THE UTILIZATION OF PRESSURE-TREATED ASPEN BY RUMINANTS

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THE UTILIZATION OF PRESSURE-TREATED ASPEN BY RUMINANTS

by

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ABSTRACT

Two experiments were conducted to determine the effect of dietary pressure-treated aspen (populas tremuloides) on the performance characteristics and physiological responses of ruminants.

In the first experiment, four mature rams fitted with rumen fistulae were assigned to a 4x4 Latin-square design to determine the effect of the wood-product on diet digestibility and various physiological parameters. The wood product replaced alfalfa on a dry matter basis at 0%, 15%, 30% and 45% levels in isonitrogenous diets. The rams were allowed a 14 day adjustment period prior to a 5 day total collection period. During the collection period, feed was restricted to 90% ad libitum levels and water was available free choice. Blood and rumen samples were taken 2 days after completion of the collection period at 0, 1, 2, 3, 4, 6, 8, 12 and 24 hours post-feeding.

In the second experiment, 36 young steers were used to determine the effect of replacing corn silage with the wood-product on feedlot performance. The steers were randomly assigned to three treatment groups (control, 15% wood and 30% wood) of 12 steers each and allotted to 3 replicates of 4 steers per pen. The 3 rations were calculated to be isonitrogenous. Feed, water and minerals were supplied free choice over the 139 day growth trial.

All dietary levels of wood had significantly ($P \leq 0.05$) lower values of dry matter and gross energy digestibility than the control diet, however, crude protein

and crude fibre digestibility, nitrogen retention and ruminal pH were not affected.

Dietary wood did not significantly ($P \leq 0.05$) affect ruminal acetic, isovaleric or valeric acid levels of the rams, however, high levels of wood significantly ($P \leq 0.05$) lowered propionic, butyric and isobutyric acid levels from 0 to 4 hours post-feeding.

Ruminal ammonia, blood urea nitrogen, blood ammonia and blood glucose levels were significantly ($P \leq 0.05$) affected at various sample times by the dietary wood component.

In the steer trial, no significant ($P \leq 0.05$) differences in average daily gains or feed intakes were observed among treatments, however, the feed/gain ratio of the 30% wood fed steers was significantly ($P \leq 0.05$) elevated compared to the control fed animals.

The wood product had a limited negative effect on the performance and physiological parameters of ruminants. Although it did appear to have a lower energy availability compared to alfalfa hay or corn silages, a lower price would compensate for this difference.

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INTRODUCTION

In recent years, a great deal of interest has developed in the more efficient utilization of various industrial by-products. Of interest to many is the possibility of either feeding low quality roughages to ruminants to act solely as a dietary roughage component or the treatment of these by-products to increase energy availability. To date, on-farm use of many of the new developments in this area is limited, however, as research progresses, utilization of these products may become commonplace.

Cellulose and hemicellulose, representing up to 70% of the dry weight of shrubs and trees are the most abundant organic substances occurring in the world, (Baker et al. 1975). In most woody materials however, these fractions are not available to ruminal microorganisms due to the lignocellulose complex, the high degree of crystallinity of cellulose, and other factors, (Anthony et al. 1969). These fractions may be modified for increased availability by chemical and physical processes, (Anthony et al. 1969). Utilization of wood products in this manner is highly desirable as millions of tons of wood residues are produced annually throughout the world. To date, these have not been utilized efficiently, (Tarkow and Feist 1969).

Depending upon species, untreated woods have a dry matter digestibility (DMD) of 0 to 30%. Energy availability from these products is not large enough to "drive" the digestive process itself. Therefore, the use of untreated

woods is limited to a small portion of the ruminant's diet, (Bender et al. 1970).

Due to structural differences, hardwoods are much more digestible than softwoods. Aspen wood and aspen bark have digestibilities of approximately 30% and 50% respectively. Whole tree aspen could supply a considerable amount of energy and roughage to ruminants.

Many wood by-products are available from industry. In some chemical pulp-mill operations, "fines" can be recovered which are free of undesirable chemicals. Due to prior chemical treatment, the fines are low in lignin content and thus represent a highly digestible source of energy for ruminants (Baker et al. 1973).

Many mechanical pulp mills allow large piles of sawdust to accumulate with no recourse but to burn them and thus contributing to air pollution. Also, chemicals such as phosphates, sulfates and nitrates within the sawdust may be "leached-out" to the soil. Phosphates may be bound in soil aggregates but other chemicals may find their way into bodies of water as pollutants, (Buckman and Brady 1969).

A number of companies are presently harvesting trees for the production of livestock feed. These products are "whole-tree" chips, (i.e. bark, wood and leaves). Not only is whole-tree harvesting a potentially profitable venture, it also maintains a balance between flora and fauna in harvested areas as the younger trees provide a source of feed and shelter for wildlife, (Steneker 1976).

Industry is finding more and more uses for wood by-products, however, there remains a large portion wasted. The untreated wood may be used as a source of bulk in high concentrate diets or could be treated to increase its nutritive value.

In a world of ever-increasing population, every approach in holding-pace with the increasing food demand must be examined as there is not a single solution, (Bender et al. 1970).

This study was undertaken to determine the replacement value and the physiological effects of feeding a pressurized-treated aspen-product to ruminants.

LITERATURE REVIEW

Roughages

Ruminants require a certain portion of their diet to be roughage material. Roughage stimulates the rumen wall to promote rumen condition and rumination. Rumination stimulates salivation, the saliva acting as a buffer to ruminal acids produced. This maintains rumen pH and provides for more efficient fermentation, (Baker et al. 1973). The bulk added by the roughage tends to hold the remainder of the feed in the rumen for longer periods of time allowing for a more sustained and efficient fermentation.

Roughage functions also as a diluent of high energy rations and aids in preventing abnormalities of the gastro-intestinal (GI) tract and liver, (Dinius et al. 1970).

Roughage is the main component influencing the level of voluntary food consumption (VFC). Due to its bulk, high levels of roughage in diets will decrease the rate of digesta flow, thus decreasing VFC, (Donefer et al. 1969, Clarke and Dyer 1973).

Carbohydrates

The ruminant is able to utilize celluloses through the use of cellulolytic enzymes associated with bacterial cells within the rumen. Although rumen microorganisms are able to degrade carbohydrates such as cellulose and hemicellulose, their ability to do so is severely limited in highly lignified materials such as wood. A major portion of

the cellulose, hemicellulose and other carbohydrates are unavailable due to a chemical and/or physical association with lignin. To liberate this energy, a treatment which ruptures, loosens or removes the lignin barrier is needed, (Coxworth et al. 1976). Other modifications of wood fibre such as destruction of the crystalline nature of cellulose will also increase availability, (Dekker and Richards 1973).

Cellulose is the most abundant carbohydrate comprising the cell wall and is associated with hemicullulose and the pectic substances. These three components are termed collectively, "plant structural carbohydrates". Lignin is often included in tables of plant carbohydrates even though it is not a "true" carbohydrate. Its association with the structural carbohydrates makes this classification necessary. Its relationship with cellulose, hemicellulose and other substances imparts special characteristics to the plant fibre, (Spiller and Amen 1975).

It is necessary to understand the chemistry of these components to fully appreciate the effect of treatment and to realize maximum efficiency in treatment of roughages.

Cellulose

Cellulose consists of unbranched chains of 1400-10,000 glucopyranose units linked by $1 \longrightarrow 4$ β-D-Glycosidic bonds, (Hansen et al. 1958). In nature, cellulose is found in a crystalline state with molecular orientation parallel

to the fibre axis or in an amorphous state which is a loose arrangement with no specific orientation, (Spiller and Amen 1975). The more crystalline structure is resistant to degradative "attack" by rumen microorganisms and, to a certain extent, treatment is directed towards the destruction of this uniformity.

Crystalline aggregates are interspersed with amorphous regions. These aggregates are termed "micelles" and are short relative to cellulose chain length, (Hansen et al. 1958). The cell walls are made up of many layers comprising the primary and secondary walls. These consist mainly of cellulosic materials but may include pectins, lignins, polysaccharides, polyuronides and silica. Between adjacent cells exists the middle lamella containing mainly pectins, (Hansen et al. 1958).

Hemicellulose

Hemicellulose is the major structural carbohydrate associated with cellulose, (Spiller and Amen 1975). Hemicellulose includes short-chain glucans which exist either in the cellular fibrils or outside the fibrils in the surrounding polysaccharide. Polymers of xylose, arabinose, mannose, galactose and probably other mannose units such as fucose and rhamnose are also found in the hemicellulose fraction. These contain mixtures of sugar units and uronic acid units which may be methylated or acetylated, (Hansen et al. 1958; Spiller and Amen 1975; Pigden and Heaney 1969).

Hemicelluloses have been divided into two groups, hemicellulose A and B. Hemicellulose A consists of high molecular weight glycans as opposed to low molecular weight glycans comprising hemicellulose B, (Hansen et al. 1958).

Hemicellulose availability is comparable to that of cellulose, (25-90%), (Pigden and Heaney 1969). The degree of its association with lignin or encrustation with other materials determines the extent of its utilization by the ruminant, (Hansen et al. 1958; Pigden and Heaney 1969).

Pectins

The pectins are found dissolved in the middle lamella as calcium and magnesium salts. They promote the adhesion of adjacent cell walls. Pectins consist of long chains of D-galacturonic acid residues or six member pyranose ring structures, (Hansen et al. 1958).

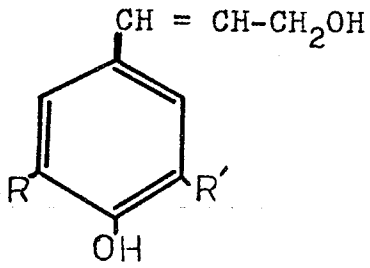
Lignin

Lignin is the main non-carbohydrate component found in the cell wall. Harkin (1973), referred to lignin as "one of nature's most enigmatic entities" as, although it is known that lignin functions in supplying strength and rigidity to plant materials, its chemistry is not fully understood, (Pigden and Heaney 1969).

Lignin is a high molecular weight condensation product containing one or more types of aromatic compounds. The determined structure of lignin depends on the extraction procedure used to isolate it. Up to 50% cyclohexyl

derivatives are released upon hydrogenation. Therefore, a large portion of the lignin is made of phenyl derivatives. The phenyl ring may contain methoxyl groups in the meta position and hydroxyl or phenyl ether linkages in the para position to a side chain. Part of the lignin molecule, (five-position as the benzene ring), is connected with a side chain of another unit via a carbon-carbon linkage, however, some of these five-carbon positions are free, (Hansen et al. 1958).

Spiller and Amen (1975) describe lignin as "a polymer originating from 3-phenyl propanoid monomers; p-coumaryl, coniferyl or sinapyl alcohols, interconnected in a random sequence and in a variety of ways". They suggest the following structure as one "lignin-unit":



R = R' = H-p-coumaryl alcohol

R = H R' = OCH_3-coniferyl alcohol

R = R' = OCH_3-synapyl alcohol

Although lignin is either chemically or physically associated with a large portion of cellulose and hemicellulose, (Bender 1975), the fact that lignin may also bind with nitrogen has been ignored in hypothetical structures of lignin complexes. It is believed that nitrogen is either

bound to or is an integral fraction of the lignin complex, (Hansen et al. 1958).

A physical or chemical association with lignin results in severe depression in the availability of that substance to rumen microorganisms, (Bender 1975).

In forages, lignin content increases with maturity, however, this does not occur in woody materials. Lignin content will vary between species but the degree to which it limits availability varies, (Allinson and Osbourn 1970; Pigden and Heaney 1969).

For example, the digestibility of softwoods is low compared to hardwoods. This difference in availability is not entirely due to the level of lignin present, instead, the difference in the arrangement of the lignin molecules themselves is the major factor. Hardwood lignins are such that they prevent three-dimensional cross-linkages. Soft-lignins, on the other hand, form three-dimensional structures which effectively block enzymatic degradation, (Bender et al. 1970). This factor, prevents softwoods from responding adequately to treatments for increased nutritive value.

Until recently, lignin was thought to be indigestible, however, it has been shown to undergo changes during ruminant digestion, (Allinson and Osbourn 1970).

Lignin will complex with other components within a diet post-ruminally forming indigestible condensation products. The components of the lignin fraction found to be most digestible were soluble in alkali solutions and were

therefore contained in the nitrogen-free extract, (NFE), (Allinson and Osbourn 1970).

Lignin does not affect the rate at which fibre is digested, instead, it affects the total amount of fibre digested, (Lechtenberg et al. 1974). Allinson and Osbourn 1975, and Baker et al. 1975, found significant, ($P \leq 0.05$), negative correlations between dry matter digestibility, cellulose digestibility, forage dry matter intake, voluntary food consumption, (VFC), and lignin content.

Lignin appears to be a major obstacle to microbiological degradation of plant carbohydrates. Delignification would seem a straightforward approach to increase tha availability of lignin-bound nutrients to rumen microorganisms.

Although lignin removal is an effective means of increasing the nutrient availability of low-quality roughages, it is not the sole inhibitory factor present in these materials.

Silicic Inhibition

Cell wall silica adds structural strength and is associated with disease resistance in plants, (Van Soest and Jones 1968). Two forms of silica exist within plant cells, the soluble and insoluble forms, (Hogan and Weston 1971). Silica has been proven to inhibit utilization of plant structural carbohydrates through encrustation or as a soluble cellulolytic inhibitor, (Van Soest and Jones 1968;

Guggolz et al. 1971). Hogan and Weston (1971), have demonstrated the soluble form of silica to exert an additive effect to the indigestibility of many plant materials.

The chemistry behind silicic-inhibition was proposed as follows. "Undissociated silicic acids polymerize to form polymeric silicic acid. These deposit within the cell wall, thereby acting as a barrier to microbiological degradation, (Hogan and Weston 1971).

Treatment of silica-containing by-products is desirable, as silica's inhibitory effect may rival that of lignin's, (Van Soest and Jones 1968).

Although silica decreases the availability of many forages or straws such as ground rice hulls, (Hogan and Weston 1971), reed canary grass, coastal bermuda grass, and tall fescue, (Van Soest and Jones 1968), its effect on digestibility of woody materials has not been established. Assuming levels of silica to be low in woody by-products, silica's effect may be of little consequence.

Principles of Treatment of Low Quality Roughages

Treatments altering the crystalline orientation of cellulose effect an increase in the swelling capacity of the wood fibre allowing greater penetration of the fibre by rumen microorganisms. Treatment of wood may also affect the association of cellulose with lignin allowing better utilization by rumen microorganisms, (Dekker and Richards 1973).

Treatment of low quality roughages is also directed towards the unavailable hemicellulose fraction. Hemi-

cellulose, for the same reasons as cellulose, is limited in its availability, however, its response to chemical treatment differs substantially from that of cellulose. For example, hemicelluloses are soluble in alkali solutions whereas celluloses are not as easily solubilized. Celluloses which are not soluble in 17.5% sodium hydroxide (NaOH), solutions are termed "α-celluloses", or "true" celluloses. Celluloses which are soluble in 17.5% NaOH and form a precipitate in acid are termed "β-celluloses", and those which do not form a precipitate in acid and are soluble in base, are termed "γ-celluloses". This is an important factor to consider in chemical treatment of these products, as solubilized carbohydrates may be lost due to leaching or washing.

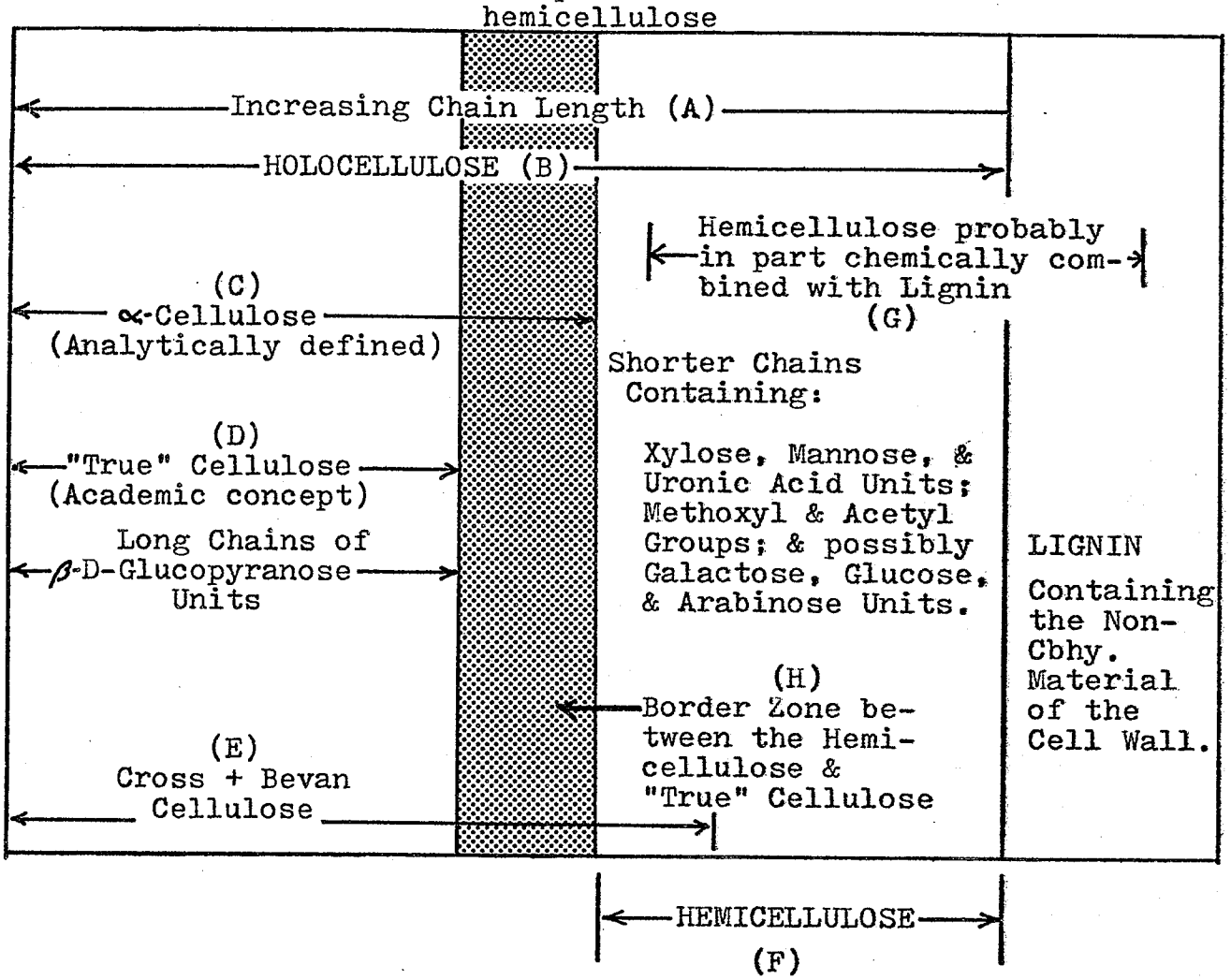
The relationship between cellulose and hemicellulose as outlined by Hansen et al. (1958), is shown in Table 1.

Treatment of silica-containing low quality roughages with 12 to 16% NaOH converts silica present to an ionic state, (ionic silicate). This form of silica may be easily removed by washing the product following treatment, (Hogan and Weston 1971; Fritschel et al. 1976).

Van Soest and Jones (1968), found the effect of silica in the following regression equation:

Dry Matter Digestibility = .98 (100 - cell walls) - 12.9 + cell wall (1.473 - .789 log lignin) - 3.0(SiO_2).

TABLE 1. The relationship between cellulose and hemicellulose



(A) The solubility of the different fractions may be used as an indication of the comparative length of the chain; for example, ∝ -cellulose, which is closely related to true cellulose, is insoluble in 17.5% NaOH solution and has molecules of an estimated degree of polymerization greater than 200, whereas the hemicelluloses are insoluble in dilute alkali and are thought to have usually around 50 units in each chain.

(B) Holocellulose = cellulose + the hemicelluloses.

(C) As mentioned above, ∝ -cellulose is the material that is insoluble in 17.5% NaOH. This is merely an arbitrary method; however, it will contain more than just glucose units which are contained in the "true cellulose".

Continued.....

Table 1 (Continued)

(D) The "true cellulose" is long chains of β-D-glucopyranose units.

(E) "Cross and Bevan cellulose" is the term used to designate the cellulose fraction obtained by the method developed by these investigators. This fraction contains little lignin, but does contain other cell-wall constituents not attacked by boiling NaOH (1%) followed by chlorine and sodium sulfate treatment. Polyuronide hemicelluloses are removed with the lignin.

(F) Hemicellulose.

(G) The fact that all of the hemicelluloses cannot be obtained free from lignin without degradation of the hemicelluloses is sometimes explained by the theory that there may be a bond between lignin and hemicelluloses in some way.

(H) This shaded portion could be determined either with the cellulose (α-cellulose) or with the hemicelluloses, depending upon whether cellulose is determined as only D-glucose units (putting it in the hemicellulose category) or as a chemically standardized procedure (α-cellulose) which would put it in the cellulose fraction.

Hansen et al. 1958.

Hence, treatment of low quality roughages is directed toward:

a) The removal of lignin or a loosening of the association of plant carbohydrates with lignin allowing access to bacterial enzymes, (Bender 1975).

b) Changes in the crystalline nature of cellulose as a means of increasing the swelling capacity of the fibre in aqueous solutions and providing greater access to ruminal microorganisms and their associated enzymes, (Dekker and Richards 1973), and

c) the removal of silica, (Van Soest and Jones 1968).

The need to utilize wood by-products and various agricultural wastes more efficiently requires an inexpensive chemical, physical or biological method which will affect the above factors, (Coxworth et al. 1976).

Utilization of Untreated Wood Products

Many researchers have investigated the incorporation of untreated wood products in a ruminant diet. Although these products contribute very little energy to the animal, they are inexpensive and have exhibited beneficial effects as a result of their incorporation. High levels of untreated wood products cannot be fed due to their low levels of digestible energy, (Bender et al. 1970).

The dry matter digestibility of untreated wood products is variable. Softwoods, due to their lignin framework, are low in digestibility, (i.e. 0 to 7%), (Baker et al. 1975), whereas a hardwood, such as aspen, may

reach a digestibility of 40%, (Mellenberger et al. 1971). Clearly, if untreated wood products are to be incorporated in livestock rations, it is more desirable to include a relatively digestible product. Most research in this area has focused on feeding digestible hardwoods.

Anthony et al. (1969), conducted two experiments evaluating the effect of untreated oak sawdust on growing sheep and steers. In the sheep growth trial, levels of 10% (D.M. basis), oak sawdust did not affect average daily gain, (ADG), or feed efficiency, (FE). Palatability problems were not encountered and steers consuming 10% oak sawdust did not exhibit a decrease in feed efficiency. As no differences were observed between gains or FE in the animals, improved utilization of other ration components is implied. This is in part due to the wood fibre's effect of stimulated rumination and extended fermentation, (Kitts et al. 1969). Steers fed 15%, (D.M. basis), oak sawdust exhibited a decrease in ADG and in feed intake. Animals consuming high levels of oak sawdust displayed signs of rumen parakeratosis and had a rougher hair coat. Anthony et al. (1969), concluded that 15% sawdust levels were excessive and 10% represented the optimum level of incorporation.

Untreated alder sawdust was fed to growing beef calves to levels of 35% D.M. At 13.3% and 27.2% alder sawdust levels, an elevated ADG was noted over 0%, (control), and 35% sawdust levels. FE decreased as the level of wood increased. A slight decrease in dressing percent occurred

as the level of dietary wood was increased, (Kitts et al. 1969).

Slyter and Kamstra (1974), examined the potential of pine sawdust, a softwood, in replacing alfalfa in ruminant diets. At the 15% level of incorporation, (D.M. basis), no significant ($P \leq 0.05$) differences were noted in FE, ADG or in feed intake. The occurrence of liver abscesses was significantly ($P \leq 0.05$) reduced in the wood-fed steers. This is a characteristic response to dilution of highly concentrated diets with a roughage source. No significant ($P \leq 0.05$) differences were observed in dressing percent, carcass grade, marbling, fat thickness, rib eye area, percent kidney fat, or in taste from wood fed steers.

High levels of untreated aspen bark, (72.5% D.M. replacing alfalfa), were fed to ewes and lambs and performance evaluated, (Fritschel et al. 1976). In maintenance rations, bark was effectively utilized by ewes and cows, however, animal performance was lowered in growth trials. From a practical standpoint, a bark residues may be incorporated to levels slightly higher than their corresponding woods as they are more digestible. This has been attributed to their higher concentration of fatty constituents, (Millett et al. 1970). Other factors, such as type and degree of lignification may also be involved.

Physical Treatment of Wood Products

Physical treatment of low quality roughages reduces particle size and affects the association of plant car-

bohydrates with lignin. The reduction of particle size may be desirable as it increases the surface area available for ruminal degradation, (Clawson et al. 1970). The smaller particle size, however, decreases ruminal retention time causing inefficient utilization of the plant fibre, (Pigden and Heaney 1969). Physical treatments include grinding, hammer milling, vibratory ball milling and high energy electron irradiation.

Grinding and hammer milling increase the surface area of the substrate. Clawson et al. (1970), found in vitro cellulose digestibility was rapidly increased as particle size decreased. Apparently, grinding removes or breaks down encrusting materials such as lignin and allows direct access to the wood fibre. The increased passage rate may decrease the efficiency of utilization of the roughage, (Clawson et al. 1970).

Vibratory ball milling, (VBM), was investigated in a number of studies as a means of increasing the nutritive value of wood products. This process involves bombarding the wood with high speed ball bearings in an enclosed container over a period of time. Baker et al. (1975), found In Vitro Dry Matter Digestibility, (IVDMD), was rapidly increased to 30 minutes VBM. Response to further milling was limited. Aspen and red oak, both hardwoods, reached an 80% and 67% IVDMD at six hours milling time and a five day IVDMD incubation. This was not merely a solubilization effect, as there was evidence of disruption of the ligno-

cellulose association also. The nature and distribution of the lignin framework was the major factor affecting the efficiency of this process. Millett et al. (1970), found softwoods were less responsive to VBM than hardwoods.

Due to the selective response noted by all studies of different woods to VBM, this process has limited value in increasing availability of low quality roughages, (Millett et al. 1970; Heaney and Bender 1970; Baker et al. 1975).

Irradiation with high energy electrons is one of the more exotic methods of treatment of low quality roughages. Baker et al. (1975), proved this treatment effective in increasing the nutritive value of aspen, however, softwood response was limited. High energy electrons cause:

1) destruction of the lignocellulose bond,
2) destruction of bacteriostatic compounds in wood, and
3) disruption of the crystalline structure of cellulose, (Kitts et al. 1969).

Yu Yu et al. (1976), summarized the effect of irradiation as "delignification, depolymerization, and destruction of the crystalline nature of cellulose".

IVDMD of aspen increased from 55% to 78% at a dosage of 10^8 "roentgen equivalent physical", (rep), (Millett et al. 1970). Spruce digestibility was elevated to 14% from 3% following this treatment, however, its energy availability remained too low to be considered as a source of energy. Although effective, irradiation treatments will most likely

remain economically infeasible, (Heaney and Bender 1970).

It appears that physical treatments, particularly grinding and hammer milling are useful as they increase the efficiency of subsequent chemical treatment. The increased surface area permits a more effective penetration of the wood fibre by chemical reagents.

Chemical Treatment of Wood Products

Sodium Hydroxide (NaOH)

The potential of chemical treatment has been studied as economical means of increasing the nutritive value of low quality roughages. These treatments are directed towards the many digestibility-limiting factors outlined. On reading the literature, one will quickly notice the abundance of research concerning the effect of NaOH on roughages. Although NaOH is not the most effective treatment for this purpose, on the basis of cost, effectiveness and relative safety, it is a desirable method of treatment. Its only disadvantages are its high cost relative to other hydroxides and the effect of sodium-containing manure on soil structure, (Coxworth et al. 1976; Klopfenstein 1975; Buckman and Brady 1969).

NaOH effectively elevates the digestibility of materials with a high silica content. NaOH levels of 8% (dry matter basis (D.M.)) will dissolve the soluble silica fraction and may be washed from the product, (Hutanwatr et al. 1974). However, as stated earlier, the relevance

of "silicic inhibition" to the digestibility of wood products is limited.

Although NaOH is only partially effective in reducing the lignin content of plant materials, (Yu Yu et al. 1976), it effectively increases the swelling capacity of the wood fibre allowing greater access by rumen microorganisms.

NaOH treatment effects breakage of uronic ester bonds by saponification, (Baker et al. 1975; Erlinger and Klopfenstein 1975; Millett et al. 1970; Tarkow and Feist 1969). In effect, polymeric units are broken leaving approximately 90 to 99% of the total carboxyl content of the wood fibre unesterified compared to 30% unesterified in raw wood, (Tarkow and Feist 1969). Broken cross-links increase the "fibre saturation point", (FSP), of the wood fibre. The FSP is a measure of the quantity of water which fibre will absorb through swelling. Thus, an increase in FSP is indicative of an increased swelling capacity. Other cross-links are undoubtedly present which are resistant to NaOH treatment and prevent maximum swelling of the wood fibre, (Tarkow and Feist 1969).

The increased FSP effects:

i) an improved diffusion condition for water soluble nutrients,

ii) improved enzyme- substrate interactions, and,

iii) an increase in the maximum molecular weight of globular protein capable of diffusing into the wood fibre, (Tarkow and Feist 1969).

Lambs when fed corn cobs treated with 4% NaOH or 4% NaOH with urea, consumed more food and gained more rapidly than lambs fed water-ensiled cobs, water-ensiled cobs and urea or cobs treated with ammonium hydroxide, (Rounds et al. 1976).

Sheep and calves fed 3.5% NaOH-treated straw mixed with silage consumed similar quantities of dry matter as those fed silage diets alone, (Terry et al. 1975). These workers concluded that alkali-treated straw could replace up to one-half of the dry matter in a grass silage diet and yet sustain similar rates of gain.

Two similar studies (Maeng et al. 1971; Ololade and Mowat 1975), revealed treated straw was palatable and highly digestible. Sheep fed the NaOH treated straw invariably took less time to consume their feed allotment than those fed alfalfa silage. The digestibility of dry matter, cell wall constituents, (CWC), cellulose, acid detergent fibre, (ADF), and gross energy, (GE), were significantly, ($P \leq 0.05$) increased for treated straw compared to alfalfa silage.

Bhattacharya and Warner (1968), discovered young animals often show a favourable response in terms of feed intake and growth when fed an alkali-treated roughage. Lactating cows fed 5%, (w/w), alkali-treated roughage exhibited a 12 to 17% depression in feed intake. The 5% alkali-treated roughage increased water consumption and ruminal pH. The body was, however, able to adjust to these physiological changes.

Treatment with higher levels of NaOH, (i.e. exceeding 8% w/w), may cause health problems due to the residual alkali present (Chandra and Jackson 1971). Tarkow and Feist (1969), found residual NaOH present as luminal NaOH or sodium acetate.

Treatment of the residual alkali or other reagents present may be desirable. This may be accomplished through washing or neutralization of the product following chemical treatment.

Neutralization of alkali through the addition of acids is possible and perhaps more desirable than a washing step as it eliminates the wash water problem as well as contributing to the nutritional value of the product. For example, acetic acid would provide a source of energy, (Chandra and Jackson 1971), and phosphoric or sulfuric acid would supply phosphorous and sulfur to the organism, (Dekker and Richards 1973).

Neutralization with acetic acid or dilute hydrochloric acid, (HCl), caused significant ($P \leq 0.05$), increases in IVDMD over the control following 12% NaOH treatment of rice hulls, (Hutanwatr et al. 1974). Washing was slightly more effective than neutralization in elevating IVDMD. In this study, 12% NaOH treated rice hulls left a high level of residual chemical and a form of removal was necessary. Perhaps the 12% treatment itself was excessive as most studies have determined the optimal level of NaOH treatment to be 8% or less (w/w). (Dekker and Richards 1973;

Donefer et al. 1969; Chandra and Jackson 1971; Gharib et al. 1975; Feist et al. 1970).

Drying following chemical treatment significantly ($P \leq 0.01$), increased dry matter digestibility by 2 to 3%. The heat of drying causes the hydroxyl ion to further react with the substrate due to a more concentrated alkali environment, (Hogan and Weston 1971; Hutanwatr et al. 1974).

Although these treatments may augment the nutritive value somewhat, they represent an extra processing expense which may not be realized by the increased nutritive value of the product. Generally, treatment to remove residual alkali is not necessary if lower levels of alkali or other reagents (8% DM), are used in treatments, (Chandra and Jackson 1971; Fritschel et al. 1976; Maeng et al. 1971).

Mixtures of Alkali

NaOH in combination with other hydroxides will efficiently increase the digestibility of lignocellulosic materials. Both Rounds et al. (1976), and Klopfenstein (1975), have demonstrated a combination of 3% NaOH and 1% calcium hydroxide ($CaOH_2$), to increase ADG and feed intake over a 4% NaOH treatment. Rounds et al. (1976), obtained similar results with 3% NaOH and 2% potassium hydroxide, (KOH), combination.

Ammoniation

Treatment of low quality roughages with ammonia has a chemical effect similar to NaOH, however, the reaction

rate is slower. The cleavage of the cross-links between polysaccharide chains does not lead to the formation of ionized carboxyl groups, but rather to amide groups. Thus, maximum swelling capacity realized is similar to that following NaOH treatment, (Tarkow and Feist 1969; Baker et al. 1975; Millett et al. 1970). The amides and ammonium salts produced are responsible for a 9 to 10% elevation in crude protein (CP), levels as non-protein nitrogen (NPN). The ammonia odour is lost if the product is aired for about one week, (Baker et al. 1975; Coxworth et al. 1976).

Erlinger and Klopfenstein (1975), studied the utilization of the ammoniated product as a supplementary nitrogen (N), source. They found the differences in the N-availability between the ammoniated product and urea-N were not apparent in the performance of growing and finishing steers. As long as the portion of N supplied by the ammoniated product does not exceed 30% of the total N present and is introduced to the animal gradually, the N present will be utilized efficiently.

Kernan, (personal communication, 1976), has studied the effect of ammoniation of crop residues. Baled wheat straw was covered with a polyethylene sheet and filled with anhydrous ammonia through plastic tubing. Allowing this to react for a period of six to thirty days, depending on ambient temperature, created a product similar in DMD and CP content to a medium quality hay. To date experimental data is not available.

Ammoniation is less costly than NaOH treatments and provides a source of NPN. Also, manure from livestock consuming this product does not contain residual chemicals which would damage soil structure, (Coxworth et al. 1976).

Mixing the ammoniated product with a fermented feed may be desirable. This would trap the ammonia present and reduce the odour problem. Although ammoniation is effective, the mechanics of treatment and perhaps the necessity of feeding it with a fermented feed create problems which are yet unsolved, (Kernan 1976).

Peroxyacetic Acid

Kamstra et al. (1976), have adapted the use of peroxyacetic acid, (peracetic acid), as a delignifying agent of low quality roughages. Peracetic acid is employed as a delignifying agent in the pulp and paper industry. Complete delignification is possible with proper conditions of acid concentration, treatment time and temperature. Treatment of ponderosa pine sawdust caused little damage to the cellulose or hemicellulose fractions during lignin removal (Kamstra et al. 1976). Costs of the acid are high and practical application would demand local production of the acid. This involves a controlled reaction between hydrogen peroxide and acetic anhydride. Treatment conditions are quite hazardous.

Although peroxyacetic acid treatment is effective as a delignifying agent, (Kamstra et al. 1976), its use, on

a practical basis is limited.

Miscellaneous

Other studies have evaluated the use of KOH, (Anderson and Ralston 1973; Rounds et al. 1976), calcium hydroxide, (Coxworth et al. 1976; Rounds et al. 1976), sodium sulfide alone or in combination with NaOH, (Chandra and Jackson 1971; Gharib et al. 1975; Baker et al. 1973; Dekker and Richards 1973), sodium sulfite, (Chandra and Jackson 1971; Clarke and Dyer 1973; Dekker and Richards 1973; Gharib et al. 1975), $NaCHO_2$, (Anderson and Ralston 1973), chlorine compounds, (Chandra and Jackson 1971; Yu Yu et al. 1976; Gharib et al. 1975; Smith et al. 1970), sulfur dioxide, (Baker et al. 1975), and a number of other chemicals in their ability to increase the digestibility of low quality roughages.

Many chemicals have been evaluated, however, their cost has generally precluded their practical application. Many of these treatments have been adapted from the pulp and paper industry as delignifying processes where treatment costs are low relative to the product's value, however, profits in the livestock industry rely on inexpensive, practical feeding regimes and the future use of most of the exotic chemical treatments for feeding purposes is doubtful.

Biological Treatment of Wood Products

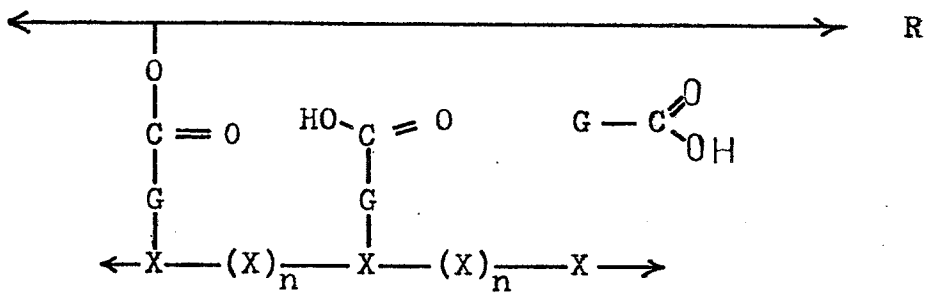
Biological treatments of roughages have also been evaluated. White-rot fungi, (WRF), will decompose lignin as

well as cellulose and hemicellulose in wood, (Baker et al. 1975). Some WRF will remove lignin at a rate exceeding that of hemicellulose and cellulose removal leaving a product of low lignin content and increased digestibility. Baker et al. (1973), found hardwood lignins were more efficiently removed by fungii than softwood lignins. Fungal degradation is a very slow process and one would need to guard against contamination with toxic fungi and molds, (Coxworth et al. 1976).

Yu Yu et al. (1976), investigated the use of cellulases and pectinases as means of increasing the nutritive value of straw. However, neither of these two types of enzymes were able to decrease fibre content or increase the IVDMD of straw. The lignocellulose complex is responsible for this poor response.

Steam Pressure Treatment

Steam pressure treatment is a physical treatment effecting a chemical response in fibre. Although not developed recently, its use in production of livestock feed is only now reaching widespread interest. Steaming wood fibre allows original acetyl groups of the fibre to "split-off", (Bender et al. 1970), through the rupture of polymeric cross-links:



"Lower chain represents a hardwood xylan chain with a free carboxyl group and an esterified carboxyl group functioning as a "cross-link" between the xylan chain and some other polymeric unit" - Tarkow and Feist (1969).

The acid produced is sufficient to bring about a degree of hydrolysis which also increases the digestibility of the wood, (Bender et al. 1970). Other cross-links would be present which are resistant to this form of treatment, (Tarkow and Feist 1969). The effect of this treatment is one of increased fibre saturation point, (FSP), and consequently, increased fibre availability to rumen microorganisms, improved diffusion conditions for water soluble materials present, and a small increase in the maximum molecular weight of globular protein capable of diffusing into the wood fibre, (Tarkow and Feist 1969). It is doubtful that steam treatment affects the lignocellulose complex to a large extent.

The use of steam treatment has not been investigated as fully as NaOH treatment but its chemical effect is known to be similar. The percentage increase in FSP following NaOH treatment is predictable. The wood fibre behaves as a polyelectrolyte allowing a hyper-swollen state in the wood fibre at elevated pH. The presence of an acid, such as those

produced in steam treatment, prevents the formation of a complex polyelectrolyte system and consequently steam treatment may be slightly less effective, in this respect, than NaOH treatment, (Tarkow and Feist 1969).

Steam pressure treatment exerts its effect rapidly as a function of time, pressure and temperature. Bender (1970), suggested that aspen reached the IVDMD, (48 hrs), of medium quality hay following a two hour treatment at 165 to 170°C at 100 to 115 psi. This liberates 4 to 5% acid as acetic acid equivalent. Increasing treatment temperature to 200°C releases 6% acetic acid equivalent in one-half hour but additional benefits, in terms of product quality, were not noted over conditions liberating 5 to 6% acetate equivalent. Various carbohydrates in the wood fibre are "carmelized" as a result of the elevated temperature. This gives the product a molasses odour and may contribute to the palatability of the product.

Drevjany et al. (1976), fed nine levels of aspen (0 to 80%) replacing corn grain, (D.M. basis), to 18 bull calves for 98 days. The wood product was similar to the "Bender-Heaney" product described above.

Wood stimulated feed intake per kilogram, (kg), of body weight, (BW), to a level of 60% incorporation. Calves consuming 80% dietary wood still consumed more DM per kg of BW than did control fed animals, (Drevjany et al. 1976).

Feeding of wood to levels of 30% of the DM intake improved average daily gain, (ADG), (Drevjany et al. 1976).

This supports the work of Heaney et al. (1973). Their steers, when fed a similar product at 30% DM gained weight as rapidly as did the control on corn silage. Drevjany et al. (1976), found levels of 70 to 80% steamed aspen depressed ADG. On the basis of ADG, the 60% level of wood represented the upper practical limit of incorporation.

The feed conversion ratio was not affected at levels of 40% DM and below. At higher levels of dietary wood, the feed conversion ratio was rapidly decreased, (Drevjany et al. 1976).

The calves in Drevjany's study were left on full feed until time of slaughter so that digestive organs could be characterized as normal. No effects on the weight of the full reticulo-rumens were found between treatments. Thus, rumen impaction did not occur at high levels of wood incorporation.

Abnormalities were not evident in any of the livers, kidneys or reticulo-rumens examined. Steamed aspen appears to decrease carcass quality, in terms of warm carcass weight and dressing percent at levels exceeding 40%, (Drevjany et al. 1976). Heaney et al. (1973), found significant, ($P \leq 0.05$), depressions in backfat thickness, (BFT), at the 30% DM level of dietary wood but dressing percent and longissimus dorsi area were not affected significantly, ($P \leq 0.05$).

Rumen samples were taken in Drevjany's study from the calves for pH and VFA determination. No significant, ($P \leq 0.05$), differences were found in ruminal pH between

treatments however, some VFA levels were affected. Contrary to expectation, Drevjany found increasing levels of wood in the diet did not significantly, ($P \leq 0.05$), increase the acetate/propionate or acetate/butyrate ratios. Although dietary aspen did not affect the production of acetic or propionic acids, butyric acid levels were lowered somewhat by high levels of dietary wood. High levels of wood significantly, ($P \leq 0.05$), decreased isovaleric and valeric acid production. A depression in the level of these VFAs may be of some consequence to the organism as these are important glucogenic compounds, (Drevjany et al. 1976).

Drevjany et al. (1976), demonstrated high levels of wood significantly lowered blood glucose, (BG), levels. At elevated levels of dietary wood incorporation, animals were forced to utilize the wood cellulose, hemicellulose and added molasses as the sole source of glucogenic materials. Consequently, available energy, measured as BG, was lowered.

At levels of 30% dietary wood and above, Drevjany et al. (1976), noted elevated levels of blood urea nitrogen, (BUN). This is indicative of a decrease in the efficiency of utilization of N-sources present. Ammonia which is released in the rumen, is either converted to bacterial protein or absorbed across the rumen wall into the circulatory system. This form of nitrogen is converted to urea in the liver as a waste product for excretion. Ammonia is lost to the circulatory system if energy is unavailable to power amination reactions or to provide carbon-skeletons for

amino acid synthesis.

Drevjany et al. (1976), examined the BG/BUN ratio. This ratio serves as an indication of units of energy available for N-utilization. An unfavourable BG/BUN ratio implies an imbalance exists. Animals consuming rations exceeding 30% dietary wood exhibited a lowered BG/BUN ratio.

In neither Drevjany et al's. (1976), or Heaney et al's. (1973), studies were health or palatability problems encountered at levels of 30% and 40% dietary wood. Palatability of the product itself is apparently high as it has a pleasant aroma and may increase dry matter intake.

Steam Treatment - Acid Hydrolysis

Steam treatment of woody by-products in conjunction with acid hydrolysis has also been studied. Albin (1976), conducted an experiment to evaluate the use of hydrolyzed hardwood sawdust in heifer diets. The hydrolysis procedure is patented and would involve steaming with the addition of sulfuric or a similar acid. This effect is similar to the steam pressure process outlined but the acid hydrolysis of the product would be more complete due to the degree of dissociation of the strong acid added. In Albin's study (1976), the effect of incorporating 19.75% and 39.5% hydrolyzed hardwood sawdust as a grain replacement was evaluated. The feeding period lasted 117 days during which time animal health was excellent. Initially

levels of 39.5% sawdust significantly, ($P \leq 0.05$), decreased ADG over control, however, a continuous improvement was observed throughout the trial. Feed intake was not affected significantly, ($P \leq 0.05$), at the 19.75% level of incorporation. Albin (1976), found significant, ($P \leq 0.05$), increases in the feed per gain ratio as the level of dietary wood increased and concluded the wood to be 60% of the value of corn when fed to levels of 40% on a dry matter basis.

Hydrolyzed wood-fed animals exhibited lower values for dressing percent, grading and cutability score (Albin 1976). A slight decrease in carcass quality is a characteristic response if levels of dietary processed wood exceed 30% DM. This is often noted in finishing animals as the wood cannot supply the energy needed for fat deposition. The effects of wood incorporation in growing rations would go unnoticed if animals were finished without high levels of wood in their diets.

Economic Considerations

In summary, the economic importance of treatment of low quality roughages depend upon:

a) the market price of traditional feed,
b) the cost of harvesting and transportation, and
c) cheaper methods to supplement low protein products for nutritional deficiencies, (Kamstra et al. 1976).

Trembling aspen, (Populas tremuloides), is the most prevalent of four species of aspen found in Manitoba. "Available" aspen stands are located in the southeast and southwest section of the province. Although large aspen

stands do exist in the north and northeast area of the province, utilization of these stands is impractical due to their location, (Neilson and McBride 1974). Eighteen percent of the merchantable wood within Manitoba is aspen-poplar. Included in its uses are lumber, plywood, veneer, particle board and fuel wood, (Steneker 1976). Despite its many uses, a large portion of the harvested wood remains wasted through the non-use of sawdust and other by-products. Perhaps these by-products could be more efficiently utilized through treatment and incorporation into ruminant diets.

MATERIALS AND METHODS

Ram Digestibility Trial

A ram digestibility trial and a steer growth trial were conducted to determine the effects of feeding pressure-treated aspen-poplar (*populas tremuloides*) to ruminants. The treated aspen was supplied by Stake Technology Ltd. of Ottawa who own patents on the treatment process. Unfortunately, Stake Technology was not able to provide details of the pressure-steam process.

In the ram digestibility trial, four mature rams (average body weight of 62 kg) fitted with rumen fistulae were randomly assigned four treatments in a 4x4 Latin-square design (Table 2), (Dunn and Clarke 1974) to determine the effect of replacing ground alfalfa hay with the treated wood product. Four levels of wood (0%, 15%, 30%, 45%) replaced alfalfa on a dry matter basis, (Table 3). Proximate analysis of the 4 rations is shown in Table 4.

The rations were mixed in a horizontal "Marion" mixer for 10 to 15 minutes to ensure thorough mixing and then pelleted in a "California" pellet mill (0.5 cm). The diets were adjusted to 13% crude protein using soybean meal (SBM) and urea.

After a four week post-fistulation recovery period, the rams were placed in metabolism crates and assigned a wood treatment level. The rams were allowed two weeks for adjustment to their new diets before each of the four collection periods. *Ad libitum* feed consumption was measured during this time.

Table 2. Randomization of the 4x4 Latin square design

Period	Experimental ram diets			
	Control 0% Aspen	15% Aspen	30% Aspen	45% Aspen
1	d[1]	b	c	a
2	c	a	d	b
3	b	c	a	d
4	a	d	b	c

(Dunn and Clarke, 1974)

[1]Letters a-d refer to one of four rams.

Table 3. Composition of the experimental ram rations

Treatment	Dietary component (% DM)							
	Alfalfa	Aspen	Corn	Urea	SBM	Molasses	Dical	TMS[1]
Control	45	0	50	0	0	3	1	1
15% Aspen	30	15	49.1	0.9	0	3	1	1
30% Aspen	15	30	46.2	1.5	2.3	3	1	1
45% Aspen	0	45	39.9	1.5	8.6	3	1	1

[1]TMS - Trace Mineralized Salt (% content represents the actual level of the element).

NaCl	96.5% min.
Zn	.400% as Zinc Oxide
Fe	.160% as Ferrous Carbonate
Mn	.120% as Manganous Oxide
Cu	.033% as Copper Oxide
I	.007% as Calcium Iodate
Co	.004% as Cobalt Oxide

Table 4. Proximate analysis of the experimental ram rations (% DM)

Item	Experimental ram diets			
	Control	15% Aspen	30% Aspen	45% Aspen
Crude protein	13.18	13.47	13.70	13.79
Ether extract	3.22	2.46	2.52	2.82
Crude fibre	16.99	18.33	20.89	23.46
Ash	6.68	5.35	4.24	3.52
Calcium	0.96	0.67	0.53	0.38
Phosphorous	0.50	0.46	0.43	0.42
Gross energy (kcal/kg)	4,357	4,406	4,453	4,601
Acid detergent fibre	19.37	22.18	26.00	30.54
Permanganate lignin	5.57	5.71	6.12	6.59
Cellulose	13.96	15.59	20.09	24.13
Insoluble ash	Negligible	Negligible	Negligible	Negligible

During the 5 day total collection period fecal material was collected in vinyl bags attached to the sheep, and urine was collected in plastic bottles. At the start of the collection period the rams were weighed and a measured amount of feed (90% ad libitum) was given once daily over the 5 day collection period. Water was supplied ad libitum and consumption was recorded. Weigh-back samples, if any, and feed samples were taken daily for dry matter analysis.

After collection, feces were weighed and mixed thoroughly in a "Hobart Model 600" mixer before sampling. The fecal samples were placed in plastic sample bags and stored at -4°C until further analysis could be performed.

Throughout the collection period daily urine volume was determined and a 5% sample was frozen daily for further analysis. To prevent loss of urinary ammonia, 20 ml of concentrated sulphuric acid were added daily to the empty collection bottles. After completion of the collection period, the urine samples were thawed and combined within treatments and periods and filtered. Urinary-nitrogen levels were determined according to official methods of the AOAC, (macro-Kjeldahl) (1975).

Following completion of the collection period, rumen digesta and blood samples were taken at 0,1,2,3,4,6,8,12 and 24 hours post-feeding. Rams were fed at 90% ad libitum levels supplied at one feeding in the morning and consumed over a 24 hour period. The 0 and 24 hour samples were taken prior to the introduction of the animal's daily feed allotment.

Rumen digesta samples were taken from 0 to 24 hours

post-feeding through the rumen fistulae. Since the dietary wood increased the viscosity of the rumen contents, conventional rumen sampling techniques were not possible. Instead, a modified grain-probe (Figure 1) was used and a 200 ml core sample taken. A "Radiometer Copenhagen Model 26" pH meter was used to determine the pH of the rumen contents. Immediately following, 0.5 ml of 20% mercuric chloride was added to the sample and thoroughly mixed to prevent further microbial fermentation. One ml of concentrated sulphuric acid was also added to prevent loss of ruminal ammonia nitrogen. The rumen digesta samples were then chilled overnight.

Digesta samples were centrifuged at 3100 rpm in a swinging-bucket "International Model U" centrifuge for 10 minutes. The rumen fluid supernatant was then decanted into sample bottles and frozen until further analysis was possible.

At each time period, 15 ml blood samples were taken from the jugular vein with a "Vacutainer". These were chilled overnight then centrifuged at 3000 rpm for 10 minutes in a "Sorvall GLC-1" swinging-bucket centrifuge. The serum supernatant was then pipetted into sample vials and frozen until analysis could be carried out.

Feed and fecal samples were dried in a forced air dryer at 60^{o}C and percentage dry matter, crude protein (macro-Kjeldahl), and crude fibre were determined according to AOAC procedures, (1975). Gross energy levels were determined with an "Adiabatic Parr Oxygen Bomb Calorimeter".

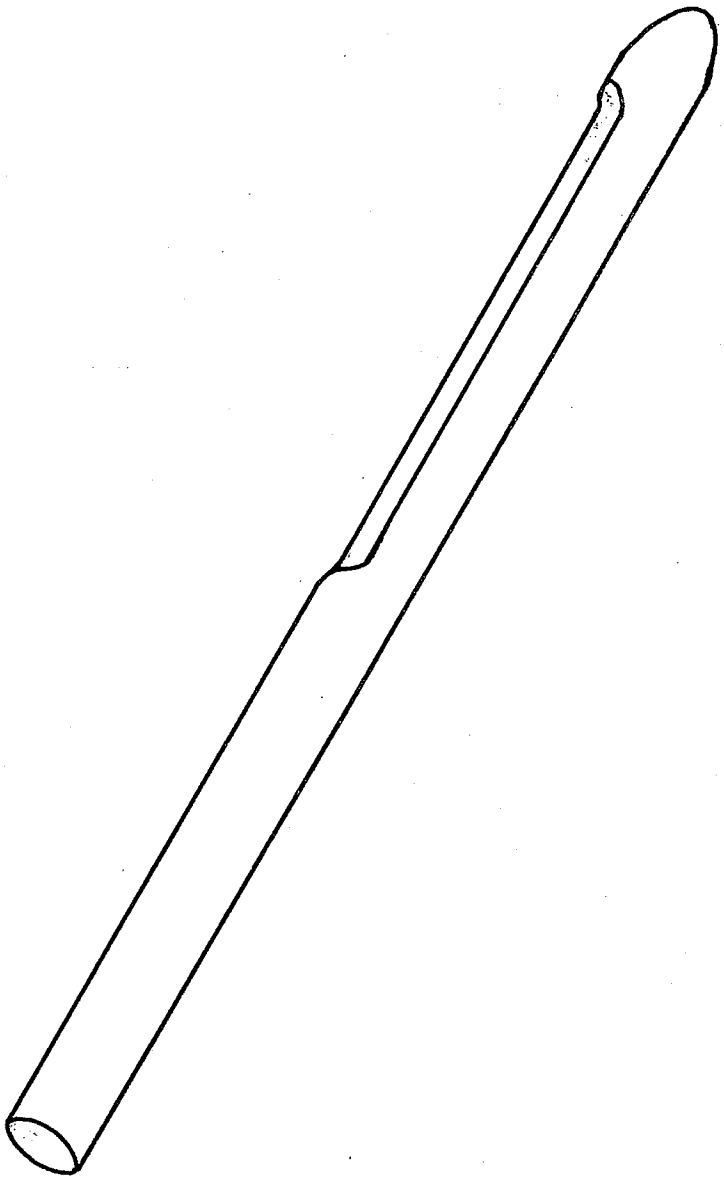


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Figure 1. Rumen Sampling Probe.

Dry matter, gross energy, crude protein and crude fibre digestibilities as well as nitrogen retention of the experimental treatments were determined on completion of the 4x4 Latin square. Percent digestibility and nitrogen retention formulae are illustrated in Appendix I.

Steer Growth Trial

To determine the effect of dietary wood on steer feedlot performance, 36 steers (average body weight of 246.5 kg) of Hereford, Charolais and Selkirk breeding were randomly assigned to three dietary levels of wood (0%, 15% and 30% D.M.) of 3 replicates per treatment and fed for 139 days.

All steers were injected with vitamins A, D, and E and weighed on two consecutive days prior to the initiation of the trial. The mean value of the two initial weighings was taken as the starting weight of each animal. The steers were then weighed at monthly intervals throughout the growth trial.

The composition of the three isonitrogenous (12% CP) experimental diets is shown in Table 5. The wood supplement was hand-mixed daily with corn silage and ad libitum levels of each ration were offered to each pen. As the consumption of each ration increased, the amount offered daily was increased proportionately. All feed remaining in the feeder at the end of each week was removed and weighed. Feed samples were taken weekly for dry matter analysis (AOAC, 1975). Throughout the feeding period, water and minerals were available free-choice.

Table 5. Composition of experimental steer growth rations

Treatment[1]	Dietary component (% DM)					
	Corn silage	Aspen	Urea	SBM	Barley	Dical
Control[2]						
15% Aspen	75.83	15	1.67	3.50	3.00	1.00
30% Aspen	60.73	30	1.67	6.60	0	1.00

[1]All steers had access to a mineral box containing a mixture of 70% dicalcium phosphate and 30% TMS (Table 3).

[2]The control diet consisted of corn silage free-choice with 1 kg of 47.3% SBM, 43.7% barley, 6.0% urea, and 3.0% dicalcium phosphate supplement per head per day.

Over the feeding trial, feed intake, average daily gain, feed conversion ratio and animal health were closely followed. The steers remained on full-feed until completion of the trial. On days 138, 139 and 140, the steers were weighed prior to their morning feeding. The mean value of these 3 weighings was taken as the final weight of the steers.

To complement data obtained from the ram trial, blood and rumen samples were taken from 2 randomly selected steers per pen, (6 per treatment) towards completion of the growth trial. Samples were taken approximately 2 hours post-feeding. To accomplish this, the steers were fed at staggered intervals.

Twenty-five ml of steer rumen fluid were collected through a stomach tube attached to a "strainer-bullet". A portable "Photovolt Model 120A" pH meter was used to determine ruminal pH. To prevent further microbial fermentation, two drops of 20% mercuric chloride were added to the sample. Two drops of concentrated sulphuric acid were also added to prevent ruminal ammonia loss. The rumen samples were frozen until further analysis could be performed.

After thawing and filtering the ram and steer rumen fluid samples, rumen ammonia levels were determined with a "Technicon Flame Photometer IV" autoanalyzer, (Bolleter et al. 1961). To determine rumen volatile fatty acid levels, 5.0 ml of rumen fluid were pipetted into centrifuge tubes,

mixed with 1.0 ml of 25% meta-phosphoric acid and capped. After equilibrating for 1/2 hour, the rumen samples were centrifuged at 2500 rpm for 10 minutes in a "Sorvall GLC-1" swinging-bucket centrifuge. Acetic, propionic, isobutyric, butyric, isovaleric, and valeric acid levels were determined with a "Burrell Single Flame" gas chromatograph packed with a 20% NPGS, 2% H_3PO_4 on Firebrick 60/80 column.

Steer blood samples (plasma) were taken from the jugular vein with "Vacutainers" and chilled overnight. The blood samples were centrifuged at 3000 rpm for 10 minutes in a "Sorvall GLC-1" swinging-bucket centrifuge and the plasma pipetted into sample vials. Ram and steer blood glucose, blood urea nitrogen, and blood ammonia levels were determined using a "Technicon Flame Photometer IV" auto-analyzer according to Bittner and McCleary (1963), Marsh et al. (1965), and Bolleter et al. (1961), respectively.

The physiological effects of dietary wood were studied through quantitation of rumen and blood metabolites. Analysis of variance of the ram data was completed as a 4x4 Latin square at the 5% level of significance. The "Student-Neuman-Keul" test for multiple comparisons was used where significant ($P \leq 0.05$) differences were detected between treatments. Polynomial and linear regression analysis were completed on dry matter and gross energy digestibilities, (Dunn and Clarke, 1974).

Analysis of variance was completed on average daily gain, feed intake and the feed conversion ratio of the steers as a completely randomized design according to Dunn and Clarke (1974) ($P \leq 0.05$).

RESULTS

Ram Digestibility Trial

Results of the ram digestibility trial are shown in Table 6. The dry matter digestibilities (DMD) of the three wood-containing diets were significantly ($P \leq 0.05$) reduced relative to the control diet. Dry matter intake (per kilogram of body weight)$^{0.75}$ (kg BW)$^{0.75}$ was lowered, although non-significantly ($P \leq 0.05$), by the 15% and 45% diets.

Gross energy digestibilities (%) (GED) of the 3 wood-containing diets were also significantly ($P \leq 0.05$) lower than that of the control diet. Gross energy intake per (kg BW)$^{0.75}$ paralleled the decline observed in dry matter intake per (kg BW)$^{0.75}$ (Table 6).

Polynomial regression analysis of dry matter and gross energy digestibilities demonstrated a better "fit" to the data than did linear regression analysis. Figures 2 and 3 illustrate the regression lines of DMD and GED respectively. The polynomial regression equations are shown below:

$$\% \text{ DMD} = 73.84 - 0.463\ x^{*} + 0.0061\ x^{2}$$

$$\% \text{ GED} = 72.68 - 0.540\ x + 0.0071\ x^{2}$$

*x = percent dietary aspen (DM)

The crude protein digestibility (CPD) of the 4 experimental diets was found to be independent of the

Table 6. The digestibility and intake per kg $BW^{0.75}$ of the experimental ram rations[1]

Treatment	Dry matter		Gross energy	
	Percent digestible	Intake/ kg $BW^{0.75}$/day (grams)	Percent digestible	Intake/ kg $BW^{0.75}$/day (megacalories)
Control	73.88±5.36[a2]	80.0± 6.9	72.84±5.86[a]	0.348±.030
15% Aspen	68.18±4.31[b]	73.2±16.9	66.18±5.02[b]	0.322±.073
30% Aspen	65.55±5.32[b]	78.4±12.3	62.95±6.22[b]	0.350±.055
45% Aspen	65.36±7.35[b]	63.2±18.8	62.91±7.66[b]	0.292±.086

.....Continued

Table 6 (Continued)

Treatment	Crude protein		Crude fibre		
	Percent digestible	Intake/ kg $BW^{0.75}$/day (grams)	Percent digestible	Intake/ kg $BW^{0.75}$/day (grams)	Water consumption intake/day (kg)
Control	67.68±4.92	10.36±1.00	38.00±19.55	13.26±1.36	8.07±1.45
15% Aspen	67.87±3.67	9.86±2.23	24.38±12.24	13.40±3.04	7.32±1.36
30% Aspen	65.07±4.62	10.72±1.65	30.33± 8.15	16.38±2.55	8.14±1.17
45% Aspen	68.93±4.60	8.70±2.61	37.00±16.67	14.82±4.42	7.71±1.58

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same column are significantly different ($P \leq 0.05$).

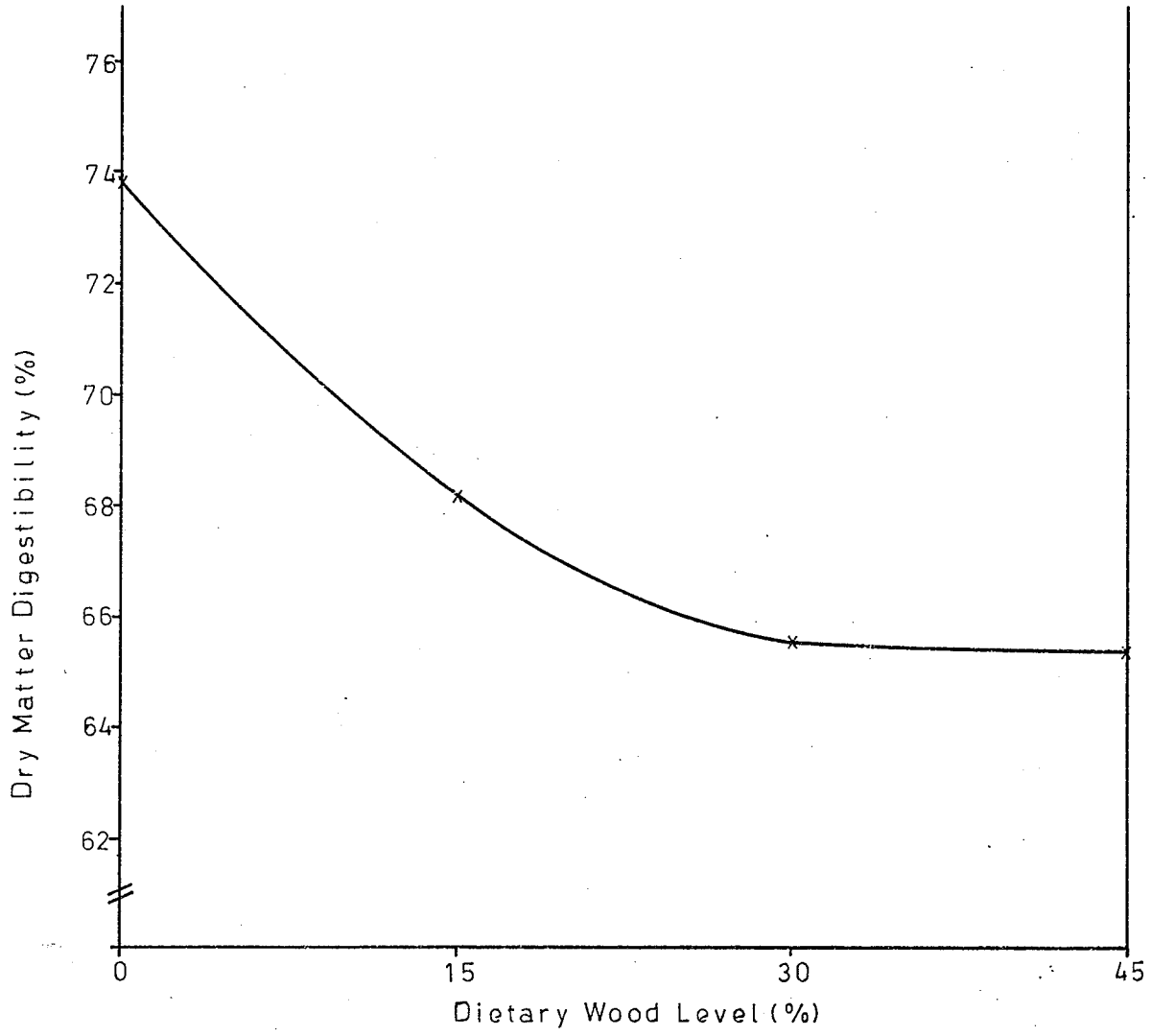

Figure 2. The effect of dietary aspen on dry matter digestibility of the experimental rations.

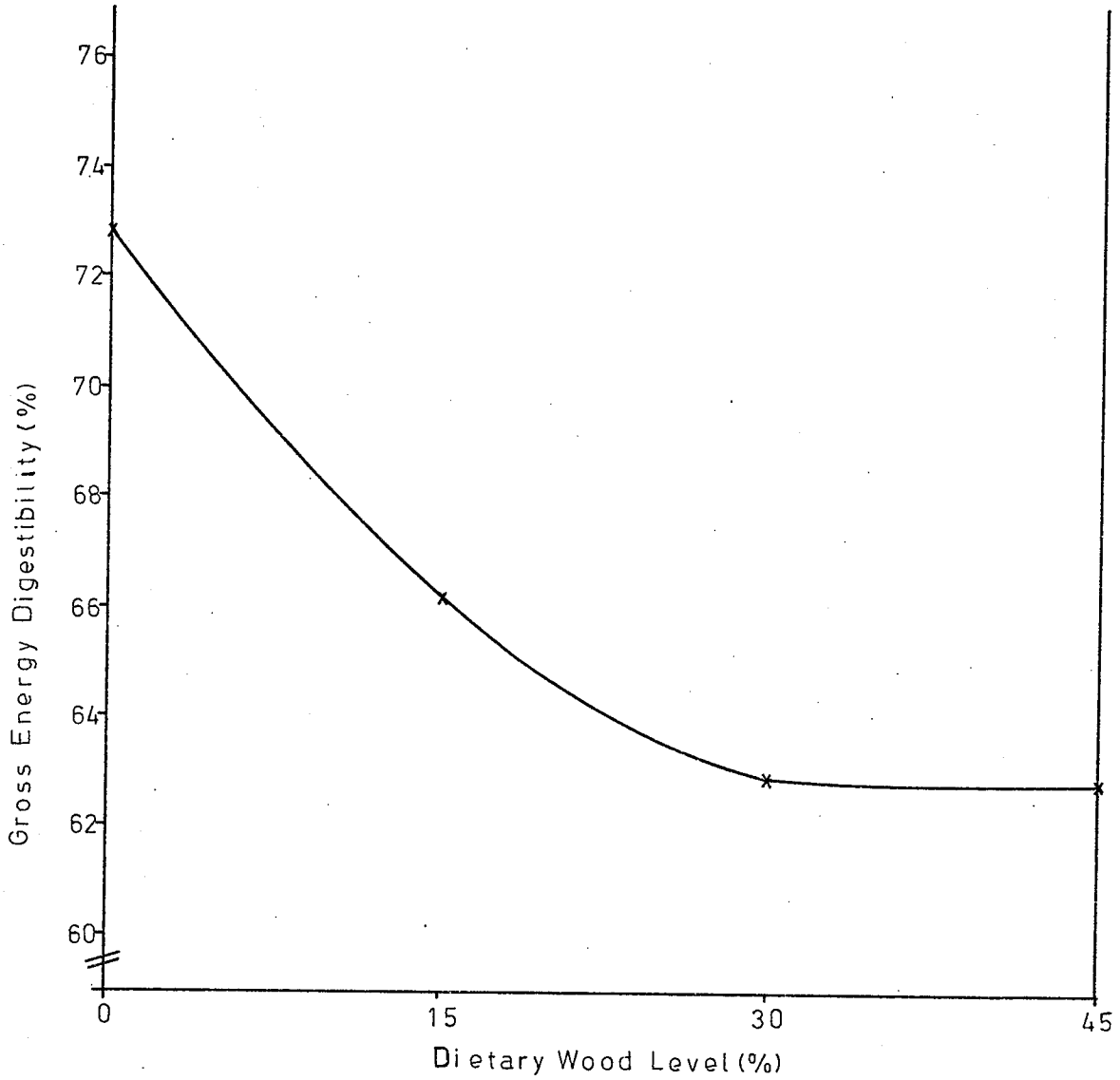

Figure 3. The effect of dietary aspen on gross energy digestibility of the experimental rations.

dietary wood level ($P \leq 0.05$). Since the diets were isonitrogenous, crude protein intake per $(kg\ BW)^{0.75}$ paralleled the level of dry matter intake per $(kg\ BW)^{0.75}$. (Table 6).

Although significant ($P \leq 0.05$) differences were not evident, crude fibre digestibility (CFD) values were variable. The 15% treatment lowered the CFD considerably relative to the control treatment. The higher levels of dietary wood (30% and 45%) elevated the CFD near that of the control diet, (Table 6). The crude fibre intake per $(kg\ BW)^{0.75}$ of the 4 treatments was influenced by the changing dietary fibre level and the dry matter intake of the respective diets. The dietary fibre level increased as the proportion of wood in the diet increased. The crude fibre intake per $(kg\ BW)^{0.75}$ of the 30% treatment was elevated over the three other experimental treatments.

Although significant ($P \leq 0.05$) differences were not apparent, all wood-fed animals exhibited lowered values of nitrogen (N)-retained, N-retained per $(kg\ BW)^{0.75}$, percent N-retained, and percent N-retained per $(kg\ BW)^{0.75}$ relative to the control fed animals, (Table 7) (Appendix 1). The 30% and 45% diets had little effect on these measurements beyond the effect of the 15% diet.

Values for water consumption corrected for the moisture level of the diets are presented in Table 6. Dietary wood did not significantly ($P \leq 0.05$) affect this measurement.

Table 7. The influence of dietary aspen on the nitrogen retention of rams[1]

Treatment	N retained per day		Percent N retained[2]	
		g per kg $BW^{0.75}$		g per kg $BW^{0.75}$
Control	14.04±3.03	0.602±.150	36.5± 9.8	1.57±.46
15% Aspen	10.48±2.25	0.464±.127	29.2± 4.6	1.29±.25
30% Aspen	11.18±1.70	0.480±.094	28.0± 2.6	1.20±.13
45% Aspen	9.12±3.59	0.416±.185	30.3±10.9	1.39±.63

[1]All values are means of 4 observations ± standard error.

[2]Appendix 1.

Ruminal pH, ammonia, and volatile fatty acid (VFA) data are presented in figures 4 through 7 and Appendices 2 through 11.

Dietary wood did not influence ruminal pH significantly ($P \leq 0.05$). In all treatments, ruminal pH fell rapidly within 1 hour post-feeding and was maintained to 12 hours post-feeding. (Figure 4) (Appendix 2).

Generally, the higher levels of urea in the diets containing high levels of wood significantly ($P \leq 0.05$) elevated ruminal ammonia levels at 1 through 12 hours post-feeding (Figure 5) (Appendix 3). Peaks in ruminal ammonia levels were noted at 1 hour and at 6 to 8 hours post-feeding in all treatments.

At 0, 1, 4 and 12 hours post-feeding significant ($P \leq 0.05$) differences in total VFA levels were noted among the 4 experimental treatments (Figure 6) (Appendix 4). At the 0 hour sampling time, both the 15% and 45% treatments lowered total VFA levels relative to the control treatment. At 1 hour post-feeding a significant ($P \leq 0.05$) difference in total VFA production between the 45% diet and the other 3 diets was noted. The 45% diet, as well as the 15% diet significantly ($P \leq 0.05$) lowered total VFA production relative to the control and 30% diets at the 4 hour sampling time. At 12 hours post-feeding a significant ($P \leq 0.05$) difference between the control and 45% treatments was noted. Although

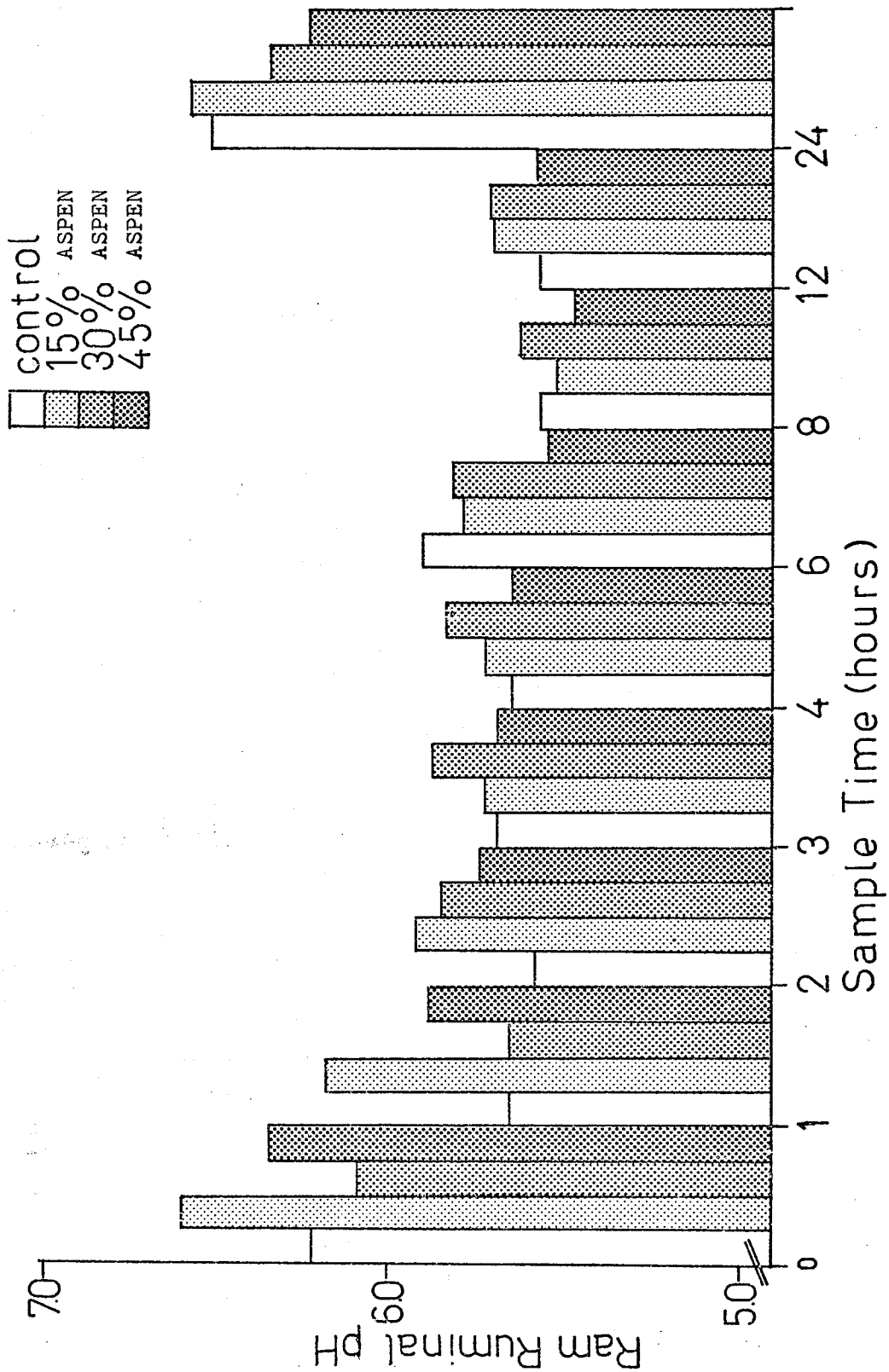

Figure 4. The effect of dietary aspen on ram ruminal pH.

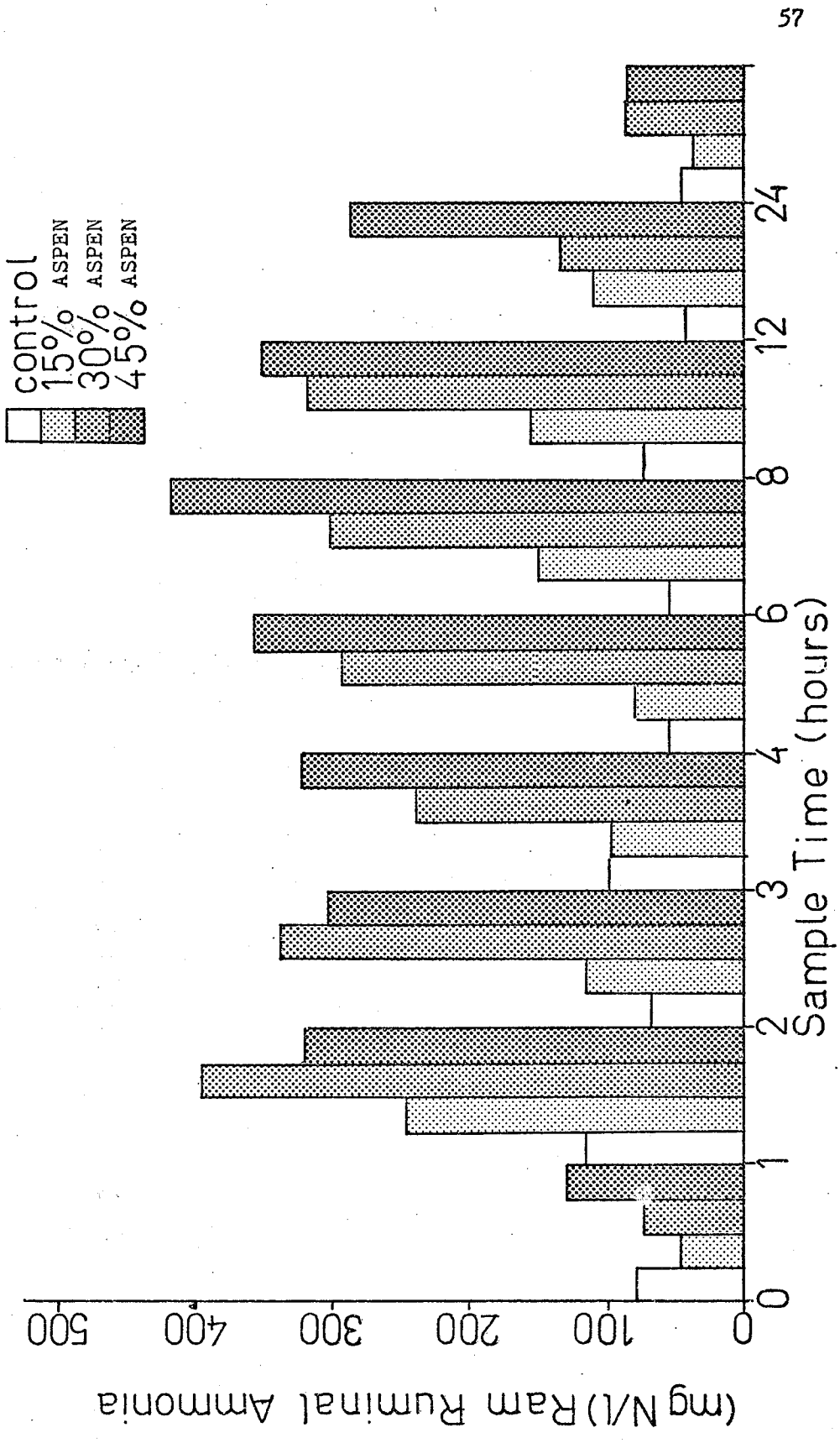

Figure 5. The effect of dietary aspen on ram ruminal ammonia levels.

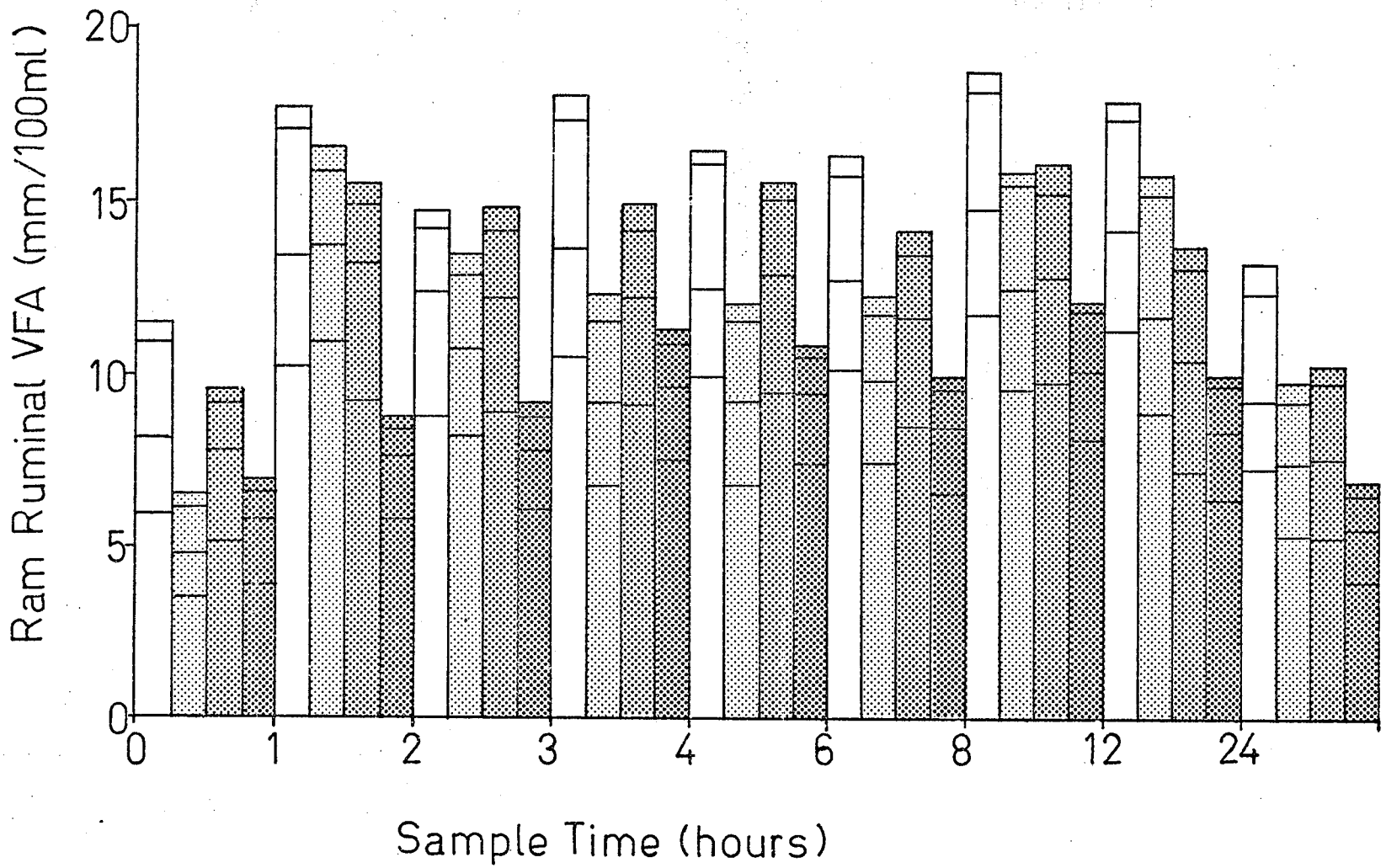

Figure 6. The effect of dietary aspen on ruminal volatile fatty acid levels of the rams.

significant ($P \leq 0.05$) differences at other sample times were not apparent, generally, the dietary wood effected lowered total VFA levels relative to the control diet.

Although non-significant ($P \leq 0.05$), the ruminal acetic acid levels of the wood-containing diets were lowered relative to the control diet throughout the 24 hour sampling period (Figure 6) (Appendix 5).

Propionic acid levels were lowered significantly ($P \leq 0.05$) at 0, 1 and 4 hours post-feeding (Figure 6) (Appendix 6). At the 0 hour sampling time the 15% diet depressed propionic acid production compared to the control and 30% treatments. At 1 hour post-feeding, the 45% diet affected lower propionic acid production relative to the 3 other experimental diets. A difference in propionic acid production between the 45% and 30% diets was noted at 4 hours after feeding. Throughout the 24 hour sampling period the 30% wood fed animals displayed the highest level of propionic acid production, and the 45% wood fed animals, the lowest.

Significant ($P \leq 0.05$) differences in isobutyric acid production were evident at 0 and 4 hours post-feeding (Figure 6) (Appendix 7). At the 0 hour sampling time, all diets containing wood exhibited lowered isobutyric acid levels compared to the control diet. Also, differences between the 30% and 15% diets and between the

45% and 15% diets were noted. At 4 hours post-feeding, the 15% and 45% wood-fed animals exhibited lowered ruminal isobutyric acid levels relative to the control-fed and 30% wood-fed animals.

Ruminal butyric acid levels were lowered considerably by dietary wood inclusion (Figure 6) (Appendix 8). At the 0 hour sampling time, all wood-containing diets significantly ($P \leq 0.05$) lowered butyric acid production. Significant ($P \leq 0.05$) differences were noted at 1 and 4 hours post-feeding between the control-fed animals and the 45% wood-fed animals. At the 2 hour sampling time the 45% wood-fed animals exhibited lowered butyric acid levels relative to the control-fed and 15% wood-fed animals. Generally, a decline in butyric acid production occurred as increasing levels of wood were added to the diet. Other differences did not reach significance ($P \leq 0.05$).

Although high levels of wood changed the production patterns of both isovaleric and valeric acids somewhat, none of the differences between treatments were significant ($P \leq 0.05$) (Figure 6) (Appendices 9 and 10). Generally, valeric acid production was elevated by the 30% treatment and inhibited by the 45% treatment relative to the control and 15% treatments throughout the 24 hour sampling period.

The effect of dietary wood on the acetate to propionate ratio over the 24 hour sampling period is illustrated in Figure 7 (Appendix 11). At 1 hour post-feeding, a significant ($P \leq 0.05$) difference was noted

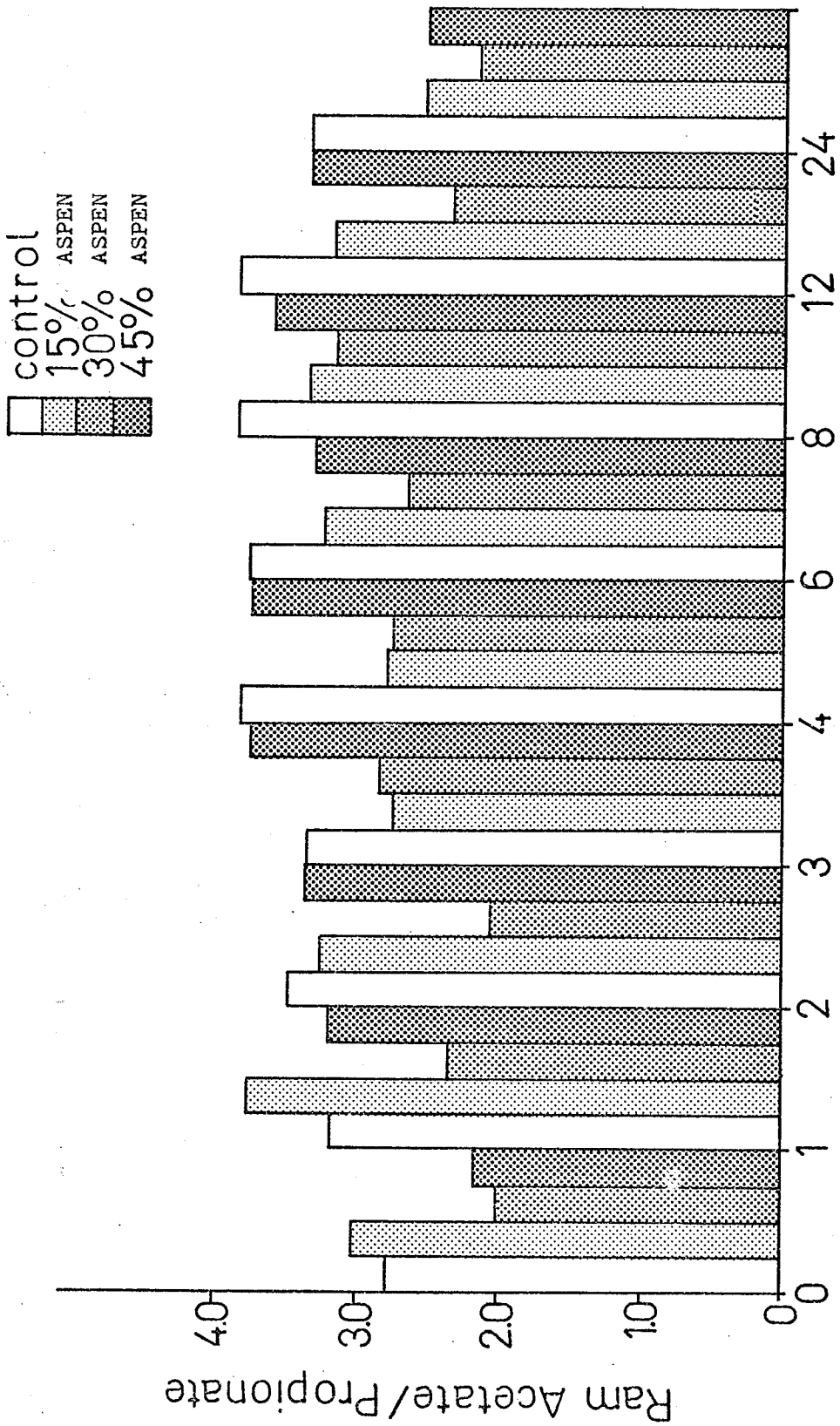

Figure 7. The effect of dietary aspen on the ram acetate/propionate ratio.

between the 15% and 30% treatments while at the 12 hour sampling time the 30% and control treatments were found significantly ($P \leq 0.05$) different. Although other significant ($P \leq 0.05$) differences were not observed, the 30% diet effected a large response in this ratio throughout the sampling period.

Figure 8 illustrates energy and nitrogen release of the 4 experimental treatments. Relative to one another, the ratio of available energy to available nitrogen among treatments differed greatly.

The effects of the experimental diets on blood glucose, (BG), blood urea nitrogen (BUN), serum ammonia and the BG/BUN ratios as shown in figures 9 to 12 respectively (Appendices 12 to 15). Significant ($P \leq 0.05$) differences in BG levels were determined at 3 and 4 hours post-feeding. At the 3 hour sample time, the 45% diet depressed BG levels relative to the 3 other experimental diets. At the 4 hour sample time, the 30% wood-fed animals exhibited lowered BG levels relative to the control-fed animals. For all treatments, peaks in BG levels were noted at 4 and 12 hours post-feeding, (Figure 9) (Appendix 12).

The 45% treatment significantly ($P \leq 0.05$) elevated BUN levels over the control and 15% treatments at 6 hours post-feeding. At the 8 and 12 hour sampling times BUN levels for both the 30% and 45% wood-fed animals were significantly ($P \leq 0.05$) higher than the control-fed and 15% wood-fed animals (Figure 10) (Appendix 13). For all

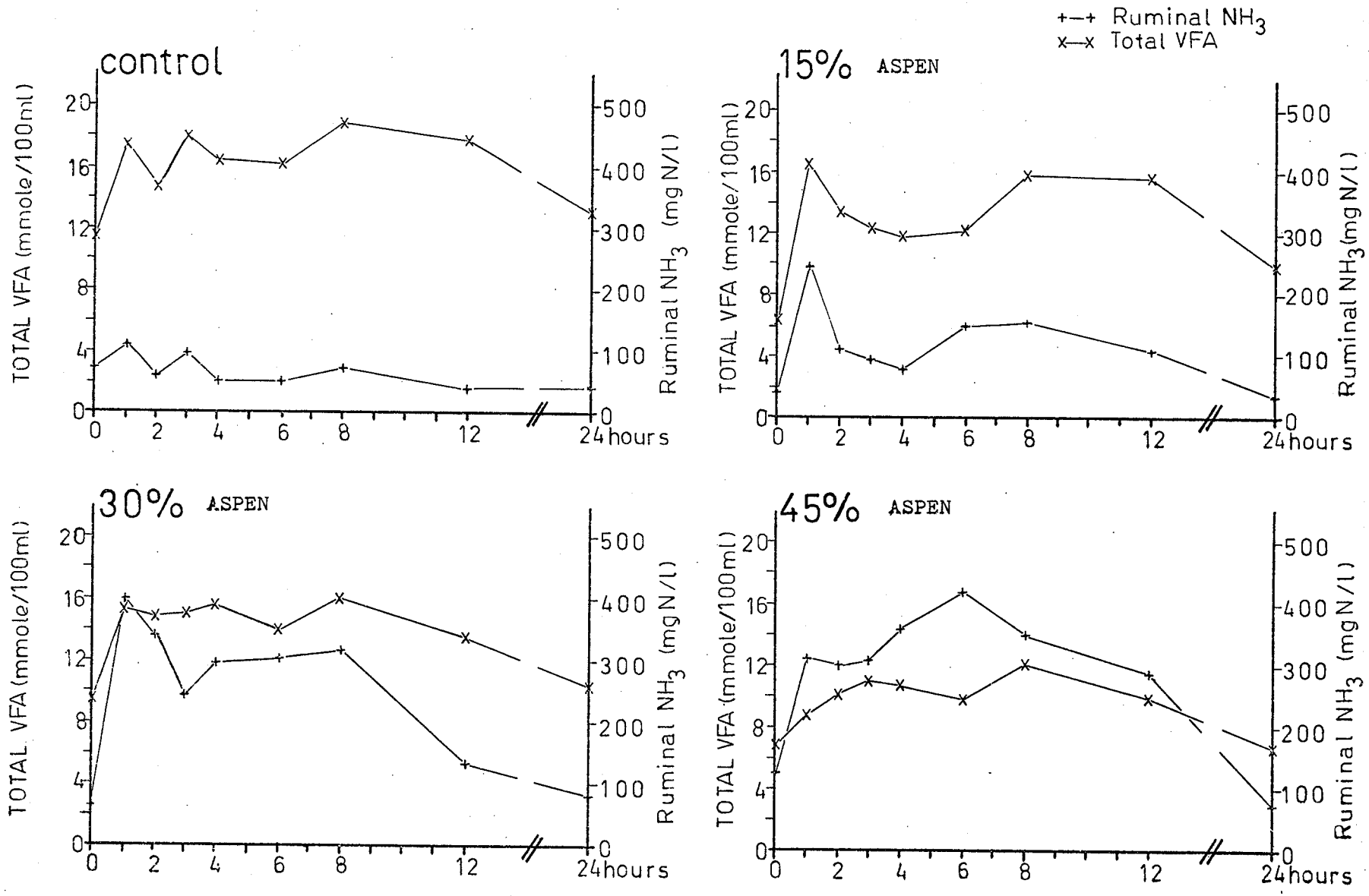

Figure 8. The effect of dietary aspen on the total VFA and ruminal ammonia levels of the rams.

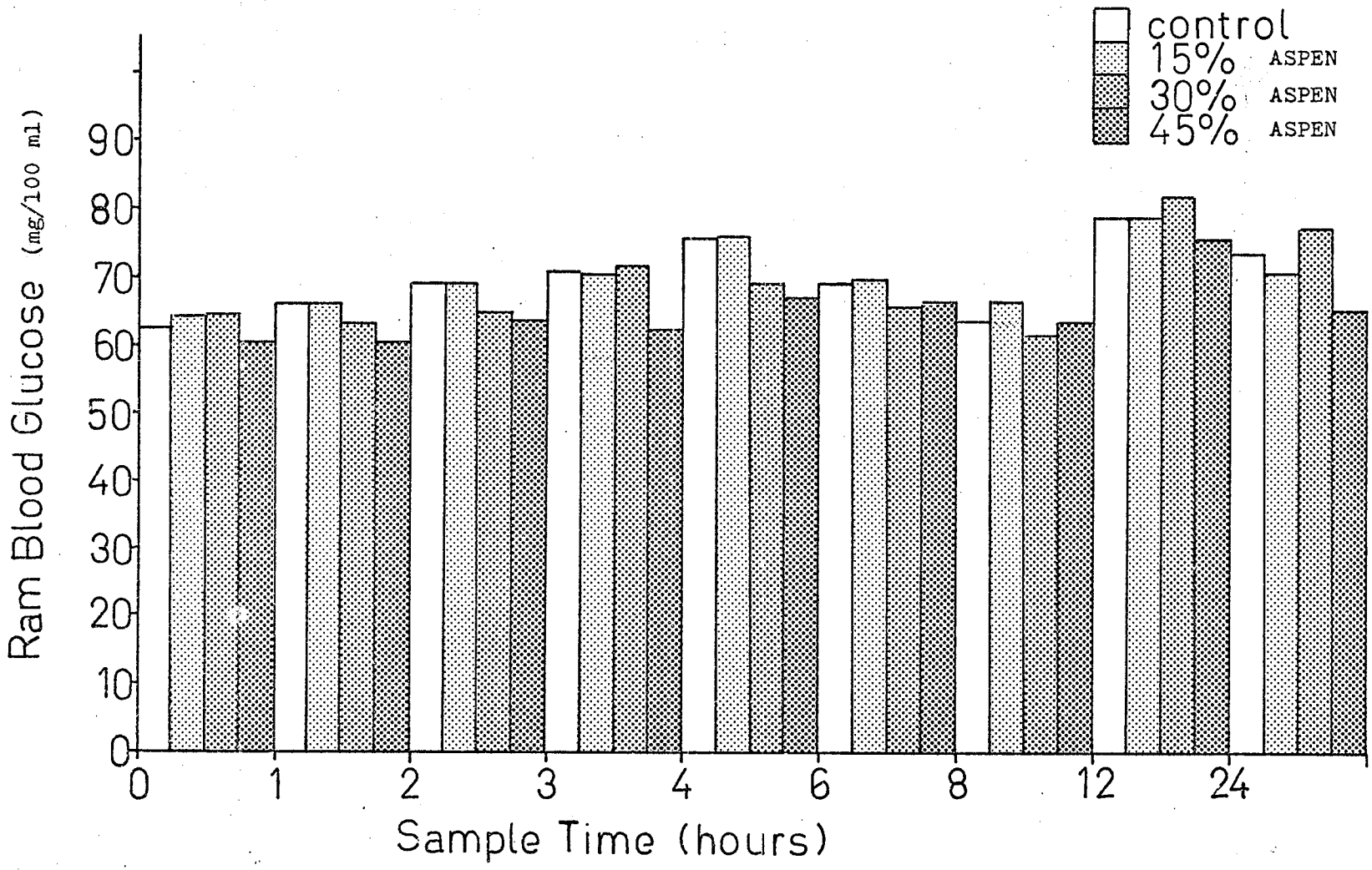

Figure 9. The effect of dietary aspen on ram blood glucose levels.

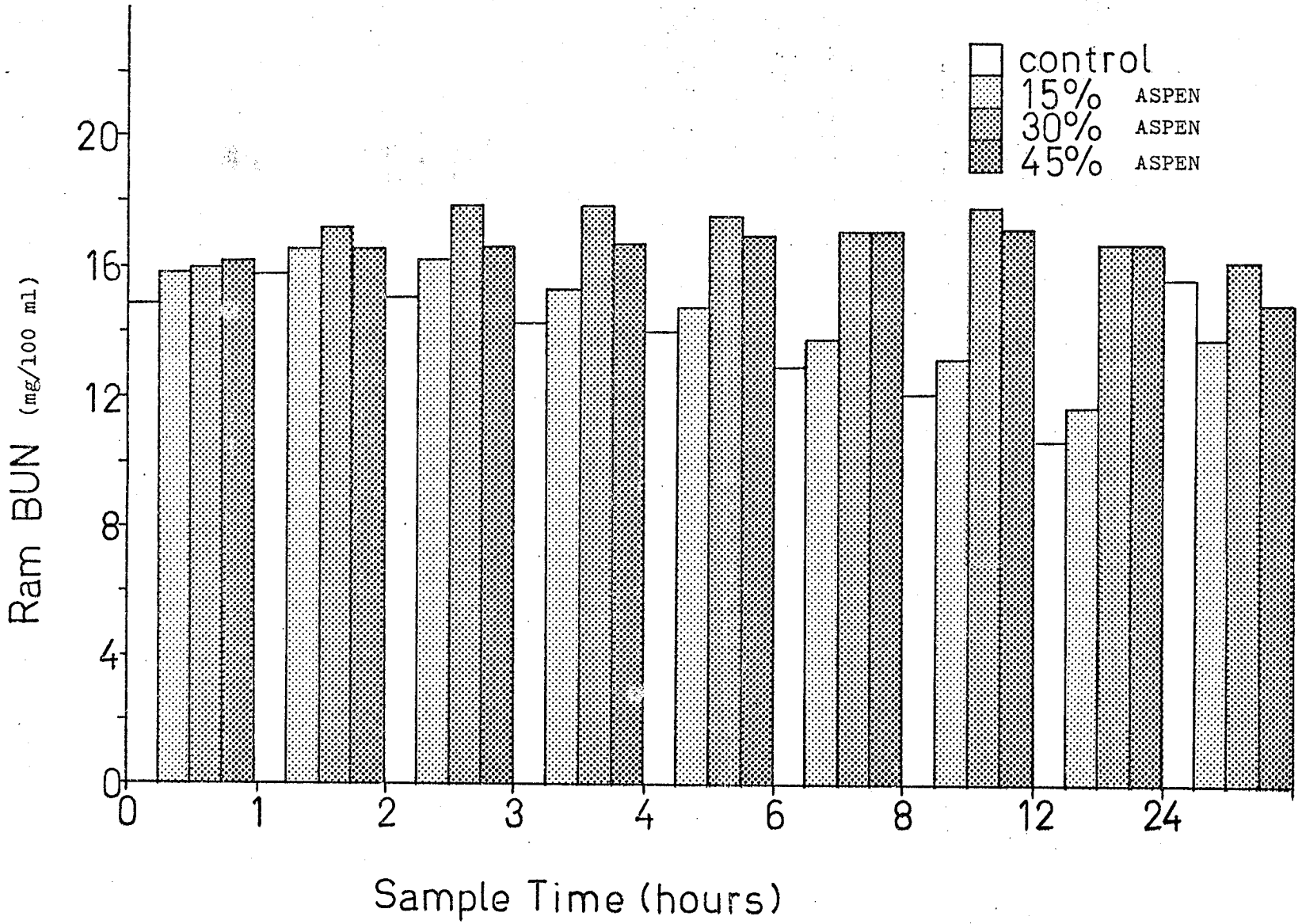

Figure 10. The effect of dietary aspen on ram blood urea nitrogen levels.

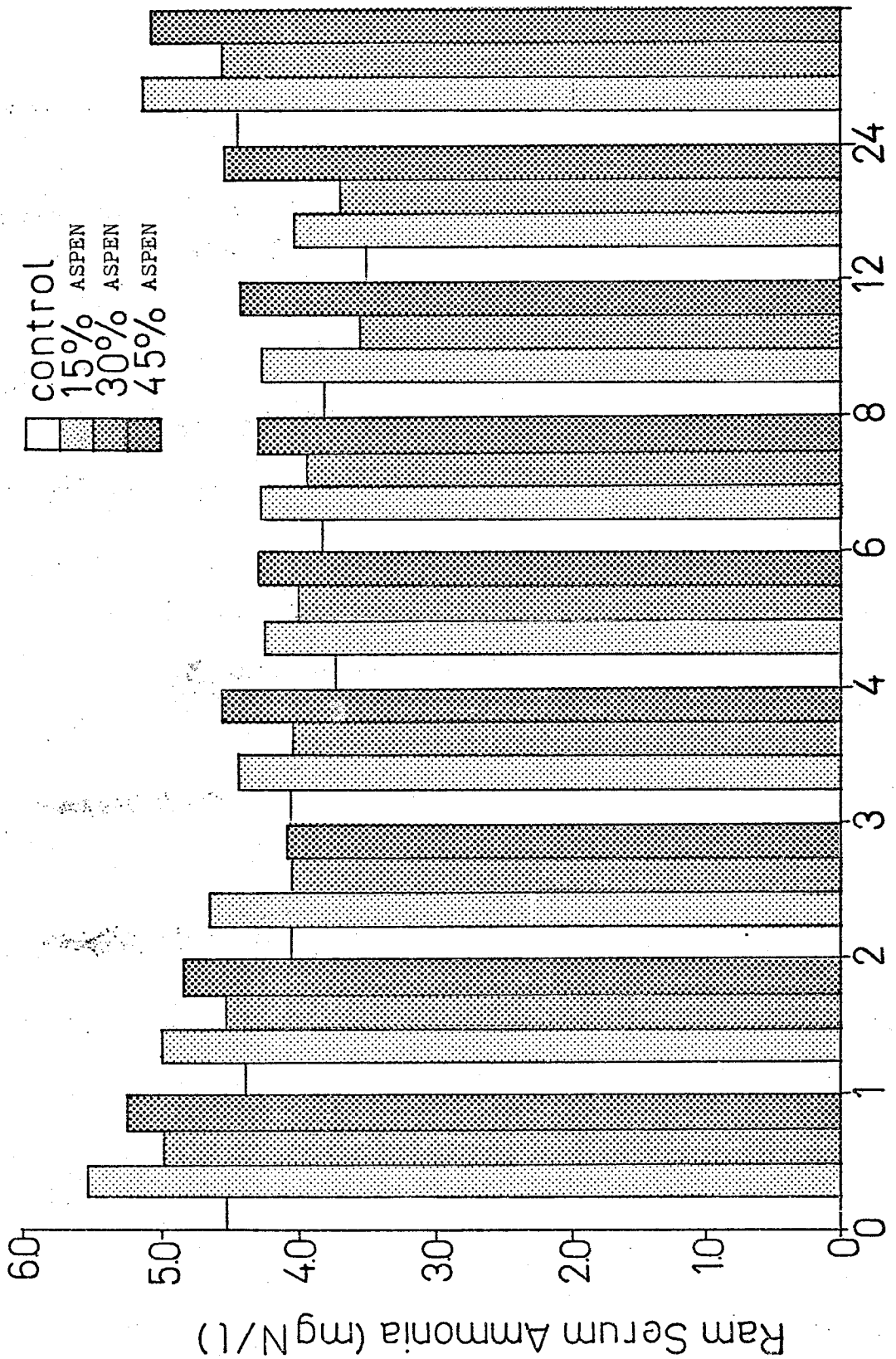

Figure 11. The effect of dietary aspen on ram serum ammonia levels.

treatments, BUN levels were elevated within 1 to 2 hours post-feeding after which those of the 30% and 45% treatments fell rapidly.

At the 0, 6 and 12 hour sampling times significant ($P \leq 0.05$) difference in serum ammonia among the four treatments were noted (Figure 11) (Appendix 14). At the 0 hour sample time, the 15% and 45% wood-fed animals exhibited higher serum ammonia levels relative to the control diet. At 6 hours post-feeding, the 15% and 45% diets elevated serum ammonia levels over the control diet as well as the 30% diet. At the 12 hour sampling time serum ammonia levels of the 45% wood-fed animals were elevated over the control-fed and 30% wood-fed animals. Also, a significant ($P \leq 0.05$) difference between the 15% and control rations was detected.

The effect of the 4 experimental diets on the BG/BUN ratio is shown in Figure 12 (Appendix 15). The 30% diet had the largest effect on this ratio. At 4, 6 and 8 hour sampling times, the 30% diet significantly ($P \leq 0.05$) lowered this ratio relative to the control and 15% diets. Although other differences were apparent, they did not reach significance ($P \leq 0.05$).

Steer Growth Trial

A summary of the steer growth trial is presented in Table 8. No significant ($P \leq 0.05$) differences were found in the average daily gains (ADG) among treatments.

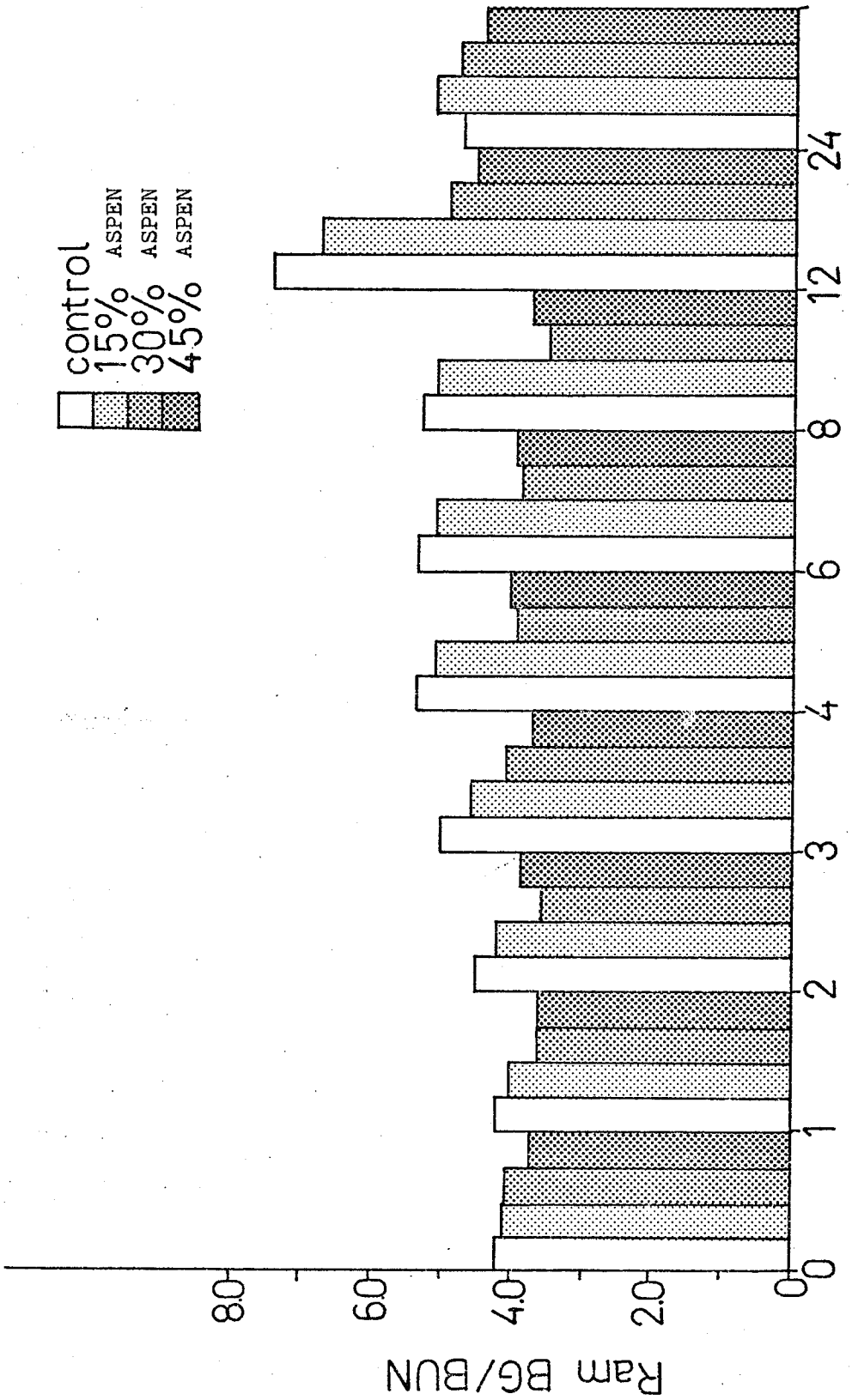

Figure 12. The effect of dietary aspen on the ram BG/BUN ratio.

Table 8. The performance of feedlot steers consuming 0, 15 and 30% treated aspen[1]

Treatment	Body weight				DM feed intake		
	Initial (kg)	Final (kg)	Gain (kg)	ADG[3] (kg)	Total (kg/day)	Grain	Feed/gain[3]
Control	246.2	393.6	147.4	1.06±.01	6.28	0.82	5.92±.25[a2]
15% Aspen	246.8	394.6	148.8	1.07±.02	7.04	0.46	6.57±.13[ab]
30% Aspen	246.6	391.4	144.8	1.04±.10	7.14	0.47	6.86±.25[b]

[1]All values are means of 12 observations ± standard error.

[2]Values with different superscripts within the same column are significantly different ($P \leq 0.05$).

[3]These values are expressed ± their standard error.

Although dietary wood appeared to stimulate feed intake, the apparent increase was not significant ($P \leq 0.05$).

The feed/gain ratio of the wood-fed steers was elevated relative to the control-fed steers. The 30% treatment significantly ($P \leq 0.05$) increased the feed/gain ratio compared to the control treatment (Table 8).

The presence of wood in the steers' diets did not affect ruminal pH levels, however, ruminal ammonia levels were lowered considerably by the 2 wood-containing diets relative to the control diet (Table 9).

The blood glucose levels of the wood-fed steers fell slightly relative to the control-fed steers. The BUN levels of the wood-fed steers rose steadily as the level of dietary wood increased. Consequently, the BG/BUN ratio of the wood-fed steers fell sharply relative to the control-fed steers (Table 9).

The plasma ammonia levels of the 15% wood-fed steers were slightly higher than the ammonia levels of the control-fed and 30% wood-fed steers (Table 9).

Steer ruminal VFA data are presented in Table 10. The 15% wood diet appeared to stimulate total VFA, acetic, propionic, isobutyric and butyric acid production relative to the control and 30% diets. The dietary wood did not affect valeric and isovaleric acid levels or the acetate to propionate ratio of the steers greatly.

Table 9. The effect of dietary aspen on steer blood and rumen metabolite levels

Treatment	Ruminal pH[1] levels	Ruminal[2] ammonia levels (mg N/l)	Blood[1] glucose (mg/100 ml)	BUN[1] (mg/100 ml)	BG/BUN[1]	Plasma[1] ammonia levels (mg N/l)
Control	7.17±0.18	103.3±50.7	110.7±13.8	9.42±2.46	11.75±5.30	3.42±.63
15% Aspen	7.02±0.27	51.8±27.5	97.8±10.9	13.15±2.40	7.44±1.88	3.98±.75
30% Aspen	7.22±0.10	57.2±34.3	100.7±25.1	15.36±2.71	6.55±1.61	3.28±.52

[1]All values are means of 6 observations ± standard error.

[2]All values are means of 4 observations ± standard error.

Table 10. The effect of dietary aspen on steer ruminal VFA levels[1] (mm/100 ml)

VFA	Experimental steer diets		
	Control	15% Aspen	30% Aspen
Acetic	5.50 ±1.70	6.02 ±1.93	5.47 ±1.63
Propionic	1.33 ± .44	1.54 ± .44	1.35 ±0.38
Isobutyric	0.048±.009	0.105±.094	0.058±.021
Butyric	1.22 ±.50	1.77 ±1.04	1.24 ±.52
Isovaleric	0.137±.054	0.101±.040	.103±.051
Valeric	0.095±.028	0.104±.031	0.078±.026
Total	8.33 ±2.64	9.64 ±3.17	8.30 ±2.56
Acetate/propionate	4.14 ±0.49	3.91 ±0.50	4.50 ±0.36

[1]All values are means of 6 observations ± standard error.

DISCUSSION

Nutrient Intake and Digestibility

The data presented in this study suggest that the processed wood product was inferior as an energy source compared to alfalfa hay or corn silage.

The wood fibre appeared to lower dry matter intake per $(kg\ BW)^{0.75}$ of the 15% and 45% wood fed rams, however, it did not greatly affect the ram intake of the 30% diet compared to the control diet. Although a large amount of variability was evident, the differences noted were not significant ($P \leq 0.05$) and were due to animal, period and error effects rather than a treatment effect.

Gross energy and crude protein intake per $(kg\ BW)^{0.75}$ paralleled dry matter intake per $(kg\ BW)^{0.75}$ as the diets were isonitrogenous and fairly isocaloric. However, as the crude fibre content of the 4 diets increased with the level of wood incorporated, crude fibre intake per $(kg\ BW)^{0.75}$ was elevated per unit of dry matter intake. These results support the work of Kamstra *et al.* (1976) and Mellenberger *et al.* (1971). The lowered values for both dry matter digestibility and gross energy digestibility are indicative of the quality of the wood product relative to alfalfa hay.

The pressure-steam treatment is limited in its effect of increasing the availability of the wood fibre. It likely increases the "fibre-saturation-point" (FSP) of

the product through rupture of cross-linkages between carbohydrate chains, however, other factors limiting cellulose and hemicellulose availability, such as their physical and chemical association with lignin, would not be affected by this treatment, (Tarkow and Feist 1969).

The elevation in the FSP increases the "swelling-capacity" of the product allowing greater enzymatic and microbial penetration of the wood fibre. This effect provides for a more efficient utilization of the wood fibre,(Tarkow and Feist 1969).

It is difficult to explain the variability noted in the crude fibre digestibility (CFD) among treatments. It is unlikely that the wood fibre differed from alfalfa fibre so drastically that a different microbial population was required for fibre degradation. As the primary difference between the experimental diets was their energy availability, diets with similar CFD would be expected to display similar values of GED. Since the GED of the experimental diets fell as the level of dietary wood increased, the actual CFD values should have also decreased. As this trend was not evident in the CFD of the experimental diets, these values are difficult to explain.

The wood product, containing less than 1% crude protein, contributed very little to the crude protein content of the experimental diets. The crude protein digestibility (CPD) of the experimental diets would not

be influenced by dietary wood unless it interfered with the utilization of other protein sources present. As significant ($P \leq 0.05$) differences in CPD among treatments were not observed, the dietary wood did not interfere with nitrogen digestibility of the experimental diets.

Energy Utilization of the Wood Product

Church (1969) and Clarke and Dyer (1973) have stated that measurement of ruminal VFA production is an accurate estimate of the energy availability of a feedstuff to ruminal microorganisms. The VFA data collected in this study support the GED data, i.e. high levels of dietary wood lowered total VFA production. This response was exhibited as an inhibition of propionic, butyric, and to a lesser extent, acetic, isobutyric and valeric acid production. Clarke and Dyer (1973) obtained similar results in a finishing steer trial feeding unprocessed Douglas Fir sawdust at a level of 70% of the total dry matter of the diet. In another study, Drevjany et al. (1976) reported that the inclusion of a pressure-treated aspen product in growing steer diets had little effect on acetic or propionic acid production to levels of 80% dietary wood inclusion. In both of these trials, however, the dietary composition differed greatly from the dietary composition of the diets formulated for this study.

In Clarke and Dyer's (1973) study, the Douglas Fir replaced barley to levels of 70% of the total dry matter.

This would result in large differences in digestible energy between the control and wood-containing diets, thus influencing VFA production. In Drevjany et al.'s (1976) study, the level of molasses increased as the level of dietary wood increased, thus compensating for the lower energy availability from the dietary wood component. Consequently, VFA production was not adversely affected by the inclusion of wood in these diets.

The VFA production data would suggest that the wood product was an inferior energy source to alfalfa hay. The depression in VFA production occurred within the first 4 hours post-feeding, suggesting that an extended fermentation period was required for near-equivalent energy release from the wood fibre as compared to the alfalfa fibre.

The lowered acetate/propionate ratios of the wood-fed rams in this study are not in agreement with the results of Drevjany et al. (1976). These authors suggested that the wood product had little effect on the acetate/propionate ratio to levels of 80% dietary wood inclusion.

The 30% wood-fed rams exhibited higher VFA levels relative to the 15% and 45% wood-fed rams. Also, the 15% wood-fed steers demonstrated elevated VFA production compared to the control-fed and 30% wood-fed steers.

Similar responses in VFA production were noted by Drevjany et al. who reported optimal VFA production in

steers consuming 20% dietary wood. Although this would appear to be strong evidence in support of the present study, their results are based on only two observations per treatment and the use of their data as supportive material must be applied with caution. It appears that the VFA response to dietary wood is not a simple function of the level of dietary wood incorporation but that other regulatory factors must be involved.

On discussing the beneficial aspects of dietary wood incorporation, Kitts et al. (1969) suggested that the "beneficial effects of incorporation of sawdust in beef cattle rations was possibly due to the fibre stimulating rumination and supporting a more sustained rumen fermentation thereby resulting in more efficient use of other digestible fractions". With increased rumination, saliva flow would be elevated, increasing the buffering capacity of the rumen. Perhaps this effect is maximized at or near the 30% level of dietary wood incorporation in rams, thus accounting for the elevation in VFA production with this treatment group.

Energy release may also be indicated indirectly through measurement of blood glucose (BG) levels. Little glucose is absorbed from the gastro-intestinal tract, instead, it is synthesized via gluconeogenic pathways from other energy and amino acid sources, (Church 1969). Generally, the wood-fed rams and steers exhibited lowered

BG values relative to the control-fed animals which was similar to and supported the GED and VFA data. Many factors influence BG levels and it is therefore difficult to attribute a change to the diet. The dietary wood component may have been partly responsible for the differences noted among treatments, however, other factors such as stress may have been involved.

The Effect of the Wood-containing Diets on Nitrogen Metabolism

A characteristic response of a ruminant to dietary wood is one of increased nitrogen (N) excretion (Pfander et al. 1969). A decline in N retention indicates nitrogen is being wasted by the organism. N wastage occurs if insufficient energy is available to ruminal microorganisms to provide carbon skeletons and energy for amination reactions. N is converted to ammonia within the rumen and is lost to the circulatory system via the rumen epithelium if not incorporated into bacterial protein (Church 1969).

The major factor contributing to the lowered N-retention of the wood-fed rams was the high urea content of the wood-containing diets. The urea was rapidly degraded in the rumen to ammonia and required a rapidly fermenting energy source to incorporate the released ammonia into bacterial protein. As the ram control diet contained only plant protein sources, ammonia was probably

released more slowly and thus, more efficiently converted into bacterial protein.

The dietary wood fibre was partly responsible for the lowered N retention noted for the wood-fed rams. As demonstrated by the GED and VFA data, the wood product was unable to supply as much energy to the microbial population for protein synthesis, thus further contributing to N waste.

The elevated blood ammonia levels of the wood-fed rams are indicative of N waste. Higher blood ammonia levels of the steers were not noted as their ruminal ammonia levels did not parallel the ram ruminal ammonia levels.

Urea is synthesized in the liver from ammonia and other nitrogenous compounds and, once released to the circulatory system, is measured as blood urea nitrogen (BUN) (Drevjany et al. 1976). Following synthesis it is usually excreted by the kidneys although it may re-enter the rumen via the saliva or the rumen epithelium, (Phillis 1970). Elevated BUN levels, like ammonia levels, indicate an inefficient utilization of N by the ruminal microorganisms. The elevated BUN levels of the wood-fed rams and the 30% wood-fed steers indicate that the wood-containing diets contributed to N waste. The 15% level of dietary wood did not appear to affect steer BUN levels.

Little effect on N retention was noted beyond the 15% level of wood incorporation. This supports the belief that the N source was largely responsible for the lowered N retention of the wood-fed animals. The 15% diet contained 0.9% urea and the 30% and 45% diets contained 1.5% urea. If higher levels of soybean meal or other conventional protein sources had been substituted for urea, this effect may not have been as noticeable.

A more accurate "picture" of energy availability to nitrogen availability may be observed on examination of the BG/BUN ratio. In both the ram and steer trials, lowered BG/BUN levels were noted for the wood-fed animals. Drevjany et al. (1976) observed similar effects on this ratio as the level of dietary wood was increased. An unfavourable BG/BUN ratio indicates that an imbalance between the ratio of available energy to available nitrogen exists, however, the consequence of an imbalance is difficult to assess (Drevjany et al. 1976).

Steer Feedlot Performance

The dietary wood had little effect on the weight gains of the experimental steers. These results support two similar studies (Drevjany et al. 1976 and Kitts et al. 1969) which evaluated average daily gains as a performance characteristic.

Feed intake increased as the proportion of dietary wood was increased. This response is in agreement with similar studies conducted by Drevjany et al. (1976), Albin (1976) and Kamstra et al. (1976). The palatability of the wood product may account for this response as the steam-pressure treatment carmelizes various carbohydrates giving the product a molasses odour. This may have encouraged the wood-fed steers to consume higher quantities of their feed allotment.

The smaller particle size of the wood product compared to the corn silage could account for the elevated feed intake of the wood-fed steers. Less time may be required to break the wood fibre down sufficiently to allow passage through the gastro-intestinal tract.

The lowered feed/gain ratio of the wood-fed steers relative to the control-fed steers is in agreement with Albin (1976) who fed hydrolyzed hardwood sawdust and Kamstra et al. (1976) who fed untreated aspen chips to steers. In this study the differences in feed/gain may not be due entirely to the energy availability of the wood product. The control-fed steers received more grain supplement per head per day (0.82 kg) than the wood-fed steers (0.46 kg) throughout the growth trial, and were thus placed at an immediate advantage.

SUMMARY

Two experiments were conducted to investigate the effect of dietary pressure-treated aspen on the performance characteristics and physiological responses of ruminants.

In the first experiment, four rumen-fistulated mature rams were randomly assigned to one of four dietary levels of aspen replacing alfalfa on a dry matter basis (0%, 15%, 30% or 45%) in a 4x4 Latin-square design and allowed 14 days to adapt to their new diets. This adaptation period was followed by a 5 day total collection period and a 24 hour blood and rumen sampling period. Blood samples for blood ammonia, urea nitrogen and glucose determination were taken from the jugular vein and rumen samples for ruminal pH, ammonia and VFA production were taken via the rumen fistulae over the 24 hour sampling period. All animals received their respective diets (90% ad libitum) throughout the collection and sampling periods at one feeding each morning.

After completion of each period of the 4x4 Latin-square the rams were assigned a new diet and allowed 14 days adaptation.

Dry matter, gross energy, crude protein, and crude fibre digestibilities as well as nitrogen retention of the four treatments were determined.

Dry matter, gross energy, crude protein and crude fibre intake per $(kg\ BW)^{0.75}$ were not significantly

($P \leq 0.05$) affected by any of the wood-containing diets.

Dietary wood significantly ($P \leq 0.05$) lowered both dry matter and gross energy digestibilities, but had no effect on crude protein and crude fibre digestibilities ($P \leq 0.05$). Dry matter and gross energy digestibility regression equations are shown below:

$$DMD = 73.84 - 0.463\ x + 0.0061\ x^2$$

$$GED = 72.68 - 0.540\ x + 0.0071\ x^2$$

where x = percent dry matter aspen in the diet.

Although the presence of urea in the wood-containing diets appeared to lower nitrogen retention of the respective diets, the differences observed were not significant ($P \leq 0.05$).

Dietary wood, being lower in available energy than alfalfa, significantly ($P \leq 0.05$) lowered blood glucose (BG) levels as well as total VFA production measured as propionic, butyric and isobutyric acid production. The wood-containing diets had little effect on acetic, valeric and isovaleric acid production, or the acetate to propionate ratio.

The urea-nitrogen source of the wood-containing diets was rapidly converted to ammonia in the rumen and caused an increase in ruminal ammonia levels relative to the control diet. Consequently, serum ammonia and BUN levels were significantly ($P \leq 0.05$) elevated during the

24 hour sampling period. The wood-containing diets significantly ($P \leq 0.05$) elevated the BG/BUN ratio, however, this was more a urea-nitrogen effect than a wood-fibre effect.

The wood-containing diets did not affect the water consumption or the ruminal pH of the rams.

In the second experiment, 36 young steers averaging 246 kg in weight were randomly assigned to one of three dietary levels of processed aspen replacing corn silage on a dry matter basis (0%, 15% or 30%). The three rations were isonitrogenous. Feed, water and minerals were offered free choice over the 139 day growth trial.

Throughout the trial, feed intake (FI), average daily gains (ADG), feed/gain and animal health were followed closely. ADG and FI were not significantly ($P \leq 0.05$) influenced by the addition of wood to the steers' diet. The feed/gain ratio was significantly ($P \leq 0.05$) increased by the 30% level of dietary wood incorporation over the control ration. Throughout the trial animal health was excellent.

Although the 15% wood diet stimulated VFA production of the steers, neither of the wood rations had an effect on ruminal pH. BG and BUN levels of the wood fed steers were elevated over the control fed steers. Similar to the ram data, large differences in the BG/BUN ratio were noted between the wood fed and the control fed steers.

Overall, the wood product had a limited negative effect on the performance and physiological characteristics of ruminants. Although it did appear to have a lower energy availability compared to alfalfa hay or corn silage, a lower price would compensate for this difference.

Additional research is required in other areas before large scale utilization of this product would be possible. Studies to determine the effect of dietary wood on milk production, butterfat test, calving rate, and its use in larger scale commercial feedlot operations would be desirable. Also, the optimal level of dietary wood incorporation, with respect to optimal utilization, should be determined.

Feasibility studies evaluating tree harvesting, sawdust processing, marketing and transportation costs would be necessary before this product could be utilized on a larger scale.

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LIST OF APPENDICES

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Appendix 1. Reference formula for calculation of digestibility, % N retained and % N retained per $(kg\ BW)^{0.75}$

a) $$\% \text{ digestibility} = \left(\frac{\text{intake - fecal output}}{\text{intake}} \right) 100$$

b) $$\% \text{ nitrogen retained} = \left(\frac{\text{N intake - (urinary N + fecal N)}}{\text{N intake}} \right) 100$$

c) $$\% \text{ nitrogen retained per } (kg\ BW)^{0.75} = \left(\frac{\% \text{ N retained}}{(kg\ BW)^{0.75}} \right)$$

Appendix 2. The effect of dietary aspen on ram ruminal pH[1]

Sample time (hrs. post-feeding)	Experimental ram treatments				
	Control	15% Aspen	30% Aspen	45% Aspen	$S_{\bar{x}}$
0	6.23±0.51	6.61±0.60	6.09±0.36	6.36±0.18	.10
1	5.66±0.33	6.18±0.39	5.66±0.32	5.89±0.23	.11
2	5.58±0.30	5.92±0.28	5.85±0.27	5.74±0.31	.13
3	5.69±0.23	5.72±0.25	5.87±0.32	5.68±0.28	.15
4	5.66±0.20	5.72±0.33	5.84±0.31	5.65±0.28	.15
6	5.90±0.46	5.79±0.26	5.82±0.36	5.54±0.28	.15
8	5.57±0.32	5.52±0.27	5.63±0.25	5.47±0.27	.11
12	5.57±0.31	5.70±0.37	5.71±0.47	5.57±0.47	.08
24	6.50±0.62	6.58±0.33	6.35±0.59	6.23±0.49	.11
$\bar{x}$	5.73±0.30	5.88±0.33	5.89±0.32	6.00±0.22	.09

[1]All values are means of 4 observations ± standard error.

Appendix 3. The effect of dietary aspen on ram ruminal ammonia levels[1] (mg N/l)

Sample time (hrs. post-feeding)	Experimental ram treatments				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	76.5±56.9	44.2±15.7	70.5±13.0	127.2±29.0	17.5
1	114.7±57.2^{a2}	284.4±33.9^{b}	397.3±97.5^{b}	322.6±42.8	35.0
2	68.4±47.7^{a}	115.6±53.6^{a}	339.2±102.4^{b}	306.9±51.0^{b}	32.4
3	98.8±49.6^{a}	98.1±32.0^{a}	242.2±61.2^{b}	326.3±112.5^{b}	32.8
4	53.3±27.0^{ca}	78.2±38.9^{a}	294.7±175.7^{cb}	361.3±92.6^{b}	56.3
6	52.4±25.1^{a}	150.9±72.1^{a}	302.5±95.7^{b}	420.7±85.0^{b}	36.7
8	73.3±46.4^{a}	155.5±42.8^{a}	320.4±134.9^{b}	356.0±123.4^{b}	42.4
12	39.1±11.3^{a}	112.2±43.6^{a}	134.9±121.7^{a}	288.1±67.9^{b}	36.9
24	45.3±11.3	37.0±24.0	83.2±32.8	82.9±18.8	15.0
$\bar{x}$	69.08±20.8^{a}	115.56±16.9^{a}	245.6±51.2^{b}	290.8±32.0^{b}	16.1

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 4. The effect of dietary aspen on total ruminal VFA production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	11.60±4.58[a2]	6.57±3.76[b]	9.62±2.70[ab]	6.91±2.14[b]	2.38
1	17.73±7.76[a]	16.51±3.74[a]	15.54±3.02[a]	8.73±2.14[b]	4.03
2	14.71±6.56	13.49±2.74	14.85±3.51	9.09±3.15	2.70
3	18.04±5.80	12.30±3.08	14.91±2.81	11.31±2.78	3.01
4	16.65±3.89[a]	12.02±1.42[b]	15.69±1.31[a]	10.83±1.53[b]	2.81
6	16.35±6.66	12.28±1.93	14.06±2.52	9.93±1.69	2.72
8	18.72±6.95	15.95±3.57	16.06±2.32	12.11±3.13	2.72
12	17.90±7.52[a]	15.77±3.82[ab]	13.70±1.75[ab]	9.98±1.81[b]	3.37
24	13.22±5.74	9.82±4.88	10.24±1.86	6.89±2.02	2.59
$\bar{x}$	16.10±2.43	12.75±3.20	13.85±2.35	9.53±1.82	2.73

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 5. The effect of dietary aspen on ruminal acetic acid production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	5.96±2.00	3.61±3.21	5.14±1.93	3.92±1.05	1.09
1	10.26±2.06	10.94±3.29	9.19±2.05	5.77±2.03	2.30
2	8.87±3.86	8.19±4.11	8.96±2.86	6.02±1.95	1.37
3	10.54±4.01	6.74±2.86	9.05±2.75	7.64±2.07	1.66
4	9.96±3.92	6.72±2.75	9.50±2.69	7.42±2.05	1.57
6	10.15±3.90	7.43±3.22	8.53±2.56	6.55±1.98	1.55
8	11.74±3.46	9.65±3.23	9.81±3.01	8.17±1.83	1.46
12	11.33±3.56	8.93±1.95	7.35±3.92	6.43±1.56	2.14
24	7.15±2.09	5.35±2.67	5.24±2.37	4.04±1.61	1.28
$\bar{x}$	9.55±1.91	7.51±2.23	8.09±1.78	6.22±1.49	1.38

[1]All values are means of 4 observations ± standard error.

Appendix 6. The effect of dietary aspen on ruminal propionic acid production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S_{\bar{x}}$
0	2.13±.32[a2]	1.19±.16[b]	2.56±.20[a]	1.82±.18[ab]	.58
1	3.23±.28[a]	2.91±.17[a]	3.91±.21[a]	1.81±.26[b]	.60
2	2.57±.41	2.53±.31	3.32±.36	1.81±.27	.67
3	3.16±.62	2.47±.24	3.18±.28	2.05±.26	.65
4	2.60±.32[ab]	2.39±.21[ab]	3.46±.22[a]	2.00±.19[b]	.43
6	2.70±.41	2.32±.20	3.21±.31	1.90±.19	.77
8	3.04±.48	2.87±.32	3.11±.41	2.27±.19	.86
12	2.95±.32	2.82±.14	3.10±.61	1.92±.21	.65
24	2.13±.33	2.10±.40	2.44±.30	1.60±.19	.43
$\bar{x}$	2.72±.48	2.40±.53	3.14±.20	1.91±.19	.52

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 7. The effect of dietary aspen on ruminal isobutyric acid production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	0.17±.02[a2]	0.10±.02[b]	0.12±.04[b]	0.08±.02[c]	0.04
1	0.12±.04	0.10±.04	0.10±.02	0.10±.02	0.06
2	0.14±.04	0.08±.05	0.15±.02	0.07±.01	0.07
3	0.19±.05	0.16±.03	0.15±.05	0.08±.02	0.07
4	0.14±.03[a]	0.09±.03[b]	0.11±.03[a]	0.06±.01[b]	0.04
6	0.12±.03	0.10±.03	0.09±.04	0.07±.01	0.05
8	0.14±.07	0.08±.03	0.09±.05	0.08±.02	0.12
12	0.13±.03	0.10±.04	0.08±.01	0.06±.01	0.13
24	0.14±.04	0.12±.03	0.11±.02	0.09±.02	0.06
$\bar{x}$	0.14±.03	0.10±.02	0.11±.03	0.08±.01	0.05

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 8. The effect of dietary aspen on ruminal butyric acid production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	2.85±.31[a2]	1.30±.29[b]	1.42±.18[b]	0.88±.19[b]	0.86
1	3.70±.32[a]	2.07±.29[ab]	1.85±.19[ab]	0.86±.18[b]	0.91
2	2.74±.29[a]	2.23±.21[a]	1.81±.19[ab]	0.99±.21[b]	0.93
3	3.64±.31	2.43±.37	1.93±.19	1.22±.22	1.23
4	3.51±.18[a]	2.40±.35[ab]	2.18±.18[ab]	1.13±.22[b]	.86
6	2.97±.37	2.04±.42	1.75±.36	1.19±.21	.73
8	3.43±.42	3.01±.68	2.45±.31	1.45±.22	.74
12	3.09±.36	3.57±.43	2.64±.42	1.36±.17	.74
24	3.20±.18	1.80±.54	2.13±.37	0.94±.18	.74
$\bar{x}$	3.24±.52	2.32±0.66	2.02±.37	1.11±.21	.81

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 9. The effect of dietary aspen on ruminal isovaleric acid production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	0.21±.06	0.09±.02	0.09±.03	0.08±.02	0.06
1	0.09±.03	0.05±.01	0.12±.02	0.09±.03	0.05
2	0.11±.04	0.07±.01	0.08±.03	0.07±.03	0.04
3	0.12±.04	0.12±.02	0.14±.04	0.09±.03	0.07
4	0.11±.04	0.11±.03	0.04±.02	0.10±.02	0.05
6	0.09±.03	0.07±.02	0.11±.02	0.07±.02	0.03
8	0.07±.02	0.02±.01	0.10±.03	0.06±.02	0.07
12	0.07±.01	0.02±.01	0.07±.03	0.08±.03	0.06
24	0.22±.03	0.09±.01	0.10±.02	0.10±.04	0.02
$\bar{x}$	0.12±.03	0.07±.04	0.09±.03	0.08±.01	0.03

[1]All values are means of 4 observations ± standard error.

Appendix 10. The effect of dietary aspen on ruminal valeric acid production in rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	0.28±.06	0.28±.07	0.29±.14	0.13±.06	.08
1	0.33±.03	0.44±.07	0.37±.09	0.10±.05	.04
2	0.28±.06	0.39±.01	0.54±.08	0.13±.04	.05
3	0.39±.11	0.38±.11	0.46±.11	0.23±.05	.06
4	0.33±.12	0.31±.09	0.40±.10	0.12±.04	.06
6	0.32±.06	0.31±.12	0.37±.10	0.15±.03	.07
8	0.30±.03	0.32±.14	0.50±.09	0.08±.03	.06
12	0.33±.06	0.33±.09	0.46±.09	0.13±.04	.05
24	0.38±.11	0.36±.08	0.22±.10	0.12±.05	.04
$\bar{x}$	0.33±.04	0.35±.05	0.40±.10	0.13±.04	.06

[1]All values are means of 4 observations ± standard error.

Appendix 11. The effect of dietary aspen on the ruminal acetate/propionate ratio of rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	2.80±.47	3.03±.61	2.01±.32	2.15±.54	.49
1	3.18±.26^{ab2}	3.76±.53^{a}	2.35±.61^{b}	3.19±.47^{ab}	.52
2	3.45±.56	3.24±.49	2.07±.32	3.33±.32	.47
3	3.34±.47	2.73±.52	2.85±.41	3.73±.37	.23
4	3.83±.53	2.81±.41	2.75±.43	3.71±.61	.87
6	3.76±.26	3.20±.36	2.66±.56	3.45±.72	.68
8	3.86±.27	3.36±.37	3.15±.49	3.60±.69	.69
12	3.84±.33^{a}	3.17±.29^{ab}	2.37±.37^{b}	3.35±.54^{ab}	.75
24	3.36±.41	2.55±.46	2.15±.38	2.53±.36	.74
$\bar{x}$	3.49±.36	3.09±.37	2.48±.39	3.23±.54	.68

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 12. The effect of dietary aspen on ram blood glucose levels[1] (mg/100 ml)

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	62.5±15.9	64.1±11.0	64.7± 9.1	60.6±15.0	1.43
1	65.9±13.1	66.0±11.6	63.3± 4.5	60.6±12.9	1.53
2	68.2±14.9	68.9±10.1	64.9± 8.4	63.8±10.7	1.50
3	71.3± 9.9^{a2}	70.8±12.8^{a}	72.2± 6.6^{a}	62.7± 9.7^{b}	1.25
4	75.4± 9.43^{a}	75.8±10.9^{ab}	69.0±12.8^{b}	67.8±14.1^{ab}	1.78
6	69.5±18.8	70.4±16.0	65.6±14.2	66.2±14.9	1.58
8	64.0±17.1	67.1± 4.9	61.9± 9.1	64.2±10.1	2.35
12	79.3±13.9	79.4± 6.3	82.4± 4.5	76.4± 5.7	3.07
24	74.3± 5.2	71.0± 9.0	77.2± 7.3	65.2± 8.7	2.45
$\bar{x}$	70.02±10.3^{a}	70.38±7.6^{a}	69.00±6.5^{a}	65.27±8.3^{b}	1.03

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 13. The effect of dietary aspen on ram blood urea nitrogen levels[1] (mg/100 ml)

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S_{\bar{x}}$
0	14.9±2.7	15.8±3.6	16.0±1.1	16.1±2.9	1.44
1	15.7±2.7	16.5±3.8	17.2± .5	16.5±3.0	1.27
2	15.1±1.6	16.3±3.6	17.9± .75	16.6±3.7	0.96
3	14.3±2.1	15.4±3.1	17.8±1.1	16.7±4.2	0.89
4	14.0±2.1	14.8±3.4	17.6±1.3	16.9±4.8	0.99
6	13.0±2.1[a2]	13.8±3.9[a]	17.1±1.3[ab]	17.1±5.4[b]	0.89
8	12.1±2.1[a]	13.3±4.2[a]	17.8±2.1[b]	17.2±5.9[b]	0.79
12	10.7±2.1[a]	11.8±3.9[a]	16.7±2.3[b]	16.7±5.5[b]	0.80
24	15.7±2.4	13.8±4.2	16.3±1.2	14.9±2.3	1.19
$\bar{x}$	13.77±1.6	14.59±3.6	17.15±.80	16.49±4.0	0.91

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 14. The effect of dietary aspen on ram serum ammonia levels[1] (mg N/l)

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	4.52±.61[a2]	5.54±.57[b]	4.94±.30[ab]	5.24±.86[b]	.15
1	4.39±.62	4.96±.50	4.51±.21	4.86±.78	.07
2	4.16±.29	4.68±.70	4.13±.30	4.22±.69	.27
3	4.15±.32	4.39±.49	4.08±.21	4.69±.88	.23
4	3.73±.28	4.27±.61	4.03±.36	4.31±.87	.18
6	3.86±.78[a]	4.28±1.01[b]	3.91±.52[a]	4.32±.95[b]	.09
8	3.83±.53	4.27±.78	3.63±.42	4.38±.97	.21
12	3.51±.40[c]	4.09±.42[ab]	3.68±.24[ca]	4.49±.68[b]	.12
24	4.39±.52	5.20±.26	4.55±.66	5.09±1.18	.32
$\bar{x}$	4.06±.29	4.63±.73	4.16±.19	4.58±.83	.14

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 15. The effect of dietary aspen on the BG/BUN ratio of the experimental rams[1]

Sample time (hrs. post-feeding)	Experimental ram diets				
	Control	15% Aspen	30% Aspen	45% Aspen	$S\bar{x}$
0	4.19±1.59	4.06±1.18	4.04±.81	3.76±1.85	.40
1	4.20±1.28	4.00±1.19	3.68±.30	3.67±1.59	.36
2	4.52±1.38	4.23±1.24	3.63±.62	3.84±1.80	.34
3	4.99±1.24	4.60±1.48	4.06±.79	3.75±1.88	.78
4	5.39±1.13[a2]	5.12±1.71[a]	3.92±.75[b]	4.01±1.96[ab]	.33
6	5.35±2.24[a]	5.10±1.83[a]	3.84±.92[b]	3.87±2.73[ab]	.34
8	5.29±2.78[a]	5.05±1.73[a]	3.48±.77[b]	3.73±2.20[ab]	.41
12	7.41±2.08	6.73±3.05	4.93±.56	4.57±1.75	.75
24	4.73± .88	5.14±1.96	4.74±.74	4.38± .87	.40
$\bar{x}$	5.34±1.42	5.22±1.57	4.27±.50	4.30±1.80	.36

[1]All values are means of 4 observations ± standard error.

[2]Values with different superscripts within the same row are significantly different ($P \leq 0.05$).

Appendix 16. Ram Mean Square Values of the 4x4 Latin-Square Design VFA Production, Blood and Rumen Metabolites[1]

Effect	Degrees of freedom	Ram acetic acid mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	4.99	2.11	7.48	9.91	6.82	9.62	8.57	18.40	6.57	5.39
Animal	3	4.30	9.12	6.56	4.25	0.71	5.66	4.41	0.68	2.81	4.79
Period	3	8.33	3.60	9.36	5.56	2.52	6.55	10.51	21.15	15.01	10.89
Error	6	1.23	8.93	7.58	7.63	3.20	10.94	4.66	4.90	4.94	3.67

Effect		Ram propionic acid mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	1.33*	3.04*	1.54	1.23	1.51*	1.24	0.58	1.12	0.48	1.24
Animal	3	1.45*	2.34*	1.67	1.35	0.96	1.67	1.71	1.25	0.70	1.16
Period	3	0.94*	2.30*	1.35	2.28*	1.48*	1.84	2.62*	4.21*	3.11*	1.98
Error	6	0.18	0.34	0.42	0.30	0.28	0.52	0.52	0.32	0.55	.47

[1]Presented in this table are most mean square values pertaining to the ram trial.

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Appendix 16 (Continued)

Effect	Degrees of freedom	Ram isobutyric acid mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.0033	.0048*	.0021	.0032	.0014	.0080*	.0078	.0060	.0033	.0056
Animal	3	.0004	.0021*	.0026	.0009	.0016	.0014	.0030	.0018	.0001	.0019
Period	3	.0004	.0049*	.0039	.0003	.0025	.0014	.0083	.0050	.0043	.0022
Error	6	.0009	.0001	.0036	.0010	.0012	.0005	.0084	.0017	.0025	.0023

Effect		Ram butyric acid mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	2.91*	5.50*	2.19*	4.16	3.81*	2.21	1.40	7.47	3.64	3.92
Animal	3	1.14	2.34	0.99	1.23	1.28	1.04	1.40	2.77	3.75	1.16
Period	3	1.41*	2.19	0.91	1.35	1.73	0.61	2.35	6.48	6.27	1.32
Error	6	0.26	0.97	0.27	0.91	0.76	1.12	1.40	1.60	1.73	0.91

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Appendix 16 (Continued)

		Ram isovaleric acid mean square values (hours post-feeding)									
Effect	Degrees of freedom	0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.0149	.0037	.0018	.0019	.0057	.0010	.0041	.0026	.0158	.0056
Animal	3	.0077	.0087	.0165	.0095	.0027	.0024	.0074	.0027	.0188	.0086
Period	3	.0025	.0048	.0052	.0305	.0051	.0018	.0079	.0001	.0151	.0042
Error	6	.0035	.0074	.0007	.0018	.0014	.0080	.0049	.0011	.0091	.0019

		Ram valeric acid mean square values (hours post-feeding)									
Effect		0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.0222	.0863	.1177	.0381	.0559	.0351	.0715	.0766	.0612	.0681
Animal	3	.0067	.0453	.0430	.0227	.0095	.0011	.0233	.0429	.0288	.0306
Period	3	.1411	.1067	.1279	.1419	.0986	.1124	.1179	.1679	.1951	.1003
Error	6	.0386	.0096	.1413	.0999	.0279	.0664	.1320	.0834	.0768	.0311

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Appendix 16 (Continued)

Effect	Degrees of freedom	Ram total VFA mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	23.13*	65.24*	29.14	36.19	29.37	39.41	28.51	61.73*	33.19	25.36
Animal	3	18.42*	30.05	23.95	13.45	3.44	15.19	14.14	9.53	33.21	18.18
Period	3	24.45*	34.58	22.24	26.65	12.45	12.16	40.70	74.52*	55.99	28.07
Error	6	3.37	9.84	11.18	8.88	33.12	14.13	10.17	7.78	18.79	10.92

Effect		Ram acetate/propionate mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.20	.93*	.42	.98	1.09	1.28	0.83	1.71*	1.59	0.73
Animal	3	.44	1.40*	.54	1.14	1.90	3.33	2.68	1.62	0.70	1.32
Period	3	3.93*	.80	2.33*	1.64	2.13	3.23	2.12	1.44	1.82	2.43
Error	6	.25	.17	.46	0.89	0.87	4.17	0.41	0.32	0.49	0.65

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Appendix 16 (Continued)

Effect	Degrees of freedom	Ram blood urea nitrogen mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	1.24	3.64	5.10	9.18	12.45	18.43*	31.64*	40.49*	4.58	19.09*
Animal	3	4.63	2.77	6.55	7.58	12.73	18.92*	27.43*	32.00*	6.63	13.43
Period	3	8.97	13.00	15.42	19.41	20.11	24.83*	28.36*	18.29*	12.09	21.13*
Error	6	8.28	6.50	3.69	6.28	3.95	3.16	2.51	2.53	5.63	4.06

Effect		Ram blood glucose mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	13.1	25.9	24.7	77.0*	70.2*	23.0	18.1	23.4	106.8	25.4
Animal	3	84.7*	75.7*	52.7*	51.1*	57.7	62.5*	58.0	61.6	38.9	62.3*
Period	3	580.0*	398.6*	327.4*	397.5*	357.9*	844.0*	397.7*	58.1	152.1	439.6*
Error	6	8.14	9.3	9.0	6.2	12.7	10.0	22.0	37.8	24.0	11.8

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Appendix 16 (Continued)

Effect	Degrees of freedom	Ram blood ammonia mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.76*	.29	.27	.30	.28	.23*	.51	.41*	.63	.43*
Animal	3	.70*	.45*	.24	.52	.28	.48*	.35	.22	1.25	.48*
Period	3	.64*	.71*	.33	.22	.81*	2.27*	1.33*	.54*	.40	.69*
Error	6	.09	.07	.29	.20	.13	.03	.18	.05	.42	.08

Effect		Ram BG/BUN ratio mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.10	.34	.69	1.04	2.54*	2.61*	3.79*	8.98	0.98	1.65
Animal	3	.83	.30	.73	1.19	2.29*	3.59*	3.37*	5.81	1.76	1.79
Period	3	5.88*	4.33*	5.45*	1.76	5.42*	12.43*	10.03*	6.75	2.88	5.16*
Error	6	.65	.53	.46	2.46	0.44	0.47	0.67	2.25	0.65	0.52

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Appendix 16 (Continued)

Effect	Degrees of freedom	Ram ruminal pH mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	.16	.10	.06	.06	.06	.02	.04	.06	.05	.04
Animal	3	.19*	.18	.07	.03	.03	.09	.02	.02	.13	.02
Period	3	.52*	.15	.13	.09	.12	.21	.19	.59*	.88*	.26*
Error	6	.04	.05	.07	.09	.09	.09	.05	.03	.05	.04

Effect		Ram ruminal ammonia mean square values (hours post-feeding) 0	1	2	3	4	6	8	12	24	$\bar{x}$
Treatment	3	4807	58084*	73378*	63964*	95090*	105883*	72163*	43832*	2387	41095*
Animal	3	486	3600	7686	4645	11326	4038	19512	3182	106	2106
Period	3	1559	2394	2135	6654	4995	7415	3537	7370	297	186
Error	6	1223	4884	4208	4300	12690	5380	7189	5446	904	1032

.....Continued

Appendix 16 (Continued)

Effect	Degrees of freedom	Ram dry matter digest-ibility	Ram gross energy digest-ibility	Ram crude protein digest-ibility	Ram crude fibre digest-ibility	Ram water con-sumption	Percent nitrogen retained of rams
Treatment	3	63.2*	87.3*	10.8	161.4	88.5	57.5
Animal	3	7.2	7.8	3.7	75.2	190.3	90.0
Period	3	102.0*	128.3*	64.8*	699.3*	14.4	106.6
Error	6	10.22	10.5	5.9	50.9	49.7	22.9

*Indicates a significant difference exists between treatments ($P \leq 0.05$).

Appendix 17. Mean square values of the steer ADG, feed intake and feed per gain

		Steer performance mean square values		
Effect	Degrees of freedom	Average daily gain	Feed intake	Feed/gain
Treatment	7	0.0061	0.493	.471*
Error	16	0.0072	0.888	.108

*Indicates a significant difference exists between treatments ($P \leq 0.05$).