

III. AMMONIA TREATMENT

This Chapter is essentially aimed at recalling the key success factors for which anhydrous ammonia may be used for treatment, at the same time emphasising certain practical aspects which allow mastering the treatment.

3.1. Ammonia as a reagent

Interesting research results concerning the use of caustic soda for improvement of the nutritive value of straw, encouraged many research workers to study other products. First studies concerning ammonia date back to Germany 60 years ago (KRONENBERGER, 1933). They were followed up later, principally in Scandinavia, and also in Central Europe and the then USSR, success being variable but the effects generally less marked than when using caustic soda. It was not until 1974-75 that a treatment technique for stacks was launched by livestock farmers from Norway who injected the straw with anhydrous ammonia at ambient temperature. Originally published by SUNDSTOL *et al.* (1978), the technique spread rapidly in those countries possessing ammonia supplies and who wished to improve the feed value of their straw.

Ammonia (NH_3) is a byproduct from industrial "cracking" of hydrocarbons. It is used as a raw material in the fertilizer industry and also applied directly as a fertilizer. It is a gas at normal atmospheric pressure. It is easy to liquefy and readily dissolves in water. It has a vapour pressure of 8.5 bars at 20° and a boiling point of -33.4 °C at normal atmospheric pressure. It is usually available at a very high degree of purity (99.8 %). Storage (and distribution) in liquid state requires containers able to resist high pressures (4, 6, 8.5 and 20 bars at temperatures of 0, 10, 20 and 50 °C respectively). The "proof" pressure of these containers has now been standardised at 29 bars (which provides a safety margin for extreme cases of temperatures rising above 50 °C).

Due to the volatility of ammonia at normal room temperature and pressure, treatment with anhydrous ammonia presupposes that the forages will be treated within hermetically sealed enclosures.

Hydrous ammonia (NH_4OH) is a solution of ammonia whereby the actual concentration at normal atmospheric pressure depends upon ambient temperature: it ranges from 400 to 185 g/kg as the temperature rises from 10 to 50 °C. Solutions normally available on the market are sold in plastic containers and have a concentration of 250 g of ammonia per kg.

This base is weaker than caustic soda and is thus somewhat less efficient for the alkaline hydrolysis of the forage parietal carbohydrates; it does however have the advantage of improving their nitrogen content.

3.2. Success factors for ammonia treatment

Success factors mainly involve the amount of ammonia used, its temperature, the duration of the treatment and the humidity under which treatment takes place; they also depend upon the nature of the forage to be treated and the interaction of all these parameters in a manner between which it is difficult to distinguish.

These parameters have formed the basis for various studies and synopses and one may refer to those of SUNDSTOL and COXWORTH (1984) and CORDESSE (1987). Below, a few more recent and interesting observations which have not yet been published will be described.

Mention of the treatment efficiency of these parameters presupposes knowledge of how to quantify their effect. This subject which is both important and delicate, forms the basis for a special chapter later in the text. At the moment and for the sake of simplicity, the following arguments will only be presented in terms of *in vitro* digestibility (IVD) which may be measured by laboratory methods.

3.2.1. Amount of ammonia

This is the most important parameter. A series of studies undertaken on this subject have shown that ammonia supplied in application rates which exceed 4.0 and up to 5.5 and 7.0 kg per 100 kg of straw, have only a marginally beneficial effect (SUNDSTOL *et al.*, 1979). **Figure 11a** well illustrates the effect on the *in vitro* digestibility (IDV) caused by the amount of available ammonia; this particular case concerns barley straw treated over a 4 week period at various concentrations of alkali and for a range of ambient temperatures (SUNDSTOL *et al.*, 1978). The consensus of these authors is that **application rates which exceed 4 % (of the treated straw DM content) cannot be justified**, and even less so when the other parameters fail to be duly considered. The optimum economic application rate for ammonia (either anhydrous or aqueous) certainly lies in the range of 2.5 to 3.5 kg per 100 kg DM of treated straw (in other words, between 2.1 and 3.0 kg per 100 kg of straw with an 85 % DM content).

Whatever the true reasons, and as well illustrated in **Figure 11a**, **application rates less than 2.5 % on a dry matter basis (in other words, 2.1 % of straw having an 85 % DM content) are insufficient** and will not produce expected results.

Figure 11: Influence of the ammonia dosage rate, the ambient temperature, the treatment time and the ambient humidity during treatment on the treatment efficiency of a barley straw, as measured by the in vitro digestibility of the organic matter (IVD OM %) (after Sundstolet al., 1978).

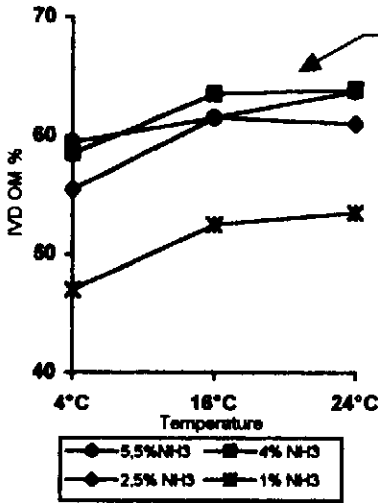


Figure 11a: Influence of temperature and ammonia dosage rate (treatment time of 4 weeks)

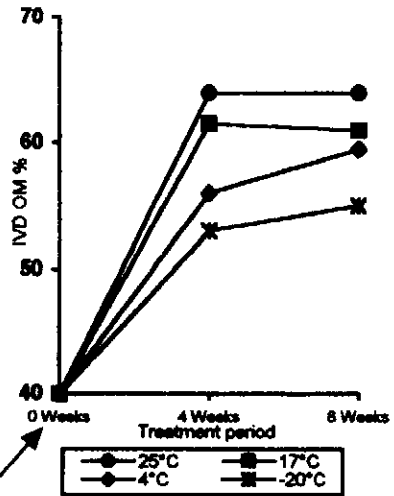


Figure 11b: Influence of temperature and treatment time (treatment with 3.4 % ammonia dosage rate with 25 % humidity)

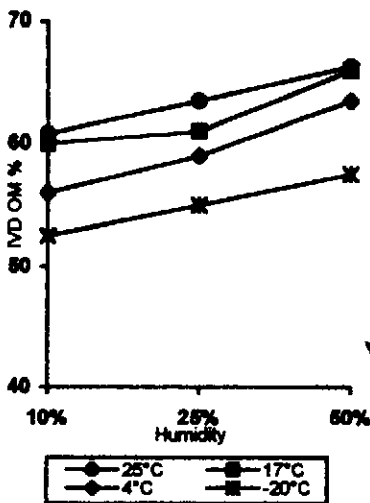


Figure 11c: Influence of temperature and humidity (treatment time of 8 weeks with 3.4 % ammonia dosage rate)

3.2.2. Temperature and length of treatment

It is difficult to dissociate these two parameters as the speed of the alkaline chemical reaction upon the straw, as in the case of many chemical reactions, is moderated in accordance with the temperature at which it takes place. This phenomenon is illustrated in Figure 11b (SUNDSTOL *et al.*, 1978).

The rapid rise in temperature during treatment due to heat released from the chemical reaction is insufficient to ensure optimum conditions for treating the stacks (without additional heat being applied). What happens in effect, is that the temperature of the straw mass approaches ambient temperature after several days (a little later if liquid ammonia is injected as this first causes a drop in temperature due to evaporation). It follows that ambient temperature will have the most significant effect on treatment efficiency.

It should also be understood that ammonia is a weaker base source than caustic soda and reacts more slowly.

It is essential to observe a treatment period determined according to ambient temperature, a longer period at low temperatures and vice et versa at higher temperatures. Certain limits must however be observed: **below an ambient temperature of 17°C, treatment should extend beyond 4 weeks** (see Figure 11b). Treatment only takes a matter of hours at a temperature of between 90 and 100 °C. In contrast in temperate regions and high tropical regions where seasonal frosts can occur at night, it is most important to **allow adequate treatment time**, for which overall efficiency will continue to improve up to 8 weeks later. For intermediate ambient temperatures between 5 and 15 °C, one should adopt similarly intermediate treatment times of between 4 and 8 weeks.

The following practical recommendations offer a good indication of the time needed for adequate ammonia treatment (SUNDSTOL *et al.*, 1978):

Ambient Temperature	Treatment Time Required
< 5 °C	> 8 weeks
5-15 °C	4 to 8 weeks
15-30 °C	1 to 4 weeks
>30 °C	< 1 week <i>at least a week (*)</i>

(after: Sundstol *et al.*, 1978)

(*) One should also understand that, apart from the alkaline effect of hydrolysis of the parietal carbohydrates, the ammonia contributes nitrogen which will be partially retained by the straw (about 2/3 overall) by adsorption (this portion is exchangeable and will gradually depart if the treated straw is left for a long time in the open air) and partially (the remaining 1/3) through chemical reaction with the straw cell walls (only this portion is solidly bonded, see § 323 below). Higher ambient temperatures and treatment periods (as well as ambient humidity as will be shown later in the text) affect the efficiency of the reaction. This is the reason why the Tunisians (and one subscribes to this viewpoint), for safety prefer to recommend in practice "at least a week" for ambient temperatures above 30 °C (see * in the last line of the above table).

3.2.3. Effect of ambient humidity on ammonia treatment

The important factor influencing ammonia treatment efficiency concerns the moisture content within the forage mass (and hence the dry matter content of the straw if this is to be treated with anhydrous ammonia). In essence, the treatment depends upon the NH_4^+ ion (NH_3 being inert) which is only liberated if NH_3 is available in the presence of water. Unfortunately, this parameter is frequently underestimated in regions where straw and other treated crop residues are very dry (such as in the Mediterranean regions, arid zones and very dry temperate zones).

Work on this subject is less well documented (but see WAISS *et al.*, 1972; BORHAMI *et al.*, 1982; CORDESSE, 1982; ALIBES *et al.*, 1983;...) than that concerning other factors and indeed studies concerning straw moisture contents below 15 % have so far been neglected. Available studies show that the increase of humidity within the treatment environment gives positive response on treatment efficiency both in terms of an increase to the IVD and in the overall nitrogen content. This relationship is shown to be nearly linear (see Figure 11c) even for low temperatures and for lengthy treatment times.

One may generally assume that the optimum moisture content range for successful treatment lies between 15 and 25 %. Even if higher moisture contents can further improve the treatment efficiency, other difficulties appear which risk to reduce any beneficial effects (such as storage problems related to the possibility of mould development).

In practice, it is vital to dampen straw which has a DM content higher than 90 % if one does not want to run the risk of "treating for nothing". Dampening the straw can be achieved by spraying water on the bales, one by

one, as the stack is made although this involves some hand labour. Another possibility consists in treating with aqueous ammonia (NH_4OH) if this is available locally (respecting the amount of alkali to incorporate). In the authors' opinion it is preferable to dampen the straw rather than to adopt this latter technique which, although very simple, is rather hazardous and with which technical personnel are usually less familiar.

3.2.4. The nature of the forage to be treated

This is an important aspect. In fact bibliographic research shows that globally, **straw responds better to treatment when it is less digestible beforehand**; treatment may not be so efficient for high quality straw. However, appropriate methods are still lacking to enable rapid distinction between low and high quality straw material.

The ability of a particular forage to respond to alkaline treatment will depend upon its botanic family, its species and its variety. Without entering into further details, this ability is related to the nature of the bonds between the phenolic acids and the lignin (ethers or esters, the former being more sensitive to the alkalis and the latter, less so). For these reasons, legumes are generally less sensitive to alkaline attack and treating leguminous stalks responds much less than when grasses are treated. There are also differences in treatment response between the grasses varieties. Research continues and some authors have already started to propose certain indices which could be evaluated such as the saponification index, the optical density, etc. (see DIAS DA SILVA *et al.*, 1990; BESLE *et al.*, 1989,...); these methods however still remain too complex to apply in practice.

This broad variation in the aptitude of different straws to respond to the alkalis (and also in nutritive values) leads also to evidence that **there is no single, universally applicable application rate, rather a range determined according to their botanic make up.** This is certainly the partial reason why trials concerning straw response to various alkali application rates have been so numerous and their results so diverse.

All this leads to the conclusion that, for the moment, one should avoid generalisations and using specific recommendations which might appear optimistic, as these might have been achieved in agro-climatic conditions and with botanic species which are quite different.

3.3. Practical applications

3.3.1. Practical treatment methods

These are described in Appendix 2.

3.3.2. Examples of practical applications

Both Tunisia and Egypt have developed field techniques for treating straw with anhydrous ammonia since more than 15 years ago. Algeria is already geared up for its development.

Tunisia, which imports both ammonia and urea for its ammonium nitrate industry and fertilizer needs, has decided to launch ammonium treatment techniques on the more extensive farms. It also plans to start up urea treatment on the smaller farms.

The country is now equipped with an ammonia storage centre and distribution network, with two main storage tanks of 20 and 2 tons capacity together with 10 supply truck-tankers of 500 kg capacity. Although presently administered by the Livestock and Pastures Office (l'Office de l'Elevage et des Pâturages), it will be soon be handed over to the private sector. Eight technicians have already received training in France.

Adoption of the practice of field level treatment has developed as follows:

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993
Number of beneficiaries	50	100	110	600	250	175	225	422	671
Treated straw (1,000 t)	0.63	2.11	1.80	7.59	4.97	2.92	2.70	3.41	5.70

Straw (from durum wheat, soft wheat and barley) is baled to a weight of 15 kg per bale and treated with ammonia at a rate of 3 kg per 100 kg gross weight of straw in stacks of between 4 and 5 tons. A standard stack consists of 4 layers of 7 bales placed lengthwise, this being dictated by the 8 m width of commercially available plastic sheeting. This standardised black plastic sheeting has a thickness of 180 microns (180 μ m). An interesting point to mention is that a layer of sheet in contact with the soil is avoided, being replaced by a bed of loose straw; hermetic sealing of the stack is ensured by tucking in the cover (some 70 cm in length and covering it with soil) into a channel dug some 25 cm deep all around the stack.

The straw is moistened by hosing or spraying if its dry matter content is found to be above 90 %.

The recommended field treatment time for this method is 3 weeks.

Egypt, which has a petrochemical industry, has been involved since 1983 in straw ammonia treatment in the large scale rice farms on the Delta, in addition to commercialising mixes of molasses and urea in either liquid or block form. The country has recently become involved also with a straw urea treatment (see below) in the small scale wheat farmers of the Nile Valley.

A total of 8 storage and distribution centres have been equipped for handling ammonia, each having one or two tanks of 4.5 ton capacity and 2 or 3 truck-tankers of 1 ton capacity. Since start-up operations, overall ammonia usage and treated straw quantities are summarised below:

Year	1986	1987	1988	1989	1990	1991	1992	1993
tons of ammonia	600	700	950	2,700	6,886	1,964	4,262	4,130
treated straw (1,000 t)	20.0	23.3	31.7	90.0	229.5	65.5	142	137.7

Basically, cubic bales of rice straw weighing 65 kg each are treated by application of ammonia at a rate of 3 kg per 100 kg of straw. Stacks are standardised to be about 10 tons in total, with some 2 m of width, 20 m in length and 3 layers high (about 1.5 m). The stack width of 2 m is dictated by the width of commercially available sheeting; this width is not optimum from the point of view of the ratio of straw quantity/plastic sheeting requirements. The plastic sheeting is locally manufactured according to national standards for thickness, etc. The straw is dampened if it becomes too dry. Recommended field treatment time is 10 days.

Whether one considers the case of either Tunisia or Egypt, ammonia straw treatment techniques have now become well understood and are producing satisfactory results at field level. Technical personnel supervising the treatment methods have been trained and receive regular up-dating training sessions, including practical experience in the field. A similar situation exists for the livestock extension officers who have the responsibility to follow up response to the extension effort on the farms. Farmers are now well familiarised with treated forages and with the principles involved in their use as feed.

Algeria, which has an established petrochemical industry and uses ammonia as a fertilizer, plans to launch a large scale ammonia treatment programme (some 160,000 tons of straw per year are envisaged). Equipment will comprise two mother tanks of 20 tons to feed 10 treatment units, each

with a 4 ton storage tank and trailed tankers of 500 and 2,000 kg capacity. Algeria is profiting from experience of ammonia treatment techniques already advanced in Tunisia and Egypt through courtesy of the FAO regional project GCP/INT/ 523/FRA, "Development of the use of crop residues and agro-industrial byproducts for animal feed".

3.4. Conclusion

Treatment of stacks of straw with anhydrous ammonia is a simple and efficient technique, well adapted to Mediterranean, sub-tropical and tropical countries which have both ammonia supplies and a distribution network, above all a road infrastructure which allows access by trucks or tractors trailing 500 kg tankers of ammonia. Training of the technical personnel is essential, as also is the need for organising maintenance of the equipment.

The main points to observe are as follows:

- **ammonia application rate:** application of too little ammonia should be considered as almost totally wasteful. Over-application is less serious and it will later be shown how to react to such a situation (Chap.9). The most frequent sources of error occur in the case of forages which are too wet from the start and where it is thus difficult to estimate their true dry matter content.
- **moisture content:** the dry matter content of forages to be treated should lie in the range of 60 to 85 %.
- **perfect hermetic sealing of the surroundings:** this is to avoid any loss of ammonia and to ensure a good chemical reaction considering the alkaline reaction and the improvement to the levels of nitrogen content.
- **treatment period:** this should never be less than one week if ambient temperature is above 30 °C and should be from 3 to 4 weeks for temperatures between 20 and 30 °C. The most beneficial treatment will be achieved right after the harvest when temperatures are high and favourable.
- **storage:** treated forage should be stored in a hermetic enclosure until it is used.