yield, composition, and nutritive value of forage sorghum silages: hybrid and stage of maturity. *M.Sc. thesis, Kansas State University, Manhattan, Kansas, USA.*

Dost, M., 1989. Grain yield, forage yield, and forage quality of different sorghum types under irrigated and dryland conditions. *Ph.D. thesis, Kansas State University, Manhattan, Kansas, USA.*

Meeske, R., Ashbell, G., Weinberg, Z.G. and Kipnis, T. 1993. Ensiling forage sorghum at two stages of maturity with the addition of lactic acid bacteria inoculant. *Anim. Feed Sci. Technol.* **43,** 165-175.

Smith, R., L., 1986. Yield, composition, and nutritive value of grain sorghum harvested as silage: stage of maturity and processing effect *M.Sc. thesis, Kansas State University, Manhattan, Kansas, USA.*

Weinberg, Z.G., Ashbell, G., Azrieli, A. and Brukental, I. 1993. Ensiling peas, ryegrass and wheat with additives of lactic acid bacteria (LAB) and cell wall degrading enzymes. *Grass Forage Sci.* **48**, 70-78.

Weinberg, Z.G., Ashbell, G., Hen, Y. and Harduff, Z. 1991. Ensiling whole wheat for ruminant feeding at different stages of maturity.*Anim. Feed Sci. Technol.* **32**, 313-320.

Weinberg, Z.G., Ashbell, G., Hen, Y. and Azrieli, A. 1993 The effect of applying lactic acid bacteria at ensiling on the aerobic stability of silages. *J. Appl. Bacteriol.* **75**, 512-518.

Weinberg, Z.G., Ashbell, G., Hen, Y. and Azrieli, A. 1995. The effect of cellulase and hemicellulase plus pectinase on the aerobic stability of peas and wheat silages. *Anim. Feed Sci. Technol.* **55**, 287-293.

Weinberg, Z.G., Ashbell, G. and Lisker, N. 1987. The effect of addition of lactic acid bacteria inoculum to wheat and maize silages in Israel. *Agronomie* **7**, 709-713.

Weinberg, Z.G. and Muck, R.E. 1996. New trends and opportunities in the use and development of inoculants for silage. *FEMS Microbiol. Rev.* **19**, 53-68.

Weinberg, Z.G., Szakacs, G., Ashbell, G. and Hen, Y. 1999. The effect of *Lactobacillus buchneri* and *L. plantarum*, applied at ensiling, on the ensiling fermentation and aerobic stability of wheat and sorghum silages. *J. Indust. Microbiol. Biotechnol.* (In press).

Silage from by-products for smallholders

Kayouli Chedly[1] and Stephen Lee[2]

[1] Institut National Agronomique de Tunisie,
43 Ave Charles Nicole 1082 Tunis, Tunisia
Tel: 002161892785 ; Fax: 002161799391 and
E Mail: chedly.kayouli@gnet.tn

[2] Brooklyn Valley, Rd 3 Motueka, New Zealand.
Tel: 00643 528 0476; Fax: 00643 5288967 and
E Mail: SteveLee@ts.co.nz

Summary

The paper summarises some of the practical experiences of the authors in formulating and making silages with and for smallholder farmers in North Africa and the South Pacific.

Livestock are an important part of the farming system in developing countries, particularly for subsistence and semi-commercial farmers. There is good potential to improve food security and family incomes by improving livestock production. This applies particularly to milk production by rural and peri-urban farmers. However, a shortage of affordable feeds of adequate quality and quantity, particularly during the dry season is a major obstacle to improving production.

Many agricultural, agro-industrial and fishery by-products have potential as animal feeds. Many of these products currently are completely unused or are largely wasted due to the inability of farmers to use them before they spoil, as a result of seasonal production peaks and troughs. Consequently these by-products often become pollutants.

Ensiling by-products is a simple and low-cost option, which can preserve feeds that are seasonally abundant for later feeding during periods of feed shortage. Ensiling can also render some previously unpalatable products useful to livestock by changing the chemical nature of the feed. Silage is a very versatile product and can be used as a basal diet or as a concentrate type supplement to other feeds such as forage. Preparations suitable for monogastrics such as pigs or ruminants can be tailored to the needs and digestive ability of the target livestock.

Information is given on the nutritive value, physical nature, and availability of a range of common by-products. Clear descriptions of how these by-products are used in silage making allow the reader to easily apply the message of this paper. Also included are practical examples of successful silage combinations, and feeding regimes including silage for different classes of livestock and desired production levels.

1. Introduction

The livestock sector plays a significant economic role in most developing countries and is essential for the food security of their rural population. It is contributing to poverty alleviation and provides elements that are essential to the national economy, such as: traction power, transport, manure as fertiliser and fuel, food, fibre, leather, savings bank, and by generating significant household cash income through sales of live animals or livestock products.

However, among the major constraints limiting the development of livestock production in many developing countries, inadequacy of animal feed resources is most often the crucial factor. Feed shortages, both quantitatively and qualitatively, are limiting livestock productivity. During ploughing of crop fields these shortages seriously affect working ability of oxen and they also depress the production of dairy and meat units managed by small-scale commercial farmers.

In many tropical countries, such as those in Africa and the South Pacific Islands, the bulk of livestock feed resources comes from grazing mainly poor quality annual and perennial grasses from natural pastures often at a late stage of maturity. In other countries, such as those in Southeast Asia, livestock farming is increasingly being limited by the restriction of grazing lands. During the long dry season (at least 6-7 months per year) animals are on poor quality feeds characterised by low palatability, low intake and low nitrogen concentration. However, crop residues (straw and stover from sorghum, millet, wheat, barley, rice, maize) play a key role in animal feeding mainly in Asia and Africa.

As there is an incipient urban market demand for milk around the largest cities in most developing countries, there is an increasing development of small-scale peri-urban dairy units mainly from pure Friesian cows. However, the smallholder dairy producers are often facing low milk yields from these exotic cattle due to the poor feeding management (lack of rations with balanced nutritive content) and/or high-producing costs because their feeding system is primarily based on purchased feeds and concentrates.

It is recognised in developed countries that the production of silage of high quality cultivated forage can be a valuable component for the development of a high-performing and low-cost system of animal production, using a relatively low level of purchased concentrates. However, this appears inappropriate for smallholders in tropical countries primarily for the following reasons:

- lack (and/or high cost) of equipment for harvesting and conservation
- production of cultivated forage is often limited due to lack of available land. Most farmers in developing countries rely for their food security on the cultivation of cereals, root crops and high value crops such as fruits and vegetables, which understandably take priority in the allocation of land.

Fruit, vegetables and root crops are increasingly integrated in the farming system and play a key role as staples in the human diet in most developing countries. Consequently, there is a wide range of valuable by-products and residues resulting from food crops cropping systems and food processing which are often inefficiently or totally under-utilised and wasted.

The ensiling of by-products is a simple and appropriate method of conservation. It is the most-effective way to improve animal feed resources through the rational use of locally available agricultural and industrial-by products likely to be available to small-scale farmers at village level. In developed countries herbage ensiling is now accepted as the major method of forage conservation and much research has been undertaken in that field (Mc Donald 1983; Thomas 1985). However very few research and extension activities are related to the various aspects of silage production from by-products.

The paper is aimed at examining some of the practical aspects of making and utilising silage from by-products by small-scale farmers. There are very large amounts of various by-products in tropical countries and it is not possible to provide a global review on this topic. Our contribution is therefore restricted to our experience in North Africa (from the first author) and experience in two projects financed by the Technical Co-operation Programme of FAO, first in Samoa, repeated subsequently in Tonga, managed by both authors.

2. Advantages of silage making from local crop residues and by-products

The problem usually encountered with agro by-products is seasonality of supply, which is often accentuated by their high moisture content. High-moisture agro-industrial by-products are often of high nutritional value. In industrial countries there are well-developed technologies for recovering by-products and converting them into protein-rich meals and/or energy-rich concentrates. However, such facilities are rarely found in tropical less-developed countries, especially at the level of small villages where by-products often become contaminating wastes: they quickly go sour, mouldy and lose considerable quantities of soluble nutrients in the effluent. Dehydration increases cost, about 250 - 300 litres of fuel and 200 kWh of electricity are required to produce one ton of dry product (88 - 90% DM). Research has shown that the ensiling of by-products is the most suitable method of conservation for long period (Lien *et al.* 1994; Bouqué and Fiems 1988; Hadjipanayiotou 1993; 1994; Kayouli 1989; Kayouli *et al.* 1993; Kayouli and Lee 1998). The main advantages of silage are:

1. it can be efficiently used for strategic off-season feeding

2. it is a means of increasing feed resource availability and form of insurance, especially for calving dairy cows

3. it can be fed to reduce pressure on pasture when required

4. it can be an efficient supplement to grazing cattle during the dry season

5. it is an inexpensive home-made feed resulting in the production of milk and beef at lower cost

6. it improves palatability, reduces significantly toxic substances present in some fresh vegetables to safe level concentrations (such as cyanogenic glucosides in fresh cassava leaves) and destroys harmful micro-organisms possibly present in poultry litter or fish wastes

7. it can provide a major diet source, as basal ration as well as a feed supplement for grazing animals.

3. By-products widely available in tropical and sub-tropical countries potentially suitable to silage making

In tropical and sub-tropical countries there is a wide range of by-products and residues from food crops and food processing that are potentially valuable feed supplements, without considering residues from cereal grain. The most common by-products from various root and tuber crops, fruit crops, agro-industry and animal industries are the following:

3.1. Brewer's spent grains

The extracted malt, or spent grain, contains 75 - 80% water when filtered off. Wet spent grain spoils rather quickly and should be used fresh or stored out of contact with air. It can be stored up to two weeks quite successfully by heaping it, treading it well and covering with sacs or plastic sheets. For longer storage, it may be ensiled in an airtight trench silo with drainage. Ensiling in tightly tied plastic bags is also an effective storage method (this method will be described in details later). Wet spent grain can be ensiled alone or in association with other ingredients, for example, with 2 - 3% molasses (to ensure proper fermentation), chopped banana by-products (trunk, pseudostems, fruit, peel) or chopped cassava. The latter has the advantage to absorb the juice from spent grain and consequently to limit losses during fermentation. The quantities to be incorporated depend on availability. However, in any case the dry matter content in ensiled mass, should not exceed 45%, in order to ensure proper fermentation.

Brewer’s spent grain is a valuable potential supplementary feed for livestock. It is a safe feed when it is used fresh or properly stored. It is a relatively bulky feed but a good source of energy and protein (Table 1). It can be used to feed beef cattle (10 - 15 kg daily) and calves (2 - 4 kg daily), however it is far more suitable in rations for dairy cows. Spent grain is a balanced feed for dairy cows and has a strong reputation for stimulating milk production. Milk yield response is very rapid and production significantly increases when lactating cows are fed spent grain supplement. Wet grain can be given in large amounts to dairy cows, up to 15 kg per day. In order to avoid off-flavours, it is recommended that spent grain be fed to cows after rather than before milking. When it is eaten in large quantities (15 - 20 kg per day), distribution of 100 - 150 g of sodium bicarbonate given twice daily is recommended in order to prevent rumen acidosis disorder.

Table 1: Nutritive value of tropical by-products potentially to be ensiled and inclusion rate in dairy cow diets.

		Per kg Dry Matter			***Per kg Fresh Matter***			
Feed Stuffs	Dry Matter	Metabo Energy	Crude Protein	Crude Fibre	Metabo Energy	Crude Protein	Crude Fibre	Inclusion Rate
	%	MJ/kg	g/kg	g/kg	MJ/kg	g/kg	g/kg	Fresh, kg/day
Spent Grain	22.0	8.2	260	130	1.8	57.2	28.6	5 - 20
Banana Stems	9.5	5.5	20	210	0.52	1.9	20.0	5 - 10
Banana skin (ripe)	15.0	6.7	42	77	1.0	6.3	11.6	2 - 5
Rejected Banana (ripe)	30.0	11.5	54	22	3.5	16.2	6.6	2 - 5
Cassava Leaves	16.0	6.7	235	190	1.1	37.6	30.4	3 - 6
Cassava Roots	28.5	12.5	16	52	3.6	4.6	14.8	5 - 15
Molasses	78.0	11.5	15	0.00	9.0	11.7	0	0.5 - 2
Breadfruit (ripe fruit)	29.8	10.8	57	49	3.2	17.0	14.6	4 - 8
Taro Leaves	16.0	6.2	223	114	1.0	35.7	18.2	1 - 2
Taro Roots	25.0	13.2	45	20	3.3	11.25	5	2 - 5
Sweet Potato (leaves)	12.0	5.8	200	145	0.7	24.0	17.4	10 - 20
Sweet potato (tubers)	30.0	13.5	70	25	4.1	21.0	7.5	5 - 10
Yams (leaves)	24.0	7.3	120	250	1.8	28.8	60	2 - 5
Yams (roots)	34.0	13.5	80	25	4.6	27.2	8.5	2 - 5
Poultry Litter	82	8.2	265	145	6.7	217.3	119.0	0.5 - 2

Table 1bis: Nutritive value of sub-tropical by-products potentially to be ensiled and inclusion rate in dairy cow diets.

		Per kg Dry Matter			***Per kg Fresh Matter***			
Feed Stuffs	Dry Matter	Metabo Energy	Crude Protein	Crude Fibre (ADF)	Metabo Energy	Crude Protein	Crude Fibre (ADF)	Inclusion Rate
	%	MJ/kg	g/kg	g/kg	MJ/kg	g/kg	g/kg	kg fresh/day
Olive cakes	45.5	3.8	40	465	1.7	18.2	211.6	2 - 4
Olive leaves	56.8	5.7	105	300	3.2	59.6	170.4	3 - 6
Grape marc	37.1	4.9	138	410	1.8	51.2	152.1	1 - 3
Sugar beet pulp	19.5	9.8	91	316	1.9	17.4	61.6	up to 20
Tomato Pulp	22.5	8.0	215	350	1.8	48.4	78.8	up to 15
Wheat Bran	89.1	8.1	160	137	7.3	142.6	122.1	1 - 3
Date palm fruit	87.6	12.0	32	50	10.5	28.0	43.8	0.5 - 1
Citrus pulp	23	10.3	75	200	2.4	17.3	46	up to 15

3.2. Banana by-products

Bananas are grown in almost all–farms in the humid tropics and constitute one of the staple foods for human consumption. Banana plant waste is of considerable importance in feeding ruminants. The by-products are the followings:

3.2.1. Rejected banana: Rejected bananas both green, immature and ripe, are a good source of energy supplement to grazing or penned animals. Dairy cows relish them and can consume them in fairly large amounts. But bananas have a low content of fibre, protein (Table 1) and minerals and should therefore be fed together with grass or other source of roughage (in order to avoid rumen disturbance) as well as with protein and mineral supplements. When the rejected bananas are widely available, a good silage can be made from chopped bananas mixed with one or several rich-protein feeds, such as poultry litter, dry spent grain, fish wastes and cassava leaves.

3.2.2. Banana leaves and pseudostems (trunks): Banana pseudostems (trunks) and leaves are useful sources of roughage in many tropical countries, mainly during the dry season. They can be chopped and fed fresh or ensiled. As pseudostems are low in protein and minerals, they are more efficiently used when supplemented with rich-protein ingredients, such as copra meal, multi-nutrient feed blocks, cassava leaves, poultry manure and spent grain.

The use of chopped and ensiled pseudostems is particularly recommended when the bunch has been harvested and plants are cut down; the large quantity of trunks available at harvest time can be safely preserved through a well planned silage operation. The silage is of good quality when chopped pseudostems are properly mixed with an easily fermentable carbohydrate (such as molasses, sliced root vegetables) and protein-rich feeds (such as poultry litter, wet spent grain).

3.3. Root crops

The major root crops that are potentially available for animal feeding in tropical countries are mostly cassava, taro, sweet potato and yams.

3.3.1. Cassava by-products: Both the roots and the leaves are valuable feed resources for dairy cattle**.**

3.3.1.1. Cassava roots: Fresh and sun-dried cassava roots are consumed by ruminants in different forms (sliced, chopped, ground) and used as a substitute for cereal grains in many countries. Cassava roots are a good energy source for dairy cattle, because they are high in carbohydrate, which is an important and readily available energy source for rumen microbes. However, they are low in protein (Table 1). They are particularly efficiently used by high producing cows and at the first stage of lactation. Cassava roots can be given in large quantities: up to 25% of total dry matter intake. However, protein and mineral supplements must be fed in order to balance the ration. As cassava roots are rich in easily fermentable carbohydrates, they constitute an excellent energetic additive when they are chopped and ensiled with other feed resources, such as fish waste, cassava leaves, banana pseudostems, spent grain, poultry litter, etc.

3.3.1.2. Cassava leaves: The cassava leaves are also a potential and valuable protein feed resource for ruminants (Table 1). It is estimated that when leaves are harvested at the same time as the roots, yields are in the range of 1 to 4 tonnes dry matter/ha. Fresh cassava leaves have been successfully fed to cattle, including dairy cows, in many countries.

Fresh raw cassava contains cyanogenic glucosides (HCN compounds) which are toxic to monogastrics. But, leaves can be fed fresh to ruminants, as rumen micro-organisms appear to be able to detoxify the HCN. However, this is easily removed during processing by sun drying or ensiling. Ensiling cassava leaves is the simplest method, not only to reduce significantly HCN concentrations to safe levels for monogastrics, but also to preserve the nutritive value of harvested cassava leaves for efficient use for off-season feeding of dairy cows. The freshly harvested leaves are first chopped and can be ensiled alone or mixed with rich-energy feeds, such as banana wastes, root vegetables, wet spent grain. The whole cassava plant (including root and aerial parts) can also be chopped and ensiled in the same way. The silage is fairly balanced for dairy cows.

3.3.2. Taro: Taro is the staple food of the population in many tropical countries. Taro by-products include roots, trimmings, leaves and stems that are all potentially valuable feed supplements. Taro roots are out-standing as a feed, particularly rich in energy. Raw taro contains substances that irritate the tongue and palate of animals, so that it must be cooked to improve their nutritional usefulness, mainly for monogastrics. The leaves are rich in protein (Table2) and are relished by cattle. Taro by-products can be chopped and ensiled in association with aforementioned feed resources. Silage making reduces considerably undesirable substances in taro by-products, which thus become more appetising.

3.3.3. Sweet Potato: Sweet potato is another root crop grown by farmers in many tropical countries. The by-products are roots, offcuts, leaves and vines. Roots have low protein, fat and fibre concentrations (Table1), but they are high in carbohydrates, whilst foliage has a lower carbohydrate concentration but higher fibre and protein concentrations (Table1). The vines, which are usually wasted, can serve as a nutritive and relished green supplement for cattle. A mixture of waste bananas, cassava roots and sweet potato tubers and leaves can be ensiled effectively without the need for additives.

3.3.4. Yams: Yams are also widely grown in many tropical countries. Their nutritional value is limited by their bitter alkaloid concentration, as well as of tannins and saponins. Yams must be cooked to improve their nutritional usefulness, when they are fed to monogastrics or calves. The by-products include roots, offcuts, leaves and vines. Vines are a valuable cattle feed and can be successfully ensiled mixed with other feed ingredients above indicated.

3.4. Wet pulps from fruit and vegetables (citrus and pineapple pulps and leaves)

Many fruits are grown in tropical countries: mango, papaya, pineapple, citrus, etc. Fruit wastes and leaves are some other potential feed resources. The most suitable method for conserving these materials is to ensile them with the aforementioned ingredients, so that they ensure a good fermentation and enhance the silage quality due to their high sugar concentration.

Almost all Mediterranean Countries produce large amounts of citrus for local consumption and export. Citrus pulp is the residue remaining after the extraction of citrus juice, it represents approximately half of the fruit and has a mean DM of 20% (Boucqué and Fiems 1988). Citrus pulp is an energy-rich feed resource with high metabolisable energy content (Table1). The ensiling of the citrus pulp, damaged fruits and leftovers, in combination with other by-products with high protein concentration, such as poultry litter and wheat bran, is a simple and appropriate method of conservation which can make a significant contribution to the feeding requirements of ruminants, mainly for high-yielding cows in early stage of lactation. In addition, ensiling citrus wastes has advantages over traditional drying, in that less energy is used, cost of processing is much reduced and there is improvement of palatability.

3.5. Fish by-products

Fish by-products are usually obtained from inedible whole fish or from waste in fish processing industries. This is an excellent source of protein and minerals for livestock, mainly for cows that have recently calved and for high-yielding cows. The ensiling of the by-products, using molasses and other easily available feeds rich in fermentable carbohydrates, such as molasses, sweet potatoes, cassava roots, is a simple and appropriate method of conservation which has been successfully applied recently in some countries. In all cases, the maximum amount of fish wastes that can be included in the silage should be 50% with a dry source of carbohydrates and much lower, about 10%, with fresh sources.

3.6. Poultry litter

Another potential feed resource is poultry litter that is available in some intensive poultry farms in developing countries. Poultry litter and manure contain about 25% crude protein on a dry matter basis, about half of which derives from uric acid that can be efficiently used by rumen microbes for protein production, poultry litter is also rich in minerals. The results of many experiments in the world indicate that dried or ensiled poultry litter can be successfully included in the feed of ruminants as a protein supplement. The ensiling of the poultry litter is a simple and appropriate method of conservation. It has proved to be an excellent ingredient for cattle feeding, and the process significantly destroys harmful micro-organisms possibly present in poultry litter. Silage made from poultry litter, chopped root crops and bananas by-products provides a balanced diet for dairy cows.

3.7. Tomato pulp

Tomato is the most popular vegetable crop grown in Mediterranean countries where there are numerous tomato-processing plants. Tomato processing residues called tomato pulp (a mixture of peel and seed) accounts for about one fifth of fresh weight and has a high nutritional value, it is a particularly protein-rich feed resource (Table 1). Fresh tomato pulp becomes sour and mouldy rapidly because it is traditionally processed during summer time and has a high moisture content, approximately 80-84 %. Consequently, it is advisable to ensile tomato pulp in alternative layers with dry by-products, such as chopped straw, wheat bran and poultry litter, so that the liquid effluent is absorbed and fed. Good-quality silages made from those combinations are successfully used to feed dairy cows and fattening steers by small farmers in Tunisia (Kayouli 1989).

3.8. Pressed olive cakes

The production of olive oil is basically confined in the Mediterranean basin. Large amounts of crude olive cakes, a residue of kernels and pulp left after oil extraction, are produced yearly. Despite its low nutritive value (Table1), this by-product is a potential feed resource mainly during feed shortage. Usually, crude olive cake stored in heaps next to the processing plant deteriorates quickly because of it is high lipid concentration between 10 and 14%. The voluntary intake of such cake decreases with storage duration. Ensiling fresh olive cake either alone or with high-quality by-products, such as wheat bran, poultry litter and tomato pulp, improves storage quality and gives a well-preserved palatable feedstuff. This technique was tried ten years ago in Tunisia (Kayouli *et al.* 1993) then successfully adopted by many smallholders in the vicinity of olive oil processing plants.

3.9. Grape marc

After pressing 100 kg of grapes, there is production of 5 - 10 kg of grape marc (seed and pulp) with about 50% DM and relatively low nutritive value (Table1). Ensiling fresh grape marc either alone or with high-quality by-products, such as wheat bran, poultry litter and tomato pulp, improves storage quality and gives a well-preserved palatable feedstuff (Hadjipanayioutou 1987).

4. Silage - making from by-products

Ensiling may be used as a general term to describe any procedure involving the storage of materials in silos or pits. However, the term is commonly used to specifically describe the storage of green fodder under anaerobic conditions that allow naturally occurring microbes to ferment plant carbohydrates to organic acids, reducing the pH in the silo, inhibiting further fermentation and preserving the crop as silage. These basic principles of silage making from grass are the same for silage-making from by-products, so attention must be paid first to ensure anaerobic conditions, i.e. the by-products must be stored air-tight at all times, and secondly, there must be sufficient natural acid in the silage to restrict the activities of undesirable bacteria (for this the ensiled material must be rich enough in carbohydrates).

In order to achieve a successful ensiling of by-products, the following points should be rigorously respected:

1. Moisture content: ensiled material should contain more than 50% moisture so that it is easy to compress it tightly in order to get better compacting and to eliminate air. However, excessive moisture, more than 75% can also be harmful, leading to an undesirable fermentation in later phases and produces sour silage, which reduces palatability and intake. Water can be added and/or wet and dry feeds can be mixed to get such moisture,

2. Length of chopping: The finer the chopping, the better the compaction and therefore storage will be more successful, due to the effective exclusion of air. Chopping in small pieces can be done by hand or with a stationary forage chopper.

3. The time it takes to fill a silo: The rapidity of filling and sealing the silo is of high priority. Because of slow filling or delayed covering can easily increase feed losses due to extended aerobic fermentation.

4. Presence of enough easily fermentable energy (naturally present or added): The major objective in silage fermentation is to achieve a stable low pH at which biological activity virtually ceases. In this way preservation is obtained whilst minimising nutrient losses and avoiding adverse changes in the chemical composition of the material. The final pH of the ensiled by-

products depends largely on the carbohydrate contents in the original materials. For this reason, protein-rich feeds with low content of energy are very difficult to ensile successfully and should be mixed with easily fermentable energy-rich products, such as molasses, rejected bananas and root crops.

The technique of silage making from by-products is extensively described by Kayouli and Lee (1998). The silage can be stored in stacked layers, packed in succession on the soil that has been covered beforehand with a plastic sheet or banana leaves. This heap, once finished, is then tightly covered with banana leaves or plastic sheets, pressed down by some heavy objects which are placed on its top. Packed silage in plastic bags that are tightly closed is also an effective storage method. This storage method is easy to handle and has the potential to produce high quality silage with less waste in a well-sealed bag. However, it is not recommended for coarse materials, such as banana trunk and cassava leaves, which can puncture the bag and render the contents useless.

After approximately 6 weeks, the farmer can open the silo and start to feed silage to animals. Silage can be suitably preserved for as long as air is kept away from the ensiled material; it is therefore possible to store air-tight silage for more than 6 months. Once the silo is open, care must be taken to cover again the ensiled material after each opening that is made to feed the animals.

5. Practical examples of successful silage combinations

Crop residues and by-products vary in their composition and physical structure. Within this paper it is impossible to provide a review of all combinations possible in silage making and therefore it will be restricted to those which have been successfully applied. However, in order to succeed in silage making**,** the following guidelines must be respected:

1. Carbohydrate or energy-rich feeds: such as crop roots, rejected bananas, and fruit wastes, can be successfully ensiled alone.

2. Energy/protein-rich by-products: such as spent grain, tomato pulp can be successfully ensiled alone.

3. Fibre-rich feeds with low energy and protein concentrations, such as banana pseudostems, olive cake, grape marc are better utilised when ensiled in combination with energy-rich by-products.

4. Protein-rich feeds with low energy-content, such as cassava leaves, fish wastes and poultry litter should not be ensiled alone. However, this type of feed can be successfully ensiled when mixed with one or several energy-rich products such as crop roots, rejected bananas, spent grain and molasses. This type of silage is highly recommended because it provides a balanced diet.

5. Incorporation of molasses to silage is optional; nevertheless, this is an excellent additive to ensure a good conservation and enhance high silage quality of any ensiled feed resource.

Incorporation rate of the different ingredients to be ensiled is function of:

- Available amount of by-products

- Animal categories to be fed. For example a high-quality silage, containing increased proportions of energy-rich ingredients such as spent grain and crop roots, should be prepared for high producing dairy cows. Whereas high proportions of cassava leaves and banana pseudostems can be used when there is seasonal feed shortage and therefore when silage would compose the bulk diet, during off-season feeding.

Several silage combinations from various by-products and crop residues have been successfully developed in two projects funded by the Technical Co-operation Programme of FAO, first in Samoa: (FAO-TCP/SAM/6611): Milk Production Areas and Small Milk Processing Units, repeated subsequently in Tonga: (FAO-TCP/TON/8821): Smallholder Forage Based Dairy Production and expanded to a South Pacific Sub-Regional basis in: GCP/SAM/007/FRA: Dairy Production and Processing Units.

As an example the following silage combination (on % weight basis):

- chopped cassava leaves (15),
- chopped cassava roots (25);
- chopped banana pseudostems (10),
- spent grain (30),
- poultry litter (10) and
- molasses (10)

was efficiently preserved, with a good smell and low pH (between 3.5 and 4.5); the silage when fed as a supplement to grazing dairy cows caused a big increase in milk production in those South Pacific Islands. The impact has been excellent; smallholders were particularly impressed by the ease with which they could use locally available materials to quickly and cheaply increase milk production. The improved performance due to supplementary feeding with silage has been manifested by fast and very significant increases of milk production. As most of project co-operating farmers are selling milk, this positive production effect of feeding silage has been directly translated into immediately increased financial returns.

Two suitable dairy rations are hereafter presented, where basal diet is grazing improved pasture under coconut plantations or cut-and-carry elephant grass.

Case 1: Basal diet while grazing improved pasture under coconut plantations:

Feed Supplements Kg/day (fresh basis)	Milk Yield, kg/day				
	5	**10**	**15**	**20**	**25**
Copra meal	1	2	3	3	3
Spent grain			5	10	10
Silage* (30% DM)		10-15	15-20	20-25	20-25

(*) as presented in the above paragraph

Case 2: Basal diet is chopped Elephant grass (cut-and-carry system)

Feed Supplements Kg/day (fresh basis)	Milk Yield, kg/day				
	5	**10**	**15**	**20**	**25**
Chopped Elephant grass	40	40	40	50	50
Copra meal	1	2	3	3	3
Spent grain		10	15	20	25
Silage (30%DM) (*)		10	15	25	25

(*) as presented in the above paragraph

Large amounts of agro-industrial by-products and crop residues produced in the Mediterranean basin (citrus pulp, grape marc, tomato pulp, olive cake, wheat bran, etc.) have been successfully ensiled in different ways as sole ingredients or in different associations. Such silage making practices are extensively practised by numerous farmers and replace conventional feedstuffs, including imported concentrates (Kayouli *et al.* 1993; Kayouli 1989; Hadjipanayioutou 1987; 1993).

Table 2: Feed intake and performance of growing lambs fed an ensiled poultry diet or concentrate diet (12 animals per treatment ; 66 days trial) (Kayouli *et al.* 1993)

	Ensiled poultry litter diet[1]	Concentrate diet
In vivo OM digestibility (%)	61.4	74.9
Retained nitrogen (g/day)	33.0	37.2
Feed intake (g DM/day)	1520.0	1098.0
Daily gain (g/day)	252.8	221.2
Feed conversion (kg DM/day)	6.1	5.4
Carcass yield (%)	47.5	45.1
Feed cost (U.S.$/kg gain)	0.4	0.8

(1): Poultry litter was ensiled with olive cakes and wheat bran in the following proportion on a dry matter basis: 45:45:10 w/w/w for the three ingredients respectively. Water was added to obtain 50 % DM in the silage, based on DM contents of the ingredients.

Screened poultry litter has been successfully ensiled with olive cakes and wheat bran (45:45:10% w/w/w, dry matter basis). After 6 weeks, results indicated that the ensiling technique is efficient for conservation of poultry litter at low cost and to eliminate health hazards. The litter silage was substituted for commercial concentrate and soybean meal and fed to lambs in a growing trial during 66 days (Kayouli *et al.* 1993). Results in Table3 show that daily gain and feed intake registered with the experimental diet were higher than those on the concentrate diet; meanwhile feed cost was lowered by 50% with the poultry litter silage group.

In another trial on beef fattening (Kayouli 1989) an experimental diet containing ensiled sugar beet pulp and poultry litter was compared to control diet (sugar beet pulp and concentrate with high content of soybean meal) fed to fattening beef during 150 days period. Animal performances (growth rate, feed conversion and carcass quality) were similar while feeding cost was reduced by 20% with the experimental diet.

6. Conclusion

In order to increase farm incomes from livestock in developing countries, an adequate low-cost feeding system must be developed.

Making silage from agricultural, agro-industrial and fishery by-products is a proven system, which offers considerable potential to improve farm incomes and profits.

Agriculture Ministries should survey the types, qualities, quantities and seasonal availability of by-products produced in their country. The current levels of utilisation should also be assessed.

Whilst farmers will tend to opt for utilising by-products they can easily identify and acquire locally, Government officers can improve by-product utilisation by assessing the "whole picture" of by-product availability and advising farmers accordingly.

Practical programmes of research and extension are recommended in each country. These should create and demonstrate a range of model feeding systems based on ensiled by-products [in addition to other available feeds]. These feeding systems would have formulations based on regional/national by-product availability, feeding requirements and critical annual periods of feed shortage.

Development of by-product silage production can yield continuity of quality feed availability even in times of drought, at low cost. Small farmers easily make these feeds with simple technology.

Different types of silage can be made by altering the formula [the choice and mix of by-products]. In this way the individual needs of different classes of livestock can be met.

Wider adoption of these technologies will benefit low-income rural communities through improved income and food security and also the wider community via the better availability of reasonably priced animal products and by a decrease in pollution formerly caused by wasted by-products.

7. References

Bouqué, C.V. and Fiems, L.0. 1988. Vegetable by-products of agro-industrial origin. *Livestock Production Science* 19, 97 - 135.

Hadjipanayiotou, M. 1987. Experience in the Near East with the utilization of non-conventional feedstuffs and the various systems of feeding. *Animal Production and Health Paper no. 54*; FAO, Rome, pp 185 - 210.

Hadjipanayiotou, M. 1993. Voluntary intake of citrus pulp-poultry litter silage by growing female Friesian calves, chios lambs and Damascus kids. *Technical Bulletin 155*. Agricultural Research Institute, Nicosia.

Hadjipanayiotou, M. 1994. Voluntary intake and performance of ruminant animals offered poultry litter olive cake silage. *Livestock Research for Rural Development* **6**:10.

Kayouli C., 1989: A strategy for animal nutrition in the dry subtropics. *International Symposium on the Constraints and possibilities of ruminant Production in the Sub-Tropics* (MOA of Egypt, ESAP, EAAP, FAO, ICAMS, WAAP), Cairo, Egypt, November 1988. Pudoc Wageningen, pp 201 - 206.

Kayouli C., Demeyer D. and Accacha M., 1993: Evaluation of poultry litter and olive cakes as an alternative feed for ruminant production in Tunisia. *Proceedings of the International Conference on Increasing Livestock Production through Utilisation of Local Resources* October 18-22, 1993 Beijing, China. pp 420 - 440

Kayouli, C. and Lee, S. 1998: Supplementary feeding for dairy smallholders in Pacific Island Countries: Fiji, Samoa, Vanuatu, Cook Islands, Solomon Islands and Tonga. In: Manual of Smallholder Milk Production in the South Pacific, (Eds. Stephen Lee, Roderick Kennard and Chedly Kayouli), FAO Sub-Regional Office for the Pacific, Apia, Samoa, pp.: 67 - 101.

Lien, L.V., Sansoucy, R. and Thien, N. 1994. Preserving shrimp heads and animal blood with molasses and feeding them with a supplement for pigs. In: Proceedings of National Seminar-Workshop "Sustainable Livestock Production On Local Feed Resources" (Eds. T.R. Preston, B. Ogle, Le Viet Ly and Lu Trong Hieu), Ho Chi Minh City, November 22 - 27, 1993. pp. 59 - 62.

Mc Donald, P. 1983: *Hannah Research Institute Annual Report* pp 59 - 67.

Thomas, C. 1985: In: Recent Advances in Animal Nutrition,. (Eds. W; Haresign and D.J.A Cole). London: Butterworths, pp 223 - 256.

The potential use of tropical silage for livestock production with special reference to smallholders

David.H.Machin

CAMBAC Associates, Manor Farm,
Draycott Cerne Chippenham, Wiltshire, England.
E-mail: davemachin@aol.com

Summary

This paper considers the range of possible raw materials that can be used by smallholders in the tropics and the various ways in which they might be preserved and used as animal feeds following ensilation. It concludes that for the systems to be applied they must be uncomplicated, safe, repeatable, have a low investment cost, use locally sourced equipment and consumables and give a rapid and significant return on any investment. The greatest potential exists where a fermentation system is used to preserve materials. It also suggests that the use of forage silages by gestating sows and growing – finishing pigs might be an effective and economically viable system of feeding for smallholders.

1. Introduction

Forages have been preserved using acids for many years and the process is referred to as ensilation. This term has also been adopted to describe the preservation and storage of protein-rich materials such as fish and animal products to be used as animal feeds. More recently this process has been used to preserve carbohydrate rich materials, either alone or on fermentation with other materials.

The essential feature of this means of preserving organic materials is the use of acids. These can either be mineral or organic, which can be provided by direct addition or produced by fermentation. Clearly the choice of acid will affect the composition and use of the ensiled product as well as having financial implications for the economic viability of its use.

For such a system to be suitable for smallholders in the tropics it must: -

- Have low investment costs.
- Be reliable and repeatable.
- Use uncomplicated technology.
- Use locally sourced equipment and consumables.
- Be safe.
- Give rapid and significant returns on investments.

This paper will therefore consider the various alternative silage production systems in the context of the above requirements.

Furthermore, since the large-scale ensilation of forage crops is well established world wide, this paper will focus on the use of wastes and by-products that otherwise would be un- on under-utilised as well as the non- conventional use of forage silage by other species than ruminants.

2. Conventional processing of perishable wastes and by-products

Traditionally, most wastes used as animal feeds are heat-treated to sterilise the materials and if the heat-treated product cannot be utilised locally or in a short time the product would then be dehydrated to facilitate storage and transport. Such processing is generally carried out where waste materials are available in large quantities on a regular basis and where the final product is of medium to high value. Such circumstances are unlikely to apply to smallholders.

Whilst cooking of perishable materials is commonly and successfully carried out by smallholders for materials that are to be used within a short time, the dehydration process is less commonly and successfully practised. The exception to this is where local fish meals are manufactured using sun drying. This type of processing is generally carried out in unhygienic conditions with the meals frequently becoming contaminated with bacteria.

Smallholders are likely to have only small to medium quantities of materials available for processing, which are likely to be used for local consumption.

In such circumstances, and where materials cannot be used immediately, the use of ensilation for the processing and storage of small to medium quantities of organic material could be a useful system.

3. Materials that could be suitable for ensilation by smallholders

Almost all organic materials could be suitable substrates for ensilation in one form or another. The decision on the approach and technique to apply will depend upon:

- The composition of the material including dry matter content.
- The type and degree of pathogenic and fermentative bacteria contamination.
- The buffering capacity of components of the material.
- The presence of potential autolysing enzymes in the main substrate or naturally present bacteria.
- The availability of other materials, such as acids, fermentable substrates and fermentative bacteria to assist inensilation.
- The cost of preservation using the technique in the prevailing circumstances.

Considering these criteria it is clear that the range of possible ensilation processes consist of the following:

- Ensilation using acids produced by the fermentation of carbohydrates within the material by naturally present bacteria or cultures of added bacteria.
- Ensilation using acids produced by the fermentation of carbohydrate rich materials added to the substrate to be preserved using fermentative bacteria as in 1.
- Ensilation using added inorganic acids such as hydrochloric or sulphuric acids or mixtures of such acids.
- Ensilation using organic acids such as formic, propionic or acetic acids or mixtures of such acids.

4. Ensilation using naturally present bacteria

This type of ensilage is typical of that carried out with plant materials having a low buffering capacity, a dry matter content higher than 20%, a fermentable carbohydrate concentration of between 5 and 20% and with naturally occurring lactic acid fermentative micro-organisms present.

This traditional silage making process has been extensively reviewed and the present paper will only consider the possible use of this type of material for animal species not traditionally fed such materials.

4. 1. The use of ensiled forages for non-ruminant animals

Whilst ensiled forages have commonly been fed to ruminants in all parts of the world, such materials have rarely been fed to monogastric animals, such as pigs, in commercial situations.

Currently, there is considerable interest in the possibility of feeding forages, including those preserved by ensilation, to pregnant sows in order to improve their reproductive performance through improved welfare. (Lee and Close 1987). In this situation it is agreed that most pregnant sows suffer stress through being fed relatively small quantities of compound feeds (approx.2.2 kg) when their appetite would be for two or three times that amount.

The main objective is to prevent such animals becoming over-fat, which is associated with breeding problems. It is proposed that by feeding such animals on low nutrient dense feeds to appetite they would be less stressed, stay within targeted weights, which could result in improved reproductive performance, longer reproductive life and lower feed costs.

Ensiled forages would be ideal materials for use in such circumstances, since pigs would be able to digest all enzymically digestible components in the upper gut and then through fermentation in their lower gut digest fibrous materials and absorb the associated products.

Similarly, work with such materials has been carried out with growing pigs. It has been demonstrated that the guts of commercial type pigs (large white, landrace, etc) are able to use such materials from about 50 kg liveweight (Machin 1990). However, where such a feeding system is practised the rate of gain has been correspondingly less than where commercial feeds were used. Nevertheless, such low cost feeds might well be financially attractive in circumstances where compound feeds are expensive and where through lower labour and housing costs a better margin can be obtained using such an approach.

The use of ensiled forages could offer considerable benefit for smallholder pig farmers in the feeding of gestating sows and growing/fattening pigs. However, due to the high nutrient demands of lactating animals this system would not be recommended for lactating sows.

The remainder of this paper will concentrate on the application of the ensilation process to store and preserve non-forage, nutrient rich, perishable materials.

5. Non-forage materials for silage production

The materials that have been preserved by ensiling can be divided into those that produce acids through anaerobic fermentation which preserve the unfermented remainder of the substrate and those that are preserved by acids added directly or produced by the fermentation of materials mixed with them. Many of these materials also undergo autolysis of the substrate using naturally containing autolytic enzymes as a secondary phase of preservation.

5.1. Fermentable substrates

These materials contain carbohydrate that can be fermented to produce acids such as lactic or acetic acid. Clearly, such a process requires the presence and action of micro-organisms. These may be naturally occurring or may be added as a separate culture (Martin and Bozoglu 1996). Similarly, some substrates may contain insoluble carbohydrates that are not readily fermentable and require enzymes to break them down into simple soluble carbohydrates that can be fermented. These can then generate acids to preserve the remainder of the material or mixture.

Examples of materials that have been used as fermentable substrates

Sugar Industry by-products	**References**
Molasses – Sugar Cane.	(Evers and Carroll 1998,)
Molasses – Beet.	(Fagbenro and Jauncey, 1998)
Sugar Cane Wastes	Alimon et al, 1994,)
Fruit Wastes	
Bananas.	(Ash and Elliott, 1991,)
Papayas.	(Bello and Fernandez, 1995,)
Pineapple.	(Bello and Fernandez, 1995, ,)
Citrus.	(Megias et al, 1998)
Apple Pomace.	(Nikolic and Jovanovic, 1986,)
Kiwi Fruit.	(Ciruzzi et al, 1996)
Grape Waste.	(Nou et al, 1981,)
Other Agro-industrial Wastes	
Brewery and distillery wastes	Pelz and Hoffman, 1997
Vegetable processing wastes	Ashbell *et al.* 1995
Milk by- products	Sander *et al.*1995
Flower wastes (carnations)	Ceron *et al* 1996)
Taro roots	Ash and Elliott 1991
Cassava root wastes	Fagbenro and Bello 1997
Bakery by-products	Bastian 1990
Olive waste	Hadjipanayiotou and Koumas 1996
Tofu wake	Niwa and Nakanisi 1995
Sisal waste	Rodriguez *et al.* 1985
Oil palm fronds	Abu Hassan *et al.* 1996

To the other extent materials rich in soluble carbohydrates, e.g., fruits, sugar cane or beet products etc. are capable of preserving materials at relatively low dry matter levels through osmotic effects alone without the need for acid fermentation.

The preceding list of materials that have been successfully ensiled demonstrate the broad range of products that can be preserved in this way. However, only those with high levels of soluble carbohydrate, such as sugar and fruit products are likely to be able to produce sufficiently high levels of acid by fermentation to assist in the storage of non-fermentable materials.

Clearly, ensilation could be a useful means of preserving a wide range of perishable materials that would otherwise be unused as animal feeds.

Examples of non-fermentable materials that have been preserved by ensilation

Slaughter house wastes	**References**
Poultry carcass waste.	Machin *et al*. 1984
Poultry viscera.	Fagbenro and Fasakin
Hatchery waste.	Deshmukh and Patterson
Feather meal.	England *et al*. 1991
Large animal carcass waste.	Machin 1986
Blood.	Le-Van-Lien *et al*. 1996
Fishery Wastes	
Waste whole fish	Machin *et al*. 1990
Shrimp by-catch	Ames and Ward
Salmon viscera	Dong *et al*. 1993
Scallop viscera	Myer *et al*. 1990
Prawn and shrimp heads	Le-Van-Lien *et al*. 1996; Evers and Carroll 1998
Crab waste	Evers and Carroll 1996
Fish viscera	Ahmed *et al*. 1996

Many of the above materials are available to smallholders in small to medium quantities in a variety of locations around the world. A simple low capital process such as ensilation could be an attractive way of preserving such materials. Quite clearly, matching the availability of suitable supplies of fermentable materials to mix with these types of materials could cause logistical difficulties. In such circumstances the use of low cost by-products such as fruit wastes would be the first choice with more expensive sugar by-products used as back up materials.

However, the main problem with such an approach for smallholders would be the higher degree of technical knowledge required to be able to change systems to meet variations in raw material availability. Unless fermentable and non fermentable proteinacious material supplies are available at the same time it might be best to place most emphasis on the use of storable fermentable materials such as molasses for this type of processing for smallholders.

6. The use of directly added acids in ensilation

Considerable research has been carried out on the preservation of perishable proteinacious wastes using added acids.(Machin 1986; Perez1995). Initial studies focussed on the use of mineral acids such as hydrochloric, sulphuric or phosphoric acids, but these alone were shown to be poor preservers ofsilages (Disney *et al.* 1977) Silages have, however, successfully been made using mixtures of organic (formic, propionic, citric, etc.) acids and mineral acids or organic acids alone (Perez 1995). Nevertheless, the use of direct addition of organic and /or mineral acids is very unlikely to be a means by which smallholders could process feed materials due to the cost and danger of handling strong acids in low technology situations.

For this reason it would appear that the most appropriate way that smallholders will be able to use the acid ensilage process will be through a natural fermentation system.

7. The use of fermentation silage

In recent years most researchers in this field have focussed on this approach to processing small to medium quantities of perishable organic materials. Although some researchers have been able to get successful fermentation using sources of fermentable carbohydrates alone mixed with non fermentable materials (Raa and Gildberg 1982) most have used lactic acid bacterial cultures to stimulate fermentation. Some of the most successful bacteria that have been used include;- *Lactobacillus plantarum*, *Streptococcus faecium* and *Pediococcus acidilactici* (Deshmukh and Patterson 1997)

However, the use of bacterial cultures would obviously be a deterrent for low technology processing by smallholders. It is therefore interesting to note that although raw materials low in lactic acid bacteria content generally benefit from the use of suitable inoculants it is not always essential that they be included (Martin *et al*.1995).

There are also reports that if the raw material already has a high concentration of lactic acid bacteria, inoculants do not improve the process (Desmulch and Patterson 1997)

It would therefore appear that smallholders could well be able to produce fermented silages without the need to produce or purchase starter cultures provided that appropriate mixtures of fermentable and non-fermentable materials are selected. To the other extent, where mixtures not capable of generating a rapid fermentation and sufficiently low pH have been tried, successful silage production has not been achieved (Urlings *et al*.1993).

In this context it is interesting to note that non-fermentable materials, which have been preserved by mixing them with fermentable carbohydrates, include poultry slaughter house wastes, hatchery waste, large animal slaughter house waste, whole waste fish (fish viscera, shrimp by-catch), shrimp and prawn heads and crab waste.

8. Health implications of feeding silage

There is considerable concern about the presence of pathogenic bacteria in food materials fed to farm animals. Unfortunately, many of the materials listed above as possible substrates for preservation through ensilage could well be contaminated with such bacteria. The acid ensilage process has been shown to be an effective means of reducing or eliminating pathogens and indicator organisms in materials such as poultry slaughter house wastes, hatchery waste and fishery waste. Many other researchers reviewed in Machin (1986) showed a range of silages to be free from coliformes, *Salmonella* spp, *Clostridia* spp, *Staphylococcus* spp, and faecal *Streptococcus* and to have a very low bacteria count or to be bacteria free. This concept is supported by Frazier and Westhoff (1978) who showed that all common bacteria which cause food-borne infections are inhibited at pH values below 4 and in the case of *Clostridium botulinum* toxication is prevented below pH 4.5.

In particular, fermentation of such inedible wastes has been shown to decrease the numbers of Gram-negative pathogens (Talkington *et al.* 1981) and viruses (Wooley *et al.* 1981).

The means by which this occurs relates to the effect of low pH, the presence of antibiotic substances produced by lactic acid bacteria and the ability of organic acids to pass over the cell membranes of micro-organisms by dissociation and lower the organisms internal pH to destructive levels (Raa and Gildberg 1982). Lactic acid bacteria also produce antibiotics and bacteriocins which are often bacteriostatic against other bacterial species (Urlings *et al.* 1993). Mineral acids do not have the same dissociating ability as organic acids and so are much less effective in silage production.

Many wastes of animal and fish origin contain autolytic enzymes, which at low pH, are able to break down large organic molecules so exposing any micro-organisms present in the waste to anti-microbial action (Backhoff 1976).

9. The use of ensiled wastes

Following ensilation most animal wastes have been successfully processed and fed to a wide range of domestic animals without problem. Perez (1995) noted that fish silages were suitable for feeding to pigs, poultry, ducks, ruminants and camels. Other researchers have successfully fed fish silages to farmed fish. Many others have shown that materials such as poultry slaughter house and hatchery waste as well as ruminant offal silage could be successfully fed to pigs, poultry, mink, fish (catfish – *Clarias gariepinus*, the common carp – *Cyprinus carpio*) compared with control feeds.

10. Conclusion

It is clear that the ensilation of waste materials could offer a simple and inexpensive means by which smallholders in certain circumstances might be able to process and preserve a wide range of materials for use in animal feeding. However, there are likely to be many situations where the correct balance of materials and knowledge are not in place and so this approach should not be applied. In particular, most benefit is likely to occur using fermentation not requiring the use of prepared bacterial innoculants.

11. References

Abu Hassan, O., Ishida, M., Dukri, I. Mohd S and Tajuddin, Z. Ahmad. 1996. Oil palm fronds as a roughage feed source for ruminants in Malaysia. *Extension Bulletin 420*. Food & Fertilizer Technolgy Center for ASPAC Region, Taipei, Taiwan.

Ahmed.J.,.Ramesh, B.S.and Mahendrakar, N.S.. 1996. Changes in microbial population during fermentation of tropical freshwater fish viscera. *Journal of Applied Bacteriology* **80**, 153-156.

Alimon., A.R., Lim,S.Y.,. I. Dahlan, Halin, I., Djajanegara, A.., and Sukmwati, A.. 1994. Effect of urea treatment on intake and digestibility of sugarcane waste by goats. *Proceedings of the 7th AAAP Animal Science Congress*, Bali, Indonesia, 2, 109-110.

Ames.G.R. and Ward, A.R. 1995. Problems of utilising shrimp by-catch in the tropics. *Tropical Science* **35**, 411-417.

Ash, A.J., and Elliott, R. 1991. Tropical crop and crop by-product additives can improve the quality of taro leaf (*Colocasia esculenta*) silage. *Journal of Agricultural Science* **117**, 233-240.

Ashbell. G.,. Weinberg, Z.G and Hen, Y.1995. Studies of quality parameters of variety ensiled broiler litter. *Animal Feed Science and Technology* **52**, 271-278.

Backhoff, H.P. 1976. Some chemical changes in fish silage. *Journal of Food Technology*. **11**, 353-363.

Bastian, R.W. 1990. The use of enzymes and bacteria to successfully upgrade animal offal. Biotechnology in the feed industry. *Proceedings of Alltech's Sixth Annual Symposium* (Ed. Lyons, T.P.) pp 405-418.

Bello, R.A. and Fernandez, Y. 1995. Evaluation of biologicl fish silage in broiler chicken. *Archivos Latinoamericanos de Nutricion.* **45,** 134-139.

Ceron, J.J., Hernandez, F., Madrid, J. and Gutierrez, C.. 1996. Chemical composition and nutritive value of fresh and ensiled carnation (Dianthus caryophyllus) by-product. *Small Ruminant Research* **20,** 109-112.

Ciruzzi. B.,. Laudadio, V.,.Vincenti., A and Marisco, G. 1996. Ensiling of refuse kiwifruit and utilisation in ruminant nutrition. *Agricultura-Mediterranea* **126**, 5-12.

Deshmukh, A.C., and P.H. Patterson. 1997. Preservation of hatchery waste by lactic acid fermentation. 1. Laboratory scale fermentation. *Poultry Science* **76**, 1212-1219.

Disney, J.G, Tatterson, I.N., and Olley, J. 1977. Recent Development in fish silage. Proceedings of Conference on Handling, *Processing and Marketing of Tropical Fish. London.* Tropical Products Institute.

Dong, F.M., Fairgrieve, W.T. Skonberg, D.I. and Rasco, B.A.1993. Preparation and nutrient analyses of lactic acid bacterial ensiled salmon viscera. *Aquaculture* **109**, 351-366.

England., M.L., Combs, D.K., and Shaver, R.D.. 1991. Aniaml protein by-products and level of undegraded intake protein indiets for early lactation dairy cows. *Journal of Dairy Science* **74**, 215.

Evers.D.J. and Carroll, D.J.1996. Preservation of crab or shrimp waste as silage for cattle. *Animal Feed Science and Technology* **59**, 233-244.

Evers, D.J. and Carroll, D.J. 1998. Ensiling salt – preserved shrimp waste with grass straw and molasses. *Animal Feed Science and Technology* **71**, 241-249.

Fagbenro, O.A., and Bello. O.O.A. 1997. Preparation, nutrient composition and digestibility of fermented shrimp head silage. *Food-Chemistry* **60**, 489-493.

Fagbenro.O.A., and Fasakin, E.A.. 1996. Citric acid ensiled poultry viscera as protein supplement for catfish (*Clarius gariepinus*). *Bioresource - Technology* **58**, 13-16.

Fagbenro.O.A, and Jauncey, K.. 1998. Physical and nutritional properties of moist fermented fish silage pellets as a protein supplement for tilapia (*Oreochromis niloticus*). *Animal Feed Science and Technology* **71**, 11-18.

Frazier. W.C., and Westhoff, D.C.1978. Food Microbiology, Third Edition, McGraw-Hill.

Hadjipanayiotou, M., and Koumas, A.. 1996. Performance of sheep and goats on olive cake silages. *Technical Bulletin Cyprus Agricultural Research Institute.* No, 176, 10pp.

Le-Van-Lien, Nguyen-Thein, Le-Viet-Ly and., Pryor, W.J. 1996. By-products from food industries: processing and utilisation for animal feed in Vietnam. Exploring approaches to research in the animal sciences in Vietnam: a workshop held in Hue, Vietnam, *ACIAR Proceedings* No. 68. 149-152.

Lee, P.A. and Close, W.H. (1987) Bulky Feeds for Pigs: a consideration of some non-nutritional aspects. *Livestock Production Science*, **16**, 395-405.

Machin.D.H.,. Hector, D.A., Capper, B.S.., and Carter, P.M.. 1984. The utilisation by broiler chickens of poultry offal hydrolysed in formic acid. *Animal Feed Science and Technology* **11**, 247-260.

Machin,D.H. 1986. The use of Formic Acid Preserved Meat and Fish Offal Silages in Pig and Poultry Feeding. *Ph.D Thesis*. Reading University. 221pp.

Machin, D. H. 1990. Alternative Feeds for Outdoor Pigs. In: Stark, B. A., Machin., and Wilkinson.(Eds) Outdoor Pigs. Principles and Practice. Chalcombe Publications, Marlow, Bucks.103 – 114.

Machin,D.H., Panigrahi ,S., Bainton, J. and Morris, T.R.. 1990. Performance of broiler chicks fed on low and high oil fish silages in relation to changes taking place in lipid and protein components. *Animal Feed Science and Technology* **28**, 199-224.

Martin,A.M., and Bozoglu, T.F. 1996. Role of lactic acid fermentation in bioconversion of wastes. *Lactic acid bacteria: current advanced in metabolism, genetics and applications.* 219-252.

Megias. M.D., Hernandez F., Cano, J.A..,.Martinez, T.A and Gallego, J.A. 1998. Effects of different additives on the cell wall and mineral fractions of artichoke (*Cynara scolymus* L). *Journal of the Science of Food and Agriculture* **76**, 173-178.

Myer, R.O.,.Johnson., D.D,. Otwell, W.S.,. Walker, W.R., and Combe, G.E.. 1990. Evaluation of scallop viscera silage as a high protein feedstuff for growing finishing swine. *Animal Feed Science and Technology*. **31**, 43-54.

Nikolic, J.A., and Jovanovic. M. 1986. Some properties of apple pomace ensiled with and without additives. *Animal Feed Science and Technology* **15**, 57-67.

Niwa, Y. and Nakanisi, G. 1995. Research on the utilisation of food by-product to growing and finishing pigs:2 The effects of Tofu cake silage feeding on growth and body fat. *Japanese Journal of Swine Science* **329**, 1-7.

Nour., A.A., Nour.,A.M., El-Shazely, K. A., Abaza, M., Borhami,B.E. and Naga. M.A., 1981. Evaluation of some agro-industrial by-products for sheep and lactating cows. *Alexandria Journal of Agricultural Research* **29**, 1125-1142.

Pelz, D., and Hoffman, S. 1997. Dewatering, compacting and ensilaging of spent grains. *Brauwelt* **15**, 436-439.

Perez, R. 1995. Fish silage for feeding livestock. *World Animal Review* **82**, 34-42.

Raa, J. and Gildberg, A. 1982. Fish Silage: A review. *C.R.C. Critical Review of Food Science and Nutrition*. **16**, 383-419.

Rodriguez, A., J.A. Riley and W, Thorpe. 1985. Animal performance and physiological disturbances in sheep fed diets based on ensiled sisal pulp (Agave fourcroydes). *Tropical Animal Production* **10**, 23-31.

Sander, J.E., Cai, T. and Barnhart, H.M. jr. 1995. Evaluation of amino acids, fatty acids, protein,fat and ash in poultry carcasses fermented with Lactobacillus bacteria. *Journal of Food Agric. Chem.* **43**, 791-794.

Talkington,F.D. Shotts,Jr, E.B. Wooley, R.E., Whitehead W.K. and Dobbins, C.N. 1981. Introduction and reisolation of selected Gram-negative bacteria from fermented edible wastes. *American Journal of Veterinary Science* **42**, 1298-1301.

Urlings, H.A.P, G.de Jonge., P.G.H. Bijker, and J.G. van Logtestijn. 1993. The feeding of raw, fermented poultry byproducts: Using mink as model. *Journal of Animal Science* **71**, 2427 – 2431.

Wooley.R.E.,. Gilbert, T.P. Whitehead, W.K. Shotts,Jr, E.B. and. Dobbins, C.N. 1981.Survival of viruses in fermented edible waste materials *American Journal of Veterinary Research* **42**, 87-90.

Grass and legume silages in the tropics

By Titterton, M.[1] and Bareeba, F. B.[2]

[1] Department of Animal Science, University of Zimbabwe, P. O. Box MP 167, Mt. Pleasant, Harare, Zimbabwe.
[2] Department of Animal Science, Makerere University, P. O. Box 7062, Kampala, Uganda.

Introduction

Livestock is recognized as being an integral component of mixed farming systems which predominate in the tropics, particularly in the developing world. Animal manure and traction make the land more productive than would be the case in their absence. Yet, it has been recognized with equal force that livestock owned in the developing world have had a devastating effect on the environment through overgrazing the natural vegetation leading to soil erosion, and ultimate desertification. Technologies aimed at achieving a balance whereby livestock can increase in productivity, so enhancing wealth for the livestock owner, while resource degradation is minimized must be developed (Steinfeld, 1998). One such technology is the conservation of forage produced during the wet season which can be fed to livestock kept in at least partially zero-grazed systems during the dry season. This may, in fact, be the only such technology that would ensure satisfying high demand for nutrients for such livestock production operations as small scale dairy farms in the semi-arid regions of the tropics (Dube, 1995).

To put the importance of ensiling tropical grasses and legumes to feed as conserved forages in the dry season in the tropics into perspective, one might ask the question "Why silage?

Why not hay? Surely with all that sun in the tropics, it should be easier and cheaper to make hay than silage?"

The answer to this lies with both season and plant physiology. A comparison can be made with countries where temperate climates allow both ensilage and hay making of rye grasses and legumes, which retain high nutritional quality and, which, with persistent rains and good soils, will provide sufficient regrowth for several cuts (New Zealand, Europe). Then there are those countries where irrigation is plentiful and cheap and legumes such as lucerne (alfalfa) can be grown in abundance for both silage and hay (USA). Other countries again have winter rainfall (Israel, Western Australia and the Cape of South Africa) where lucerne and winter wheat can be produced with relative ease.

In much of the rest of the tropics, the conditions are harsh for conserved forage. High temperatures combine with short rainy seasons on largely poor soils to produce grasses and legumes which, while able to produce high yields under good management, still deteriorate rapidly in nutritional quality after only three months of growth. Protein and digestibility both decline rapidly in tropical grasses after flowering, as lignification proceeds in most tropical grasses and legumes. In order to harvest grass and legumes of high nutritional quality, cutting has to take place at the early stage of growth, in fact while the rains are still prevalent. Unless a mower-conditioner is used with the harvested crop and it is then taken for treatment with bulk dryers in large hay sheds, it is unlikely a good hay crop can be produced at this time. This requires expensive machinery and buildings and even on the large livestock farms it is questionable as to whether it is economically justifiable.

The rains are hard and driving and will wet the entire crop which then leaches and rots. If harvesting for hay takes place after the rains, not only is the nutritional quality low but in legumes, leaf shattering is likely to occur at cutting, leaving largely poor quality stemmy hay. One could argue that with irrigation, winter (temperate) grasses and legumes could be produced for hay. This is certainly true and indeed is carried out on some of the large commercial dairy farms in the tropics. For smaller dairy farms, however, and certainly for the small-scale farms, irrigation is expensive and likely to provide better returns with horticultural crops than hay crops for livestock feeding. Thus we are left with the other option of conserving grasses and legumes, that of ensilage.

The feasibility of successful ensilage of tropical grasses and legumes

Tropical grasses and legumes are not natural ensilage material, largely because at cutting, they have a low content of water soluble carbohydrates, which are essential to successful ensilage (Table 1). This leads to them having a higher buffering capacity and leaves their proteins susceptible to proteolysis (Woolford, 1984)

However, there are a number of practices which contribute to improving the levels of fermentable carbohydrates, reduce buffering and prevent proteolysis and can succeed in producing good quality silage. These include:

1) Mixing legumes with cereal crops
2) Wilting
3) Silage additives
4) Small scale silos

Table 1. Water soluble carbohydrates WSC (mean values in g/kg DM forage followed by range in brackets) of silage forage crops.

Crop	WSC (g/kg DM)	Reference
Ryegrass	79 (5-220)	Thomas and Thomas (1985)
Maize	350 (280-510)	McDonald, *et al*., 1991
Grain sorghum	75 (56- 132)	Havilah and Kaiser (1992)
Sweet Forage sorghum	220 (180-250)	Mhere *et al*., 1999
Kikuyu	31 (23-41)	de Figueredo and Marais, 1994
Lucerne (alfalfa)	15 (4-20)	Waldo and Jorgensen, 1981

Mixing legumes with cereal crops

The main focus of research in intercropping legumes with cereal crops has been to increase grain yields of crops while improving soil fertility in farming systems in the semi-arid tropics (Willey, 1979) but little attention has, until recently, been paid to the benefits of intercropping cereal and legume for the production of high quality silage for livestock feeding.

Maize silage plays an important role as a winter feed in the livestock industries of many tropical countries. The main reasons for the popularity of maize for silage purposes is the high yield obtained in a single harvest, the ease with which it can be ensiled and its high energy value as a feed. However, its major shortcoming is undoubtedly its low crude protein content, which, on a dry matter basis, is usually of the order of 70 to 80 g/kg DM (Topps and Oliver, 1993). In the high rainfall subtropical areas of Zimbabwe and South Africa maize remains the preferred cereal crop for silage (Titterton, 1997) producing higher yields and higher energy content than grain sorghum, forage sorghum or pennisetums, as shown in Table 2.

Table 2. Yield, dry matter and energy content of maize and forage sorghum silages produced on sand and clay soils [1]

Crop	**Yield and energy content of silage**		**Reference**
	Yield (t DM/ha)	MJ/kg DM	
Maize (Var. SC BW93[1])	14.7	10.2	Titterton, 1997
Kikuyu	4.1	7.5	deFigueiredo and Marais, 1994
Grain sorghum (Var. MR Buster)	7.3	10.0	Cole et al., 1996
Forage sorghum (Sugargraze)[1,2]	7.4	9.5	Titterton, 1997

[1] These crops were produced at Henderson Research Station, Mazowe, Zimbabwe, av. yearly rainfall 980 mm.

[2] Sugargraze is a variety of forage sorghum recommended for silage, produced by Pacific Seeds, Australia.

In the semi-arid regions of the tropics, however, maize, being very susceptible to moisture stress, is questionable as the crop of choice for silage. Generally yields are poor and energy values much lower than that found in the higher rainfall areas. Alternative crops such as grain sorghums, forage sorghum and forage pennisetums which are drought tolerant yet high yielding, have been researched as silage crops and found to be suitable (Havilah and Kaiser, 1992; Mhere, *et al*., 1999) although it has been concluded after an evaluation of grain and forage sorghums in Australia that sweet forage sorghums offered better potential than grain sorghums under dryland conditions (Cole et al., 1996). Sweet forage sorghum yields have been higher under dryland conditions (Mhere, *et al*., 1999) than in the high rainfall area of Zimbabwe. Again, however, the limitation in terms of nutrient quality is the low protein content, which was, in forage sorghum and pennisetums, approximately 70g/kg DM and 95 g/kg DM respectively (Mhere *et al*., 1999). One method of improving the protein content of the silage is to add a protein rich crop to the cereal crop. This can be done either by intercropping the cereal crop with a legume or growing them as sole crops and mixing them at ensilage. The feasibility, therefore, of ensiling these crops with legumes has been investigated.

Maasdorp and Titterton (1997) examined the effect of intercropping (in-row) of fifteen tropical legumes with a variety of long-season maize popularly used for silage in Zimbabwe. Of these, forage and grain soybeans, lablab (dolichos bean) velvet bean, sunnhemp and cowpea proved the most promising but in-row intercropping with the maize which was at a density of 65 000 plants/ha did not prove to be viable; with the exception of velvet bean and lablab, the proportion of legume in the biomass was only 15%, not sufficient to make a significant difference to protein yield. Velvet bean and lablab swamped the maize, reducing maize yield. Indeed, it has been shown that proportion of legume and crude protein content of the silage was significantly affected by maize plant density and the time of sowing of each crop. Kaiser and Lesch, (1977) showed dolichos bean proved to be at its maximum proportion of 24% when maize plant density was at 54 000 plants/ha and crude protein content of the silage was 110 g/kg DM. In the same study, however, there was apparently no benefit in intercropping soybean with maize for mixed crop silage, whatever the density of maize. Maasdorp and Titterton (1997) showed that, by planting lablab and velvet bean into a maize crop two weeks after sowing maize, maize yield was not depressed and the legume dry matter yield constituted about 30% of total dry matter yield, bringing silage crude protein content to about 10.5%. Further research is required into the planting pattern and sowing times of maize and legume. While in-row intercropping is apparently the preferred regime for machine harvesting, where single-row cutting is the common practice, between row intercropping may be more beneficial in the case of small-scale farming systems where crops are cut by hand. Here, it is likely there would be less competition between maize and legume and there should be a greater contribution of legume to total yield, with significant improvement in protein content. There are many other benefits of intercropping: reduced soil erosion, incidence of pests and less labour requirements for weeding (Saleem, 1995).

When sole crops of maize and legumes were mixed at harvesting 50:50 by volume for ensilage (Titterton and Maasdorp, 1997) it was found that with all fifteen legumes, fermentation quality was acceptable (pH of the range 3.7-4.5; NH_3: N ratio < 12.0) with the exception of velvet bean, sunnhemp and silverleaf desmodium, while crude protein content had increased from 77 g/kg DM in pure maize silage to a range of 93 g/kg DM (yellow lupin) to 153 g/kg DM (forage soyabean). In the case of maize and dolichos bean it was 128 g/kg DM. This trial used recycled plastic garbage bags, in which the maize and legume was layered before compression with a tobacco press and the bags sealed with string. The quality of the silage gave an indication that this might be a suitable method for ensilage of mixed crops for small scale dairying.

When seven legumes (forage soya, grain soya, silverleaf desmodium, lablab, cowpea, lupin and velvet bean) were layered with maize for ensilage in pits, the silage was similar in quality to that of the same legumes proportionately mixed with maize in bags and were found, with the exception of silverleaf desmodium, to be of no significant difference to that of pure maize silage in palatability (dry matter intake) and effect on milk yield in Holstein dairy cows (Taruona and Titterton, 1996).

Agroforestry also offers potential for improving protein content of mixed silages. The addition of wilted <u>Amaranthus hybridus</u> to maize (1:1) at the time of ensiling resulted in good fermentation and raised the crude protein content of the silage from 6.9% to 11.6% and reduced the crude fibre content (Bareeba, 1977). Maasdorp and Titterton (1999) successfully ensiled, on a fresh mass ratio of 50:50, the leaf material of four varieties of forage tree legumes with maize with improvement of crude protein content to 14%, 15.5%, 17.2% and 18.7% in maize/Calliandra calothyrsus, maize/Glyricidia sepium, maize/ Leucaena leucocephala and maize/Acacia boliviana silages respectively. Only in the maize/Calliandra silage was organic matter digestibility significantly reduced, while in the other three, it was similar to that of maize silage. A similar trial is planned for forage tree legumes ensiled with forage sorghums and pennisetums.

As with maize, soybean has proved to be of little benefit when intercropped with grain sorghum (Kaiser *et al*., 1993). Sweet forage sorghum on the other hand, when intercropped with lablab in a planting pattern of 1 row sorghum and 1 row lablab, produced silage of good fermentable quality with a crude protein content of 120 g/kg (Mhere, *et al*., 1999). Sorghum and lablab silage has been produced elsewhere with reasonable success (Ojeda and Diaz, 1992; Singh *et al*., 1988).

Forage pennisetums have been successfully intercropped with legumes (Gill and Tripathi, 1991 and Bhagat, Prassad and Singh, 1992, Mhere *et al*., 1997) and ensiled with and without legumes (Mhere, *et al*., 1999; Crowder and Ghheda, 1982 and Bareeba, 1992) Mhere *et al*., 1999 found however, that soil type, planting pattern and weather had significant effects on proportion of legume in both forage sorghum and forage pennisetum crops.

Wilting

Tropical grasses and legumes need to be cut early in the vegetative stage for ensilage while protein and digestibility are high. However, mitigating against this is the relatively high moisture content of the plants at this stage, which can adversely affect fermentation quality of the silage. (McDonald *et al.*, 1991)

Ensiling material with less than 30% dry matter may create an environment which is totally anaerobic (suited to clostridial bacteria) rather than microaerophilic (suited to lactic acid bacteria). In addition, it may result in the loss of valuable nutrients as water and soluble nutrients accumulate at the bottom of the silo as silage effluent. In pit or bunker silos, this effluent can seep away and be lost to the silage. On the other hand, research into time of wilting has produced extremely variable results due, apparently, to weather conditions such as humidity, wind speed and ambient temperature prevailing at the time of the trial (McDonald *et al.*, 1991). Warm humid conditions, such as are found in the high rainfall, tropics, are not conducive to rapid field drying. Biochemical losses from respiration could be higher than losses from unwilted silage and digestibility of the silage is reduced (Thomas and Thomas, 1985). On the other hand, in the semi-arid tropics, it may be possible to achieve rapid wilting in the ideal three to five hours (Michelina and Molina, 1990; Alberto *et al.*, 1993) without resultant decline in digestibility and (Mayne and Gordon, 1986a) and improvement in fermentable quality of silage (Thomas and Thomas, 1985). This may only occur in silages which, without wilting are below 30% dry matter. In studies by Mhere *et al.*, 1999 while increasing wilting time within 12 hours showed no effect on digestibility of mixed forage sorghum/legume and pennisetum/legume silages; pH increased significantly. The dry matter content of these silages was, without wilting, already about 30% and higher, and within 6 hours was up to 40% and higher. This indicates that wilting reasonably dry crops in the field actually results in poorer fermentation probably due to decreasing effective compression in the silo. If the wilting period is extended over several days, soluble carbohydrates will be lost, protein nitrogen contents may be reduced and deamination of amino acids may increase (Henderson, 1993). Another factor which may be of importance is the silo. In pits or bunkers, where the large quantities of effluent produced by very wet material is lost and indeed may be a serious pollutant, wilting under the right conditions may be of benefit. In silos, particularly small ones, where the effluent is sealed in, however, this may not be so critical. In a study of small-scale silos (Ashbell *et al.*, 1999 and Titterton *et al.*, 1999) there are indications that the effluent, being retained in the silage, prevents mould and contributes to good fermentation in forage which has been coarsely chopped and manually compressed in the silo. In other words, the normal criteria for successful ensilage do not apparently apply when the silage is sealed into small portable silos.

In summary, wilting only appears to be necessary if crops in the field are still very wet at harvesting,, conditions are conducive to rapid drying and large silos are used to store the silage.

Additives

Additives are used to improve silage preservation by ensuring that lactic acid bacteria dominate the fermentation phase. Additives can be divided into three general categories: 1) fermentation stimulants, such as bacterial inoculants and enzymes, 2) fermentation inhibitors such as propionic, formic and sulphuric acids and 3) substrate or nutrient sources such as maize grain, molasses, urea and anhydrous ammonia (Woolford, 1984; Henderson, 1993 and Bolsen *et al.*, 1995). A number of trials produced the conclusion that only strong acids, either alone or in combination with formaldehyde have the potential consistently to modify fermentation (Thomas and Thomas, 1985). However, these have largely lost popularity due to both cost and handling difficulties on the farm. Bacterial inoculants have inherent advantages over other additives, including low cost, safety in handling, a low application rate and no residues or environmental problems. However, results of their application are variable probably due to the differing ensilage conditions prevailing at time of application. However, when applied together with enzymes which degrade plant cell walls and starch which could provide additional sugars for fermentation to lactic acid, they appear to have achieved improvement in fermentation and nutritional quality of tropical grasses and legumes (Bolsen, 1999) Studies with kikuyu grass silage, however, suggested that the grass needs to be rapidly wilted before an inoculant is added for an improved fermentation to be achieved (de Figueiredo and Marais, 1994) since there was no improvement when inoculants were added to unwilted grass. In a comparison of maize meal with a commercial silage additive (containing bacterial inoculant and enzymes), Mhere *et al.* (1999) found however that when added to forage sorghum/legume and forage pennisetum/legume mixtures, maize meal (5% of biomass) improved dry matter and both additives improved the nutritional content but had no significant effect on fermentation quality. This may be accounted for by the fact that the silages were stored in small sealed silos where, since the effluent was retained in the silage, there was no benefit to fermentation of the addition of either additive.

On small scale farms, commercial additives, which comprise inoculants and enzymes, may be be too costly or unavailable. It is likely therefore that the third category of additive will be of most benefit to silage made on small holdings. Possibly the most important benefit of additives such as maize or sorghum grain or cassava meal is to improve dry matter in early cut crops when moisture content is high and rapid drying (wilting) is not possible or where effluent is lost to the silage through seepage. Tropical grasses have been successfully ensiled when supplemented with maize meal (Onselen and Lopez, 1988) cassava meal (Panditharane *et al.*, 1986) and sorghum grain (Alberto *et al.*, 1993).

Molasses is the carbohydrate source used most frequently and is of particular benefit when applied to crops low in soluble carbohydrates such as tropical legumes and grasses. Good silages have been reported when molasses was applied at 3-5% (Bareeba, 1977; Sawatt, 1995). However, if the treated silage has a very low dry matter content, most of the carbohydrate source may be lost in the effluent during the first few days of ensilage in pits or bunkers.

Applying urea or anhydrous ammonia to silages has an adverse effect on fermentation and nutrient quality of silages, particularly high moisture forage sorghums (Bolsen, 1999), although Sarwatt (1995) obtained good silage by applying 0.5% urea to maize, sorghum and Rhodes grass in Tanzania. An additive with a urea/molasses blend is possibly the best combination to apply to tropical grasses if they are cut in early vegetative stage (Bolsen, 1999). More research is needed in this field, particularly in the ensilage of natural pasture tropical grasses.

Conclusion

In the tropics, particularly the semi-arid tropical regions, where the major constraint to livestock production is the lack of availability of fodder, conservation through ensilage of forage produced in the rains is likely to be the practice adopted by most small holder livestock owners, particularly those in dairy or beef production. It has been shown that ensilage of forage can be carried out with simple technology and that forages such as tropical grasses, forage legumes, forage tree legumes, forage sorghum and pennisetums can be produced and ensiled successfully this way. However, there is still much to be researched in how the quality of these silages, both in terms of fermentation and nutrition, can be improved through the use of intercropping or mixing at ensilage and with the use of additives. There is also potential for the ensilage of many agro-industrial by-products with forages and legumes and this needs increased attention in the field of research into low cost feeds for livestock.

References

Ashbell, G., T. Kipnis, Z.G. Weinberg, Y.Hen, A. Azriell, S.Kaller and M. Titterton. 1999. Developing a technology for ensiling forage crops for small-holder cattle owners in developing countries. In Proc. XIIth Int. Silage Conf. on Silage Production in Relation to Animal Performance, Animal Health, Meat and Milk Quality. Uppsala, Sweden. July 5, 1999.

Alberto, G., J.S. Portella and O.L.P. de Oliveira. 1993. Effect of addition of ground sorghum grain and of wilting on elephant grass. Grassland and Forage Absts. 65 (2).

Bareeba, F.B. 1977. The ensilage characteristics and nutritive value of maize, amaranthus-enriched maize and sorghum silages preserved with either molasses or formaldehyde. M. Sc. (Agric) Thesis, Makerere University, Uganda.

Bareeba, F.B. 1992. Forage conservation and utilisation. Nomadic Peoples 31: 91-96

Bhagat, R.K. , N.K. Prassad and A. P. Singh. 1992. Nitrogen levels and spacing of hybrid Napier intercropped with legumes. J. Res. Birsa Agric. Uni.4(1): 67-69

Bolsen, K.K. 1999. Silage management in North America in the 1990s. In (Eds. T.P. Lyons and K.A. Jacques) Biotechnology in the Feed Industry. Proc. Alltech's 15th Ann. Symp. Nottingham University Press, Nottingham, U.K. pp233-244.

Bolsen, K.K., G.Ashbell and J.M. Wilkinson. 1995. Silage additives. *In* (Eds. A.Chesson and R.J. Wallace) Biotechnology in Animal Feeds and Animal Feeding. VCH Press, Weinhein, Germany. Pp 33-54

Cole, C.A., A.G. Kaiser, J.W. Piltz and S. Harden. An evaluation of sorghums for silage production in Northern New South Wales. *In* (Eds. M.A. Foale, R.G. Henzell and J.F. Kneipp) Proc. III Aust. Sorghum.Conf. Tamworth, Australia. Feb, 1996. Aust.Inst.Ag.Sci., Melbourne. Occ. Publ. No. 93.

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

de Figuerido, M and J.P. Marais. 1994. The effect of bacterial inoculants on kikuyu silage quality . J. Agric. Sci. Cambridge. 122: 53-60.

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

Gill, A.S. and S.N. Tripathi. 1991. Intercropping leucaena with particular reference to hyprid Napier varieties. *In* Range Management and Agroforestry. 12 (2): 201-205.

Havilah, E.J. and A.G. Kaiser. 1992. Sorghums for silage: a review. Proc. 2nd Aust. Sorg. Conf. February 4th-6th, Gatton. Pp 338-54.

Henderson, N. 1993. Silage additives. Anim. Fd. Sci. and Technol. J. 45:35-56.

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

Maasdorp, B.V. and M. Titterton. 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. J. An.Fd. Sci. and Technol. 69: 241-261.

Maasdorp, B.V. and M. Titterton. 1999. The use of planted trees for fodder. *In* (Ed. T. Smith) Proc. Workshop on Livestock Production Research in the Semi-Arid Tropics, held by Dept. for Int. Devel. (DFID) Matopos, Zimbabwe. Feb.1999.

Mayne,C.S. and F.J. Gordon (1986b). The effect of harvesting system on nutrient losses during silage making. 2. In -silo losses. Grass and Forage Sci. 41: 17-26.

McDonald, P., A.R. Henderson and S.J. E. Heron. 1991. *In* The Biochemistry of Silage. 2nd Ed. Chalcombe Publications. Marlow, UK.

Mhere, O., B.V. Maasdorp and M. Titterton. 1999.*In* (Ed. T. Smith) Proc. Workshop on Livestock Production Research in the Semi-Arid Tropics, held by Dept. for Int. Devel. (DFID). Matopos, Zimbabwe. Feb**,** 1999.

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

Ojeda, F. and D. Diaz. 1992. Study of different proportions of sorghum and Lablab purpureus ensiled with and without additives. Grasslands and Forage Science Abst. 64: 1994.

Onselen, V. J. van and J. Lopez. 1988. Effect of addition of carbohydrate sources and of a commercial enzymatic product on the chemical and nutritional composition of elephant grass (Pennisetum purpureum) silage. Revista da Sociedade Brasiliera de Zootecnia. 17(5): 421-427. (Summary in English).

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

Saleem, M.A.M. 1995. Mixed farming systems in Sub-Saharan Africa. *In* (Eds. R.T. Wilson, S. Ethui and S.Mack) Livestock Development Strategies for Low Income Countries: Proceedings of the Joint FAO/ILRI Roundtable on Livestock Development Strategies for Low Income Countries. ILRI, Addis Abbaba, Ethiopa. 27Feb-27Mar.1995.

Sarwatt, S.V. 1995. Studies on preservation and evaluation of some tropical forages as silage. Ph.D. Thesis. Sokoine University of Agriculture. Tanzania.

Singh, C.H., K.S. Kohli, and D.N. Singh. 1988. Genetic improvement of forage legumes. In: Singh, P. (Ed.) Pasture and Forage Crops Research: Third International Rangeland Congress. New Dehli, India.

Steinfeld, H. 1998. Livestock and their interaction with the environment: an overview. In (Eds. M. Gill, T. Smith, G.E. Pollott, E. Owen and T.L. J. Lawrence) Food, lands and livelihoods- setting agendas for animal science. British Society of Animal Science. Occ. Publ. No. 21 pp 67-76.

Taruona, M. and M.Titterton. 1996. Effect of mixed-crop maize and legume silages on dry matter intake and yield and quality of milk of Holstein dairy cows. *In* Proc. Workshop on Maize for Crop/Livestock interaction in Sub-Saharan Africa held by Rockefeller Foundation. Africa University, Mutare. Zimbabwe. October, 1996.

Titterton, M. 1997. The feasibility of using forage sorghum in drought years for silage in Zimbabwe. *In* (Ed. R. Kirk) Proc. Annual General Meeting on Forage production for dairying in Zimbabwe, Grasslands Society of Zimbabwe. August, 1997.

Titterton, M. and B.V. Maasdorp. 1997. Nutritional improvement of maize silage for dairying: mixed crop silages from sole and intercropped legumes and a long season variety of maize. 2. Ensilage. J. An. Fd. Sci. and Technol. 69: 263-270.

Titterton, M., O. Mhere., B. Maasdorp, G. Ashbell, T. Kipnis, Z. Weinberg and Y.Hen.1999. The use of plastic bags and simple technology to ensile mixed cereal and legume crops for small-holder dairy cattle feeding in the dry season of semi-arid areas.. *In* (Ed. T. Smith) Proc. Workshop on Livestock Production Research in the Semi-Arid Tropics, held by Dept. for Int. Devel. (DFID). Matopos, Zimbabwe. Feb**,** 1999.

Thomas, C. and P.C. Thomas. 1985. Factors affecting the nutritive value of grass silages. *In* (Eds. D.J. Cole and W. Haresign) Recent Advances in Animal Nutrition. Butterworths, London. Pp 223-256**.**

Topps, J.H. and J. Oliver. 1993. Animal Foods of Central Africa. Zimb.Agric. J. Tech.Handb. 2,135.

Waldo, D. R. and N. A. Jorgensen.1981. Forage for high animal production: nutritional factors and effects of conservation. J. Dairy Sci. 64:1207.

Willey, R.W. 1979. Intercropping: its importance and research needs. II. Agronomy and Research Approaches. Field Crop Absts. 32 (2. Feb.1979.

Woolford, M.K. 1984. *In* The Silage Fermentation. Marcel Dekker, New York.

Use of ensiled forages in large scale animal production systems

Tom Cowan

Australian Tropical Dairy Institute, University of Queensland, Gatton 4345, Australia. E-mail: rtc@warigal.uqg.uq.edu.au

Summary

Incorporating silage into large scale feeding systems is often a matter of reallocating resources, rather than introducing totally new resources, and it is consistently more difficult to show a profit from reallocating resources than from introducing new ones. It is therefore imperative that the purpose of incorporating silage be clear. These purposes are defined as, drought feeding, production increases, an aid to pasture or crop management, utilisation of excess growth, balancing nutrients in the diet, and the storage of wet feed products. A general financial model is proposed for assessing the financial benefits of incorporating silage.

It is concluded that silage is most likely to be profitable when used to increase productivity or balance nutrient content of the diet. Special purpose crops such as maize and legumes will normally be used in these roles, and their use in the feeding program will be integrated with other demands on modern production systems, such as quality assurance and sustainability.

Introduction

Large scale and intensive systems of ruminant production are relatively new to tropical and subtropical zones. Though traditional systems of feeding were often intensive, utilising hand harvested forages and crop by-products; it is only recently that herds are being aggregated together in large-scale production units. This has been made possible by improvements in pasture and forage crop technology, or the availability of crop by-products from centralised processing facilities.

Silage has played an uneven role is these developments. There has been a tendency to equate the role of silage in these systems with that in temperate zones, and consequently much of the attention has been on the harvesting and storage of excess growth in the growing season for subsequent feeding during the dry season. The results of this practice have generally been disappointing. More recently attention has focused on the ensiling of special purpose crops, using these to increase productivity of the land, and this approach shows more promise. Ensiling has also been a convenient way of storing some wet by-products, such as pineapple skins and brewers grains.

Over the past 20 years there have been major advances in the technology of making and feeding silage (O'Kiely and Muck 1998). Much of this development has occurred in temperate zones, and there are needs for further research in tropical zones, in areas such as manipulation of microbial fermentation and the development of grass and legume crop silage. In general, however, the technology is adequate, and the difficulties are in integrating silage into profitable feeding systems.

This paper attempts to provide some guidelines to assist in integrating silage into feeding systems. Much of the information will be drawn from the experiences of dairy production systems in tropical and subtropical Australia.

Uses of silage

In large scale farming the use of silage is a business input. As with any business input it is essential to understand clearly the purpose of this input, and the likely consequences of its use. With silage the question is somewhat complicated by the fact that it is often a rearrangement of inputs already in the feeding system, rather than an additional input. It is consistently more difficult to demonstrate a profitable outcome from the rearrangement of inputs compared with an additional input (Cowan 1997).

The purpose for using silage has often been poorly defined. Very few feeding systems experiments have been done, and the bulk of the literature is on the making and feeding of silage. The introductions to these reports are dominated by reference to surpluses or gross deficiencies of forage at particular times of the year, and it is assumed that overcoming these will be advantageous to the farm business.

The advantages of using silage have generally been grouped under the following headings.

- As a drought reserve; where silage is made from pasture or crop in times of plenty and stored for a period of 1 to 20 years. The silage is fed to animals only in times of extreme feed deficiency.

- To increase productivity; where silage is routinely made as a means of increasing the amount of feed available to cows. The storage period is consistently less than 1 year, and the practice is often associated with a change from pastures to crops as a form of land use.

- To aid in the management of pasture or crop; where the pasture or crop is removed as silage to enable benefits to be accrued from other management practices. Examples are the increased tiller density and production of temperate pastures when excess growth is removed early in the growing season, and the removal of a crop to enable the earlier planting of a subsequent crop.

- The use of excess growth; where the rationale is that it is a waste to allow excess growth to mature and decay *in situ*, and it should be harvested for use in the future.

- To balance the nutrient content of the diet; where the silage is made with the intention of feeding it to provide nutrients lacking in feeds available at that time. Examples are the use of legume silage to feed with maize silage, maize silage to feed with grazed legume pastures, or silage of relatively high fibre content to feed with pastures of low fibre content.

- To enable storage of potentially unstable material; where the ensiling process ensures the feed can be used over an extended period. An example is the ensiling of wet by-products. This use is similar to that in the preservation of feeds through the addition of chemicals or exclusion of air from feeds such as high moisture grains.

All of these have the underlying assumption that it will be profitable to use silage in the feeding system.

Financial model

Given the wide array of potential types of silage and purposes of use, it is important to have an overall framework for the financial assessment of incorporating silage into the feeding system (Cowan and Kerr 1984). The model below allows at least the main sources of revenue and cost to be taken into account in planning for a silage program.

Net financial benefit =	increased income during feeding	+ indirect benefits	- penalty during silage making	- costs of silage
	Additional L milk, by price/L	e.g. extra days crop growth, or improved pasture growth	Loss of production, by price/L	Operating costs. Labour costs. Capital costs.

The key parameters influencing additional income during feeding are the quantity of silage fed and the quality of the silage in relation to the other feeds available to the animal at that time. The increased income must be substantial for the practice to be profitable, and to achieve this a large quantity of silage must be fed. In northern Australia, many farmers found that making small amounts of silage did not improve their financial position. Costs do not reduce in direct proportion to the amount of silage made, and a small advantage in milk production at one time of the year does not generate sufficient income to cover these costs. For example, farmers with herds of around 100 cows found that making in the order of 100 to 300 tonnes of maize silage did not provide a net benefit. These farmers have quickly separated into those who stopped using silage and those who make larger quantities, in the order of 1000 tonnes.

The quality differential is very important in intensive production systems. Though silage is normally fed during periods when alternate feed supply is low, poor quality silage can further reduce intake of paddock feed and give only a small net gain in milk output. This has been most obvious in attempts to use tropical grass silage in dairy feeding programs. The quality of the tropical grass silage is relatively low, with dry matter digestibility in the order of 55%, and it is usually fed during winter when the quality of the scarce feed resource is high. In northern Australia this is often grazing oats, irrigated ryegrass pasture, or tropical grasses which are growing slowly at this time but are of a higher quality. The net effect has been a very modest increase in milk yield during the feeding period, which did not cover the costs of silage (Davison *et al*. 1984; Cowan *et al*. 1991).

In contrast, the feeding of maize silage in combination with grazed clover or lucerne pastures has given substantial increases in milk output (Stockdale and Beavis 1988; Cowan *et al.* 1991). The combination of high energy content in the maize and high protein content in the legume enabled these feeds to be complementary.

The estimation of indirect benefits is often specific to the farm, although the 2 cases referred to above occur relatively widely. Fulkerson and Michell (1985) found that by removing the early growth of a temperate pasture they achieved an increase in milk yield per cow over the spring to autumn period. By removing a maize crop as silage rather than grain, farmers are able to obtain an additional 50 days active growth from land by using it for another crop.

There is often a penalty to milk production during the silage making period, where silage is made from tropical pastures or crops that are being grazed, as the removal of paddocks from the grazing rotation reduces the selection differential available to the animal. Cows select strongly for leaf material and restrictions in the area allocated for grazing can reduce the selection ability (Cowan and Lowe 1998). In this situation cows consume a higher proportion of stem in the diet, and consequently the dry matter digestibility of the diet is reduced.

There may also be an indirect penalty, through less time being available for tasks such as pasture management and fertilisation, ration formulation and cow health care during busy periods of silage making.

There is a large volume of local data on the operating costs of silage. These analyses show the main variable inputs, such as land preparation, seed and fertiliser, casual labour and harvesting costs. Sensitivity analyses show that variations in crop yield and harvest and storage losses have the greatest impact on cost, rather than differences in the cost of the above inputs (Brennan 1992). However the commitment in terms of capital and the farm managers time are invariably undervalued. Often the feed-out costs are also omitted. There are virtually no total farm analyses of the cost of silage when used as a component in a feeding program based on grazed pasture or forage. By contrast there are total farm costs for feedlot operations (Nixon 1992), which invariably show a higher cost than the marginal cost often quoted for silage in grazing systems (GRM 1997).

Drought feeding

There have been consistent difficulties in justifying the use of silage as a drought reserve in intensive feeding systems. The investment in silage is often made a number of years before the silage is fed to cattle, and so the opportunity cost of the feed is high. In other words the money could have been used to pay for a more direct input to production. Secondly, the object of drought feeding is only to maintain animals, so the additional milk or beef output is very small. In large scale and intensive feeding systems there are unlikely to be substantial numbers of cattle deaths during drought, and so silage is unlikely to be used to keep cattle alive. The net effect is a very small increase in income during feeding, and a high cost of conservation.

Increasing production

A more positive use for silage in the tropics is as a means of increasing land productivity (Cowan *et al.* 1993). There is a continuing increase in the pressure to use natural resources more effectively, primarily land and water. Associated with this pressure are demands for greater control over the production system, to meet quality assurance targets, ensure animal welfare and facilitate sustainable land management practices. It can be argued that each of these goals is more likely to be achieved in a system of feeding which has a high reliance on conserved crops.

In northern Australia a typical dairy farm has 100 milking cows and uses an area of 100 ha. However, on average, two thirds of the milk production from the farm in produced from 20 ha. This is the highly fertile and irrigated land. In other countries it is the total farm area that is limited (Simpson and Conrad 1993). In many areas irrigation is used to grow high quality feed for cows, and the efficient use of water is a high priority. The combination of cropping and conservation increased dry matter production per hectare compared with pasture systems, and achieved a higher ratio of feed production to water input (Kerr *et al.* 1987).

The cropping activity developed must use crops that can be efficiently used in the feeding system. Feeds such as maize, barley, and lucerne have high conversion rates to milk production, soybeans and sorghums are intermediate, and Napier (or elephant) grass *(Pennisetum purpureum)* and sugarcane are low. Napier grass has been shown to produce very high yields of dry matter and high water use efficiency, but because of the low digestibility cannot be used in systems producing in excess of 15 L /cow/day (Anindo and Potter 1986). By contrast maize and lucerne are capable of supporting levels of production in excess of 40 L/cow/day. In northern Australia, dairy production systems have made increasing use of maize, lucerne and forage sorghum silage to complement grazed pasture, and maintain production levels in the order of 25 L milk /cow/day (Ashwood *et al.* 1993; Cowan 1997). In 1994-5, an average of 0.4 t DM /cow was fed as silage (Kerr *et al.* 1996). A similar development, using a pasture and crop rotation for dairy production, was described for Uruguay (Wallis 1997).

Kerr *et al.* (1991) used time series analyses to evaluate the effects of incorporating maize silage into a grazing system on the productivity of a dairy farm, and two further cases were reported by Cowan *et al.* (1991). Productivity increases were 21,000 to 150,000 L milk/ farm/year above the previous system based solely on grazed pasture. Much of this extra production occurred during autumn and winter, a period when there are increased price incentives for milk production. It has been consistently shown that those dairy farms which persist with using maize silage have larger herd sizes (by 40 to 60 cows), higher milk production per cow (by 600 to 2000 L), and greater total milk output (by 300,000 to 700,000 L/year), than farms not using silage (Cowan *et al.* 1991; Kaiser and Evans 1997). In a separate survey, Kerr and Chaseling (1992), observed an increase in milk yield of 0.73 L for each kg hay or silage dry matter used in the feeding program.

Trends in the development of feeding systems in subtropical Australia indicate an increasing input of conserved forage (Figure 1). The development of intensive irrigation and conservation has resulted in a decline in the proportion of milk being produced from grains and tropical grasses, and it is projected these trends will continue. Much of the silage is made from crops during summer, and fed in the autumn and spring periods when pasture supply is normally low. This has resulted in a relatively stable pattern of production throughout the year (Figure 2).

In feedlot operations there has been an increase in the amount of silage, particularly maize, in the diets of beef and dairy cattle (Kaiser *et al.* 1993; GRM 1997). High quality silages are capable of supporting the high levels of animal production demanded in such operations, are often lower in cost than grains and hay, enable higher productivity from land, and maintain a more stable rumen environment (GRM 1997). Kaiser and Simmul (1992) and Kaiser *et al.* (1998) measured daily liveweight gains of 1.0 kg for steers given diets of grain to maize silage ratios of 0:100, 54:46, and 80:20.

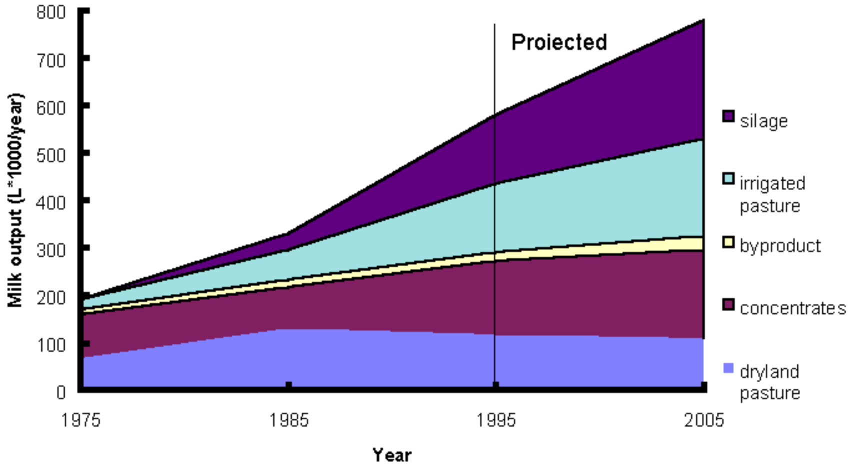

Figure 1. *Past estimates and projections of the milk output from feeds on a typical Queensland dairy farm (from Cowan et al. 1998).*

The increasing level of control needed over the production system is also influencing the move towards conserved crop systems. Farmers need to be confident they can produce a certain level and quality on a specified date. This is difficult to manage under many grazing systems, and farmers in northern Australia have adapted a combination of grazing and crop conservation to enable this control. The management of stress on the cow, from heat, parasites and walking, is sometimes a consideration.

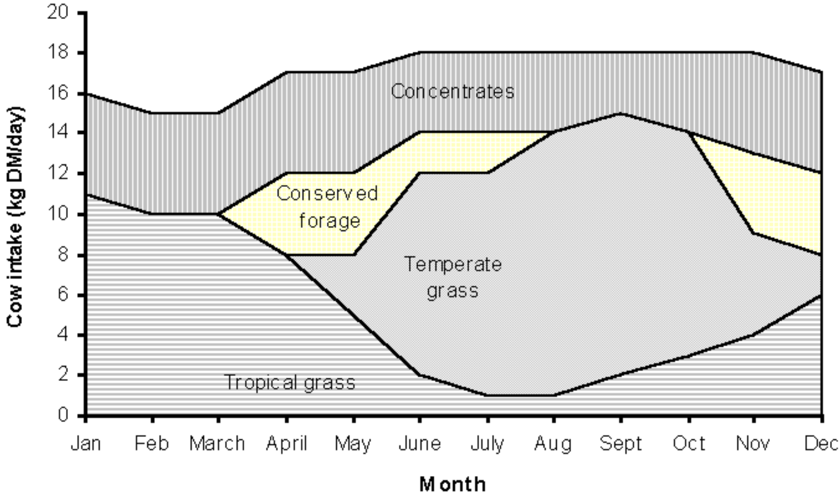

Figure 2. *Seasonal change in feed intake for a dairy cow producing 5200 L milk annually in a typical feeding system in northern Australia (from Cowan and Lowe 1998).*

There is increasing importance being placed on the sustainability of intensive ruminant production systems, and measures taken to enhance this may restrict cow movement to certain paddocks. For example the use of creek banks for shade and grazing may not be possible, and tree-planting schemes to address salinity may preclude grazing those areas by cows. However those areas could still be used to produce conserved fodder.

Management of land and pasture

This aspect of forage conservation has received considerable interest in pasture grazing systems in temperate areas. Removal of the early growth encourages greater tiller density and subsequent dry matter production (Fulkerson and Michell 1985).

Such an effect has not been shown for tropical grasses, and frequent cutting almost always leads to reduced dry matter production (Blunt and Haydock 1978).

The benefits in cropping systems can be significant. As referred to above, a silage crop can be taken some 30 to 50 days before a grain crop, thus increasing the number of days on which another crop can potentially be grown. As the land is often used for 2 or more crops annually, there is an increase in potential growth in the order of 30%.

Use of excess growth

In the modern business approach to farming the idea of ensiling an excess of forage growth simply because it is there may seem illogical, but it is often used as the justification for research and development. Davison *et al.* (1984) conserved the excess growth in a green panic based pasture in each of 3 years, and fed this back to cows during the dry season. Though the pasture was conserved as a stable and palatable silage, a result in common with other experiments (Moss *et al.* 1984), the net effect on milk production was zero. This was largely attributed to the low digestibility of such silage, and the low milk production response when it is fed to cows.

By contrast, silage made from temperate pasture, such as ryegrass (*Lolium* spp.) grown with irrigation during winter, has a high quality differential when compared with the grazed pasture on offer to cows during summer and autumn. The milk response to feeding this silage is likely to be high, and in northern Australia dairy farmers place high priority on conserving any excess of this pasture, rather than conserving the much greater excesses of summer pasture.

Recent experiments have attempted to enhance the digestibility of conserved Rhodes grass *(Chloris gayana)* by "ensiling" with sodium hydroxide (Chaudhry *et al.* 1999). The treatment was shown to cause a significant increase in digestible dry matter intake of very mature grass, but no improvement with young grass. The dry matter digestibility of treated grass was 60 and 65 % respectively; levels which are unlikely to provide a positive quality differential compared with grazed summer and winter pastures.

Balance nutrients in the diet

In northern Australia there has been a rapid adoption of irrigated temperate pastures for provision of grazing during winter and spring (Kaiser *et al.* 1993). These pastures are high in digestibility, very high in crude protein concentration and often contain a high percentage of legumes, although the quantity is usually insufficient for the total forage requirements of the herd. The supplementation of these pastures with maize silage has shown substantial benefits. Moss *et al.* (1996) showed this combination removed the need for protein supplementation of the diet unless very high levels of maize silage were being fed, and the use of maize silage in this way reduced the excessively high ammonia levels in the rumens of cows. Stockdale and Beavis (1988) demonstrated an additive effect of this combination of feeds.

Recently, there has been increasing interest in the use of legumes for ensiling in the tropics. Legumes such as lablab *(Lablab purpureus)*, cowpeas *(Vigna unguiculata)* and soybeans *(Glycine max)* have been shown to be compatible with sustainable land management practices, including zero tillage, and to conserve as silage of acceptable digestibility (Ehrlich *et al.* 1999). Dry matter yields of soybean silage was 6 t/ha, containing 17% crude protein and 42% leaf, and dry matter intakes of up to 12.5 kg daily were recorded (Ehrlich and Casey 1998). The high crude protein concentration is an advantage in tropical feeding systems, where many of the grass forages are low in protein. The legume silages are also relatively high in mineral concentration, and have a high buffering capacity. The potential benefits of these characteristics are presently being investigated (David McNeill, personal communication).

Storage of wet by-products

There are substantial quantities of vegetable and fruit waste produced from centralised food processing facilities. Much of this material is fed to dairy cows. Because of the uneven nature of supply, it is often ensiled in trenches in the ground, for subsequent use as feed. Pineapple skins were found to fall to a pH of 3.5 within 2 days of delivery, and remain at that level with no apparent reduction in feeding value (Cornack 1995).

Conclusion

The record of development of silage in tropical regions has been characterised by unclear objectives in making silage, a lack of a whole farm approach to silage evaluation, and a preoccupation with utilising excess pasture growth during the growing season.

It is concluded that where silage is considered appropriate to the feeding system, the activity should concentrate on using crops, making large amounts for individual properties, combining feed sources to enhance efficiency of nutrient use, and integrating feed planning with other demands on modern production systems, such as quality assurance and sustainability.

Acknowledgements

I thank Mr Kevin Lowe and Mr Richard Moss for comments on the manuscript, and many other colleagues for many interesting discussions on the role of silage in subtropical feeding systems.

References

Anindo, D.O. and Potter, H.L. 1986. Milk production from Napier grass (Pennisetum purpureum) in a zero grazing feeding system. *East Africa Agriculture and Forestry Journal* **52**, 106-111.

Ashwood, A., Kerr, D., Chataway, R. and Cowan, T. 1993. Northern dairy feedbase 2001. 5. Integrated dairy farming systems for northern Australia. *Tropical Grasslands* **27**, 212-228.

Blunt, C.G. and Haydock, K.P. 1978. Effect of irrigation, nitrogen and defoliation on pangola grass in the dry season at the Ord Valley, north-western Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry* **18**, 825-833.

Brennan, J.P. 1992. Economics of winter forage crops for silage. In, Advances in fodder conservation, Quirindi, New South Wales, February 1992. NSW agriculture, pp 19-20.

Chaudhry, A.S., Cowan, T. and Klieve, A. 1999. Nutritive improvement of summer grasses. *Final report, project UQ 046*, Dairy Research and Development Corporation, Melbourne, pp18.

Cornack, K.M. 1995. Increasing milk constituent yield through fibre supplementation of winter pastures in the subtropics. M. Agric. Sci. thesis, University of Queensland, pp164.

Cowan, R.T. 1997. Cost effective feeding systems for subtropical dairy farms. In: *Future Feeding Today*, Ridley Agriproducts, Australia, pp 13-24.

Cowan, R.T. and Kerr, D.V. 1984. Dairy feeding systems based on pasture and forage crop silage in the tropics and subtropics. In, Silage in the Eighties, (Eds. T.J. Kempton, A.G. Kaiser and T. E. Trigg). P G Print, Armidale, pp 384-391.

Cowan, R.T. and Lowe, K.F. 1998. Tropical and subtropical grass management and quality. In: Grass for dairy cattle. (Eds. J.H.Cherney and D.J.R. Cherney. CAB International, pp 101-135.

Cowan, R.T., Kerr, D.V. and Davison, T.M. 1991. Maize silage for dairy systems in northern Australia. In: Maize in Australia – Food, Forage and Grain. (Ed. J Moran). Incitec, pp228-235.

Cowan, R.T., Moss, R.J. and Kerr, D.V. 1993. Northern dairy feedbase 2001. 2. Summer feeding systems. *Tropical Grasslands* **27**, 150-161.

Cowan, R.T., Moss, R.J., Goodwin, P.G. and Fulkerson, W.J. 1998. Efficiency in feeding systems for subtropical dairy production systems *Animal Production in Australia* **22**, 125-128.

Davison, T.M., Orr, W. N. and Clark, R. 1984. Changes in silage use on the Atherton Tablelands, North Queensland. . In: Silage in the Eighties (Eds. T.J. Kempton, A.G. Kaiser and T. E. Trigg). P G Print, Armidale, pp 392-396.

Ehrlich, W, Cowan, T and Desborough, P 1999. Summer feed production systems using crop legumes to complement tropical grass pasture *Final report, project DAQ 110,* Dairy Research and Development Corporation, Melbourne, Australia, pp. 43.

Ehrlich, W.K and Casey, N.D. 1998. Effects of planting rate, cutting date and chopping on intake of soybean silage fed to dairy cows *Animal Production in Australia* **22**, 378.

Fulkerson, W.J and Michell, P. 1985. Effect of level of utilisation of pasture in spring on pasture composition in summer and on milk production in spring and summer. In: The challenge: Efficient Dairy Production *Proceedings of the Australia-New Zealand Dairy Production Conference,* Albury-Wodonga, ASAP/NZSAP, pp. 66-67.

GRM 1997. The expanded use of high metabolisable energy silages – phase 1. *Final report,* Meat Research Corporation, Sydney, Australia, pp. 58.

Kaiser, A.G. and Evans, M.J. 1997. Forage conservation on Australian dairy farms. *Animal Industries report 3*, NSW Agriculture, pp18.

Kaiser, A.G. and Simmul, L.K. 1992. Finishing steers on silage and grain diets. In: *Advances in fodder conservation, Quirindi, New South Wales, February 1992.* NSW Agriculture, pp 7-12.

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

Kaiser, A.G., Morris, S.G. and Piltz, J.W. 1998. Liveweight gain of yearling cattle on high quality silage based diets. *Animal Production in Australia* **22**, 379.

Kerr, D.V. and Chaseling, J. 1992. A study of the level and efficiency of production in relation to inputs for dairy farms in Queensland. *Final report, project DAQ 077,* Dairy Research and Development Corporation, Melbourne, pp 36.

Kerr, D.V., Cowan, R.T. and Chaseling, J. 1991. Estimations of the increase in milk production due to the introduction of maize silage to a dairy farm in a subtropical environment: A time series approach. *Agricultural Systems* **35**, 313-320.

Kerr, D.V., Cowan, R.T. and McKeon, G.M. 1987. A simulation model of maize growth for silage production in Queensland. *Proceedings of the 4th AAAP Animal Science Congress,* Hamilton, New Zealand, p. 456.

Kerr, D.V., Davison, T., Hetherington, G., Lake, M. and Murray, A. 1996. *Queensland dairy farm survey, 1994-5.* Department of Primary Industries, Queensland, pp. 20.

Moss, R.J., Byford, I.J.R., Winks, L., Chambers, G. and O'Grady, P. 1984. In: Silage in the Eighties (Eds. T.J. Kempton, A.G. Kaiser and T. E. Trigg). P G Print, Armidale, pp 137-140.

Moss, R.J., Martin, P.R., Ansell, J. and Davison, T.M. 1996. Amount and source of protein in concentrates fed to high producing dairy cows in a subtropical feeding system. *Animal Production in Australia* **21**, 95-98.

Nixon, A. 1992. . In: Advances in fodder conservation, Quirindi, New South Wales, February 1992. NSW agriculture, pp 25-28.

O'Kiely, P. and Muck, R.E. 1998. Grass silage. In: Grass for dairy cattle. (Eds. J.H.Cherney and D.J.R. Cherney). CAB International, pp 223-251.

Simpson, J.R and Conrad, J.H. 1993. Intensification of cattle production systems in Central America: why and when. *Journal of Dairy Science* **26**, 1744-1752.

Stockdale, C.R. and Beavis, G.W. 1988. Maize silage as a supplement for dairy cows offered pasture of high or low quality. *Animal Production in Australia* **17**, 472.

Wallis, J.A.N. 1997. Intensified systems of farming in the tropics and subtropics. *World Bank Discussion Paper No. 364,* World Bank, Washington, pp. 203.

Silage fermentation processes and their manipulation

Stefanie J. W. H. Oude Elferink[1*], Frank Driehuis[1], Jan C. Gottschal[2], and Sierk F. Spoelstra[2]

[1]Institute for Animal Science and Health (ID-DLO), P.O. Box 65, NL-8200 AB, Lelystad, THE NETHERLANDS.

[2]Groningen State University, Dept. Microbiology, P.O. Box 14, NL-9700 AA, Haren, THE NETHERLANDS.

[*]Corresponding author: Tel: +31-320-238238; Fax: +31-320-237320 E-mail: <s.j.w.h.oudeelferink@id.dlo.nl>

1. Introduction.

Fresh forage crops such as maize, grasses, legumes, wheat and lucerne can be preserved by ensiling. In many countries ensiled forages are highly valued as animal feed. In European countries such as The Netherlands, Germany and Denmark more than 90% of the forages locally produced are stored as silage. Even in countries with generally good weather conditions for hay making such as France and Italy approx. 50% of the forages are ensiled (Wilkinson *et al.* 1996). It is essential to have a good microbial fermentation process to produce high quality silage. A good fermentation process is not only dependent on the type and quality of the forage crop, but also on the harvesting and ensiling technique. In this paper our current knowledge on general silage microbiology is reviewed with the aim to aid with the choice of the best ensiling strategy to produce high quality silage.

2. The ensiling process.

Ensiling is a forage preservation method based on a spontaneous lactic acid fermentation under anaerobic conditions. The epiphytic lactic acid bacteria ferment the water-soluble carbohydrates (WSC) in the crop to lactic acid, and to a lesser extent to acetic acid. Due to the production of these acids the pH of the ensiled material decreases and spoilage microorganisms are inhibited. Once the fresh material has been stacked and covered to exclude air, the ensiling process can be divided into 4 stages (Weinberg and Muck 1996; Merry *et al.* 1997),

***Phase 1, aerobic phase*.** This phase normally only takes a few hours in which the atmospheric oxygen present between the plant particles is reduced, due to the respiration of the plant material and aerobic and facultative aerobic microorganisms such as yeasts and enterobacteria. Furthermore, plant enzymes such as proteases and carbohydrases are active during this phase, provided the pH is still within the normal range for fresh forage juice (pH 6.5-6.0).

***Phase 2, fermentation phase*.** This phase starts when the silage becomes anaerobic, and it continues for several days to several weeks, depending on the properties of the ensiled forage crop and the ensiling conditions. If the fermentation proceeds successfully lactic acid bacteria develop, and become the predominant population during this phase. Due to the production of lactic and other acids the pH decreases to 3.8-5.0.

***Phase 3, stable phase*.** As long as air is prevented from entering the silo, relatively little occurs. Most microorganisms of phase 2 slowly decrease in numbers. Some acid tolerant microorganisms survive this period in an almost inactive state, others such as clostridia and bacilli survive as spores. Only some acid tolerant proteases and carbohydrases and some specialized microorganisms, such as *Lactobacillus buchneri* continue to be active at a low level. The activity of this latter organism will be discussed in more detail further on in this paper.

Phase 4, feed-out phase or aerobic spoilage phase . This phase starts as soon as the silage gets exposed to air. During feed-out this is unavoidable, but it can already start earlier due to damage of the silage covering (e.g. by rodents or birds). The process of spoilage can be divided into two stages. The onset of deterioration is due to the degradation of preserving organic acids by yeasts and occasionally acetic acid bacteria. This will cause a rise in pH, and thus the second spoilage stage is started, which is associated with increasing temperature, and activity of spoilage microorganisms such as bacilli. The last stage also includes the activity of many other (facultative) aerobic microorganisms such as moulds and enterobacteria. Aerobic spoilage occurs in almost all silages that are opened and exposed to air. However the rate of spoilage is highly dependent on the numbers and activity of the spoilage organisms in the silage. Spoilage losses of 1.5-4.5 % dry matter loss/day can be observed in affected areas. These losses are in the same range as losses that can occur in airtight silos during several months of storage (Honig and Woolford 1980).

To avoid failures it is important to control and optimize each phase of the ensiling process. In phase 1 good silo filling techniques will help to minimize the amount of oxygen present between the plant particles in the silo. Good harvesting techniques combined with good silo filling techniques will thus minimize WSC losses through aerobic respiration in the field and in the silo, and in turn will leave more WSC available for lactic acid fermentation in phase 2. During phases 2 and 3 the farmer cannot actively control the ensiling process. Methods to optimize phases 2 and 3 are therefore based on the use of silage additives that are already applied at the time of ensiling as will be discussed in section 4. Phase 4 will start as soon as oxygen is available. To minimize spoilage losses during storage an airtight silo is required, and any damage to the silo covering should be repaired as soon as possible. During feed-out spoilage by air ingress can be minimized by a sufficiently high feed-out rate. In addition, at the time of ensiling silage additives can be applied that are able to decrease spoilage losses.

3. The silage microflora.

The silage microflora plays a key role in the successful outcome of the conservation process. The flora can basically be divided into two groups namely the desirable and the undesirable microorganisms. The desirable microorganisms are the lactic acid bacteria. The undesirable ones are the organisms that can cause anaerobic spoilage (e.g. clostridia and enterobacteria) or aerobic spoilage (e.g. yeasts, bacilli, listeria and moulds). Many of these spoilage organisms do not only decrease the feed value of the silage, but also have a detrimental effect on animal health and/or milk quality (e.g. listeria, clostridia, moulds and bacilli).

3.1. Desirable microorganisms.

3.1.1. Lactic acid bacteria. (LAB)

Lactic acid bacteria belong to the epiphytic microflora of plant material. Often the population of LAB increases substantially between harvesting and ensiling. This is probably mainly due to the resuscitation of dormant and non-culturable cells, and not by inoculation by the harvesting machinery or growth of the indigenous population. Crop characteristics like sugar content, dry matter content, and sugar composition, combined with lactic acid bacterial properties such as acid and osmotolerance, and substrate utilization will decisively influence the competitiveness of the lactic acid bacterial flora during silage fermentation (Woolford 1984; McDonald *et al.* 1991).

Lactic acid bacteria that are regularly associated with silage are members of the genera *Lactobacillus, Pediococcus*, *Leuconostoc*, *Enterococcus*, *Lactococcus* and *Streptococcus*. The majority of the silage lactic acid bacteria are mesophilic, i.e. they can grow at temperatures between 5 and 50°C, with an optimum between 25 and 40°C. They are able to decrease the silage pH to pH 4-5, depending on the species and the type of forage crop. All lactic acid bacteria are facultative aerobes, but some have a preference for anaerobic conditions (Holzapfel and Schillinger 1992; Hammes *et al.* 1992; Devriese *et al.* 1992; Weiss 1992; Teuber *et al.* 1992). Based on their sugar metabolism lactic acid bacteria can be classified as obligate homofermenters, facultative heterofermenters or obligate heterofermenters. Obligate homofermenters produce more than 85% lactic acid from hexoses (C-6 sugars) such as glucose, but cannot degrade pentoses (C-5 sugars) such as xylose. Facultative heterofermenters also produce mainly lactic acid from hexoses, but in addition they also at least degrade some pentoses to lactic acid, and acetic acid and/or ethanol. Obligate heterofermenters degrade both hexoses and pentoses, but unlike homofermenters they degrade hexoses to equimolar mounts of lactic acid, CO_2, and acetic acid and/or ethanol (Hammes *et al.* 1992; Schleifer and Ludwig 1995). Obligate homofermenters are species such as *Pediococcus damnosus* and *Lactobacillus ruminis*. Facultative heterofermenters are for example *Lactobacillus plantarum*, *Lactobacillus pentosus*, *Pediococcus acidilactici*, *Pediococcus pentosaceus*, and *Enterococcus faecium*. To the obligate heterofermenters belong members of the genus *Leuconostoc*, and some *Lactobacillus* sp. such as *Lactobacillus brevis* and *Lactobacillus buchneri* (Devriese *et al.* 1992; Weiss 1992; Holzapfel and Schillinger 1992; Hammes *et al.* 1992).

3.2. Undesirable microorganisms.

3.2.1. Yeasts.

Yeasts are eucaryotic, facultative anaerobic, heterotrophic microorganisms. In silages anaerobic as well as aerobic yeast activity is considered undesirable. Under anaerobic silage conditions yeasts ferment sugars to ethanol and CO_2 (Schlegel 1987; McDonald *et al.* 1991). This ethanol production in silage does not only decrease the amount of sugar available for lactic acid fermentation, but it can also have a negative effect on milk taste (Randby *et al.* 1998). Under aerobic conditions many yeast species degrade the lactic acid to CO_2 and H_2O. The degradation of lactic acid causes a rise in silage pH, which in turn triggers the growth of many other spoilage organisms (McDonald *et al.* 1991).

Yeast populations can reach up to 10^7 colony forming units per gram during the first weeks of ensiling, prolonged storage will lead to a gradual decrease in yeast numbers (Jonsson and Pahlow 1984; Middelhoven and Van Balen 1988; Driehuis and Van Wikselaar 1996). Factors that affect the survival of yeasts during storage are the degree of anaerobiosis, and the concentrations of organic acids. The presence of oxygen enhances survival and growth of yeasts during storage (Jonsson and Pahlow 1984; Donald *et al.*1995), whereas high levels of formic or acetic acid reduce survival during storage (Driehuis and Van Wikselaar 1996; Oude Elferink *et al.* 1999). Initial yeast activity appears to be enhanced in crops with a low initial pH (< 5), e.g. due to the addition of acid additives, and in crops with a high sugar content, e.g. potatoes, orange peels or sugar beets. These crops often result in silages high in ethanol and low in lactic acid (Henderson *et al.* 1972; Ashbell *et al.* 1987; Weinberg *et al.* 1988; Driehuis and van Wikselaar 1996). Silage additives developed to inhibit yeast activity are described in section 4.3.

3.2.2. Enterobacteria.

Enterobacteria are facultatively anaerobic. Most silage enterobacteria are regarded to be non-pathogenic. Nevertheless, their growth in silage is undesirable because they compete with the lactic acid bacteria for the available sugars, and in addition they can degrade protein. This protein degradation does not only cause a reduction in feeding value, but also leads to the production of toxic compounds such as biogenic amines and branched fatty acids. Biogenic amines are known to have a negative effect on silage palatability (Woolford 1984; McDonald *et al.* 1991; van Os and Dulphy 1996), especially in animals that are not yet accustomed to the taste (van Os *et al.* 1997). Moreover, the ammonia formed through proteolysis increases the buffer capacity of the ensiled crop, thus counteracting a rapid decrease of silage pH. A special characteristic of enterobacteria is their capability to reduce nitrate (NO_3) to nitrite (NO_2) under silage conditions. In silage nitrite can be degraded by enterobacteria to ammonia and nitrous oxide (N_2O), but it can also be chemically degraded to NO and nitrate (Spoelstra 1985; 1987). With air NO is oxidized into a mixture of gaseous, yellow-brown nitrogen oxides (NO_2, N_2O_3, N_2O_4). Gaseous NO and NO_2 have a damaging effect on lung tissue, and can cause a disease with pneumonia-like symptoms known as "silo filler's disease" (Woolford 1984). To prevent animals from getting in contact with gaseous nitrogen oxides they should not be housed in buildings adjoining silos during silo filling or the first week of silage storage (O'Kiely *et al.* 1999). Despite the above mentioned problems, a little nitrite reduction is considered positive for silage quality, because the formed nitrite and NO are very effective inhibitors of clostridia (Woods *et al.* 1981, Spoelstra 1985).

Enterobacteria will not proliferate at low pH. Ensiling methods that induce a rapid and sufficient drop in silage pH will therefore help to decrease enterobacterial growth (McDonald *et al.* 1991).

3.2.3. Clostridia.

Clostridia are endospore-forming anaerobic bacteria. Many clostridia ferment carbohydrates as well as proteins, thus causing problems such as the reduction in feeding value and the production of biogenic amines, similarly as has been described for enterobacteria. Furthermore, clostridia in silage impair milk quality. This is due to the fact that clostridial spores can survive the passage through the alimentary tract of a dairy cow. Clostridial spores present in silage are transferred to milk, via feces and fecal contamination of the udder. The acid tolerant *Clostridium tyrobutyricum* is the most relevant species for the dairy industry. In addition to carbohydrate fermentation *C. tyrobutyricum* can degrade lactic acid to butyric acid, H_2 and CO_2 according to the following overall reaction:

$$\textbf{2 lactic acid} \dashrightarrow \textbf{1 butyric acid} + \textbf{2 } \mathbf{H_2} + \textbf{2 } \mathbf{CO_2}$$

This butyric acid fermentation does not only counteract the lactic acid fermentation in silage and cheeses, but it also is responsible for a significant gas production, causing a cheese defect called "late blowing" in hard and semi-hard cheeses such as Emmental, Grana, Gouda and Parmesan (Gibson 1965; Goudkov and Sharpe 1965, Klijn *et al.* 1995).

Some clostridia can cause serious health problems. An extremely toxic *Clostridium* sp. is *C. botulinum.* This organism can cause botulism, which can be deadly for cattle. Fortunately, *C. botulinum* has a limited acid tolerance, and does not grow in well-fermented silage. Incidences of animal botulism caused by silage contaminated with *C. botulinum* could nearly always be attributed to the presence of a cadaver (e.g. mouse, bird, etc.) in the silage (Kehler and Scholz 1996).

A typical "clostridial silage" is characterized by a high butyric acid content of more than 5 g/kg dry matter, a high pH (over pH 5 in low dry matter silages), and a high ammonia and amine content (Voss 1966; McPherson and Violante 1966). Ensiling methods that cause a rapid and sufficient drop in silage pH will help to prevent the development of a "clostridial silage", because similar to enterobacteria, clostridia are inhibited at low pH. Furthermore, clostridia are more susceptible to a low availability of water (i.e. a low water activity (a_w)) than lactic acid bacteria (Kleter *et al.* 1982; 1984, Huchet *et al.* 1995). For this reason decreasing the a_w-value of a crop, e.g. by wilting to a higher dry matter content, can be a way of selectively inhibiting clostridia (Wieringa 1958). Finally, clostridia will also be inhibited by nitrite and NO or compounds that are degraded in silage to nitrite and NO (Spoelstra 1983; 1985).

3.2.4. Acetic acid bacteria.

Acetic acid bacteria are obligate aerobic, acid-tolerant bacteria. Thus far all acetic acid bacteria that have been isolated from silage belonging to the genus *Acetobacter* (Spoelstra *et al.* 1988). The activity of *Acetobacter* ssp. in silage is undesirable because they can initiate aerobic deterioration, due to the fact that they are able to oxidize lactate and acetate to carbon dioxide and water. Generally, yeasts are the main initiators of aerobic spoilage, and acetic acid bacteria are absent, or play only a minor role. However, for whole crop corn silages there is evidence that acetic acid bacteria alone can initiate aerobic deterioration (Spoelstra *et al.* 1988). Furthermore, selective inhibition of yeast also can increase proliferation of acetic acid bacteria in silage (Driehuis and van Wikselaar 1996).

3.2.5. Bacilli.

Bacilli are like clostridia endospore-forming rod shaped bacteria. Nevertheless, they can easily be distinguished from clostridia due to the fact that they are (facultative) aerobes, whereas all clostridia are obligate anaerobes (Claus and Berkeley

1986; Cato *et al.* 1986). Facultative aerobic bacilli ferment a wide range of carbohydrates to compounds such as organic acids (e.g., acetate, lactate, and butyrate) or ethanol, 2,3-butanediol, and glycerol (Claus and Berkely 1986). Some specific *Bacillus* sp. are able to produce antifungal substances, and have been used to inhibit aerobic spoilage of silage (Phillip and Fellner 1992; Moran *et al.* 1993). Except for these specific strains, the proliferation of bacilli in silage is generally considered undesirable. Not only are bacilli less efficient lactic and acetic acid producers than lactic acid bacteria (McDonald *et al.* 1991), they can also enhance (later stages of) aerobic deterioration (Lindgren *et al.* 1985; Vreman *et al*, in press). Furthermore, high numbers of *Bacillus* spores in raw milk have been associated with high spore numbers in fresh cow feces (Waes 1987; te Giffel *et al.* 1995). In seems very plausible that bacillus spores are transferred from silage to milk via feces similar to clostridial spores (Vreman *et al*, in press). Psychrotrophic *B. cereus* spores are considered to be the most important spoilage organism of pasteurized milk (te Giffel 1997). High numbers of these (psychrotrophic) *B. cereus* spores have been found in silages (Labots *et al.* 1965; te Giffel *et al.* 1995).

To decrease bacillus growth in silage, storage temperatures should not be too high (Gibson *et al.* 1958) and air ingress should be minimized (Vreman *et al*, in press). In addition, initial contamination of fresh plant material with soil or manure should be prevented (McDonald *et al.* 1991; Rammer *et al.* 1994).

3.2.6. Molds.

Molds are eucaryotic microorganisms. A mold-infested silage is usually easily detected by the large filamentous structures and colored spores that many species produce. Molds develop in parts of the silage were (a trace of) oxygen is present. During storage, this is usually only in the surface layers of the silage, but during aerobic spoilage (phase 4) the whole silage can become moldy.

Mold species that regularly have been isolated from silage belong to the genera *Penicillium*, *Fusarium*, *Aspergillus*, *Mucor*, *Byssochlamys*, *Absidia*, *Arthrinium*, *Geotrichum*, *Monascus*, *Scopulariopsis* and *Trichoderma* (Pelhate 1977; Woolford 1984; Frevel *et al.* 1985; Jonsson *et al.* 1990; Nout *et al.* 1993). Molds do not only cause a reduction of feed value and palatability of the silage, but can also have a negative effect on human and animal health. Mold spores are associated with lung damage and allergenic reactions (May 1993). Other health problems are associated with mycotoxins that can be produced by molds (Oldenburg 1991; Auerbach 1996). Depending on the type and amounts of toxin present in the silage heath problems can range from minor digestive upsets, small fertility problems, and reduced immune function, to serious liver or kidney damage, and abortions (Scudamore and Livesey 1998). Some important mycotoxin producing mold species are *Aspergillus fumigatus*, *Penicillium roqueforti*, and *Byssochlamys nivea*. Especially *P. roqueforti*, a species which is acid tolerant and can grow at low levels of oxygen and high levels of CO_2, has been detected as the predominant species in different types of silages (Lacey 1989; Nout *et al.* 1993; Auerbach *et al.* 1998; Auerbach 1996). There is still uncertainty under which conditions mycotoxins are formed in silage. A heavily infested silage does not necessarily contain high amounts of mycotoxins, and not all types of mycotoxins a mold species can produce have to be present in one silage (Nout *et al.* 1993; Auerbach 1996). For Aflatoxin B1, a mycotoxin of *Aspergillus flavus*, it is known that in can be transferred from animal feed to milk. However, thus far it is unknown if a similar transfer can occur with mycotoxins from *P. roqueforti*, or *A. fumigatus* (Scudamore and Livesey 1998).

Ensiling methods that minimize air ingress (e.g. good compaction and covering of the silo), and additives that prevent initiation of aerobic spoilage, will help to prevent or limit mold growth.

3.2.7. Listeria.

Members of the genus *Listeria* are aerobic or facultatively anaerobic. Regarding silage quality the most important *Listeria* spp. is the facultative anaerobic *L. monocytogenes*, because this species is a pathogen to various animals and man. Especially animals with a suppressed immune system (e.g. pregnant females and neonates) are susceptible to *L. monocytogenes* infections (Jones and Seeliger 1992). Silage contaminated with *L. monocytogenes* has been associated with fatal cases of listeriosis in sheep and goats (Vazquez-Boland *et al.* 1992; Wiedmann *et al.* 1994). In addition, Sanaa *et al.* (1993) have identified poor quality silage as one of the main sources of contamination of raw milk by *L. monocytogenes*. Growth and survival of *Listeria* in silage are determined by the degree of anaerobiosis, and the silage pH. *L. monocytogenes* can tolerate a low pH of 3.8-4.2 for long periods of time only if (small amounts) of oxygen are present. Under strictly anaerobic conditions it is rapidly killed at low pH (Donald *et al.* 1995). Silages that have a higher chance of aerobic surface spoilage, such as big bale silages seem, to be particular liable to *Listeria* contamination (Fenlon *et al.* 1989). *L. monocytogenes* generally does not develop in well fermented silages with a low pH. Thus far the most effective method to prevent growth of *L. monocytogenes* is to keep the silage anaerobic (McDonald *et al.* 1991).

4. Silage additives.

In the past decade it has become increasingly common to use silage additives to improve the ensiling process. The choice of additives appears to be sheer limitless if one looks at the large number of chemical and biological silage additives that are commercially available. The UKASTA Forage Approval Scheme of the UK for example lists more than 80 products (Rider 1997).

Fortunately, the choice of a suitable additive is less complicated than it seems, because the modes of action of most additives fall within a few categories (Table 1).

Table 1, Categories of silage additives (adapted from McDonald *et al*. 1991).

Additive category	Selection of Active ingredients	Remarks
Fermentation stimulants	Lactic acid bacteria Sugars (molasses) Enzymes	May impair aerobic stability
Fermentation inhibitors	Formic acid* Lactic acid* Mineral acids Nitrite salts Sulfite salts Sodium chloride	Inhibition of clostridia
Aerobic deterioration inhibitors	Lactic acid bacteria Propionic acid* Benzoic acid* Sorbic acid*	
Nutrients	Urea Ammonia Minerals	Can improve aerobic stability Can improve aerobic stability
Absorbents	Dried sugar beet pulp Straw	

*or corresponding salt

Between products of one category differences exist in product properties such as general effectiveness, suitability for certain crop type, and ease of handling and application. These factors, together with the price and availability, will determine what product will be the most adequate for a specific silage. A drawback of some of the chemical additives is that they can be corrosive to the equipment used, and/or can be dangerous to handle. The biological additives are non-corrosive and safe to handle, but they can be costly. Furthermore, their effectiveness can be less reliable, since it is based on the activity of living organisms. Proper storage of these biological additives by the manufacturer, retailer and farmer is of vital importance. Despite these disadvantages, in Europe and the USA bacterial inoculants have nowadays become the most commonly used additives for corn, and grasses and legumes that can be wilted to above 300 g DM kg^{-1} (Bolsen and Heidker 1985; Pahlow and Honig 1986; Bolsen *et al.* 1995; Kung 1996; Weinberg and Muck 1996). In the Netherlands the absolute as well as the relative amount of silages treated with bacterial inoculants has increased in the past 4 years. Last year 13.7 % of all grass silages in the Netherlands was ensiled with an additive, of these treated silages 31 % was treated with an inoculant, 37% with molasses and 29% with fermentation inhibitors (Hogenkamp 1999).

4.1. Additives improving silage fermentation.

Assuming good harvesting and ensiling techniques initial silage fermentation (phase 2) can still be sub-optimal. This can be due to a lack of sufficient numbers of suitable lactic acid bacteria or a lack of sufficient amounts of suitable water-soluble carbohydrates, or both.

The amount of water-soluble carbohydrates necessary to obtain sufficient fermentation depends on the dry matter content and the buffer capacity of the crop. Weissbach and Honig (1996) characterized the relation between these factors as follows,

FC = DM (%) + 8 WSC/BC

FC = fermentation coefficient
DM = dry matter content
WSC = water-soluble carbohydrates
BC = buffer capacity.

Forages with insufficient fermentable substrate or too low a dry matter content have a FC < 35. In these forages sufficient fermentation can only be achieved if the sugar content of the material is increased, either by adding sugars directly (e.g. molasses) or by adding enzymes that release extra sugars from the crop. In forages with a FC of 35 or more sufficient fermentable substrate is available. Also, adding suitable lactic acid bacteria can accelerate and improve the ensiling process. In high dry matter silages with reduced water availability the presence of suitable, osmotolerant lactic acid bacteria could become a limiting factor in the ensiling process. It has been shown that these bacteria represent only a small percentage of the indigenous microflora on forage crops (Pahlow and Weissbach 1996). Forages with a dry matter content above 50% are considered difficult to ensile (Staudacher *et al.* 1999).

The formula of Weissbach and Honig (1996) does not apply for crops with a low nitrate content such as extensively managed grasses and immature whole crop cereals, because these crops are more liable to clostridial fermentations than crops with a moderate nitrate content (Spoelstra 1983; 1985). Inoculants that increase lactic acid fermentation might be useful to inhibit clostridial activity. The minimum number of lactic acid bacteria required to inhibit clostridial activity was found to be at least 100 000 colony forming units per gram of fresh crop (Weissbach and Honig, 1996; Kaiser et al., 1997).

4.2. Additives inhibiting silage fermentation.

Fermentation inhibitors could in theory be used for all types of forages. However, in practice they are generally only used in wet crops with a low water-soluble carbohydrate content and/or high buffer capacity (McDonald 1991). In the Netherlands salts from acids have become the most popular fermentation inhibitors (Hogenkamp 1999). An advantage of these salts is that they are easier and safer to handle than their corresponding acids.

Silage additives inhibiting silage fermentation can reduce clostridial spore counts. In wilted grass silages a decrease in spore counts by a factor 5 to 20 has been observed. A similar decrease in spore counts could be obtained by adding molasses, a fermentation stimulant. To inhibit clostridial growth the most effective fermentation inhibitors appear to be additives based on formic acid, hexamethylene and nitrite (Hengeveld 1983; Corporaal *et al.* 1989; van Schooten *et al.* 1989; Jonsson *et al.* 1990; Lättemäe and Lingvall 1996).

4.3. Additives inhibiting aerobic spoilage.

Is clear that to inhibit aerobic spoilage, spoilage organisms, in particularly the ones causing the onset of deterioration (i.e. yeasts and acetic acid bacteria) have to be inhibited in their activity and growth. Some additives which have proven to be effective in this respect include chemical additives based on volatile fatty acids such as propionic and acetic acid, and biological additives based bacteriocin producing micro-organisms such as lactobacilli and bacilli (Woolford 1975a; McDonald *et al* 1991; Phillip and Fellner 1992; Moran *et al.* 1993; Weinberg and Muck 1996).

Furthermore, it is known that sorbic acid and benzoic acid have a strong antimycotic activity (Woolford 1975b; McDonald *et al.* 1991). Recently, it was discovered that *Lactobacillus buchneri* is a very effective inhibitor of aerobic spoilage. The inhibition of spoilage appears mainly due to the capability of *L. buchneri* to anaerobically degrade lactic acid to acetic acid and 1,2-propanediol, which in turn causes a significant reduction in yeast numbers (Driehuis *et al.* 1997; Oude Elferink *et al.* 1999; Driehuis *et al.*, in press). This reduction in yeast numbers is in agreement with the finding that volatile fatty acids such as propionic acid and acetic acid are much better inhibitors of yeasts than lactic acid is, and that mixtures of lactic acid and propionic and/or acetic acid have a synergistic inhibitory effect (Moon 1983). The results of

Moon (1983) also explain why biological inoculants that promote homofermentative lactic acid fermentation, in most cases do not improve, or even decrease, aerobic stability (Weinberg and Muck 1996; Oude Elferink *et al.* 1997).

Biological additives based on the propionate producing propionibacteria appear to be less suitable for the improvement of silage aerobic stability, due to the fact that these bacteria are only able to proliferate and produce propionate if the silage pH remains relatively high (Weinberg and Muck 1996).

4.4. Additives used as nutrients or absorbents.

Certain crops are deficient in essential dietary components for ruminants. The nutritional quality of these crops can be improved by supplementation with specific additives at the time of ensiling. Additives that have been used in this respect are ammonia and urea to increase the crude and true protein content of the silage, and limestone and $MgSO_4$ to increase the calcium and magnesium contents. The above mentioned additives generally have no beneficial effect on silage fermentation, but urea and ammonia can improve the aerobic stability of silage (Glewen and Young 1982; McDonald *et al.* 1991).

Absorbents are used in crops with a low dry matter content to prevent excessive effluent losses. Good results have been obtained with dried pulps such as sugar beet pulp and citrus pulp. Straw can also be utilized, but has a negative effect on the nutritive value of the silage (McDonald *et al.* 1991).

4.5. Combined additives.

Most commercial additives contain more than one active ingredient in order to have a high efficacy and a broad range of applicability. Very popular are for example combinations of inoculants stimulating homofermentative lactic acid fermentation together with sugar releasing enzymes, or combinations of fermentation and aerobic deterioration inhibiting chemicals such as formic acid, sulfite salts and propionic acid (Rider 1997; Arbeitsgemeinschaft der norddeutschen Landwirtschafskammer 1999).

New additives are currently being developed that decrease the negative effect of homofermentative lactic acid fermentation on aerobic stability. Promising results have been obtained by combining homofermentative or facultative heterofermentative lactic acid bacteria with chemicals such as ammonium formate and sodium benzoate (Kalzendorf 1992; Bader 1997), or by combining facultative heterofermentative lactic acid bacteria with the obligate heterofermentative *L. buchneri.*

5. Silage fermentation in tropical silages.

Ensiling of forage crops or industry by-products could make an important contribution to the optimization of tropical and sub-tropical animal production systems, but thus far it has not yet been widely applied (Wilkins *et al.* 1999). This is not only due to the low prices for animal products, the low levels of mechanization, and the high costs of silo sealing materials, but also due to the lack of ensiling experience. More research is needed to address the specific problems associated with tropical silages. Tropical grasses and legumes have for example a relatively high concentration of cell wall components and the low level of fermentable carbohydrates compared to temperate forage crops (Catchpoole and Henzell 1971; Jarrige *et al.* 1982). Furthermore, on average storage temperatures in tropical climates are higher than in temperate climates, which might give bacilli a competitive advantage over lactic acid bacteria (Gibson *et al.* 1958). In addition, it has to be taken into account that some silo sealing materials cannot withstand intense sunlight, and thus might impair the aerobic stability of the silage. Nevertheless, it seems likely that ensiling technologies from temperate climates can be modified for tropical conditions.

6. References

Arbeitsgemeinschaft der norddeutschen Landwirtschaftskammern 1999. Grünfutter- und Feuchtgetreidekonservierung. 5th ed. Arbeitsgemeinschaft der norddeutschen Landwirtschaftskammern, Oldenburg, Germany.

Ashbell, G., G. Pahlow, B. Dinter, and Z.G. Weinberg 1987. Dynamics of orange peel fermentation during ensilage. *J. Appl. Bacteriol.* **63**,275-279.

Auerbach, H. 1996. Verfahrensgrundlagen zur Senkung des Risikos eines Befalls von Silagen mit *Penicillium roqueforti* und einer Kontamination mit Mykotoxinen dieses Schimmelpilzes. Landbauforschung Völkenrode, Sonderheft 168, p. 1-167, Ph.D. diss. Universität Hohenheim, Germany.

Auerbach, H., E. Oldenburg, and F. Weissbach 1998. Incidence of *Penicillium roqueforti* and roquefortin C in silages. *J. Sci. Food Agr.* **76**,565-572.

Bader, S. 1997. Möglichkeiten zur Steuerung des Gärungsverlaufes bei der Grünfuttersilierung durch kombinierte Anwendung biologischer und chemischer Zusätze. Landbauforschung Völkenrode, Sonderheft 176, p. 1-110. Ph.D. diss. Universität Bonn, Germany.

Bolsen, K.K., G. Ashbell, and J.M. Wilkinson 1995. Silage additives. p. 33-54. In: R.J. Wallace and A. Chesson (ed.) Biotechnology in animal feeds and animal feeding. VCH Verlagsgesellschaft mbH, Weinheim, Germany.

Bolsen, K.K., and J.L. Heidker 1985. Silage Additives USA. Chalcombe Publications , Canterbury,UK.

Catchpoole, V.R., and E.F. Henzell 1971. Silage and silage-making from tropical herbage species. *Herbage Abstracts* **41**,213-221.

Cato, E.P., W.L. George, and S.M. Finegold 1986. Genus *Clostridium*. p. 1141-1200. In: P.H.A. Sneath, N.S. Mair, M.E. Sharpe, and J.G. Holt (ed.) Bergey's Manual of Systematic Bacteriology. Williams and Wilkins, Baltimore, MD, USA.

Claus, D, and R.C.W. Berkeley 1986. Genus *Bacillus*. p.1105-1139. In: P.H.A. Sneath, N.S. Mair, M.E. Sharpe, and J.G. Holt (ed.) Bergey's Manual of Systematic Bacteriology. Williams and Wilkins, Baltimore, MD, USA.

Corporaal, J., H.A. van Schooten, and S.F. Spoelstra 1989. Invloed van toevoegmiddelen op de kwaliteit van slecht voorgedroogd kuilvoer. *PR Rapport Nr 119*, Proefstation voor de Rundveehouderij, schapenhouderij en paardenhouderij, Lelystad, The Netherlands.

Devriese, L.A., M.D. Collins, R. Wirth 1992. The Genus *Enterococcus*. p. 1465-1481. In: Balows, A., H.G. Trüper, M. Dworkin, W. Harder, K.-H. Schleifer (ed.) The Prokaryotes. 2nd ed. Springer Verlag, New York, USA.

Donald, A.S., D.R. Fenlon, and B. Seddon 1995. The relationships between ecophysiology, indigenous microflora and growth of *Listeria monocytogenes* in grass silage. *J. Appl. Bacteriol.* **79**,141-148.

Driehuis, F., S.J.W.H. Oude Elferink, and S.F. Spoelstra 1997. Inoculation of silage with a strain of *Lactobacillus buchneri* inhibits yeast growth and improves aerobic stability. Abstract 3.18. In:Workshop Proc. Lactic 97, Caen, France. 10-12 Sept. 1997. Caen, France.

Driehuis, F., S.J.W.H. Oude Elferink, and S.F. Spoelstra. Anaerobic lactic acid degradation in maize silage inoculated with *Lactobacillus buchneri* inhibits yeast growth and improves aerobic stability. *J. Appl. Microbiol.* (in press.

Driehuis, F., and P.G. van Wikselaar 1996. Effects of addition of formic, acetic or propionic acid to maize silage and low dry matter grass silage on the microbial flora and aerobic stability. p. 256-257. In: D.I.H. Jones, R. Jones, R. Dewhurst, R. Merry, and P.M. Haigh (ed.) Proc. 11th Int. Silage Conference, Aberystwyth, UK. 8-11 September 1996. IGER, Aberystwyth, UK.

Fenlon, D.R., J. Wilson, and J.R. Weddell. 1989. The relationship between spoilage and *Listeria monocytogenes* contamination in bagged and wrapped big bale silage. *Grass Forage Sci*. **44**,97-100.

Frevel, H.-J., G. Engel, and M. Teuber 1985. Schimmelpilze in Silage und Rohmilch. *Milchwissenschaft* **40**,129-132.

Gibson, J. 1965. Clostridia in silage. *J. Appl. Bacteriol.* **28**,56-62.

Gibson, T., A.C. Stirling, R.M. Keddie, and R.F. Rosenberger 1958. Bacteriological changes in silage made at controlled temperatures. *J. Gen. Microbiol.* **19**,112-129.

Giffel, M.C. te 1997. Isolation, identification and characterization of *Bacillus cereus* from the dairy environment. Ph.D. diss. Wageningen Agricultural University, The Netherlands.

Giffel, te M.C., R.R. Beumer, B.A. Slaghuis, and F.R. Rombouts 1995. Occurence and characterization of (psychrotrophic) *Bacillus cereus* on farms in the Netherlands. *Neth. Milk Dairy J.* **49,**125-138.

Glewen, M.J., and A.W. Young 1982. Effect of ammoniation on the refermentation of corn silage. *J. Anim. Sci.* **54**,713-718.

Goudkov, A.V. and M.E. Sharpe 1965. Clostridia in dairying. *J. Appl. Bacteriol.* **28**, 63-73.

Hammes, W.P., N. Weiss, and W. Holzapfel 1992. The Genera *Lactobacillus* and *Carnobacterium*. p. 1535-1594. In: Balows, A., H.G. Trüper, M. Dworkin, W. Harder, K.-H. Schleifer (ed.) The Prokaryotes. 2nd ed. Springer Verlag, New York, USA.

Henderson, A.R., P. McDonald, and M.K. Woolford 1972. Chemical changes and losses during the ensilage of wilted grass treated with formic acid. *J. Sci. Food. Agr.* **23**, 1079-1087.

Hengeveld, A.G. 1983. Sporen van boterzuurbacteriën in kuilvoer. *Report 88.* Proefstation voor de Rundveehouderij, schapenhouderij en paardenhouderij, Lelystad, The Netherlands.

Holzapfel, W.H., and U. Schillinger 1992. The Genus *Leuconostoc*. p. 1508-1534. In: Balows, A., H.G. Trüper, M. Dworkin, W. Harder, K.-H. Schleifer (ed.) The Prokaryotes. 2nd ed. Springer Verlag, New York, USA.

Honig, H., and M K.Woolford 1980. Changes in silage on exposure to air. p. 76-87. In: C. Thomas (ed.) Forage Conservation in the 80s. *Occasional Symposium No. 11.* British Grassland Society, Hurley, Berkshire, UK.

Hoogkamp, W. 1999. Koeien smullen van kuilgras met bacteriemengsels. *Boerderij- Veehouderij* **84,**32-33.

Huchet, V., D. Thuault, and C.M. Bourgeois 1995. Modélisation des effets du pH, de l'acide lactique, du glycérol et du NaCl sur la croisance des cellules végétatives de *Clostridium tyrobutyricum* en milieu de culture. *Lait* **75**,585-593.

Jarrige, R., C. Demarquilly, and J.P. Dulphy 1982. Forage Conservation. p. 363-387. In: Hacker, J.B. (ed.). Nutritional limits to animal production from pastures. Commonwealth Agricultural Bureau, Farnham Royal, UK.

Jones, D., and H.P.R. Seeliger 1992. The genus *Listeria.* p. 1595-1616. In: Balows, A., H.G. Trüper, M. Dworkin, W. Harder, K.-H. Schleifer (ed.) The Prokaryotes. 2nd ed. Springer Verlag, New York, USA.

Jonsson, A., H. Lindberg, S. Sundås, P. Lingvall, and S. Lindgren 1990. Effect of additives on quality of big-bale silage. *Anim. Feed Sci. Technol.* **31**,139-155.

Jonsson, A., and G. Pahlow 1984. Systematic classification and biochemical characterization of yeasts growing in grass silage inoculated with *Lactobacillus* cultures. *Anim. Res. Develop.* **20**,7-22.

Kaiser, E. and K. Weiss 1997. Fermentation process during the ensiling of green forage low in nitrate. 2. Fermentation process after supplementation of nitrate, nitrite, lactic-acid bacteria and formic acid. *Arch. Anim. Nutr.* **50**,187-200.

Kalzendorf, C. 1992. Über die Möglichkeiten einer kombinierten Anwendung von Milchsäurebakterien und Natriumformiat als Silierzusatz. Ph.D. diss. Humboldt University of Berlin, Germany.

Kehler, W., and H. Scholz 1996. Botulismus des Rindes. *Übersichten zur Tierernährung* **24**, 83-91.

Kleter, G., W.L. Lammers, and A.E. Vos 1982. The influence of pH and concentration of lactic acid and NaCl on the growth of of *Clostridium tyrobutyricum* in whey and cheese 1. Experiments in whey. *Neth. Milk Dairy J.* **36**, 79-87.

Kleter, G., W.L. Lammers, and A.E. Vos 1984. The influence of pH and concentration of lactic acid and NaCl on the growth of of *Clostridium tyrobutyricum* in whey and cheese 2. Experiments in cheese. *Neth. Milk Dairy J*. **38**, 31-41.

Klijn, N., F.F.J. Nieuwenhof, J.D. Hoolwerf, C.B. van der Waals, and A.H. Weerkamp 1995. Identification of *Clostridium tyrobutyricum* as the causative agent of late blowing in cheese by species-specific PCR amplification. *Appl. Environ. Microbiol.* **61**,2919-2924.

Kung Jr., L. 1996. Use of additives in silage fermentation. p.37-42. In: Direct-fed Microbial, Enzyme and Forage Additive Compendium, Miller Publishing Co., Minnetonka, MN, USA.

Labots, H., G. Hup, and Th. E. Galesloot 1965. *Bacillus cereus* in raw and pasteurized milk. III. The contamination of raw milk with *B. cereus* spores during its production. *Neth. Milk Dairy J*. **19**,191-221.

Lacey, J. 1989. Pre- and post-harvest ecology of fungi causing spoilage of foods and other stored products. *J. Appl. Bacteriol.* **67**(Suppl.),11S-25S.

Lättemäe, P., and P. Lingvall 1996. Effect of hexamine and sodium nitrite in combination with sodium benzoate and sodium propionate on fermentation and storage stability of wilted and long cut grass silage. *Swed. J. Agr. Res*. **26**,135-146.

Lindgren S., K. Petterson, A. Kaspersson, A. Jonsson, and P. Lingvall 1985. Microbial dynamics during aerobic deterioration of silages. *J. Sci. Food Agr*. **36**, 765-774.

May, J.J. 1993. Respiratory problems associated with work in silos. p. 283-290. In: Proc. NRAES National Silage Production Conference. Syracuse, USA. 23-28 Feb. 1993. Syracuse, USA.

McDonald P., A.R. Henderson, and S.J.E. Heron 1991. The Biochemistry of Silage. 2nd edition. Chalcombe Publications, Marlow, Bucks, UK.

McPherson, H.T., and P. Violante 1966. Ornithine, putrescine and cadaverine in farm silages. *J. Sci. Food Agr.* **17**,124-127.

Merry, R.J., K.F. Lowes, and A. Winters 1997. Current and future approaches to biocontrol in silage. p. 17-27. In*:* V. Jambor, L. Klapil, P.Chromec, and P. Prochazka. (ed.) Proc. 8th Int. Symposium Forage Conservation, Brno, Czech Republic. 29 Sept.-1 Oct. 1997. Research Institute of Animal Nutrition, Pohorelice, Czech Republic.

Middelhoven, W.J., and A.H.M. van Baalen 1988. Development of the yeast flora of whole-crop maize during ensiling and subsequent aerobiosis. *J. Sci. Food Agr*. **42**,199-207.

Moon, N.J. 1983. Inhibition of the growth of acid tolerant yeasts by acetate, lactate and propionate and their synergistic mixtures. *J. Appl. Bacteriol.* **55**,454-460.

Moran, J.P., D. Pullar, and T.R. Owen 1993. The development of a novel bacterial inoculant to reduce mould spoilage and improve the silage fermentation in big bale silage. p. 85-86. In: P. O'Kiely, M. O'Connell, and J. Murphy (ed.) Silage Research 1993, Proc. 10th Int. Conf. Silage Res., Dublin, Ireland. 6-8 Sept 1993. Dublin City University, Dublin, Ireland.

Nout, M.J.R., H.M. Bouwmeester, J. Haaksma, and H. van Dijk 1993. Fungal growth in silages of sugarbeet press pulp and maize. *J. Agr. Sci*. **121**, 323-326.

O'Kiely, P., T. Turley, and P.A.M. Rogers 1999. Exposure of calves to nitrogen dioxide in silage gas. *Vet. Rec.* **144**, 352-353.

Os, M. van, and J.P. Dulphy 1996. Voluntary intake and intake control of grass silage by ruminants. *Reprod. Nutr. Develop.* **36**, 113-135.

Os, M. van, A.M.van Vuuren, and S.F. Spoelstra 1997. Mechanisms of adaptation in sheep to overcome silage intake depression induced by biogenic amines. *Brit. J. Nutr.* **77**, 399-415.

Oude Elferink, S.J.W.H., F. Driehuis, and S.F. Spoelstra 1997. Improving aerobic stability of maize silage with heterofermentative lactic acid bacteria as inoculants. p. 130-131. In*:* V. Jambor, L. Klapil, P.Chromec, and P. Prochazka (ed.) Proc. 8th Int. Symp. Forage Conservation, Brno, Czech Republic. 29 Sept.-1 Oct. 1997. Research Institute of Animal Nutrition, Pohorelice, Czech Republic.

Oude Elferink, S.J.W.H., F. Driehuis, J. Krooneman, J.C. Gottschal, and S.F. Spoelstra 1999. *Lactobacillus buchneri* can improve the aerobic stability of silage via a novel fermentation pathway, the anaerobic degradation of lactic acid to acetic acid and 1,2-propanediol. p. 266-267. In*:* T. Pauly (ed.) Proc. 12th Int. Silage Conference, Uppsala, Sweden, 5-7 July. 1999. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Pahlow, G., and H. Honig 1986. Wirkungsweise und Einsatzgrenzen von Silage-Impfkulturen aus Milchsäurebakterien. 1. Mitteilung. *D. Wirtschaftseig. Futter* **32**, 20-35.

Pahlow, G., and F. Weissbach 1996. Effect of numbers of epiphytic lactic acid bacteria (LAB) and of inoculation on the rate of pH-decline in direct cut and wilted grass silages. p.104-105. In*:* D.I.H. Jones, R. Jones, R. Dewhurst, R. Merry, and P.M. Haigh (ed.) Proc. 11th Int. Silage Conf., Aberystwyth, UK. 8-11 Sept. 1996. IGER, Aberystwyth, UK.

Pelhate, J. 1977. Maize silage, Incidence of moulds during conservation. *Folia Veterinaria Latina* **7**,1-16.

Phillip, L.E., and V. Fellner 1992. Effects of bacterial inoculation of high-moisture ear corn on its aerobic stability, digestion, and utilization for growth by beef steers. *J. Anim. Sci.* **70**, 3178-3187.

Rammer, C., C. Östling, P. Lingvall, and S. Lindgren 1994. Ensiling of manured crops - Effects on fermentation. *Grass Forage Sci.* **49**, 343-351.

Randby, Å.T., I. Selmer-Olsen, and L. Baevre 1999. Effect of ethanol in feed on milk flavor and chemical composition. *J. Dairy. Sci.* **82**, 420-428.

Rider, S. 1997. Forage additives. Farmers Weekly, 21 November (Suppl.) S1-S16.

Sanaa, M., B. Poutrel, J.L. Menard, and F. Serieys 1993. Risk factors associated with contamination of raw milk by *Listeria monocytogenes* in dairy farms. *J. Dairy Sci.* **76**, 2891-2898.

Schlegel, H.G. 1987. General Microbiology. 6th ed. Cambridge University Press, Cambridge, UK.

Schleifer , K.H., and W. Ludwig 1995. Phyogenetic relationships of lactic acid bacteria. p. 7-18. In: Wood, B.J.B. and Holzapfel, W.H. (ed.) The Genera of Lactic Acid Bacteria, Blackie Academic & Professional, London, UK.

Schooten, H.A. van, Corporaal, J., and S.F. Spoelstra 1989. Effect van verschillende oogstmachines en melasse op de kwaliteit van slecht voorgedroogd kuilvoer. *PR-rapport nr.118*. Proefstation voor de Rundveehouderij, schapenhouderij en paardenhouderij, Lelystad, The Netherlands.

Scudamore, K.A., and C.T. Livesey 1998. Occurence and significance of mycotoxins in forage crops and silage, a review. *J. Sci. Food Agr.* **77**, 1-7.

Spoelstra, S.F. 1983. Inhibition of clostridial growth by nitrate during the early phase of silage fermentation. *J. Sci. Food Agr.* **34**, 145-152.

Spoelstra, S.F. 1985. Nitrate in silage. A review. *Grass Forage Sci.* **40**, 1-11.

Spoelstra, S.F. 1987. Degradation of nitrate by enterobacteria during silage fermentation of grass. *Neth. J. Agr. Sci.* **35**, 43-54.

Spoelstra, S.F, M.G. Courtin, and J.A.C. van Beers 1988. Acetic acid bacteria can initiate aerobic deterioration of whole crop maize silage. *J. Agr. Sci. Camb.* **111**, 127-132.

Staudacher, W., G. Pahlow, and H. Honig 1999. Certification of silage additives in Germany by DLG. p. 239-240. In: T. Pauly (ed.) Proc. 12th Int. Silage Conference, Uppsala, Sweden, 5-7 July. 1999. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Teuber, M., A.Geis, and H. Neve 1992. The Genus *Lactococcus*. p. 1482-1501. In: Balows, A., H.G. Trüper, M. Dworkin, W. Harder, K.-H. Schleifer (ed.) The Prokaryotes. 2nd ed. Springer Verlag, New York, USA.

Vazquez-Boland, J.A., L. Dominguez, M. Blanco, J. Rocourt, J.F. Fernandez-Garayzabal, C.B. Gutierrez, R.I. Rascon, and E.F. Rodriguez-Ferri 1992. Epidemiologic investigation of a silage-associated epizootic of ovine listeric encephalitis, using a new *Listeria*-selective enumeration medium and phage typing. *Am. J. Vet. Res.* 53, 368-371.

Vos, N. 1966. Über die Amin- und Ammoniakbildung im Gärfutter. *D. Wirtschafteig. Futter* **12**, 161-171.

Vreman, K., S.F. Spoelstra, and S.J.W.H. Oude Elferink. Aerobic spores occur in vast quantities insilages from laboratory and farm silos. *D. Wirtschaftseig. Futter* (in press).

Waes, G. 1987. Boterzuurbacteriën in melk en in kuilvoer. *Landbouwtijdschrift* **40**, 925-932.

Weinber, Z.G., G. Pahlow, B. Dinter, and G. Ashbel 1988. The effect of treatment with urea, sorbic acid, or dehydration on orange peel silage. *Anim. Feed Sci. Technol.* **20,**335-342.

Weinberg, Z.G., and R.E. Muck 1996. New trends and opportunities in the development and use of inoculants for silage. *FEMS Microbiol. Rev.* **19**, 53-68.

Weiss, N. 1992. The Genera *Pediococcus* and *Aerococcus.* p. 1502-1507. In: Balows, A., H.G. Trüper, M. Dworkin, W. Harder, K.-H. Schleifer (ed.) The Prokaryotes. 2nd ed. Springer Verlag, New York, USA.

Weissbach, F., and H. Honig 1996. Über die Vorhersage und Steuerung des Gärungsverlaufs bei der Silierung von Grünfutter aus extensivem Anbau. Landbauforschung Völkenrode, Heft 1,10-17, Germany.

Wiedmann, M., J. Czajka, N. Bsat, M. Bodis, M.C. Smith, T.J. Divers, and C.A. Batt 1994. Diagnosis and epidemiological association of *Listeria monocytogenes* strains in two outbreaks of listerial encephalitis in small ruminants. *J. Clin. Microbiol.* **32**, 991-996.

Wieringa, G.W. 1958. The effect of wilting on butyric acid fermentation in silage. *Neth. J. Agr. Sci.* **6**, 204-210.

Wilkins, R.J., L. Syrjälä-Qvist, and K.K. Bolsen 1999. p. 23-35. In: T. Pauly (ed.) Proc. 12th Int. Silage Conference, Uppsala, Sweden, 5-7 July. 1999. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Wilkinson, J.M., F. Wadephul, and J. Hill 1996. Silage in Europe, a survey of 33 countries. Chalcombe Publications, Welton, UK.

Woods, L.F.J., J.M. Wood, and P.A. Gibbs 1981. The involvement of nitric oxide in the inhibition of the phosphoriclastic system in *Clostridium sporogenes* by sodium nitrite. *J. Gen. Microbiol.* **125**, 339-406.

Woolford, M.K. 1975a. Microbiological screening of the straight chain fatty acids (C1-C12) as potential silage additives. *J. Sci. Food Agr.* **26**, 219-228.

Woolford, M.K. 1975b. Microbiological screening of food preservatives, cold sterilants and specific antimicrobial agents as potential silage additives. *J. Sci. Food Agr.* **26**, 229-237.

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