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SUMMARY - After recalling the morfological components of straw as well as their chemical composition, a short description of the different treatments used to improved its nutritive value was made. Besides, the main chemical and physiological modifications occuring during the tratments were presented. As the animal plays an important role in all the subjects, comments were made either in rumen microbial requirements or on the standarization of *in vivo* digestibility measurements. Figures from the literature were compared and analysed emphasizing the differences that usually one can find between authors. Caution must be taken when these values are to be extrapolated to other conditions. Finally, one experiment is evaluated regarding the problem of supplementing straw *vs* treating straw.

Key words: Straw, nutritive value, treatment, supplementation

RESUME - "Valeur nutritive de la paille traitée". Après un rappel des composantes morphologiques des pailles ainsi que leur composition chimique, on a présenté une brève description des différents traitements utilisés pour améliorer sa valeur nutritive. En outre sont décrites les principales modifications chimiques et physiologiques qui ont lieu lors des traitements. Etant donné que l'animal joue un rôle important dans tous les aspects, des commentaires sont émis tant sur les besoins du rumen en faune microbienne que sur la standardisation des mesures de digestibilité in vivo. Des valeurs prélevées dans la littérature ont été comparées et analysées en soulignant les différences que l'on trouve habituellement selon les auteurs. Ces valeurs sont à manipuler avec précaution si l'on veut les extrapoler à d'autres conditions. Finalement, on évalue une expérience concernant le problème de la supplémentation de la paille par rapport au traitement de la paille.

***Mots-clés** : Paille, valeur nutritive, traitement, supplémentation*

Introduction

The nutritive value of treated straw will depend on the morphological components of the straw as well as the chemical composition, and the type and extension of the treatment.

In a recent paper, Bhargava *et al.* (1988) examined the proportion, chemical composition, and ruminal degradability of the morphological components of barley straw, and found that the proportions in the harvested straw dry matter (DM) as leaf blade, leaf sheath, stem and chaff were 12.8, 31.4, 50.0, and 5.8%, respectively. Leaf blades had the highest amount of N and stems the lowest. DM losses from nylon bags

decreased in the order; leaf blades > leaf sheath > whole plant > chaff > stems. Leaf blades also had the highest potential degradability and degradation rate. However, to understand the mode of action of the different treatments on straw, it is necessary to know the composition and structure of the cell wall components, which will be briefly described in the following paragraphs.

Structural organization of cell wall

The young plants have a thin wall that thickens as the plant grows. This results in a physical barrier to the cell content digestion (chemical, enzymatic or microbiological).

Cell content is usually very easily digested and its nutrients are ready available. However, the cell wall components are available and digested to a certain extent, and this is a limiting factor in terms of animal nutrition. Therefore, cell wall thickness, that changes with age, time and weather, is the main factor affecting forage digestibility.

Cross section of the straw, observation shows the existence of 3 layers; sclerenchyma, parenchyma and pith. The sclerenchyma is a tissue made of lignified and thick-walled dead cells. The parenchyma is a tissue made of thin-walled living cells and the pith is a spongy cellular tissue.

However, when the leaf of a cereal plant is observed in a transversal section, three components can be seen; epidermis, sclerenchyma and mesophyll. Within the sclerenchyma appear the phloem and the xylem which is a lignified component.

Looking more closely into the cell wall structure, one can see the cell lumen, then a secondary cell-wall, a middle lamella and a primary cell wall. Middle lamella is made of pectin and no cellulose. The primary cell-wall is thin and made of cellulose fibrils loosely bound to pectic polymers, hemicelluloses and structural proteins.

Secondary cell wall is generated by the primary cell-wall when highly oriented cellulose and hemicellulose fibrils are deposited inside the primary cell-wall. Lignin starts from the primary cell-wall at the corners of the cell and penetrates into the secondary cell-wall. When lignification is completed, the cell dies.

Chemicals components of cell-wall

The main compounds present in the cell wall are; cellulose, hemicellulose, pectines, some proteins, lignin, silica, cutin, phenolic acids, tanins and the Maillard reaction products.

Cellulose

Is the most abundant molecule in nature. The molecule is apparently simple

because it is a linear polymer of up to 10 000-15 000 β-glucose units 1,4 linked (β-1,4 glucopyranosyl units).

But it is complicated by its three-dimensional structure, with H bonds both between and within chains.

It is present, in nature, in the crystalline form organized as fibrils, with main chains strongly linked together. This explains its mechanical strength and resistance to enzymic degradation and chemical hydrolysis.

Hemicelluloses

Hemicelluloses have been defined as alkali soluble cell wall polysaccharides closely associated with cellulose, composed mainly of D-Glucose, D-Galactose, D-Mannose, D-Xylose and L-Arabinose units joined together in different combinations.

Hemicellulose is usually formed around the cellulose fibrils. In Graminae, hemicelluloses are mainly xylans. Xylans from straws are made of 50-200 β-1,4 linked Xylopyranosyl units. Of the hemicellulose fraction, Uronic acids vary between 2-4%; Xylose is around 80%; Arabinose about 15-20%; Galactose 3-4% and Nannose 0.5-1%.

Pectin substances

They are a group of associated polysaccharides abundant in soft tissues. Pectin is a linear chain of D-Galacturonic acid units with some methyl esters. D-Galactose, L-Arabinose and D-Xylose are attached as side chains.

Lignin

It is not a single compound but a family of polymers of phenylpropane units organized in a complex cross-linked three-dimensional structure. It originates from three basic compounds derivatives from phenylpropane.

In the lignin of Graminae, all the three residues (called P-Hydroxyphenyl (H); Guaiacyl, G and Syringyl, S) can be found.

During lignification process, the relative amounts of G or S increase rapidly. Phenolic acids such as ferulic acids and p-cumaric acid has been observed in the cell wall, linked preferentially to the hemicellulose molecules by cross esther bounds which could act as lignin precursor and would explain the possibility of hemicellulose-lignin complexes formation.

Together with p-coumaric acid and ferulic acid in the "trans" forms, other phenolic acids are present in cereal straws (p-hydroxybenzoic acid, vanillic acid, s-p-coumaric acid and cis-ferulic acid).

Amongst the combined phenolic acids, trans-p-coumaric acid and trans-ferulic acid are predominant (0.1-0.7% DM).

Other components

Ethanol reflux extraction is responsible for the liberation of about 10% of the DM from the straw. The extract contains low molecular weight carbohydrates for about 1% (Fructose, Glucose, Sucrose, Arabinitol and Mannitol).

Interrelations between cell-wall constituents

Xylose and Glucose have the same molecular structure, the only difference is that the presence of C_6 in glucose-xylans chains is very similar to that in cellulose chains and form hydrogen bonds with them in the cell-wall.

Lignin is encrusted into the cell-walls, mainly linked to hemicelluloses (but also to other cell-wall constituents) by covalent bonds, so forming the ligno-carbohydrate complex responsible for the poor digestibility.

Phenolic acid (trans-p-ferulic and trans-p-coumaric) monomers have been found to be ester-linked to xylans (to terminal arabinofuranosyl residues) and also to non-carbohydrate polymers such as lignin, suberin and cutin. Acetyl groups have been found as well.

All together form a vast macromolecular Matrix in the secondary cell wall, responsible for degradability and digestibility. Recently Chesson (1988) reviewed the available data on the chemistry of phenolic-carbohydrate complexes founded in the cell wall of plants of agricultural significance, in relation to the limitations such complexes may impose on the digestion of lignified plant material by ruminal microorganisms. Polysaccharides at the surface of the cell wall are selectively degraded, leaving exposed phenolic material to accumulate. During the course of cell wall degradation, this preferential retention and accumulation of phenolic material, ultimately builds to a level where it effectively forms an inert layer protecting the underlying wall from further attack. The rate at which this inert layer develops reflects the initial phenolic content of the wall, being relatively rapid in intensively lignified walls while failing to develop in primary walls with a very low phenolic content. The extent to which lignin is bonded to polysaccharide is also going to contribute, likely, to the retention of lignin at the cell wall surface, and is of particular significance when considering chemically treated crop residues.

Much remains to be discovered about the topochemistry and ultrastructural distribution of lignin within the tissues and cell walls of plants. This lack of knowledge has a number of practical implications, limiting our ability to predict the nutritive value of a feedstuff just from chemical data; or the response likely to ensue from treatments designed to enhance the nutritive value. Historically, the chemistry of the extraction, solvolysis, hydrolysis, and analysis of cellulose and lignin from plant material. The

analyses used to determine their relative content are empirical (i.e., the value of the cell wall preparation is defined by the conditions used rather than a molecular entity). As a result, it is difficult to compare the results of analyses of one type of plant to another (Barton, 1988).

With regard to the subject of biological structure of lignocellulose, as related to its degradation in the rumen, Akin (1988) noted that polymeric lignin binds structural carbohydrates, rendering the sugars unavailable for microbial fermentation. In addition, low molecular weight phenolic compounds (e.g., phenolic acids) also appear to bind glucans and xylans in an indigestible complex. Specially detrimental to forage digestibility is p-coumaric acid; this acid is also toxic to ruminal microbes at lower concentrations than other acids. Ruminal fungi appear to have a greater potential to degrade lignocellulosics than bacteria do.

Treatments of straw

Treatment with sodium hydroxide (NaOH) and ammonia

After a first period (until 1920's) of studies on boiling straws in NaOH solution, even under pressure, Beckman and Fingerling introduced their method consisting of soaking fibrous by-products in cold NaOH solution (1-1.5% for 12 hours) followed by washing out with water to neutrality.

The original method has now been replaced by a modification of the Dip-treatment method (Sundstøl, 1981). By this method, the straw is also soaked in a 1.5% solution but for 30 min-1 h only, after which it is stored 4-6 days instead of rinsing. The organic matter digestibility of dip treated straw is increased from 45-50% to 70-75% (Sundstøl 1988a). With this method there is no loss of dry matter and the pollution problems were greatly reduced.

Alternatively "on the farm" procedures have been developed for dry treatment of straw with sodium hydroxide. Systems where the solution is sprinkled over long form straw and there after mixed thoroughly or sprayed over chopped straw in a mixer wagon or even treating the straw during the process of bailing, have been described (Sundstøl, 1988).

Amongst the other chemicals, NH_3 is the most suitable because, besides hydrolysing the ligno-cellulosic linkages, as the other alkalis do, it contributes to the nitrogen fraction. The chemical was not used, in practice, to a great extent until 1970. Since then, a number of methods have been developed, varying according to the conditions of each country or region. Ammonia is used in pure form (anhydrous), in water solutions (aqueous) and in solid compounds, e.g. urea.

Ammonia treatment of low quality roughages was reviewed recently by Sundstøl and Coxworth (1984).

When materials with high sugar content (>5%) are treated with anhydrous ammonia at high temperatures, the poisonous component 4-methyl imidasol can be formed which may cause hyperexcitability in farm animals and may also be transfer into the milk of dairy cows (Perdok and Leng, 1985). Sheep fed ammoniated immature hay, appeared to have neurological symptoms indicative of toxicity. Mason *et al.* (1990) concluded that immature leafy ray grass hay was not a suitable substrate for ammoniation, specially if it is an oven treatment. 4-methylimidazole was either infused or fed to sheep by Karangwa *et al.* (1990). The neurotoxin was found to distribute rapidly in the extravascular compartment (28 min) after infusion and had similar biological half lives (about 9.5 h) for either route of administration. With pure straw treated at low temperatures, the risk of this disturbance should be negligible.

The added N is another advantage together with increased digestibility and intake. However, most of this N is excreted in the faeces which, according to Michalet-Doreau *et al.* (1990), could be due: (i) to the attachment of the N to the indigestible cell wall (or non digested in the rumen) or (ii) to the poor utilization of this N by the rumen bacteria or to an increase of microbial N as a consequence of an extra hind gut fermentation.

Other chemical treatments

Recently, there has been attempts to use other chemical treatment of feedstuffs to enhance digestibility. Kerley *et al.* (1986) reported a new chemical treatment using alkaline hydrogen peroxide (AHP). These authors showed that NDF digestibility increased from 42.1% for sheep fed non treated straw, to 81.0% for sheep fed AHP-treated straw-based diets, and that digestible DM intake, was increased nearly threefold when sheep were fed AHP-treated straw compared to control straw diets. Electron micrographs showed that this treatment allowed more complete bacterial colonization and more rapid degradation of the cell wall. Effects of alkaline hydrogen peroxide (H_2O_2) treatment on cellulose crystallinity and cell wall phenolic monomer and monosaccharide composition, were measured using cotton and wheat straw (Kerley *et al.*, 1988). In another experiment (Cameron *et al.*, 1990), showed that there were trends to increase fat and decrease protein concentration in the milk as O_2H_2 treated straw replaced alfalfa and corn silage. Although the use of this treatment will be determined by economics, the potential for practical application appears very encouraging.

Ben-Ghedalia and Rubinstein (1986) evaluated the ability of another oxidizing agent, ozone, to increase the digestibility of screened manure fiber. *In vitro* DM digestibility was increased from 36.2 to 65.2% by ozone treatment. Ozone treatment resulted in greater improvements in digestibility than 5-8% NaOH treatment, but ozonation produced compounds that inhibited DM disappearance unless the substrate was washed before incubation (Narasimhalu *et al.*, 1989).

Sulphur dioxide (SO_2, 62.6 g per kg) was used by O'Shea and Baldwin (1986) to improve the *in vitro* digestibility of barley straw from 45 to 80%. When treated straw was fed to lambs as 40% of the total diet, *in vivo* straw digestibility was increased approximately 11 percentage units.

Alexander *et al.* (1987) reported that sulphur dioxide (SO_2), ozone and alkaline hydrogen peroxide, selectively degraded phenolic material without modifying the carbohydrate content of the straw. The degradability of ozone-treated straw was substantially increased, whereas SO_2 treatment had a lesser effect and treatment with alkaline hydrogen peroxide was largely ineffective.

Miron and Ben-Ghedalia (1987) studied the effect of increasing fermentability of wheat straw by SO_2 or by SO_2 + cellulase on several nutritional parameters in sheep. They reported that the content of soluble compounds inside the cell in the straw, was increased by the SO_2 treatment and further increased by the combined SO_2-cellulase treatment. The increase in the content of rapidly fermentable sugars in the straw, was associated with a gradual decrease in the proportion of ruminal acetic acid and an increase in butyric acid. Overall, the authors suggest that it is possible to convert straw into a highly fermentable material by a combined treatment of SO_2 and cellulase, but regarding N metabolism, the combination is not superior to the SO_2-treated material. Ground wheat straw was treated with 0, 2, 4 and 6% ethanolamine and stored for four days at 40°C (Flachowsky *et al.*, 1988). Ethanolamine treatment resulted in a decrease in fiber content and an increase in *in situ* digestibility.

Several of these treatments are still to be proved or at least tested and some, like the chlorine based oxidisers, depress digestibility. At present, it seems that no effective alternatives to sodium hydroxide or to ammonia are possible.

Microbial treatments

Microbial treatment methods for improvement of poor quality forages and roughages, have not been used in practice to date, but it may prove to be one of the most promising in the future. The main problem in the biological upgrading of poor quality materials, is to find suitable microorganisms which decompose lignin without using too much of the hemicellulose and cellulose.

Zadrazil (1984), reviewing microbial conversion of poor quality products into feed, concludes that *in vitro* digestibility of fungal substrates, decreases at the beginning of colonization by white rot fungi and increases afterwards. During incubation, the contents of soluble substances (being part of them sugars) increase.

Not surprisingly, enzymes such as cellulase and hemicellulase are ineffective in the initial degradation of such lignified cell walls. However, a single lignase, produced by the soft-rot fungus *Phanerochaete chrysosporium* is capable of cause a high degree of depolymerisation (Tien and Kirk, 1983). At present, the levels of lignase produced by basidiomycete fungi are not sufficient for the biological pre-treatment of straw to be a commercial proposition. However, using recombinant DNA engineering techniques, it is conceivable a possible modification of the lignase genes and thus the proteins, to increase their efficiency and stability. Regarding this objective, several research groups have now cloned and sequenced the lignin gene from *Phanerochaete chrysosporium* (Tien and Tu, 1987; Zhang *et al.*, 1986), a pre-requisite for future manipulation of the gene.

Other "fermentation" processes have also been tried for the upgrading of low quality products (Seal and Eggins, 1976), but if the "fermentation" process cannot be controlled, the quality of the product cannot be guaranteed and even toxic substances may be formed. Recently, fungal treatment of rice straw improved intake and N balance better than urea treatment did (Rai *et al.*, 1989).

It may be concluded, however, that with sufficient knowledge of the biology of higher fungi and solid-state fermentation, a low-cost technology for the conversion of lignocelluloses could be developed (Zadrazil, 1984).

Many methods in which the material undergoes a combination of physical and chemical treatment, have also been developed. For example, Adebowale *et al.* (1989) reported that gaseous ammonia appeared to be an effective source of alkali to use in combination with H_2O_2 for treatment of barley straw. Brand *et al.* (1989) treated wheat straw with alkaline H_2O_2 and reported increased DM, OM, cell wall and ADF digestibility by sheep. Urea supplementation was necessary, however, to stimulate voluntary intake.

Straw may also be "ensiled" with other chemicals such as NaOH, $Ca(OH)_2$, etc., at a relatively-high moisture content. No practical method for microbial treatment of fibrous materials has been developed yet, but the scope for such a method may prove to be great.

The improvement in digestibility is frequently used to express the effectiveness of straw treatment. However, in most cases, this improvement is accompanied by a significant increase in the straw intake.

Chemical and physical modification in straw during different treatments

The changes that take place when low quality roughages are treated with alkali, are of physical as well as chemical nature. It is well known that the materials are normally softer after chemical treatment than they were before. This may be one of the reasons for the higher intake found for treated material (Sundstøl, 1988). Another important change, that takes place during alkali treatment, is a swelling of the plant cell wall. This is probably most pronounced for wet NaOH treated materials, and was confirmed by Harbers *et al.* (1982). It may be reasonable, however, that a certain amount of moisture in the material is needed to obtain this swelling effect. When the cell wall is expanded and the surface ruptured, the rumen microbes will have better access to the structural carbohydrates and consequently the digestibility is enhanced.

Straw treatments with alkaline reagents, in particular sodium hydroxide and ammonia, have been extensively used. There are several chemical reactions going on during alkali treatment.

Saponification of ester linkages between acetic acid and phenolic acids, and polysaccharides and or lignin, as well as such linkages between uronic acid residues

of xylans in hemicelluloses and lignin, would be expected to occur during the alkaline treatment of straw material (Theander and Aman, 1984).

If the temperature is high enough, in the presence of alkali, lignin undergoes cleavage of other linkages between phenylpropane units, and free phenolic groups are formed. As a result of the accompanying decrease in the molecular weight and cleavage of linkages to the hemicelluloses, an increased solubility of lignin in the alkaline solution will occur.

During alkaline treatments, the hemicelluloses are expected to be partly solubilized and the cellulose to be more accessible by an alkaline swelling effect. Therefore, an enrichment in cellulose is observed, as the consequence of removal of hemicelluloses and lignin. Besides, the cleavage of linkages between lignin and hemicelluloses sets cellulose free. That is because cellulose is embedded in the hemicellulose-lignin complex which is destroyed by the action of the alkali.

Studies by Lindberg *et al.* (1984) indicate that xylans are partly translocated during aqueous NaOH-treatment, to a position in the straw cell walls where they are more available to ruminal digestion.

Another reaction that contributes to the neutralization of NaOH-treated straw, is the so called "peeling reaction", by which sugar residues are released from the reducing sugar end-unit of the polysacharide and other aliphatic acids (Whistler and BeMiller, 1958).

More recently Grenet and Barry (1990), using scanning electron microscopy and chemical tissue staining methods, demonstrated that tissues of NH_3-treated wheat straw were digested more quickly than controls. Further, apparent tissue lignification was not changed although treated straw fluoresced less in ultraviolet light and had more reactive sugar residues available.

As a conclusion, one can say that alkali treatments operate not by reducing or destroying the phenolic components, but by breaking specific lignin-carbohydrate linkages. Free lignin, released from its association with polysaccharide, is solubilised when exposed at the cell wall surface, and the building up of an inert phenolic layer rate is correspondingly reduced (Chesson, 1984).

After analyzing the chemistry and the efficiency of the treatment, one can be confronted with a feedstuff that, according to the standard wet chemistry analysis, would show the values that frequently can be seen in the different published feed composition tables.

Besides, it is interesting to see, with treatments like NH_3, how much of the used nitrogen would remain in the straw and, when subjected to the *in vitro* methods of evaluation, how many improvements shall be due to those treatments.

But here comes the main question: is the extension of the treatment effect dependent or independent of the animal?

Let us comment this subject under two main points.

i. Rumen microbial requirements,
ii. Standardization of *in vivo* digestibility measurements

Rumen microbial requirement

It is not possible to quantify the nutritive value of a residue or a by-product for a ruminant, when the requirements of its rumen microbes were not taken into consideration.

The definition of microorganisms minimal requirements for the different nutrients is not easy to determine and it is, still today, a controversial issue.

It has been possible, through the rumen simulation techniques using artificial rumen models like Rusitec, to obtain values which could be accepted as reference values.

Therefore, and according to Michelle-Durand (Durand, 1987), the total N required is about 26 g per kg of Digestible Organic Matter. The contribution of recycled N can reduce this value in 10 to 40% depending on the level and type of N present in the diet.

The sulphur concentration must be about 1.8 g of S per kg of Digestible Organic Matter. However, the optimum level of S will depend on its quality and availability in covering the microorganisms requirements in the rumen. For traditional feedstuffs, the S fraction associated to the proteins, will probably show a similar degradability to that one shown by the protein itself, which varies a lot from one feedstuff to another. For cereal straw, the S degradability will usually be below 0.3.

About 5 g of soluble P per kg of Digestible Organic Matter seems to be sufficient to cover the requirements of the rumen microbes.

Regarding the branch chain fatty acids and the vitamin B complex, it is known that they improve the fiber digestion and crossed feeding among microorganisms. However, their level of requirement is, still today, hard to define.

In general, one can say that the pH shall not decrease below 6.0 and that all nutrients should be given on a continuous way, specially when the feeding source is slowly degraded, which often occurs with the forages.

Standarization of *in vivo* digestibility measurements

Regarding the standardization of *in vivo* digestibility measurements and from what has been said before, it is not possible to evaluate straw, specially untreated straw, fed alone because of the unbalance caused in the rumen microflora.

Besides, if it is going to be measured within a mixed diet, the other components

must be roughages and the level of starchy feedstuffs must be minimal to prevent an interaction with the type of microorganisms that is going to be promoted in the rumen-reticula.

On the other hand, one must define that if it is a value to be tabulated, then the level of intake must be adjusted close to the maintenance level, because there is a direct effect of the intake level on digestibility. This will cause the digestibility of straw remains independent of its proportions in diet, and one can avoid the effect derived from interaction. From a practical point of view, the requirements of an adult male sheep can be standardized at about 40 g DM per $kg^{0.75}$, corresponding to about 26 g of Digestible Organic Matter per $kg^{0.75}$. Another advantage is the no existence of refusals (always hard to measure and evaluate).

Other important parameter to take into consideration, is the collection period. Sixteen days has been considered as the minimal period of time required, where the last 6 days would be the collection period; however, it is recommended a collection period of at least 10 days for straw. The adaptation period varies from one to several weeks, depending on the type of feedstuff the animals are eating before the experimental diet.

For practical reasons, these experiments are conducted on adult male sheep and therefore, care must be taken when their results are to be applied on cattle or goats.

The number of animals depends on the variability expected, but 4 is, usually, the minimum number accepted.

Coming to values found in the literature, it is interesting to analyze the values published by Wanapat *et al.* (1985) for barley straw (Table 1) and compare OM and CF digestibility of untreated and treated straw in different types of treatments. From Table 1, it can be seen that almost all treatments improve both parameters, but the traditional Beckman method of NaOH treatment was the most effective for the OM digestibility and the urea was the less effective one.

For the fiber fractions, the best one was a combination of a treatment and a supplementation (NaOH + Urea) and the worse one was, again, the urea treatment.

Concluding remarks

Coming back to a point raised in the beginning of this paper, the comparisons between treated material must take into consideration the quality and type of straw.

It will be interesting to show some results (Table 2) from a work of Kjos *et al.* (1987), where a bad straw damaged by weather rain and sun would fail to show the improvement one would expect with the treatments.

But the tabulated values are obtained at maintenance and, in practice, the animals with this type of diets, would be on *ad libitum* intake, so feeding value (nutritive value

at *ad libitum* intake) must be a more realistic figure, and one must encourage colleagues to measure always this last parameter or both if the nutritive value is to be used as a tabulated figure.

Table 1. *In vivo* digestibility of barley straw treated according to different methods (Wanapat *et al.*, 1985). Three sheep per treatment

	Organic matter	Crude fiber
Untreated straw	52.4	50.6
Untreated straw + urea at feeding	52.0	60.8
Urine-treated straw	56.3	66.9
Urine-treated straw + soy bean (urease)	57.1	65.0
Urea-treated straw	56.4	66.8
Urea-treated straw + soy bean (urease)	59.0	71.4
Anhydrous NH_3, stack	67.8	79.0
Aqueous NH_3, stack	59.0	71.4
Anhydrous NH_3, vacuum-stack	66.7	79.0
Anhydrous NH_3, oven	63.6	74.5
Beckmann (NaOH)-treated straw	75.7	83.5
Wet (NaOH)-treated straw (cir. method)	72.8	86.8
Dip (NaOH)-treated straw	73.6	88.9
Dip (NaOH)-treated straw + urea	74.8	91.1
Dry (NaOH)-treated straw	67.8	81.8
Dry (NaOH)-treated straw, pelleted	64.7	74.9
Significance (P)	0.001	0.001
SEM	1.4	2.3

In fact, from Table 1 it can be seen that there was not much improvement when the untreated straw was supplemented with urea, but this could be expected as it has seen before, the N is not the only essential nutrient required by the rumen microbes and the straw is also poor in ready available energy, S, P, etc.

Finally, I would like to comment on the problem of supplementing straw or treating straw.

The problem is that not all the experiments are design to evaluate the effect of the treatments and at the same time to compare it to the effect of the supplementation.

Recently, at Fonte Boa we have conducted an experiment on sheep, comparing straw treated with urea and supplemented with soy bean meal together with untreated straw when the animals were at *ad libitum* intake. Table 3 shows the *in vivo* digestibility values of this experiment.

Table 2. Organic-matter digestibility (%) of good-quality straw, weather-damaged straw of wheat, barley and oats fed untreated and alkali treated to two sheep (Kjos *et al.*, 1987)

Quality of straw	Treatment	Wheat straw	Barley straw	Oat straw
Good quality	Untreated	50.6	54.9	58.7
	Ammonia-treated	62.5	61.8	66.3
	Dip treated (NaOH)	70.9	69.1	71.9
Weather-damaged	Untreated	46.2	50.7	56.0
	Ammonia-treated	56.9	60.7	65.5
	Dip-treated (NaOH)	69.5	69.9	70.9

The main conclusion was that for the overall parameters like DM, OM, or Energy, there was no significative effect between treatment and supplementation.

However, when one comes to the fiber fraction, like ADF and NDF, the treated straw was the only one significantly different from the untreated or the supplemented one.

Therefore, one can say that a well balanced and supplemented straw, when good conditions are given to the rumen microbes, would improve very much the way the animal is going to digest the straw, but the fiber fraction was not affected and this is only obtained with an efficient treatment.

Finally, I would like remember the difficulties found by the different colleagues in getting prediction equations for straw nutritive value (NV) based on chemical or *in vitro* parameters, and the differences and corrections needed when we are dealing with treated straw.

In conclusion, and to appreciate the NV of treated straw, there is still a lot of work to be done on the understanding of the cell wall structure and organization, as well as its chemistry and the mode of action of the different treatments. Besides the requirements of the rumen bacteria, their adaptation and optimization of the conditions to degrade and digest the straw are fundamental parameters to be known.

Finally, the utilization of treated straw in practical conditions needs more a feeding value than a nutritive value, which means a measure of the voluntary feed intake of the straw.

Table 3. *In vivo* digestibility (%). Mean values (n = 8) ± standard error (Ramalho Ribeiro, unpublished results)

	DM	OM	CP	ADF	NDF	ADL	Energy
Untreated straw	39.5±0.7 a	42.1±0.7 a	-77.4±11.8 a	44.3±1.0 a	47.3±1.3 a	8.5±2.9 a	41.6±1.1 a
Supplemented straw	49.5±0.6 b	52.1±0.6 b	46.3±2.6 b	47.7±1.0 a	51.0±1.3 a	10.3±3.0 a	52.2±0.8 b
Treated straw	46.8±1.3 b	48.5±1.5 b	40.1±3.6 b	55.1±1.0 b	60.7±0.8 b	17.4±2.8 a	50.5±1.3 b

[a,b]For each parameter, different letter means a statistical significant different value for a 5% level of significance

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