Topic 18

18. Chemical and physical treatment of roughages to improve digestibility

18.1 Introduction to chemical treatment

18.2 Physical treatment of roughages

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Learning Objectives

On completion of this topic you should be able to:

- Describe some chemical treatments that can be applied to low quality feeds to improve their nutritive value to ruminants.
- Explain why particle size can impact on the digestion of roughages.
- Describe some physical treatment options for improving the digestibility of low quality roughage sources for ruminants.
- Explain why urea is often used for improving the utilisation of low quality roughages.

Key Terms and Concepts

Chemical Treatment; Physical Treatment of roughages.

Introduction to the Topic

Many countries of the world rely on low quality roughages as the primary source of nutrients for ruminant animals. Australia is an example of this. In poorer nations that are densely populated, opportunities to supplement these animals with products such as cereal grain, urea or molasses is limited. In addition to this, production systems in these countries are typically intensive, with one family owning only a few head of livestock. In such situations, cattle may be used for milk production for the family, draft to prepare the soil for planting and reproduction to produce offspring. These type of production requirements placed significant demands on the animal. Therefore, the need for strategies aimed at improving the quality of available roughages sources is needed.

This topic will introduce you to several examples of chemical and physical treatment of roughages to improve their nutritive value for livestock. These are strategies that are often used in production systems such as those mentioned above.

18.1 Introduction to chemical treatment

During the 70s and 80s there was considerable interest in the chemical treatment of straw and other of low quality roughages for ruminant feeding. There's a tremendous amount of fibrous crop residue that is underutilised and which has the potential for animal feeding. These resources include cereal crops stubbles, rice straw and mature pasture. The principal method of treatment was based on the use of an alkali. Early research showed very exciting increases in the digestibility of roughages in response to treatment with sodium hydroxide. Sheep and cattle fed treated roughages show benefits in terms of increased feed intake in addition to the expected improvements associated with higher digestibility of the roughage. Based on this early success additional research was conducted to examine other sources of alkali and a number of studies investigated the use of calcium or potassium hydroxide as alternatives to sodium hydroxide. There was also a great deal of work on the use of ammonium hydroxide particularly from the point of view of treating straw with anhydrous ammonia and urea.

Although the treatment of low quality roughages with hydroxide is very effective as a way of increasing digestibility and improving animal performance, a number of logistical, safety and environmental issues have limited the use of chemical treatment under commercial conditions.

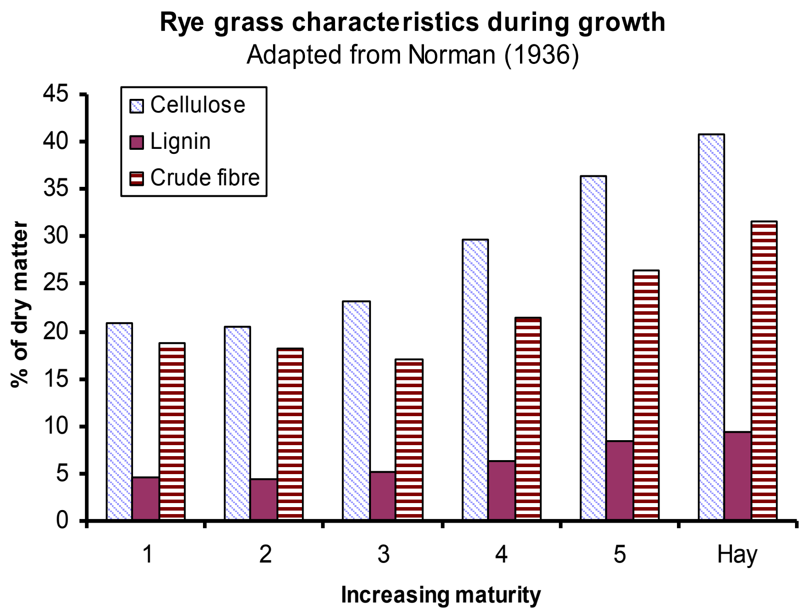
What is straw and what does the hydroxide treatment accomplish?

The major components of straw include structural carbohydrates such as cellulose, non-starch polysaccharides and lignin. It is the amount of lignin and its distribution in the plant material that has the greatest effect on digestibility. The cellulose is made up of glucose molecules connected through □-1-4 linkages. These bonds it cannot be split by mammalian enzymes. However, cellulose can be utilised by bacteria during fermentation and broken down to form the VFA. When lignin surrounds the cellulose, it effectively prevents bacterial attachment and reduces digestibility both through its own inert properties and by forming a barrier to the digestible cellulose. The lignin is mainly present in the stems and nodes: it is also present in reasonably high concentration in some leaf material. Lignin is a family of related polymers of a three-dimensional structure made up of phenol propane units. Lignin has a number of functions which are essential for the plant. Together with other components in cell walls, lignin is responsible for structural strength and has outstanding properties in resisting microbial attack. These characteristics unfortunately present the major impediment to digestion of the plant material by microbes and by the animal's digestive enzymes.

There is little protein in straw and what protein there is, is mainly associated with the cell walls and is not readily digestible. The ash content of straw can vary from around 6% in barley and wheat to around 19% in the case of rice. The high level of ash in rice is mainly because of high silica levels. Silica taken up by the plant roots is deposited in the cell walls and together with lignin has a negative effect on bacterial breakdown of the plant fibre. The combination of lignin and silica in rice straw makes this material almost indigestible.

As shown in Figure 18-1, lignin content does not rise as quickly as cellulose concentration during maturation of the cereal plant but the lignin has a disproportionate effect on digestibility. Alkali treatment forms the basis of the wood pulping process used for paper manufacture. The effect of the alkali is to cleave internal linkages, lignin, the non-starch polysaccharides (NSP) and cellulose. Degradation of the lignin and NSP makes the cellulose more accessible for hydrolysing enzymes. During alkali treatment of fibrous material the structural NSP are also partly solubilised.

Figure 18-1 Rye grass characteristics during growth (adapted from Norman 1936).



The application of heat together with alkaline conditions can solubilise the lignin with formation of free phenols. Steaming at temperatures over 160°C can increase digestibility through auto hydrolysis and because the lignin melts at these high temperatures.

Sodium hydroxide treatment to increase digestibility and intake of roughages

As early as 1942 W. S. Ferguson had shown improved digestibility of fibrous foragers through treatment with sodium hydroxide. In Australia Roy Kellaway and colleagues at Sydney University developed practical ways of treating large quantities of cereal stubbles and the methods were adopted by many producers.

Table 18-2 shows the effect of different methods of alkali treatment of barley straw on in vivo digestibility in sheep (Wanapat *et al.* 1985). Treatment with sodium hydroxide involved soaking of straw for 30 minutes in a solution containing 15 g sodium hydroxide/litre. Aqueous ammonia treatment involved application of 120 g ammonia solution (25%)/kg of straw followed by 8 weeks' storage prior to feeding.

There are three major problems in using sodium hydroxide. The first is the danger to operators and the risk of being splashed with the strong sodium hydroxide solution. It is highly corrosive and particularly dangerous if it comes into contact with skin and eyes. The second issue is the high sodium level and its adverse impact on the environment. High sodium levels can also have adverse effects on the animal and there are reports of kidney damage in dairy cattle fed high levels of sodium over long periods of time. High levels of sodium can also a negative input on the environment. The final aspect, common to all alkali treatment processes, is the corrosion and damage to equipment.

Table 18-2 Effect of sodium hydroxide and aqueous ammonia on digestibility of barley straw by sheep (Wanapat *et al.* 1985).

Treatment of barley straw	In vivo digestibility %
Untreated	50.8
Sodium hydroxide	75.2
Aqueous ammonia	65.7

Treatment with urea or ammonia

Many common bacteria found on plant materials have urease activity and urea is therefore rapidly degraded to carbon dioxide and ammonia if it is added plant biomass under natural conditions. Provided there is sufficient water present, ammonia rapidly forms ammonium hydroxide.

Urea ——> ammonia + water ——> ammonium hydroxide

Urea is far safer to handle than ammonium hydroxide and can be applied to straw in an aqueous solution. There have been numerous studies to determine the optimum concentration of urea and the appropriate time between application and feeding the straw. It is generally agreed that around 5% urea should be used (50 kg urea per tonne of straw) and that the straw should then be covered or ensiled for at least four weeks prior to being used. Once it is in a sealed container or pit, it is stable for long periods of time. The concentration of anhydrous ammonia required for the same effect is closer to 3%. The use of anhydrous ammonia has the advantage of easy application to large stacks of straw as a gas. This method of treatment is still popular in some parts of Europe where large piles of cereal straw are covered with black plastic prior to introducing hydrous ammonia from a mobile tank.

The methods of harvesting, chopping the material, applying the urea/ammonia and the facilities for storage and equipment for feeding out the treated material are all critical in determining the success and attractiveness of this procedure. As it involves large quantities of material, it is highly desirable to have the process of harvesting and filling the pit or silo highly mechanised. In situations where mechanisation is not available the job of harvesting, filling silos and feeding out is tedious and unpopular. The onerous nature of the task makes this a very cost-effective but labour-intensive method of treating crop by-products. The method is of relatively minor importance in many parts of the world where one might think it would be ideal technology.

NOTE: In combination with heat, ammonia can at times form potentially dangerous compounds with carbohydrates. In rare cases, ammoniated straw fed to cattle can cause “bovine bonkers” (Perdok & Leng 1985).

Treatment with other chemicals

The “ideal” chemical for enhancing the digestibility of cereal straw is:

· non-hazardous to handling by humans;

· non-corrosive to machinery;

· non-polluting to soils and water;

· not a source of chemical residues in animals, faeces or urine;

· readily available and cheap relative to improvements in feed value.

Even though many different classes of chemicals including alkalis, acids, salts, oxidising agents, sulphur compounds and surfactants have been tested, no totally satisfactory alternative to sodium hydroxide or urea/ammonia has emerged. Calcium hydroxide appears to be a satisfactory alternative and calcium oxide when used in conjunction with urea has also produced reasonably good results.

Is chemical treatment a practical alternative?

In assessing whether chemical treatment is justified, it is worth considering the alternative of allowing animals to harvest their material in the paddock and to feed a supplement to bring the total diet up to the desired standard. When the animal harvests the material itself by grazing, there are no costs of harvesting, transport, storage or feeding out. When one considers the complete cost of straw treatment, the alternative of using supplements such as lupins or cereal grain for grazing animals often becomes an attractive option.

18.2 Physical treatment of roughages

There are various ways in which the physical characteristics of a roughage may be altered including grinding, chopping and pelleting. These methods can be considered under four categories:

1 ***Particle size***—reducing particle size in order to increase the surface area for microbial fermentation of fibrous components in the rumen or hind gut or to expose more of the material to pre-feeding treatments;

2 ***Handling***—to produce a material that is easier to handle or compact during the processes of ensiling or storage;

3 ***Density***—to increase the density of the material so that animals are able to increase their intake; and

4 ***Mixing***—in order to mix other ingredients with the roughage to balance the nutrients supplied to the animal and improve the animal's ability to digest the fibrous material and/or consume more of it.

Grinding to reduce particle size

Although this is one of the simplest mechanical processes in the treatment of any feedstuff, it is still an expensive and relatively unpleasant task. The efficient handling of the large quantities of roughage requires expensive mechanisation and the process of grinding uses large quantities of energy. Even in large efficient operations the cost of grinding hay or straw is estimated to be over $20/tonne. In addition to the cost is the unpleasant working environment involved in the grinding operation. It is invariably noisy and dusty. Operators are therefore required to wear protective equipment to limit the damage to hearing and the inhalation of dust. The question is therefore whether it is a process that is cost- effective when all of these factors are considered.

There are clear benefits in terms of increased digestibility of fibre via microbial fermentation as the particle size is decreased in both roughages and grains. It is unlikely that the increased digestibility alone pays for the cost and irksome nature of the task in grinding hay or straw (see Table 18-3). Even in situations where feed intake and live-weight gain are increased as a result of grinding, benefits in terms of feed conversion efficiency are rarely achieved. Where the quality of roughage is very low, grinding normally has little if any effect on intake and animal performance. However, in the preparation of completely mixed rations and pelleted diets, it is essential to break down the particle size for effective mixing and/or pelleting.

Table 18-3 Effects of milling hay and straw on intake and growth of cattle. The digestibility use of hay on its own was 51% and straw 30%. The diets contained roughage, lupins and barley to give digestibility of the hay diet of 70% and of these straw diet 55%. (Jones, May and Barker, 1988).

	Straw–based		Hay –based		Least sig diff
	Milled	Long	Milled	Long	LSD (0.05)
Dry matter intake (kg/day)	4.45	4.47	8.81	6.91	0.62
Live–weight gain (kg/day)	0.25	0.27	1.35	0.90	0.17
Intake/gain (kg/kg)	18.6	18.0	6.5	7.7	1.66

Pelleting and cubing

The processes of pelleting and cubing are similar in that the feeds are ground (in the case of pelleting) or chopped into small particles (in the case of cubing) before being compacted under pressure and at elevated temperatures to form pellets or small wafers up to 3 cm in diameter.

The process of pelleting normally describes feeds containing high levels of cereal grain finely ground and treated with steam to produce gelatinisation of starch before the mixed feed is extruded through dies of 0.2 to 1 cm in diameter. In order to remain intact during handling and feeding out, pellets must be made out of material with the particle length less than half the diameter of the pellets. Pelleted feed is easy to handle in bulk and can be fed out automatically using tubular distribution systems. This ease of handling, the high density of the feed and the flexibility of this feeding method to deliver a complete balanced diet are attractive features. The process of pelleting comes at a reasonably high price and is only economically attractive where the cost of labour or storage are significant factors. The pelleted feeds are also very convenient for smaller scale operators not wishing to invest in mixing and storage equipment. When buying in the pelleted feeds there is also no need to maintain stocks of lots of individual ingredients covering mineral, vitamin and amino acid supplements.

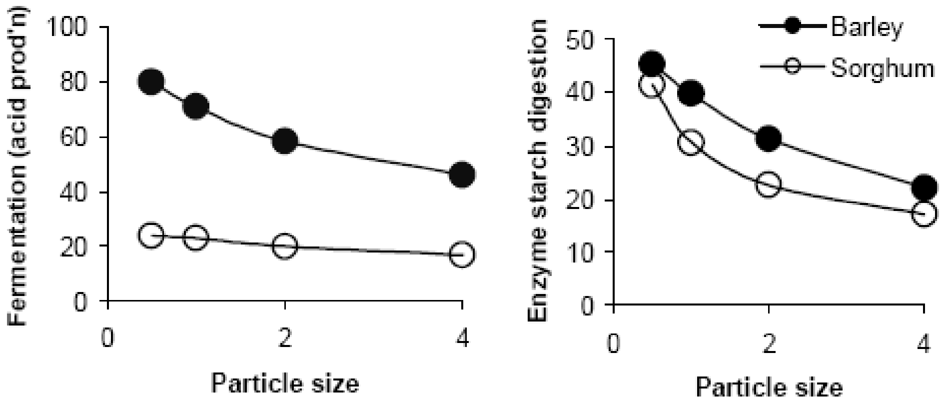
The process of cubing is mainly used for hay transport and feeding. It is a process that is very popular in the United States for preparing lucerne hay for export and for feeding lucerne hay to dairy cattle and horses. It is best described as a "micro hay baler" and produces "chunks" of compressed feed approximately 3 cm x 3 cm that are easily handled using conveyor belts and mechanical shovels and have a sufficiently high density for export in container loads. This method of feed preparation has also become popular in the live animal export industry where it is well suited to limited storage and cramped on-board feeding systems.

The processes of cutting (or chaffing), cubing or pelleting can also do a lot to reduce wastage of roughage. When long hay is fed to cattle or sheep there is often wastage due to trampling and spreading the feed around. However there are additional costs in terms of feed troughs required to take advantage of the chopped, high density mixed diets and these additional expenses must be considered against the benefits. Roughages can be efficiently utilised by implementing good management practices such as use of the "waste not" feeder for round-bale hay and mobile silage carts.

Particle size and grain feeding

Particle size can have a large effect on the rate of fermentation and intestinal digestion of cereal grains. It is also significant that the relationship between particle size and rate of fermentation or digestion is not the same for all grains. Adjusting particle size when preparing grain for cattle feeding therefore provides a significant management tool to alter the site and extent of digestion. The results summarised in Figure 18-2 show the differences between barley and sorghum grain in their response to grinding through different screen sizes. These results suggest that finely grinding sorghum does not significantly affect rate or extent of fermentation but has a very significant effect on intestinal digestion. On the other hand the particle size of barley grain has a similar effect on rate of fermentation as it does on intestinal digestion.

Figure 18-2 Effect of particle size on fermentation and intestinal digestion of barley and sorghum (Bird *et al.* 1999).



Readings

The following readings are available on CD:

- Djajanegara and Doyle (1989) The intake and utilisation of urea-treated rice straw by sheep in deffering body condition. *Australian Journal of Agricultural Research*. **40**: 1037-1045.
- Liu *et al*. (2002) In vitro gas production measurements to evaluate interactions between untreated and chemically treated rice straws, grass hay and mulberry leaves. *Journal of Animal Science*. **80**: 517-524.
- Moran *et al.* (1983) The utilization of rice straw fed to zebu cattle and swamp buffalo as influenced by alkali treatment and leucaena supplementation. *Australian Journal of Agricultural Research*. **34**: 73-84.

Self Assessment Questions

1. What are the advantages and disadvantages in NaOH treatment of cereal straw?
2. How does the alkali treatment improve digestibility?
3. Compare the benefits and costs of feeding long hay or chaff to cattle.
4. What are the benefits in using pelleted diets for dairy cows?

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