PHYSIOLOGICAL AND NUTRITIONAL EFFECTS ON ANIMALS OF FEEDING CHEMICALLY TREATED WHEAT STRAW

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PHYSIOLOGICAL AND NUTRITIONAL EFFECTS ON ANIMALS OF FEEDING CHEMICALLY TREATED WHEAT STRAW

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ABSTRACT

Two series of experiments were conducted to determine the long term effects of feeding NaOH treated diet to steers and to compare NaOH treated and NH_3 treated diets. The three diets used in the experiments were based on 60% of untreated, 5% NaOH treated or 3.5% NH_3 treated Neepawa wheat straw.

The dry matter digestibility of the diets were not significantly ($P > 0.05$) different between treatments. Organic matter, nitrogen free extract (NFE), crude fiber (CF) and digestible energy were significantly ($P < 0.05$) higher for the NaOH treated diet.

Mean dry matter intakes ($g/kgW^{0.75}$) were not significantly ($P > 0.05$) different between treatments. Feed conversion efficiency was significantly ($P < 0.05$) higher for the NaOH diet compared to the control or NH_3 diet.

Sodium hydroxide treatment significantly ($P < 0.05$) increased urinary nitrogen in the short term. Nitrogen retention increased significantly ($P < 0.05$) in the long term for all treatments especially by steers fed the control diet. There was consistently low nitrogen retention by the steers fed the NH_3 diet compared to those fed the control or NaOH diet.

Total volatile fatty acids (VFA) concentration in rumen fluid of steers fed NaOH treated diet was significantly ($P < 0.05$) higher than those for the control or NH_3 group. There were no significant ($P > 0.05$) treatment differences in molar proportions of acetic,

propionic, iso-butyric, n-butyric, iso-valeric and n-valeric acids. However, acetic and propionic acids tended to decrease with time while n-butyric acid increased for all treatments. Iso-butyric, iso-valeric and n-valeric tended to decrease with time in the rumen fluid of steers fed NaOH diet.

Rumen fluid sodium, potassium and chloride concentrations decreased in the long term for all treatments. Potassium concentration, however, was significantly ($P < 0.05$) higher in the rumen fluid of steers fed NaOH diet compared to that of the control and NH_3 group. Osmolarity decreased with time for all treatments but remained significantly ($P < 0.05$) higher for the NaOH treatment throughout the experimental period. Rumen fluid pH was relatively low for the NaOH treatment.

The steers fed NaOH treated diet increased water intake (liters/day) by 40.7% in the short term and by 19.3% in the long term compared with the control. Urinary excretion by the same steers increased by 215% and 63% during the short and long terms respectively over the control. Fecal water and urine volumes (liters/day) of steers fed NaOH treated diet declined by 55 and 86.4% respectively in the long term.

Sodium hydroxide treatment increased urinary sodium by 84 and 58.3 g/day respectively in the short and long term over the control. Larger quantity of potassium (g/day) was also excreted in the urine by steers on the NaOH diet, though its concentration (mEq/l) was higher for the control and NH_3 treatments. The concentration of chloride decreased with time and was lowest for the NaOH diet.

Urinary urea, creatinine and osmolarity were ($P < 0.05$) significantly low for the NaOH treatment. No significant ($P > 0.05$) treatment difference in urine specific gravity. The urinary pH was significantly ($P < 0.05$) high for the NaOH treatment in the short term but no significant ($P > 0.05$) treatment difference was found in the long term. High sodium intake had more negative effect on potassium balance in the short term.

Despite the increased intake of sodium, steers fed the NaOH diet were able to maintain their plasma sodium level relatively constant within the normal range. High intake of sodium also had little effect on the plasma level of potassium, calcium, magnesium, phosphorus, chloride and bicarbonate. No consistent result was obtained with blood carbon dioxide and oxygen. Blood hematology was not affected by NaOH or NH_3 treatment. Microscopic examination of the kidney, liver, and rumen tissues showed little evidence of pathological changes in the organs.

Steers fed the NaOH diet gained 25.3% faster and had 36.9% better feed conversion compared with the control. No significant ($P > 0.05$) treatment difference was found between the control and NH_3 diets. Heavier carcasses were obtained from steers fed the NaOH diet compared with the control. There was little differences between treatments in dressing percentage and ribeye area. Fat over rib was significantly ($P < 0.05$) higher for carcasses from steers fed the NaOH treated diet.

The ability of steers to adapt to prolonged ingestion of the 5% NaOH treated diet and show improved performance was demonstrated.

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AUTOBIOGRAPHY

The author was born at Kalongo in Acholi District, Uganda. He received his primary education at Kalongo and his secondary education at St. Vignato and St. Joseph College Gulu. He attended his high school education at St. Mary's College, Kisubi. He obtained his B.Sc. (Agric) and M.Sc. (Agric) from Makerere University, Kampala, Uganda.

In 1968/70 he worked as pasture agronomist and in 1971/73 he was in charge of beef cattle and goat improvement program under the Ministry of Agriculture. He was appointed lecturer in the Department of Animal Science, Makerere University in 1973. He served as an external examiner for Agricultural Diploma candidates at Arapai Agricultural College for two years. He was awarded CIDA scholarship in September, 1975 to pursue further studies in beef cattle production leading to a Ph.D. degree at the University of Saskatchewan, Saskatoon.

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1. INTRODUCTION

The main problem with lignocellulosic materials as ruminant feed is the presence of complex polymers with resistant cross-links and high lignin content and bonding. Another common feature of low quality roughage is the highly crystalline nature of the cellulose molecule. These factors together with the inherent low crude protein content of lignocellulosic materials are largely responsible for the low digestibility and intake of these materials. The nutritional consequence is reduced efficiency of utilization of the potential energy of roughages such as cereal straws by the ruminants.

Various techniques have been used to improve the digestibility and intake of straws so as to enhance their feeding value. The methods involving the use of alkali especially sodium hydroxide and ammonia have received more attention and are advanced in development and application. However, the use of sodium hydroxide, besides improving the digestibility of crop residues, also increases the concentration of sodium in the treated materials unless washed several times.

Since animals must excrete excess sodium from their bodies to maintain homeostasis, ingestion of a high sodium diet could potentially put stress on animals fed such material. This could interfere with animal performance in the long term.

Furthermore, the presence of the excreted sodium in the manure could impose limitations on the application of manure as a fertilizer or soil conditioner in poorly drained soils.

Little information is currently available in the literature on the long term effects of feeding high sodium diets to ruminants. The present studies were undertaken to determine: (a) the effects of prolonged ingestion of a high sodium diet on physiological processes; and (b) to evaluate the effects of diets containing sodium hydroxide treated or ammonia treated wheat straw on steers feedlot performance and carcass characteristics.

2. LITERATURE REVIEW

SECTION A

2.1 GENERAL CONSIDERATION

Crop residues form one of the world's largest sources of carbohydrate; yet billions of tons of these materials are wasted or underutilized yearly (Owen, 1976; Klopfenstein, 1978; Anderson, 1978). Historically cereal straws and stovers, which account for the largest proportion of crop residues, have been neglected as feedstuffs in Canada and the United States because of an abundance of inexpensive cereal grains (Coxworth, 1976; Walker et al, 1977). In recent years, however, the situation has drastically changes due to sharp increases in prices of cereal grains. Thus the future of the traditionally accepted norm of feeding high cereal grain rations to beef cattle now appears non-economic. Consequently, there is a growing pressure to develop alternative feeds for ruminants that will not be in direct competition as human food but of good enough quality to give sustained animal production at low cost.

The unique ability of ruminant animals to convert cellulosic plant materials into meat, milk or wool indicates that a logical approach is to switch ruminants especially beef cattle

back to more utilization of cellulosic materials which they are adapted to digest and thrive on. Processed cereal straws could be valuable emergency feed during periods of shortage of conventional forages. Alternatively, when feed costs dictate straw could be used strategically in maintenance and production rations to reduce cost (Coxworth, 1976).

2.2 COMPOSITION OF LIGNOCELLULOSIC MATERIAL

(a) Composition

The composition and proportion of plant cellular contents and cell wall constituents are of considerable importance to ruminant nutritionists. This is because the chemical composition, particularly the proportion of cellulose, hemicellulose and lignin influence the nutritive value of lignocellulosic materials. Table 1 gives a compilation of the results of analyses of roughages by the detergent procedures of Goering and Van Suest (1970). With the exception of materials like hulls and sawdust, cell-walls account for 60-80% of the plant dry-matter. The table also shows that there is considerable variation in the composition of cell-walls. Variation in the chemical composition of straws have been shown to depend on variety, location and cultural practices employed in growing the cereal crop from which they are obtained (Van Soest, 1969; Kharat, 1974; Saleem and Jackson, 1975).

TABLE 1

The chemical composition of some roughages as determined by the detergent fibre analysis of Goering and Van Soest (1970)(percent of dry matter)*

Roughage	Cell contents	Cell-walls	Hemicellulose	Cellulose	Lignin	Silica	Reference
Barley straw	19	81	27	44	7	3	Fernandez Carmona & Greenhalgh (1972)
Oat straw	27	73	16	41	11	3	Saxena et al (1971)
Paddy straw	21	79	26	33	7	13	Sharma (1974)
Wheat straw	20	80	36	39	10	6	Sharma (1974)
Sorghum stover	26	74	30	31	11	3	Sharma (1974)
Chickpea straw	38	62	20	30	10	2	Johnson & Pezo(1975)
Lucerne straw	31	69	19	38	11	1	Johnson & Pezo(1975)
Sugarcane bagasse	18	82	29	40	13	2	Sharma (1974)
Sugarcane trash	20	80	26	36	10	2	Sharma (1974)
Paddy hulls	14	86	14	39	11	22	Hutanuwatr et al (1974)
Cottonseed hulls	9	91	15	59	13	0	Johnson & Pezo(1975)
Sawdust	8	92	14	55	21	2	Sharma (1974)
Sawdust	2	98	14	50	32	1	Johnson & Pezo(1975)
Poplar bark	33	67	12	34	21	--	Gharib et al(1975 b)

*Adapted from Jackson (1977).

According to Van Soest (1969) chemical constituents of plants may be divided into the structural components of the cell wall (lignin, cellulose and himicellulose) and the more soluble and readily digestible cellular contents (sugars, starch, fructosans, organic acids, lipids and nitrogeneous fractions). The cell wall components of plant materials are made up of lignocellulose complexes which may be divided into two main classes; the matrix and the fiber polysaccharides (Bailey, 1973). This complex is generally characterized by close physical and chemical association of its main components (lignin, cellulose and hemicellulose) which together accounts for most of the cell wall constituents of plants (Pigden and Heaney, 1969). On a dry matter basis, lignocellulose ranges from 40% in immature forages to 75% at maturity, and up to 91% in immature trees (Pigden and Heaney, 1969). These high levels of lignocellulose together with the manner in which the components are associated have drastic consequences on digestibility of low-quality roughage such as straws (Morrison, 1959, Maynard and Loosli, 1969; Gould, 1969; Tarkow and Feist, 1969; Harkin, 1973).

(b) Nutritional Implication

The polysaccharide fractions (cellulose and hemicellulose) of the structural components are of nutritive value to rumen microbes and indirectly to the host animals as sources of carbon

and energy. According to Cowling and Brown (1969), the accessibility of cellulose and hemicellulose to extracellular enzymes of the cellulolytic microorganisms is determined by their distribution within the cell wall and partly by the structural relationships with lignin and other cell wall components.

Lignin in itself is of no nutritional value but because of its physical and chemical association with the cellulose and hemicellulose acts as a barrier (Pigden and Heaney, 1969). The covalent lignin-carbohydrate bonds which tightly hold plant polysaccharides together interfer with the digestibility of plant fibre by rumen and ceacum micro-organisms (Morrison, 1959; Maynard and Loosli, 1959; Gould, 1969; Tarkow and Feist, 1969). The attachment of lignin to other polysaccharides imposes physical limitation by preventing swelling of the plant fibre to a condition suitable for penetration by microbial polysaccharidases (Tarkow and Fiest, 1969). Therefore, there are chemical and physical effects of lignin which constitute metabolic blockage to enzymic hydrolysis (Gould, 1969; Rees, 1963).

Cellulases normally digest cellulose either by removing cellubiose units from the non-reducing end of the polymer or by random attack anywhere inside the straight poly-β-1→4-D-glucopyranoside chain (Harkin, 1973). In the presence of covalent lignin - carbohydrate bonds, the non-glycosidic

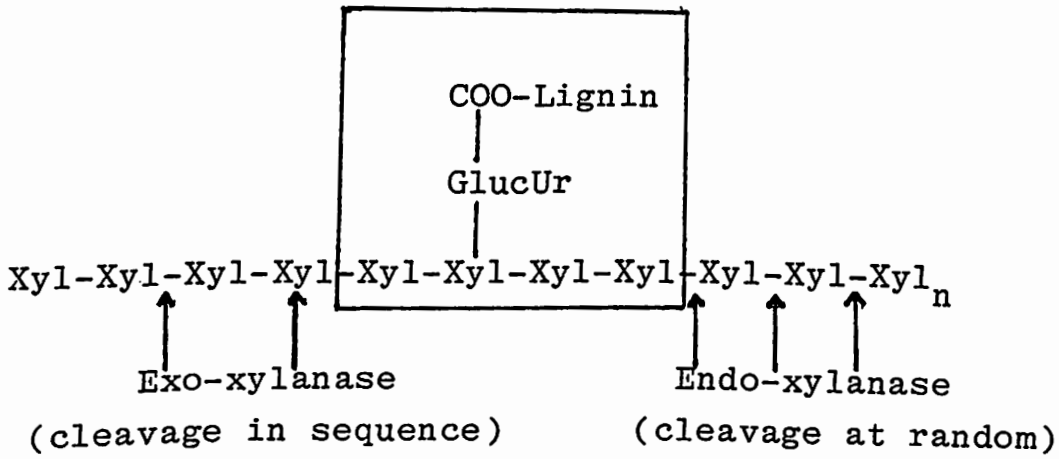

Figure 1. Likely ligno-glucuronosyl-xylose portion of a ligno-xylan resistant to xylandase hydrolosis (adapted from Harkin, 1973).

cross-link inhibit progress of digestion of cellulose derivatives because enzyme like xylanases normally cannot approach closer than 2-3 sugar molecules away from the cross-line (Harkin, 1973). With a cross-link, e.g., from a xylan through a glucuronic acid derivative to lignin (Fig. 1), the portion encircled would remain undigested by xylanases.

While lignin does impede the rate and extent of digestion, the plant cell wall polysaccharides still show marked differences in their rate and extent of digestion when lignin is not a barrier (Barton and Akin, 1977). Thus the relationship of anatomical characteristics to digestibility should include considerations of the association of cell wall polysaccharides with lignin as well as of the type, site, degree of crystallinity and extent of lignification (Barton and Akin, 1977).

2.3 FACTORS AFFECTING THE UTILIZATION OF LIGNOCELLULOSIC MATERIALS

2.3.1 DIGESTIBILITY

Apparent digestibility has long been used as an index of both the nutritive value and feeding value of forages (Ulyatt, 1973). An exhaustive review of the factors which influence the digestibility of forages has been given by Raymond (1969). These factors include genetic and agronomic variations, seasons and stage of growth; processing and animal species.

a) Plant species

The cell contents and the nature of the association of the lignocellulose complex vary considerably among and within plant species and are influenced further by plant source (Pigden and Heaney, 1969). For example, on a dry matter basis, cellulose content accounts for 46%, 34%, 27% and 25% of DM of spruce, rye straw, rye grass and alfalfa respectively (Pigden and Heaney, 1969). Since rumen micro-organisms difficulty in digesting roughages is associated primarily with these plant components, their relative proportions can influence the digestibility of roughages (Pigden and Heaney, 1969).

b) Stage of maturity

Generally as plants grow the structural carbohydrates principally cellulose and hemicellulose together with lignin increase in proportion to provide strength and rigidity to the plants; with concomitant decline in cell content and crude protein. Lignin contents range from 3.7% in young forages to 10-14% in straw. Over a range of maturity legumes have much less cell wall materials than grasses but have a higher lignin content (Pigden and Heaney, 1969).

The manner in which lignin is bonded to other polysaccharides appears to be the main cause of reduced digestibility of mature lignocellulosic materials (Van Soest, 1964, Dehority et al 1962, Elly et al 1953).

c) Agronomic variations

Soil fertility, temperature, moisture, light, seasons and fertilizer application all affect the growth of plants and the pattern in which cell wall contents are laid. Hence they influence the digestibility of roughages indirectly. Nitrogen fertilizer is known to lower cellulose and hemicellulose by promoting rapid growth (Reid and Jung, 1965; Ford, 1973). Rye pasture and winter grown alfalfa were found to contain lower levels of cellulose and were higher in digestibility than the ones grown in the spring-summer season (Harkin, 1973).

d) Feed preparation

The effect of chopping, grinding and pelleting roughages on their digestibility has been well documented (Macdonald et al, 1969; Minson, 1963; Meyer et al 1964; Burt, 1966; Pigden and Heaney, 1969). Extreme reduction in particle size of roughages usually depresses their digestibility by increasing rate of passage thereby giving little time for rumenal and ceacal micro-organism to act on the ingested feed.

e) Level of intake

As the level of intakeincreases (Brown, 1966) some depression in apparent digestibility occurs. This has been attributed to the reduction in digestibility of crude fibre and NFE fraction of roughages (Riewe and Lippke, 1969). According to Blaxter

(1962), intake increases with faster rate of passage of ingested food. This results in food being exposed to the action of digestive enzymes for a shorter period; hence reduction in digestibility. Thus any factor other than pathological ones, which increases the rate of passage of feed through the GIT (e.g. grinding, pelleting) would tend to increase feed intake and decrease digestibility.

f) Ruminant species

When intake is standardized to metabolic body size and physiological function (Riewe and Lippke, 1969) both cattle and sheep appear to digest forages high in cell content equally well (Swift and Bratzler, 1959; Donefer, et al, 1966). This implies that the often reported differences in digestibility due to ruminant species are confounded with variations in intake, body size, physiological status and feed quality.

2.3.2 VOLUNTARY INTAKE

The voluntary intake of roughage is commonly defined as the amount eaten when the roughage is offered ad lib. It is usually expressed as kg/day, or $g/kg^{0.75}$ body weight / day. Extensive and comprehensive reviews on the factors affecting the regulation of intake by ruminants and the mechanisms involved have been written (Balch and Campling, 1962; McClymont, 1967; Balch and Campling, 1965; Forbes, 1970; Baile and Mayer,

1970; Baumgardt, 1970; Arnold, 1970; Bines, 1971; Jones, 1972; Baile and Forbes, 1974; Journet and Remond, 1976). Physiological status of the animal, the nervous system, feed quality and palatability are major factors that influence both the short-term and long-term controls of food intake.

Intake will vary with factors such as body size, sex, age, species, previous nutrition and production state (pregnancy, lactation, growth, fattening). A combination of the above factors determine the energy demand of an individual animal. Consequently each animal attempts to eat to satisfy this demand and achieve energy balance. Thus changes in an animal's physiological status will cause a shift in its energy demand (Ulyatt, 1973). Feed quality and availability together with other environmental factors influence the actual amount of energy intake.

a) Short term control of food intake

Ruminant digestion influences the response of animals to feed in three main ways: (i) by affecting the amount consumed, (ii) by determining the amounts of nutrients obtained from the feed and (iii) by influencing the nature of nutrients obtained (Balch, 1977). Hence ruminant digestion largely controls the use made of energy and the nitrogen fraction of a given diet.

Physical factors associated with the rate of breakdown of ingested feed and emptying of the reticulo-rumen account for

a considerable proportion of variations in intake of feeds having digestible energy content of less than 12.5 kJ (2.5 Kcal) per gram DM (Baumgardt, 1970) or 2.2 Kcal ME/gm DM (Ulyatt, 1973). Thus feeds below approximately 65-70% digestibility would tend to prevent constant energy intake being achieved as a result of physical restriction of feed intake (Blaxter et al 1961; Conrad et al 1964; Baile and Forbes, 1974). Straws, hays and native pastures generally fall below the 65-70% apparent digestibility and consequently their intake is largely influenced by rumen capacity (fill), rate of breakdown and rate of passage (Crampton et al 1960; Blaxter et al 1961).

The rate of breakdown of roughages in the rumen is largely a function of their composition, both chemical and physical, though factors such as changes in buffering capacity of the rumen and the lower GIT can modify fermentation rate (Van Soest, 1965; Weston, 1966; Ulyatt, 1973). The rate of passage in turn depends on the rate of diminution of particles of ingested feed to a size small enough to pass through the reticulo-omasal orifice (Troelsen and Campbell, 1968). There is also evidence which suggests that the physical organizations of molecules within the structural carbohydrate of roughage may have a profound influence on the rate of microbial digestion of such material within the rumen (Bailey and Jones, 1971; Jones and Bailey 1973; Barton and Akin, 1977). So the rate

of breakdown in the rumen may depend not only on the amount of structural carbohydrate in the roughage but also on the way it is organized within the plant cell walls. Another indication of resistance to break down in the rumen has been demonstrated in eating and ruminating time experiments (Hogan et al 1969). As ruminating and eating time per 100 g OM intake increased, so OM intake decreased.

It is evident, therefore, that the primary factor determining the intake of roughage lower than 65-70% digestibility is the rate of breakdown in the rumen. As rumen load of digesta is reduced by microbial digestion, the facilitative urge of hunger, involving the nervous system and stretch receptors (Bell, 1963; Baile and Forbes, 1974) may reassert itself allowing the animal to commence eating again. However, distension of the abomasum or duodenum can cause a negative feedback signals resulting in decreased motility of the reticulum and reduced digesta flow (Phillipson and Ash, 1965) and hence depression of intake.

The voluntary intake of feed of higher than 65-70% digestibility is not controlled primarily by its resistance to breakdown in the rumen; instead the control becomes more metabolic in origin. Both thermostatic and chemostatic mechanisms have been suggested (Brobeck, 1948, Andersson and Larsson, 1961; Balch and Campling 1962; Mayer and Sudsarch, 1959; Baile and

Mayer, 1970, Baile and Forbes, 1974).

With ruminants, the concentrations of volatile fatty acids (VFA), particularly acetic and propionic acids, have been proposed as likely metabolites involved in a chemostatic control mechanism (Baile and Mayer, 1970). It is suggested that receptors sensitive to the concentration of these VFA are located in the rumen wall. In addition, changes in propionate concentration may be sensed by receptors in the portal system. All these suggested factors serve to point out that the regulation of food intake is multifactorial in nature (Brobeck, 1955).

b) Long Term Control of Intake

Long term control of feed intake by ruminants has been postulated to be controlled by lipostatic mechanisms (Kennedy, 1953). While its existence seems real, the mechanism involved still remains obscured (Baumgardt, 1970). According to this theory, the feedback for energy blanace is mediated by the release of free fatty acids (FFA) from adipose tissue (Baile and Forbes, 1974). In an experiment with dairy cows, Journet and Remond (1976) observed that after calving a high level of plasma FFA corresponded to low intake initially and thereafter intake increased until plasma FFA had decreased to about 300 μ eq/1. Results in support of this observation were reported by Thye *et al* (1970); Davenport and Rakes (1969), Emery *et al* (1969).

c) Palatability

Ruminants use the senses of taste, smell, sight and touch in the choice of their feeds (Arnold, 1970; Baile and Forbes, 1974). When selection opportunity exist, sensory appraisal of feed quality would determine which feed would be eaten (Baile and Forbes, 1974); with little impact on animal performance. However, if selection is limited and the food offered is not palatable to the animal, there will be a general decrease in feed intake with resultant reduction in animal performance (Baile and Martin, 1972; Bell, 1963). With no choice (Tribe and Gordon, 1950), as the need for food increases the influence of food preference tend to decline and in extreme situations the animal will readily consume not only materials ordinarily considered unpalatable but even that which is completely indigestible or even poisonous.

According to Balch and Compling (1962) and Baile and Forbes (1974), sensory cues were more important in the initiation of eating than in the determination of the total amount eaten.

d) Influence of Supplementation on Roughage Intake and Utilization

Supplementation influences the utilization of lignocellulosic materials by ruminants by altering protein to energy ratio. The magnitude and direction of influence can however, be modified by feeding frequency. The latter with proper manipulation, ensures optimum fermentation and intake of the mixed diet

(Ørskov, 1975). Thomas (1974) stated that the ruminant's microbial symbionts are preoccupied with altering the configurations of organic molecules for their benefit and indirectly for the benefit of the host animal. Anderson and Anderson (1977) showed that rumen microflora upgraded roughage protein which resulted in increased chemical energy concentration of about 0.5 kcal/g protein added. This increment in spectral energy density (SED) is of great significance to the host animal. Thus, if the microbial requirement of nitrogen is not met voluntary intake will be low (Ørskov, 1976), but when nitrogen requirement is corrected intake will increase. This has been attributed to an increase in rate of fermentation resulting from the increased population of bacteria. For roughage based-diet the microbial need for N will depend on the level of digestible energy and the level of protein degradability. This finding led Miller (1973) and Ørskov (1976) to conclude that for efficient ruminant digestion, and hence intake, the needs of the micro-organisms and of the host animals must each, separately, be considered. If either is not met the efficiency in feed utilization by the animal will fall. The provision of feed supplement to ensure optimum consumption of cellulosic materials must, therefore, be oriented towards meeting the needs of both the rumen microflora and the host animal in terms of protein and energy (Balch, 1977).

The addition of nitrogenous compounds like urea or Starote (Campling et al, 1962; Hensley and Moir, 1963), certain minerals

like sulfur and cobalt (Blaxter, 1962) or C_4 and C_5 long chain fatty acids (Hemsley and Moir, 1963) are various means which have been tested for improving intakes of very low nutritive value roughages.

Donefer et al (1969) reported that although NaOH treatment resulted in an increase of energy digestibility of oat straw, an adequate supply of nitrogen was necessary to increase the rate of microbial digestion and thus the voluntary intake of the diet. Improved intake of straw by 40% was demonstrated by introducing a dilute solution of urea into the rumen (Campling et al, 1962). Limitation imposed by inadequate nitrogen level in low-quality forages was noted by Zafren (1960) and led him to choose ammonium hydroxide to treat straw because of its nitrogen contribution.

Nevertheless, non-protein nitrogen (NPN) has proved to be an economic nitrogen supplement for low quality roughages (Tribe, 1952; Chalupa et al, 1973). The importance of NPN as protein substitutes in ruminant nutrition is through improved rumen fermentation and microbial protein contribution (Chalupa, 1976; Ørskov, 1976; Leng and Preston, 1976). These authors have pointed out, however, that the most important consideration in identifying a situation in which NPN would be beneficial and in establishing the amount of NPN to use, is the nature of the basal diet especially the types and concentration of both the N and energy-yielding components.

Molasses has been widely used to supply energy in ruminant rations (Mather et al, 1953; Davis et al, 1954; Preston et al,

1967; Leng and Preston, 1976) and to improve palatability of NaOH treated straw (Rexen and Thomsen, 1976). Supplementation of low quality roughages with urea and molasses increased feed intake and liveweight gain of penned and grazing sheep and cattle (Combe and Tribe, 1962). In contrast, large intake of molasses reduced cellulose digestion (Loosli, 1963). This adverse effect of high intake of molasses has been attributed to competition between cellulolytic and amylolytic bacteria for nutrients with the latter group being favoured at low pH (El-Shazly et al, 1961). Increased production of lactic acid from fermentation of molasses would lower rumen pH and reduce the activity of cellulolytic bacteria (Zafren, 1960).

2.4 LIGNOCELLULOSIC MATERIAL AS ANIMAL FEEDS

Lignocellulosic materials are by far the most abundant renewable natural resources. Besides direct utilization by man, they can be extremely valuable as a food source for herbivores. The great majority of domestic ruminants have always thrived on cellulosic materials in grazing ecosystems. Reid (1970) predicts that this situation will increase rather than decrease as human population continues to grow and the resulting crisis in world food supplies becomes more critical. Thus it seems inevitable that in future more lignocellulosic materials will be used as food sources for ruminants. This is reflected in the renewed interest in developing cheap and efficient methods for improving the feeding value of these materials.

(a) As Roughage

Roughage in proper amount and quality is required in the ruminant ration to provide tactile stimulation of the reticulo-rumen walls and to promote cud-chewing. The latter in turn increases salivation, cellulolytic digestion and the supply of buffer for the maintenance of rumen pH. The net result is the regulation of the type of rumenfermentation (Baker et al, 1975; Ørskov, 1975; Sudweeks, 1977).

This ability of the cellulosic material to influence the type of rumen fermentation is of considerable importance in three distinct aspects of ruminant nutrition (Ørskov, 1975): (i) control of energy losses associated with methane production; (ii) reduction or elimination of excess heat losses in subsequent utilization of VFA produced and (iii) achievement of optimum partition of energy into useful animal products. There is evidence that the most efficient utilization of VFA is determined by the ratio of non-glucogenic to glucogenic (NGR) components (Ørskov, 1975). A ratio of 2.25 to 3.00 is considered to give optimum utilization for growing and fattening animals; and a ratio of 3.00 to 3.50 for dairy cows.

The NGR are influenced by the ratio of roughage to concentrate which influences the type of rumen fermentation (Donefer et al, 1963; Bath and Rook, 1963). Diets containing high levels of cereal grains and low proportion of roughage, for example, usually cause elevated level of propionic acid (Frank et al, 1972;

Thomas, 1975) and reduces the acetate to propionic ratio (Ørskov, 1975; Schingoethe et al, 1976) and lowers pH (Hale and Shell, 1975; Ørskov, 1975). Lack of roughage in ruminant ration is also responsible for nutritional disorders as depressed butterfat, displaced abomasum in dairy cows (Choppock et al, 1972; Latham et al, 1974; Annison and Bickenstaffe, 1974; Welch and Smith, 1975); liver and rumen abscesses and acidosis (Wise et al, 1968; Harvey et al 1968; Bide and Dorwand, 1975; Allison et al, 1975).

(b) As Energy Feed

The major potential value of lignocellulosic materials is as an energy source. The gross energy content per unit weight of cereal grain and straw, for example, is virtually identical (Owen, 1976). This potential is often difficult to achieve because of low digestibility. According to Donefer et al (1969), 50 to 70% of the potential energy of young forages can be utilized by ruminant animals. But with increased lignification and crystallinity of cellulose and hemicellulose at maturity, only 20 to 50% of the potential energy is realized from most untreated roughages like straws.

The inherent low nitrogen content of most cereal straws also reduces the activity of cellulose and hemicellulose digesting microorganisms in the rumen; thereby leading to poor energy utilization. Mineral and soluble carbohydrate contents of many lignocellulosic materials may also be too low for efficient

cellulose and hemicellulose breakdown by rumen microogranisms. Supplementation of such diets with a minimum of 1% N and with 5 to 10% of readily available carbohydrate has been suggested (Pigden and Heaney, 1969). To achieve moderate production from ruminants, concentrate supplementation of straws may have to be considerably higher than 20% (Andrew et al, 1972). Physical processing, chemical treatments, irradiation or biological upgrading have also been shown to increase the nutritive value of low quality roughages significantly (Jackson, 1977; Owen, 1976).

(c) Feed Potential

Quantitatively, lignocellulosic materials are enormous sources of carbohydrates. However, with the exception of forages not much of the cellulosic materials have been used adequately as livestock feeds due to the problems of low intake and digestibility. Worldwide estimate of cellulosic agricultural by-products (Table 3) reflect the vast quantity available (Owen, 1976). Annual world production of bagasse has been estimated to exceed 100 million tons (Srinivasan, 1969). Cereal straw production in Canada alone is considerable (Table 2).

According to Coxworth (1976), the use of processed straw in Saskatchewan (assuming a value equivalent to average quality hay) would be equivalent to creating between 2 to 3 million acres of new tame hay land. These statistics, though rough estimates, emphasize the potential of cellulosic materials as energy source for ruminants. However, the key to making lignocellulosic materials

TABLE 2. Canadian Straw Production in 1975*

Straw	Canada Tons x 10^6	(%)	Prairies Tons x 10^6	(%)	Saskatchewan Tons x 10^6	(%)
Wheat	23.5	52	22.5	53	14.5	67
Barley	10.5	23	9.8	23	3.1	14
Oats	6.1	13	4.9	12	1.9	9
Others	5.2	12	5.1	12	2.2	10
Total	45.3	100	42.3	100	21.7	100

*Adapted from Coxworth et al, 1977.

more valuable feeds for ruminants lies in finding cheap and practical chemicals, physical or biological method which will improve their nutritive value. Alkali treatments are currently attracting great interest and are described below.

2.5 METHODS OF ALKALI TREATMENT OF STRAWS

Three approaches have been developed. (i) Treatment of chopped straw with concentrated NaOH solution using the "dry" method (Rexen, 1972; Rexen and Moller, 1974; Rexen and Thomsen, 1976). (ii) Treatment of chopped straw with a dilute aqueous solution of NaOH alone or a mixture of NaOH and $Ca(OH)_2$ followed by anaerobic ensiling of the damp material (Elpat'evskij, 1962; Klopfenstein and Woods, 1970) using the modified Beckmann's method. (iii) Treatment of straw in loose, baled or chopped form with either aqueous ammonia (Zafren, 1962; Waiss et al, 1972) or anhydrous ammonia (Martynov, 1972; Kernan et al, 1977).

TABLE 3. Estimated quantity of fibrous waste by-products generated from major world crops (excluding wood) in 1971*

	X 10^6 DM (Mt)									
	UK	Europe	N & C America	South America	Asia	Africa	Oceania	USSR	China P. Rep.	World
Cereal straws (1)										
Wheat	4.1	67.7	51.7	8.1	43.9	7.6	7.4	78.2	27.2	295.9
Rye	0.2	13.4	1.6	0.3	0.7			10.2		26.4
Barley	7.3	43.8	20.9	1.0	10.1	4.1	2.5	30.6		120.3
Oats	1.2	15.9	15.8	0.6	0.5	0.2	1.2	12.8		48.2
Maize		70.0	264.0	47.3	33.3	38.4	0.5	19.6		473.1
Millet and sorghum		0.9	42.2	9.0	37.4	36.0	2.2	5.1		132.8
Rice, paddy		1.5	4.5	7.8	151.0	6.5	0.3	1.2	88.4	261.2
Cereal straws total	12.8	213.2	400.7	74.1	276.9	92.8	14.1	157.7	115.6	1,357.9
Sugar cane wastes (2)										
Tops		0.1	10.7	10.2	15.9	3.3	1.5		2.3	44.0
Bagasse		0.1	14.2	13.7	21.2	4.4	2.1		3.1	58.8
Sugar beet tops (3)	0.5	8.4	2.0	0.2	0.9	0.1		6.3	0.4	18.8
Total (Sugar cane & beet wastes)										121.6

*Adapted from Owen (1976).

2.5.1 SODIUM HYDROXIDE TREATMENT METHODS

Attempts to upgrade cereal straws with sodium hydroxide date back to 1890 (Walker et al, 1977; Kellner and Kohler, 1900; and Bechmann, 1919). These early efforts had demonstrated that the delignification procedures could be used to improve the nutritive value of low-quality roughages. The process was modified in Germany (Beckmann, 1919) during World War I and became known as the Beckmann process.

a) The Beckmann Process

The Beckmann method of alkali treatment consists of soaking straw in dilute alkali solutions (8 times its weight of 1.5% NaOH solution) for a minimum of 4 hours at ambient temperature and then washing it with clean water until alkali free. The resultant straw was then fed in a wet condition to ruminants. With this mild treatment, though producing materials less digestible than that reported by Kellner and Kohler (1900), an approximately two-fold increase in digestibility was obtained compared with the original untreated straw. It increased dry matter digestibility to 60-70%. Thus the method became widely used in Europe during the war years for improving the feeding quality of straws. The major disadvantages of this methd are: (i) the large quantity of water required for washing and the concomitant leaching out of 15 to 25% of the solids originally present in the straw; (ii) the method cannot be economically industrialized or adapted for

on-the-farm use due to the high costs of treatments, (iii) it creates a pollution problem with the large quantities of water required to wash out the NaOH and; (iv) the treated product is not sufficiently dry for storage. Consequently, more recent investigations on NaOH treatment of lignocellulosic materials have aimed at modifying the original Beckmann process by reducing the NaOH and water requirements (Wilson and Pidgen, 1964; Donefer et al, 1969; Rexen and Thomsen, 1976; Walker et al, 1977; and Jackson, 1977). The spray process, in which the straw is wetted with an alkali solution (Wilson and Pidgen, 1964) is an improvement over the Beckmann method and has been developed to factory scale (Rexen and Thomsen, 1976; Walker, 1977; and Jackson, 1977) because of its great potential.

b) The "Dry" Method

The dry chemical treatment of straw with NaOH (Rexen and Thomsen, 1976) is an improvement on the experimental results performed by Wilson and Pigden (1964) and Donefer et al (1969). It has the advantages of reducing the amount of unreacted NaOH and the reaction time. The processing system consists of a chopper, lye mixer where concentrated NaOH solution is added, molasses tank and a cobspress (Figure 2). The lye mixer consists of a cylindrical chamber with a longitudinal hollow rotating shaft through which the alkali is introduced onto the chopped straw. On the shaft are placed a number of nozzles. The amount

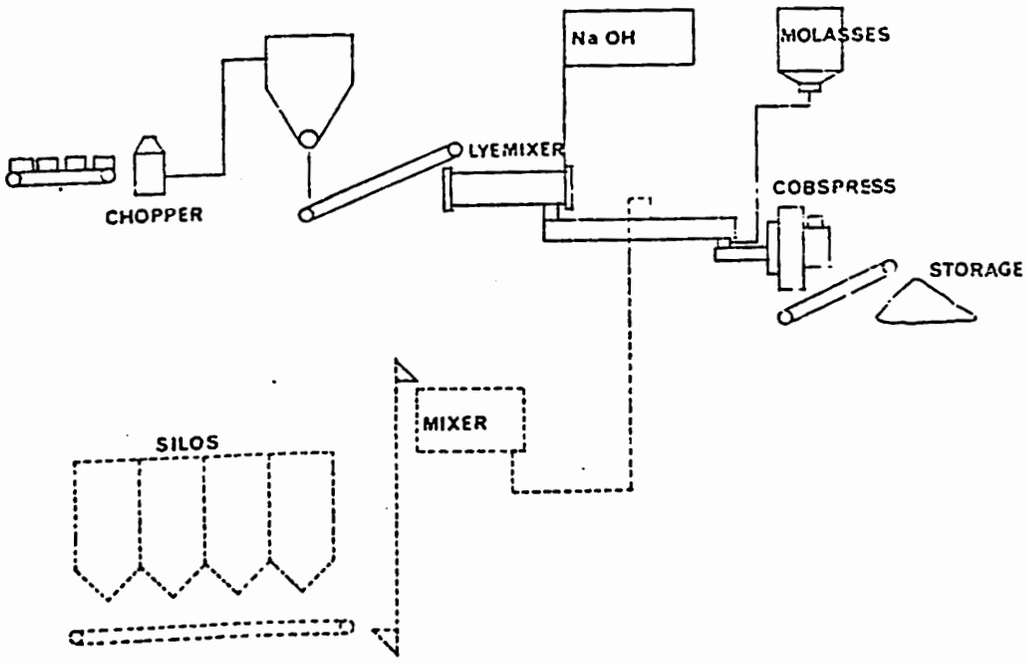

Figure 2. Flow sheet for alkali treatment by a "Dry" Method. (Adapted from Rexen and Thomsen, 1976).

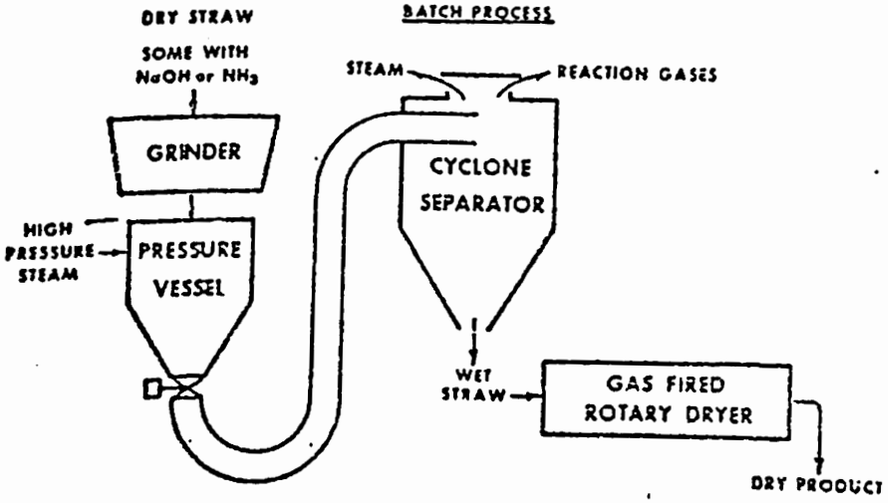

Figure 3. High pressure steam treatment. (Adapted from Walker et al., 1977).

of NaOH sprayed on the straw is automatically regulated by means of a belt weigher and an electrically controlled valve.

Part of the reaction takes place in the lye mixer and part in the press with resultant reduction in the amount of unreacted NaOH (Rexen and Thomsen, 1976). Maximum pressure varies from 100-300 atmosphere and temperature ranges from 80-100 C, thereby reducing the reaction time to approximately 20 seconds.

c) High Pressure Steam Treatment

In the high pressure steam system (Figure 3), ground straw is treated with high pressure steam in a pressure reactor with added chemicals (Walker, 1977). At the end of the reaction period (usually 10 to 90 sec.) a quick release valve is opened and the product blown into a collecting cyclone. The moisture content of the product varies from 40 to 70%. This means further drying is required for long term storage of the product. Addition of NaOH to straw prior to steam treatment generally gives a more digestible product. In terms of animal performance, the treated straw gives no better results than materials produced by less expensive methods (Garrett et al, 1974). The major disadvantages of this method are: (i) approximately 5-15% of dry matter is volatilized under high pressure treatment and serious air pollution results if the material is vented directly to the atmosphere (Walker, 1977); (ii) overtreatment with steam is also possible which would lead to poor utilization of the material and hence animal performance.

d) Alkali Soaking Process

This system is a modification of the original Beckmann process. With this process ground straw is run though an alkali soaking chamber at 100°C to minimize holding time. The soaked straw is then pressed and dried (Figure 4). Squeezed water containing excess NaOH is recycled and additional NaOH is added to it in the soaking trough to maintain NaOH treatment concentration level. Alternatively water is added as needed to maintain the equilibrium of sodium ions. Animal performance on material prepared by this process is satisfactory (Mowat, 1971) but the cost of processing needs to be worked out.

2.5.2 AMMONIATION OF STRAWS

Two common methods of ammonia treatment of roughages are: (i) ammonia treatment under conditions of high temperature and pressure (ii) ammonia treatment under conditions of atmospheric pressure and ambient temperature.

a) High Temperature and Pressure

This method is similar to that discussed for NaOH treatment (c). Apart from the uneconomic aspects of the method, the application of high temperature (above 100°C) and pressure during ammoniation causes low utilization of ammonia nitrogen in the feeds. It decreases the digestibility and utilization of other nutrients as well (Ferguson and Neave, 1943). When high temperature and

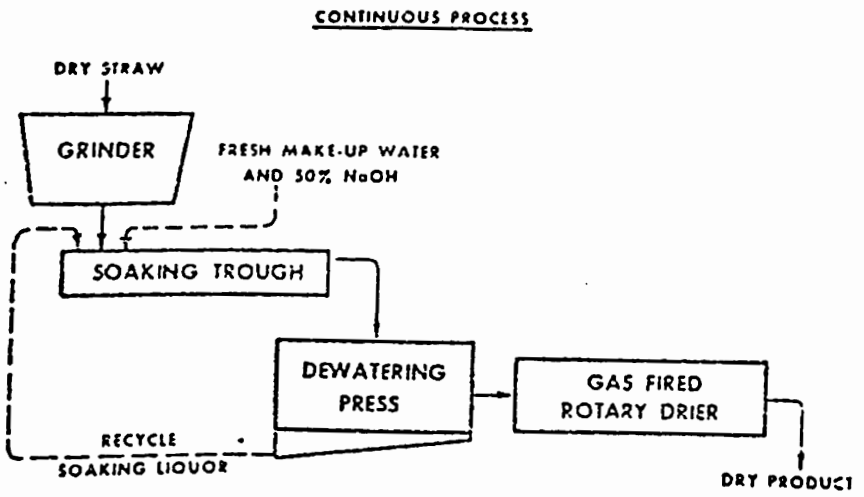

Figure 4. Alkali soaking.
Adapted from Walker et al., 1977).

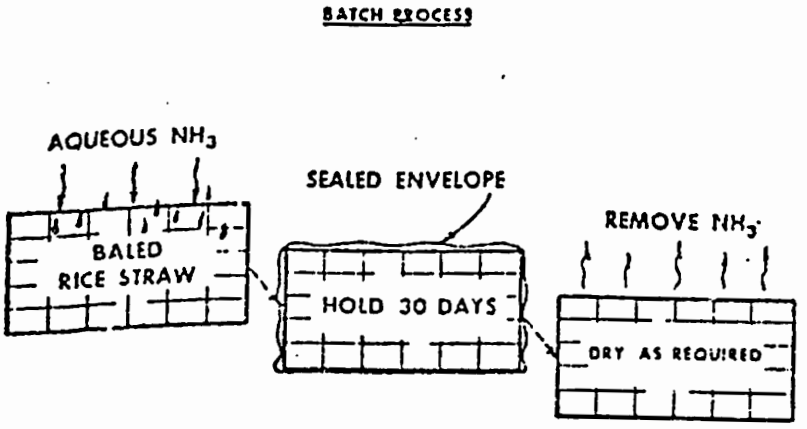

Figure 5. Ambient temperature ammoniation.
(Adapted from Walker et al., 1977).

pressure are applied during ammoniation, poorly digestible amino-sugars and toxic imidazoles such as methylimidazole and 4, 5-hydroxy imidazole can be formed. These compounds are considered to be the cause of low utilization of the ammoniated sugar beet pulp nitrogen (Chomyzyn and Ziolecka, 1972). However, at temperatures below 100°C only traces of imidazoles have been found. Similar results were obtained by Chang et al (1961) when they studied the ammoniation of whole sugarcan bagasse.

b) Ambient Temperature Ammoniation

The ambient temperature ammoniation process involves simply stacking baled straw in a gas-tight plastic envelope or any suitable enclosure. This is then followed by adding the required amount of ammonia (usually 3½% NH_3) and leaving it sealed for the required period of time, preferably 30 days (Waiss et al, 1972; Lyster, 1976; Kernan et al, 1977). The procedures involved in the ammoniation is shown in Figure 5. This type of process is currently considered as being suitable for on-the-farm operations (Kernan et al, 1977). It has a further advantage in that the ammonia bound to the straw serves as a source of non-protein nitrogen (NPN) for microbial protein synthesis in the rumen, thereby, encouraging fermentation. The main potential disadvantage of this process is that without provision for recycling the excess ammonia, the residual NH_3 can present an air pollution problem. The ammoniated straw is also more susceptible to weathering and when the free and loosely

bound NH_3 has gone, the material is susceptible to mold attack.

2.6 PRECAUTIONS WITH CHEMICAL TREATMENTS

Regardless of the methods of processing, sodium hydroxide and ammonia pose a potential health hazard if not carefully handled. Concentrated NaOH is very corrosive and can damage skin within a few minutes of contact. During hot weather or at high temperature its fumes can be carried by wind for a considerable distance from the treatment site. Thus treatment time and site must be carefully selected (Kernan et al, 1977).

Liquid anhydrous ammonia can form flammable and explosive mixtures with air within the limits of 16 to 27% of ammonia by volume (Kernan et al, 1977). This level could be reached during ammoniation of straw depending on the moisture content of the material. In the aqueous form concentrated ammonia is very toxic while the gaseous form has a very pungent and disagreeable odor. Physiological responses to various concentrations of ammonia are given in the table 4.

Based on these observations, it is imperative that maximum precautions be taken to avoid or minimize these potential hazards. Provision of protective covers, masks, and plenty of fresh water for flushing skin are essential. For on-the-farm operations, choosing a cool day when a light breeze is blowing away from houses and corrals can afford a further safety precaution.

TABLE 4. Physiological Responses to Various Concentrations of Ammonia*

Physiological Response	NH_3 Concentration ppm in air
Least detectable odour	53
Least amount causing immediate irritation to the throat	408
Least amount causing immediate irritation to the eyes	698
Least amount causing coughing	1,720
Maximum concentration allowable for prolonged exposure	100
Maximum concentration allowable for short exposure (½ - 1 hr.)	300 - 500
Amount dangerous even for short exposure (½ hr.)	2,500 - 4,500

*Adapted from Encyclopedia of Chemical Technology, Vol. 2, 2nd Ed.

2.7 MECHANISM OF DIGESTIBILITY INCREASE

Since 1890 numerous experimental results have consistently demonstrated that alkali treatment of roughages increase their digestibility (Woodman and Evans, 1947). The improvement is caused by physical and chemical changes which make the treated roughage more accessible to rumen micro-organisms (Tarkow and Feist, 1969).

The most notable physical change that occurs after alkali treatment of lignocellulosic material is the swelling of cell-walls due to increased fibre saturation point (FSP). According to Tarkow and Feist (1969) the increase in FSP following alkali (NaOH) treatment involves the relative proportion of free carboxyl group content (i.e. the unesterified carboxyl content) and the polyelectrolytic character of the uronic acid formed on saponification. The polyuronic acid under such conditions exists as a polyion and according to Flory (1953) a slightly higher swollen condition is expected with a polyion than when a polymer is in the undissociated form. Thus the increase in FSP is essentially caused by breaking of uronic ester cross-links. With ammonia the products formed are amide groups (Wang et al 1964). It was reported more recently (Whistler and Teng, 1970) that the alkali reduces the strength of inter-molecular hydrogen bonds which bind cellulose together, thus resulting in swelling. There is also evidence which suggests

that the hemicelluloses of Graminae are esterified with acetic acid and that the acetyl groups which impede the digestion of hemicellulose (Morris and Bacon, 1976) are hydrolysed by chemical treatment.

Lignin contents of alkali treated crop residue are generally not reduced (Ololade et al 1970; Klopfenstein et al 1972; Rexen and Thomsen, 1976). Some of the hemicellulose is usually reduced by alkali treatment but cellulose content remains more or less intact (Klopfenstein et al 1978). However, several workers have shown that the magnitude of response to alkali treatment by crop residues from different plant species varies (Saxens et al 1971; Sharma, 1974; Gharib et al 1975; Klopfenstein, 1978). In an experiment conducted by Jones and Klopfenstein (1967), a 4% alkali treatment dissolved a portion of the cell-wall and lignin of maize cobs but not of lucerne stems. Even 5% alkali treatment of lucerne did not dissolve its cell-walls (Summers and Sherrod, 1975). Aspen sawdust hemicellulose was not dissolved (Millet et al 1970) unless more than 6% sodium hydroxide was used; whereas with paddy straw, wheat straw and sugar bagasse even 1% of alkali solubilized some hemicellulose. These differences are thought to be due to variation in physical and chemical associations within the cell-walls between and within plant species.

These physical and chemical transformations in crop residue

resulting from alkali treatment, through variable, explain the basis of improved digestibility. The increased FSP after alkali treatment of crop residues would provide conditions for cellulolytic enzymes to penetrate more rapidly and form enzyme-substrate complex with cellulose (Stone et al, 1969). Review of results from several experiments led Klopfenstein (1978) to conclude that the modes of action of alkali treatment especially with sodium hydroxide resulted in the following: (i) solubilization of hemicellulose, and (ii) increasing the rate and extent of cellulose and hemicellulose digestion.

2.8 FACTORS INFLUENCING THE EFFECTIVENESS OF ALKALI TREATMENT

2.8.1 SODIUM HYDROXIDE

a) Effect of Levels of Sodium Hydroxide

Several studies have been concerned with the determination of the optimal levels of sodium hydroxide (NaOH) for treating various crop residues like straws. Accumulated data relating to the levels of NaOH suggest two important factors (Klopfenstein, 1978): (i) the levels of treatment for best animal respinse in ranges from 3 to 5% NaOH per 100 gm DM of crop residues; and (ii) there is a difference in response to alkali treatment as measured by in vitro and in vivo results. In general the in vitro digestibility of crop residues increased linearly with increasing amounts of

sodium hydroxide application up to 10gNaOH/100g of roughages (Jackson, 1977). The effect of the amount of NaOH on digestibility in vivo have been determined by several workers (Singh and Jackson, 1971; Ololade and Mowat, 1975; Shin et al, 1975; Singh and Jackson, 1975; Rexen and Thomsen, 1976). Both voluntary intake and digestibility increased linearly up to 3-6%NaOH/100g of straw and then level off thereafter.

However, when higher levels of NaOH are used and the PH of the treated straw was brought back to near neutral by adding organic acids such as acetic and propionic acids, a linear increase in digestibility and dry matter intake were achieved with up to 8gNaOH/100g of straw (Donefer, 1969; Fernandez, Carmona and Greenhalgh, 1972). The observed lower in vivo digestibility relative to in vitro values has been ascribed to an increased osmotic pressure of rumen fluid which would inhibit rumen microbial activity (Maeng et al, 1971; Bergen, 1970; Alolade and Mowat, 1975). This hypothesis was contradicted by Koers et al, 1970 when they added increasing amounts of KCl (1, 2 and 3%) to 4% NaOH treated maize cobs. They found no apparent depression in digestibility was observed though osmotic pressure must have increased. Intake and average daily gains were similar at all the three levels of KCl. Patchey and Mbatya (1977) observed similar animal performance indicating an associative effect between Na and K. A faster rate of passage of NaOH-treated diet through the rumen also occurs with increases in the sodium levels, thus limiting digestibility to levels lower than would be possible with slower passage (Maeng

et al, 1971).

b) Effect of NaOH Treatment Time

The length of treatment time has an important bearing on the economics of alkali treatment of straws. When the 22-hr Beckmann process was reduced to 3 hrs. (Watson, 1941; Ferguson, 1943; Williamson, 1941) a slight reduction in the digestibility of crude fiber was observed. Stone et al (1965) found no difference between 6 hrs. and 24 hrs. of NaOH treatment of bagasses. Experimental results reported by Wilson and Pidgen (1964) suggest that most of the alkali reaction with straw is completed within 10-15 min. of the treatment time. Evidence in support of the above result was also reported by Ololade and Mowat (1969). A slight decrease with time, in the amount of residual alkali present in sprayed straw, was observed by Chandra and Jackson (1971). This indicates that alkali continued to react with straw at a slow rate (Jackson, 1977). Ololade et al (1970) found that sprayed barley straw had a significantly higher digestibility after 24 hrs. than it did after one hour of treatment. It appears that treatment time at a given level of NaOH is influenced by the method of processing and the type of roughage being treated.

c) Effects of Temperature, Steam and Pressure on NaOH Treatment of Roughages

Efforts have also been directed to introducing heat during alkali-straw reaction with the aim of improving the effectiveness

of NaOH-treatment in minimum time; hence reduction in treatment cost. Of the available heat treatments, steam processing of alkali-treated roughages has recently attracted the attention of ruminant nutritionists (Jackson, 1977).

Ololade et al (1970) treated barley straw with NaOH levels ranging from 0 to 12% and heated it at different temperatures ranging from 23 to 130°C for various lengths of time. They reported an increase in in vitro dry matter digestibility (IVDMD) at all temperatures and times with increasing concentrations of NaOH up to 8%. The straw treated with 4% NaOH either at 60°C for 15 min. or at 23°C (room temperature) for 24 hrs. gave similar IVDMD. Mowat and Ololade (1969) reported similar findings although they observed little increase in energy digestibility of straw treated with NaOH levels above 4%.

Maeng et al (1971) steam processed barley straw with 6% NaOH at 100°C for 30 min. This materials was supplemented with 16% soybean meal and 3%mineral and fed to sheep. The ration was reported to besuperior to alfalfa silage in both energy digestibility (66.5%) and nitrogen retention. Guggolz et al (1971a) measured in vitro digestibilities of nine samples of grass straw steam processed with and without NaOH at 231°Cand a pressure 28 kg/cm^2 for 3 minutes. Steam treatment alone improved the digestibility of the grass straw by 50% while the addition of 3% NaOH resulted in more than double the improvement in the digestibility. Klopfenstein et al (1974) steam processed corn cobs with or without 3% NaOH at 17.5 kg/cm^2 for 10-30 seconds. The pressure treatment alone increased in vivo

dry matter digestibility by over 20%above the control; but the addition of 3% NaOH did not further increase digestibility. In another experiment (Guggolz et al, 1971b), rice straw was steam processed with 4% NaOH at 100°C for 15 min. or 60 min. and fed to sheep as 65% of their ration. Dry matter digestibility the order of 45, 55, and 61% respectively were obtained for the untreated, 15 min. steam treated and 60 min. alkali steam treated straw. In vivo studies (Garino, 1974) consistently demonstrated significant increases in digestibility and voluntary intake of straw treated with NaOH under high temperature. Ololade et al (1970) and Donefer (1972) conducted similar studies. In vitro cellulose digestibility (IVCD) was increased in every case but the degree of response varied with the type of straw both within and among plant species. Based on their IVCD prediction equation, they estimated that straws with initial IVCD of more than 35% would require 2% NaOH solution; straws with initial IVCD ranging from 25-35% would require 4% NaOH and those with IVCD less than 25% would require slightly more than 4% but less than 6% NaOH to increase the IVCD satisfactorily at 97°C for 2 hours. Donefer (1972) also concluded that there was no decided advantage in steam processing straws at higher than 100°C when low levels of NaOH were employed. The results of Garret et al (1974) lend support to the above conclusion.

d) Effect of Particle Size on Optimum NaOH Level

The reduction of particle size of low-quality roughages prior to NaOH treatment generally increases the effectiveness of alkali. Watson (1943) reported that the digestibility of crude fibre increased from 68.4 to 70.8% and NFE from 62.8 to 67% when chopped versus long straw were treated with NaOH. However, no significant difference was found in *in vivo* digestibility (Watson, 1943; Ferguson, 1943) and in composition (Hvidsten and Simonsen, 1953). Recently, Chandra and Jackson (1971) reported that NaOH is as effective in improving digestibility of chopped wheat straw as that of ground straw. *In vitro* cellulose digestibilities (IVCD) of 80% for ball-milles straw, 76% for fine ground (0.7 mm) and 65% for medium ground (1.7 mm) straw treated with 8% NaOH have been reported by Dhinsa (1972). The IVCD of the untreated straw on the other hand were 52%, 33% and 24% for ball-milled, fine and medium ground sizes, respectively. Dhinsa concluded that the magnitude of the increase in IVCD due to reduction in particle size was much smaller for NaOH-treated straw than for the untreated straw. This result could have been influenced by the quality of straw and rate of passage. Anderson and Ralston (1973) found no significant difference in *in vitro* dry matter digestibility among three particle sizes of rye grass soaked in 2% NaOH solution at the ratio of 15 ml 2% NaOH solution to kg of straw.

2.9 FACTORS INFLUENCING THE EFFECTIVENESS OF AMMONIATION

a) Effect of Levels of Ammonia

The divergence in crop residue response to ammoniation indicate that NH_3-treatment is not of a single definite nature, but that several factors combine to influence the final result. The factors involved have not been clearly determined. Waggepetensen and Thomsen (1977), reported that enzyme solubility increased with increasing NH_3 dosage (2.6 - 5.9%); the greatest effect being at the lower temperatures (15° - 30°C). At higher temperature there was a slight tendency towards a negative effect on digestibility with increasing NH_3 dosage. Sundstøl *et al* (1978), reviewed the effect of NH_3 dosage at various treatment temperatures on the *in vitro* digestibility of oat straw. The result showed a linear increase in *in vitro* digestibility with increase in NH_3 level from 1.0 to 4.0% up to a temperature of 15°C. No positive effect was found when ammonia level was increased from 4.0 to 5.5% of straw dry matter. Waiss *et al* (1972) found that a maximum effect was achieved with 5% NH_3 and a treatment time of 30 days. Most experiments, however, indicate that there is very little improvement in digestibility resulting from an increase of ammonia level above 3-4% of dry matter. The economical optimum level might even lie below 3% depending on method of ammoniation and cost of ammonia (Waagepetersen and Thomsen, 1977; Sundstøl, 1978).

b) Effect of Temperature and Pressure

Ammonia is a slow-reacting chemical requiring a longer period at low temperatures. However, its chemical reaction, can be accelerated by increasing temperature up to a certain level; thereafter no change or even a negative effect occurs. Waagepetersen and Thomsen (1977), reported increased enzyme solubility with increase in temperature up to 45°C with no increase between 45°C and 55°C. In vitro digestibility also increased as the temperature was raised from 15°C to 30°C. Temperature increases from 30°C to 45°C resulted in only a minor improvement and the general effect was significantly negative if the temperature was increased from 45°C to 55°C. Crude protein content was similarly increased by raising the temperature up to 45°C. A positive effect of increased temperature was particularly marked with low NH_3 dosages. Maximum digestibility, for example, was obtained with 2.6% NH_3 at 62°C and 4 days incubation or 5.9% NH_3 at 30°C and 3-7 days incubation. Sundstøl et al (1978), reported that at very low temperatures, about or below the freezing point of water, the action of ammonia is very slow. It appears that there is a significant interaction between treatment temperatures, time and level of ammonia. This implies that low treatment temperatures can be compensated for to a large extent by increasing the time of treatment. Alternatively, if the cost of ammonia is a

limiting factor, this could be overcome by using low dosages and increasing the temperature in the reaction chamber. This would also reduce treatment time.

The combined effects of high temperature and pressure have been investigated. Waagepetersen and Thomsen (1977), after incubation of NH_3-treated barley straw applied a pressure of approximately 250 kg/cm^2 at a temperature of 100°C for 1.5 minutes. This treatment simulated conditions in a pellet press. They found little improvement in *in vitro* digestibility and only a slight increase in crude protein content. The application of high temperature above 100°C and pressure have been found to cause not only low utilization of ammonia bound nitrogen but also decreased the digestibility and utilization of other nutrients in the treated feed (Ferguson and Neave, 1943; Davis *et al*, 1955). It is speculated that the low digestibility and poor utilization is due to changes in the availability of certain carbohydrates or to the formation of special inhibiting compounds (Waagepetersen and Thomsen, 1977) or a combination of both factors. Part of the bound nitrogen has been shown to be water soluble (Waagepetersen, 1974). About 24% is reported very loosely bound, probably as NH_4^+; 44% more firmly bound (might comprise amides), and 32% could not be evaporated by MgO or 2N NaOH (Waagepetersen and Thomsen, 1977).

Waiss *et al* (1972) reported that after ammoniation of the straw, 50% of the bound nitrogen is in the form of ammonium salt

and the remaining 50% is in some more tightly bound form. He suggested that amide formation could be a possible form which could account for much of the remaining tightly bound, slow releasing nitrogen. Poorly digestible amino-sugars and toxic imidazoles (e.g. methylimidazole or 4, 5-hydroxy imidazole) are formed during sugar beet ammoniation under high temperature and pressure; leading to low utilization of the pulp nitrogen (Chomyszyn and Ziolecka, 1972). In laboratory experiments on the ammoniation of sugar beet pulp Dudkin, et al 1969, found that with increase of temperature over 100°C the amount of sugars decreased and large amounts of heterocyclic N-compounds and imidazoles were formed. Similar results were obtained by Chang et al (1961) who studied ammoniation of whole cane bagasse.

Apart from reducing N-utilization, Waiss et al (1972) suggested that the production of methylimidazole could lead to toxicity problems since laboratory studies have shown that 4-methylimidazole is quite toxic when fed to mice. This potentially toxic compound was not detected in rice straw treated with ammonia at ambient temperature and incubated for 30 days. At temperatures below 100°C only traces of imidazoles were formed (Dudkin et al, 1969). Studies carried out by Pujszo (1964) showed that ammoniation of sugar beet pulp at ambient temperature and pressure led to ammonia being firmly bound by metoxyl groups of galacturonic acid ester of pectins resulting in the formation of polygalacteronic acid amides and ammonium compounds. These compounds are believed

to be slowly and gradually decomposed by rumen bacteria without causing toxicity.

c) Effect of Treatment Time

Treatment time is one of the most important factors influencing the effectiveness of roughages ammoniations. It interacts with temperature as well as level of ammonia and moisture content of the roughage. In many of the early experiments too short treatment times were used and consequently less satisfactory improvement in the feeding value of roughages were obtained (Sundstøl et al, 1978). Results from many experiments in which 3-4% NH_3 were applied at ambient temperature have demonstrated that for low quality roughages the following minimum treatment times (Table 5) are suitable effective results (Sundstøl et al, 1978).

TABLE 5. Minimum Treatment Period

Temperature	Treatment Time
<5°C	Requires >56 days
5 - 15°C	Requires 28-56 days
15 - 30°C	Requires 7-28 days
>30°C	Less than 7 days

Waagepetersen and Thomsen (1977) found that a combination of low temperature of low NH_3 dosage with treatment time had

positive effects on digestibility. Treatment time also had a slight positive influence on crude protein content especially with times from 3-7 days. These authors concluded that with proper insulation, there is potential in using the rapid rise in temperature (60 - 70°C) during the ammonia reaction to reduce the treatment time and the quantities of anhydrous NH_3 to 2.5-3.5%.

d) Effect of Moisture Content

The moisture content of the roughage influences the rate of reaction of anydrous ammonia, hence its effectiveness. Waiss et al (1972) found no advantage with moisture level higher than 30% and indicated that the 30% level was optimal when rice straw was treated with 5% NH_3 at ambient temperature. In contrast, Sundstøl et al (1978) reported that oat straw showed positive effects of increasing moisture content up to 50% especially when a high level of NH_3 (5 - 7%) was applied. Such high moisture content may, however, cause some distribution problems. Thus the 30% level seems to strike a compromise; but variability in initial moisture level among crop residues must be taken into account.

e) Effect of Species Variation

The inherent between and within species variations (caused by genetic and environmental variables) modify further the effectiveness of NH_3-treatment. This has an important practical implication in terms of recommendation.

The initial quality of the untreated roughage has been suggested to influence the effect of ammonia treatment. The results of experiments carried out by Waiss et al (1972), Kerman et al (1977) and Coxworth et al (1977) indicated that the improvement due to ammoniation is somewhat more pronounced for roughages with a relatively low initial digestibility than those with higher initial digestibility. The crude fibre content of a particular variety of straw (Kernan et al, 1977) was found to be somewhat negatively correlated with the in vitro digestibility of ammoniated as well as untreated straw. However, the increment in digestibility due to ammoniation was similar for both high fibre and low fibre straws. The in vitro digestibility reported by Coxworth et al (1977) showed that legumes responded moderately while sunflower residue showed little improvement in digestibility after ammonia treatment. Since legumes in general have higher lignin content than grass, the moderate response to alkali treatment by the legume residue and the inconsistent relationship between crude fibre and digestibility suggest that the nature of chemical bonding between lignin and other polysaccharides could be the over-riding factor.

2.10 TREATED CROP RESIDUES IN PRODUCTION RATIONS-VARIABILITY AND EFFECTIVENESS

2.10.1 SODIUM HYDROXIDE TREATED RESIDUES

a) Concentrate to Roughage Ratio

Several feeding experiments to determine the potential of

alkali treated crop residues as replacement of part or wholly of the more expensive conventional feeds have been reviewed (Anderson, 1978; Klopfenstein, 1978; Ward, 1978). The results are encouraging but variable. Walker et al (1977) reported that the inclusion of 72% of rice straw treated with 4% NaOH in a lamb ration resulted in slightly poorer gains as compared with the alfalfa ration. In contrast, when the treated rice straw made up only 35% of the ration, even the control ration containing untreated ground straw performed just as well as the treated straw ration. Similar observations were reported by Lamming et al (1967). In another experiment (Agrawal et al, 1976) 3% NaOH-treated paddy rice straw was supplemented with 5 levels (12-36%) of groundnut cake and fed to sheep. There was no difference in digestibility and animal performance between the untreated and treated rice straw supplemented with an amount of groundnut cake greater than 12%. Koers et al (1970) fed steers untreated and ground maize cobs sprayed with 4% NaOH + 1% KCl/100g cobs and supplemented with 20% soybean meal, vitamins and minerals. Average daily gain and feed efficiency for the untreated and treated maize cob-based rations were as follows: 0.30 and 0.72 kg/head/day; and 14.3 and 7.1 kg feed/kg weight gain. Greenhalgh et al (1976) obtained a similar trend when lambs were fattened on diets consisting of 50% barley straw (treated with 8% NaOH or untreated) and 50% concentrate mixture.

The lack of significant differences in digestibility or animal response between the untreated and NaOH-treated crop residues, when supplemented with higher levels of concentrates, suggests that at a higher level of supplementation treated crop residues are used less efficiently. This may not justify chemical processing of crop residues. These observations could indicate an important practical limitation to the use of alkali treated crop residues in higher concentrate diets.

b) Urea Supplementation

The ability of ruminants to utilize crop residues depends on rumen microbial activity which in turn depends on an adequate supply of nutrients especially nitrogen. Cereal residues have inadequate nitrogen to satisfy microbial growth requirements (Borrough et al, 1950; Shrewsbury, 1942). Supplementation of N is therefore required to achieve maximum digestibility and intake.

Donefer et al (1969) measured the effect of NaOH treatment and urea supplementation of ground oat straw. Treatment of the straw with 13.3% NaOH and neutralized with 50% acetic acid resulted in significant increases in digestibility but had no consistent effect on voluntary intake. Supplementation of the treated oat straw with 2.5% urea resulted in an average of 160% increase in voluntary intake when compared with the untreated and unsupplented treated straw. Coombe and Tribe (1962), Hemsley and Moir (1963), Weston (1967), and Faichney (1968) also showed that urea promoted faster passage rates and increased straw intake and gains.

Not all reported results, however, indicate that urea supplementation of straw gave positive response. Where the energy substrate was obtained from a fibrous source not chemically treated, supplementation with urea resulted in poort utilization and low productivity (Coombe et al, 1971). Maximum intakes of cereal residues occurred when small amounts of starch-type carbohydrates were fed in addition to urea or preformed protein (Crabtree and Williams, 1971; Fishwich et al, 1973; Andrews et al, 1972).

2.10.2 AMMONIA TREATED CROP RESIDUES

There is considerable variations in digestibility and animal performance results reported in the literature on ammoniated crop residues (Sundstøl, 1976; Coxworth, 1976). These variations could be due to the type of roughages used, dosages of NH_3 and ammoniation technique (Coxworth et al, 1976; Bergen et al, 1974; Guggolz et al, 1971a; Chomyszyn and Ziolecka, 1972; Oji et al, 1977). According to Chomyszyn and Ziolecka (1972), the amount of nitrogen in the treated roughage could increase by 100-300% above the control depending on the kind of roughage treated and the technique used.

Results from most experiments to date indicate that in spite of the variability ammonia treatment has a positive effect on intake of roughages (Round et al, 1976). When ammoniated crop residues are fed in mixed rations intake and animal performance will depend very much on the amount and nature of the components of the diet. In experiments with balanced rations containing

ammoniated materials, ammonia nitrogen of the feed was found to be utilized to the same degree as that of control feed (Chomyszyn and Ziolecka, 1972). Rumen content, pH and different N fractions as well as concentration of urea N in blood have not shown any significant differences between the animals fed balanced ammoniated and the control rations (Chomyszyn and Kowalezyk et al, 1966; Treal and Krelowska-Kulas, 1970a, 1970b). In experiments with fattening heifers addition of ammoniated feeds to protein-deficient rations increased weight gains by 7-27% and improved feed utilization by 6-27% (Witezak et al, 1969). Experiments to determine the effect of ammoniated feeds on the development of young ruminants (calves and lambs) and their later repreductive ability were conducted by Trela and Kretowska-Kulas, 1970a, 1970b). They found no negative effects from the ammoniated sugar beet pulp when it provided 16-27% ammonia-N of total N in the rations. Poor utilization of ammonia-N has, however, been demonstrated (Oji et al, 1977) with ammoniated maize stover.

The positive results of ammoniation has shown that this alkali has potential as an alternative method for improving the feeding value of low quality roughages. The variability in results suggests that more research is still required to improve the effectiveness of the ammonia treatment in terms of animal response.

2.11 RELATIVE ADVANTAGES AND DISADVANTAGES OF NaOH AND NH_3 TREATMENT

a) Digestibility, Intake and Animal Response

Both methods gave similar improvement in digestibility when comparable crop residues were properly treated (Coxworth, 1976; Walker et al, 1977). Intake and animal response were similarly improved with both chemical treatment of crop residues. However, the NaOH treated crop residues required supplementation with a N source and molasses to achieve maximum intake (Donefer et al, 1969).

b) Cost of Treatment

The current cost of treatment with either NaOH or NH_3 per kg appear similar (Coxworth, 1976). However, when considering the overall cost of processing with NaOH, the cost of supplementing sodium hydroxide processed crop residues with either preformed protein or urea to provide NPN source and that of molasses if added to improve palatability must be added. Factors like initial straw quality, differences in costs from one situation to another and variations among crop residues due to species affect all can influence cost. Therefore, caution should be used in attempting cost comparisons (Coxworth, 1978).

Ammonia is currently derived from natural gas. Thus costs and availability are closely linked to those of this non-renewable resource. The implication is that the cost of ammonia is likely to rise in the future and its availability will be

limited. These constraints, together with world wide demand for nitrogen fertilizers, pose limitations to the future supply of ammonia for processing of crop residues at low cost. Some potential solutions to the above limitations involve the following measures: (i) reduction of dosages of NH_3 from 5% to 2-3% by modification of the ammoniation technique (Waagepetersen and Thomsen, 1977); (ii) re-cycling of manure onto the land to offset fertilizer requirements (Coxworth, 1977); and (iii) generation of ammonia from natural renewable resources e.g. aerobic decomposition of manure (Hasimoto and Ludington, 1971; Adriano et al 1971).

c) Effect on Environment

With the possibility of integrating alkali treatment of crop residues like straws with animal and crop production systems, examination of the possible environmental effects due to such integration becomes necessary. The first factor concerns the possible build up of large amounts of excreted sodium ions in to soils which have received manure from animals fed sodium hydroxide treated straw. It is known that most of the sodium consumed when sodium hydroxide treated straw is fed to animals is excreted from the animal and ends up in manure (Maeng et al, 1971). Thus if such manure were recycled onto the fields, especially where there is insufficient rainfall or where soil drainage is too poor to wash away soluable ions from the top soil, a

serious build-up of sodium ions in the top 15 cm of the soil can occur (Coxworth, 1976). Such potential danger exists in parts of Western Canada (Coxworth, 1976). In contrast, the re-cycling of manure onto the fields from animals fed ammoniated straw is promising since the manute is free from excess sodium. The potential large amounts of nitrogen fertilizers in this form would undoubtedly offset some of the requirements for synthetic N fertilizers and possibly lead to no net increase in ammonia requirement in the integrated system (Coxworth, 1976). Furthermore, such manure improves soil crumb structure thereby improving soil moisture retention and filtration for optimum plant growth (Coxworth, 1976).

d) Nitrogen Enrichment

The ammonia bound to the straw during the reaction can serve as a source of non protein nitrogen (NPN) for microbial protein synthesis in the rumen; hence increased fermentation. This contribution is of particular benefit since most straws, bagasse, stovers and other low quality roughages contain low nitrogen levels (0.5 - 1.0%). However, the ability of ammonia bound in straw to serve as a NPN source still requires clarification in relation to the effectiveness of the utilization of the NPN in the ammoniated straw and the long term toxic properties when high levels of ammoniated straw is fed. In an experiment with treated rice straw (Garret et al, 1974), maize stover (Oji et al, 1977) and wheat straw (Coxworth et al, 1977) the apparent digestibility

of nitrogen was decreased. In contrast, 20-40% units increase in N apparent digestibility was reported with ammoniated barley (Sundstøl et al, 1978). The nitrogen balance studies conducted by Chomyozyn et al (1960) using ammoniated wheat straw indicated that the levels of urea, ammonia and creatinine were normal in blood and urine of sheep fed the straw.

e) Fungicidal Properties of Ammonia

Ammonia treatment also has the advantage that free ammonia acts as an effective fungicide. Guggolz et al (1971) observed that the ammoniation of straw prevented fungal growth during 30 days of storage at room temperature under damp conditions. The germination capacity of some weeds, such as wild oats, is also destroyed during ammonia treatment (Sundstøl, 1978). Knapp et al (1974) found that anhydrous ammonia (1%) was an effective agent for inhibiting molding of damp hay provided the hay was covered to ensure that free ammonia was present during storage. Corn containing 26% moisture was reported to be preserved by treatment with 2% NH_3 (Bothast et al, 1973).

2.12 THE ROLE OF SODIUM IN RUMINANT PHYSIOLOGY AND NUTRITION

SECTION B

2.12.1 GENERAL CONSIDERATION

The living cells of animals require a very special environment to maintain themselved in dynamic equilibrium and perform the complex functions and interactions which constitute the living animals. The extracellular fluid (ECF) which comprises about 15% of body weight, forms the milieu interieur - the internal environment - which bathes the body cells and by its usualconstancy of composition protects them from the drastic changes in the external environment.

Sodium is the principal electrolyte of the ECF and together with its attendant anions are largely responsible for the contribution of approximately 280 mOsm/kg of the total 290 mOsm/kg made by serum electrolytes (Fuisz, 1963). Thus the physiological importance of sodium, so far as it is known to date, is due mainly to its osmotic effects in ECF which influence cellular hydration and its functional relationship to other electrolytes especially potassium. The maintenance of sodium homeostasis is therefore, particularly critical.

2.12.2 PHYSIOLOGICAL FUNCTIONS OF SODIUM

Understanding the physiological functions of sodium requires an understanding of its relationships with potassium. These two major body electrolytes, in most physiological processes, function jointly. They are chiefly responsible for the osmotic pressure of the extracellular and intracellular body fluids. Their concentrations in

body compartments relative to other electrolytes are shown in Table 6.

Sodium in association with potassium is involved in the electrophysiology of cells. Both play a part in the development and existence of the transmembrance potential and in the generation and transmission of electrical impulses. The two ions are also indispensible components of the homeostatic machinery of animals. As essential components of enzymes (Na-K-ATPases) both ions are important in carbohydrate metabolism (e.g. glycolysis and oxidative phosphorylation reactions) and in electron transport systems (Tasker, 1971). Active transport of glucose and amino acids require the presence of sodium. Some important anticoagulants are compounds containing sodium (Tasker, 1971). Water transport in the body is coupled to sodium movement. Disturbance of physiological sodium concentration level either through deficiency or overloading of an animal with sodium can therefore, pose a health hazard.

2.12.3 SODIUM METABOLISM IN RUMINANTS

a) Regulation of Sodium Concentration in Body Fluid

Under a steady-state condition, sodium concentration remains relatively constant in extracellular fluid. This constancy is achieved by continuous fine adjustments of sodium levels by the regulatory mechanisms through control of intake and excretion of sodium. The thirst-ADH and the salt appetite-aldosterone systems are believed to be involved (Houpt, 1977). The coordinating links between these systems are not yet fully understood (Houpt, 1977).

TABLE 6: Electrolyte Concentrations in the Body Compartments (mEq/LITER)[a]

Electrolytes	Compartment		
	Intracellular fluid	Interstitial fluid	Intravascular fluid
Cations			
Sodium	15	147	142
Potassium	150	4	5
Calcium	2	2.5	5
Magnesium	27	1	2
Anions			
Bicarbonate	10	30	27
Chloride	1	114	103
Phosphate	100	2	2
Sulfate	20	1	1
Organic acids	0	7.5	5
Protein	63	0	16

[a] Adapted from Tasker, 1971.

b) Requirements and Intake of Sodium

There is still no conclusive agreement on the sodium requirements of ruminants and little information is available on the optimal K:Na ratio. Part of the reasons for these uncertainties is due to the fact that the dietary requirement of sodium is controlled by losses of this ion from the body which is extremely variable; being influenced by temperature, work and other constituents of the diet especially potassium (Tasker, 1971). Furthermore, the majority of the general accounts and recommendation of sodium and potassium requirements for ruminants are derived from monogastric studies (Ward, 1966; Pickering, 1966; Keynes and Harrison, 1967; Meneely and Battarbee, 1976). While such extrapolation may be justified for ruminants fed concentrate diets, the picture appears different for ruminants feeding mainly on forages and roughages. The natural diet of herbivores contains enormous amount of potassium but the sodium content is relatively low. The high K and low Na content in forages alters the K:Na ratio and the pattern of metabolism of the two elements from what is observed in man and dogs. As a consequence of the high K content in roughages, ruminants and other herbivores normally consume amounts of K greatly in excess of their dietary requirement (Ward, 1966).

In an experiment designed to determine the possible mechanism responsible for the sodium appetite in sheep (Beilharz and Kay, 1963), it was shown that appetite did not depend on the concentration of sodium in the rumen contents of sheep; neither was it a

direct reflection of the concentration of this ion in the plasma. Similar findings were reported by Michell (1977). The sheep in the latter experiment drank an amount of sodium that was approximately equivalent to their sodium deficit. Devlin and Roberts (1963) conducted a balance experiment with wether lambs fed diets low in potassium. They found that the sodium requirement for maintenance was near 44 mEq/l/day (1.19 g) when potassium was fed.

c) Absorption and Secretion

The factors which influence the availability of an element such as sodium include intake, digestibility, absorption, secretion and excretion. This is shown in Figure 6. Generally the load of sodium absorbed from ingested food increases by the amount digested; but increases of 2 to 4 fold occur through increased flow of saliva, gastric, biliary and pancreatic secretions which contains a considerable amount of sodium bicarbonate (Sellers, 1977). Most of the absorptive load, therefore, appears to come from secretions (Sellers, 1977) particularly in the case of ruminants. Because of the large turnover of Na; its concentration in rumen fluid usually exceeds K concentration by a factor of 1.5 to 3.0 (Ward, 1966). The source of K is dietary if forage is the sole source of feed. Bailey (1961) investigated a variety of diets and found K values in saliva of 4-70 mEq/l and in rumen fluid of 24-85

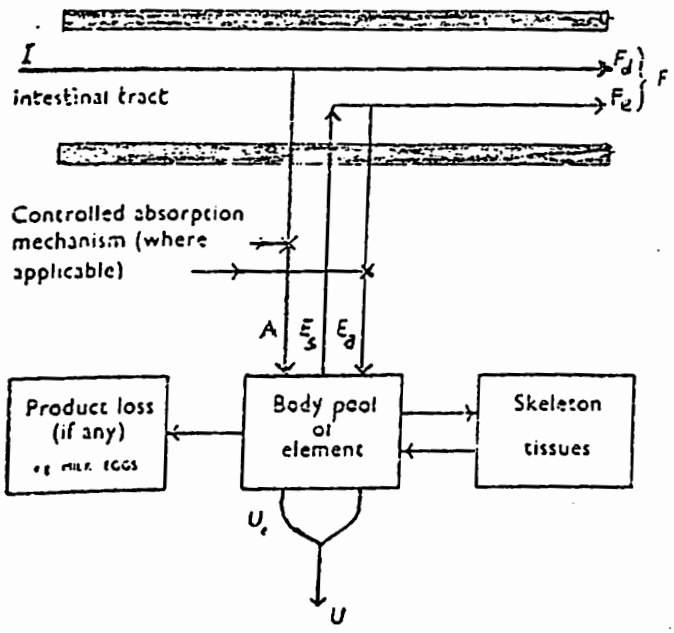

Figure 6. Scheme for mineral absorption and excretion connected with the intestinal tract.
(Adapted from Thompson, 1965).

I, intake of dietary element
F, total excretion of element in faeces
U, total excretion of element in urine
U_e, excretion of element in urine at zero net retention
F_d, faecal excretion of unabsorbed dietary element
F_e, net excretion of element of body origin into intestinal tract
E_s, total endogenous element secreted into intestinal tract
E_a, endogenous element reabsorbed from intestinal tract
A, dietary element absorbed from intestinal tract

Item	Equation (X $\frac{1}{100}$)	
% Apparent digestibility	= I-F	(1)
% True digestibility	= I-(F-F_e)	(2)
% Net retention (R)	= I=(F+U)	(3)
% Availability	= I-(F-F_e)-(U-U_e)	(4)

mEq/l. Comparable values for Na were 70 - 166 and 83 - 147 mEq/l respectively. Argenzio et al (1974) reported that the net exchange of water and electrolytes between the rumen and plasma of the herbivorous pony was associated primarily with a cyclic change in digesta osmolarity resulting from a cyclic pattern of microbial digestion and product accumulation.

Smith (1962) found that the net exchange of sodium in young calves was about 40% of the intake up to the end of the small intestine but absorption of the remaining 60% was almost complete in the large intestine. Using a marker to study absorption in calves, Petty et al (1967), estimated that an average of 133 g of sodium were secreted to the upper small intestine daily. During passage through the lower gut, 87% of the remaining sodium was absorbed from the small intestine and of the 13% left, most was absorbed from the cecum and large intestine.

Hyden (1961) and Parthasarthy and Phillipson (1953) gave evidence which indicated that Na was removed from fluid throughout the entire length of the G.I. tract by a mechanism of active absorption while K entered blood plasma only by flowing down its electrochemical gradient.

d) Excretion of Sodium

Sodium coupled with water is lost from the body in a

number of ways: (i) through sweating during vigorous exercise or in a warm environment; (ii) as fecal water loss which in ruminants can account for appreciable loss of sodium and water (Tasker, 1971); and (iii) via the kidney which is the most important route of sodium excretion in all domestic animals and man (Tasker, 1971).

Perry et al (1966) experimented with dairy heifers using ^{24}Na. They found that a four-day excretion loss of oral ^{24}Na averaged 56% via the urine and 44% via the feces. Nelson et al (1955) studied the effect of high salt intake (6% of the diet) on sodium excretion and on digestibility of nutrients by cattle and sheep. When steers consumed 3.5 g/Na, 41% was excreted in the feces and 54% via the urine. When these same steers consumed 94.4 g/Na, only 3.7% was excreted in the feces and up to 87% was lost via the urine. The authors further observed that there was a reciprocal change in fecal Na and K ratio which tended to influence the relative route of excretion.

In comparing K and Na concentration in human and bovine urine, Anderson and Pickering (1962) found a mean molar ratio (K:Na) of 0.43 (range 0.12 - 0.87) in human urine and 5.3

(range 1.65-20.8) in bovine urine. Studies on sheep showed that the K:Na ratio in urine alone was no less than 175 because only 10% of Na was excreted by this route; 90% being excreted in feces. When the overall excretory K:Na concentration ratio was considered, a value of 17 was obtained. Keynes and Harris on (1967) found a K:Na ratio of 10, while English (1966) reported a value of 6. Brouwer (1961) gave the value for the grass fed ruminant as 20. The wide variations in the K:Na ratios could have been due in part to factors like emotional disturbances of the animal caused by sampling which could give rise to a diuresis and an increased excretion of Na (Anderson, 1961; Pickering, 1965). Feeding may also produce transient alternations in the rate of Na excretion. Stacy and Brook (1964) reported that pen-fed sheep showed acute reduction in the rate of urine flow and in the rate of excretion of Na and K when given feed. The response was interpreted by the authors as a reflection of the sudden shift of extracellular fluid flow into the gut at the onset of feeding.

Pitt (1963) reported that in man less than 10% of the filtered load of K was excreted whereas approximately 50% of the filtered K was excreted by the cow - a consequence of greater dietary turnover of K in the latter species. The large turnover of K over Na in ruminants is believed to be associated with an enhanced excretory reserve capacity (Pickering, 1965). This

evolutionary adaptation enables the ruminant kidney to promote very high rates of K excretion; thus preventing hyperkalaemia.

e) The Mechanisms of Excretion and Retention in the Kidney

The functional organization of the kidney nephron in relation to reabsorption of sodium and water leading to the formation of either dilute or concentrated urine is shown in Figure 7. With excessive sodium absorption such as following the ingestion of a large quantity of sodium, the thirst-ADH system is stimulated and the resulting increased water intake and reabsorption help offset the increased osmalarity of the ECF (Houpt, 1977). As the ECF volume and sodium ion concentration increase the level of body fluid, an osmotic diuresis is stimulated leading to an increased excretion of dilute urine due to the depressed effectiveness of ADH. Reduced sodium concentration would in turn stimulate aldosterone secretion resulting in conservation of sodium. Under this situation, reabsorption of sodium in the kidney is essentially complete. When sodium concentration increases in the ECF the secretion of aldosterone is curtailed and the fraction of sodium delivered to the distal tubule is lost in urine due to lack of reabsorption by the tubular cells. Hence little sodium appears in urine in the former and large amounts excreted in the latter.

The key pathway by which changes in extracellular fluid sodium concentration influence the release of aldosterone is

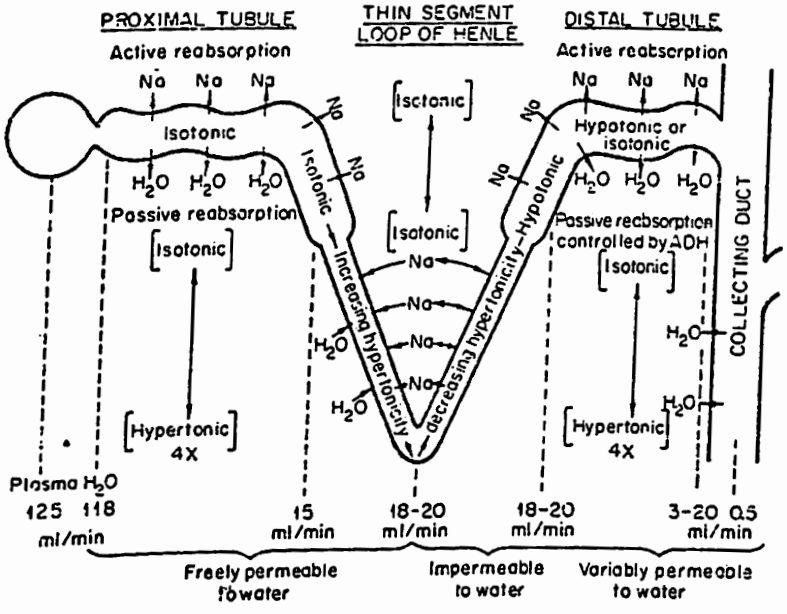

Figure 7. The functional organization of the nephron in relation to reabsorption of sodium and water and formation of dilute and concentrated urine. (Adapted from Tasker, 1971).

by the renin angiotensin system (Oparil and Haber, 1974). When there is a fall in plasma sodium concentration or renal arterial pressure, renin, a proteolytic enzyme, is released from the juxtaglomerular cells located in the afferent arterioles of the kidney glomerulus. Renin then acts in the blood stream upon angiotensinogen, a protein of hepatic origin, forming angiotensin I. The latter is enzymatically converted to angiotensin II as the blood passes through the lungs and other organs. The angiotension II then acts on the adrenal cortex and causes the release of aldosterone which acts in turn on the kidney tubules to increase the reabsorption of sodium (Figure 8). Natriuretic hormone (Wardener, 1973) and adrenocorticotropic hormone (ACTH) also have direct and indirect effects on sodium balance. The former increases sodium excretion while the latter causes the release of aldosterone thereby decreasing sodium excretion. Prolonged ingestion of excess sodium, therefore, could interfere with the release of aldosterone resulting in increased sodium excretion.

In healthy animals the thirst-ADH and salt appetite - aldosterone systems often work together. This could occur following severe hemorrhage when both the renal conservation of water and body sodium are required (Houpt, 1977). However, in mild or moderate dehydration there is usually a conflict between the two systems. In such a case the defence of ECF

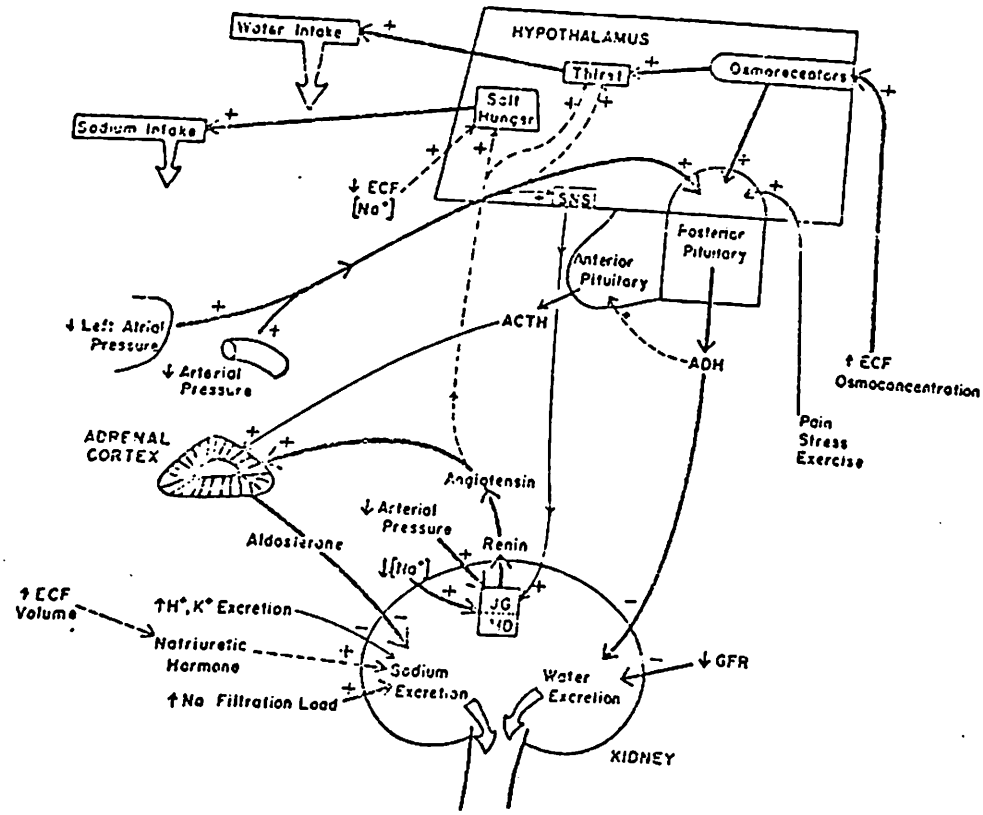

Figure 8. Control of water and sodium intake and excretion.

Key:

———— Well established pathways.
---------- Less well established pathways.

ECF = Extracellular fluid

\+ = positive effects of deviation from the normal level (increase)

\- = negative effects of deviation from the normal level (decrease)

JG = Juxtaglomerular cells

MD = Macula densa

SNS = Sympathetic nervous system

osmo-concentration takes priority and sodium is excreted in greater amounts to match the loss of water (Houpt, 1977). If the loss of ECF is great enough to seriously affect the circulating blood and hence cardiac output, the maintenance of plasma volume would then take precedence (Johnson et al 1970).

When normal water content of the body is altered, like under high sodium intake, the circulation of blood and perfusion of tissues are inevitably affected leading to abnormal metabolic processes within the body. These in turn upset chemical equilibria that are essential to health. Anderson and McCann (1956) and Andersson and Larsson (1961) reported that intake of water was regulated by the thirst centers in the hypothalamus. According to Tasker (1971) the total water available to the body is the sum of drinking water consumed, water in food consumed and water arising from oxidative metabolism in the body.

The extent to which water is excreted or reabsorbed by the distal tubule and collecting duct of the kidney is controlled by antidiuretic hormone (ADH). In the absence of ADH the distal tubule and collecting duct are impermeable to water and the filtered water is lost in the urine. High levels of ADH on the other hand, increase the reabsorption of water which in turn reduces the osmotic pressure of the ECF. Thus the ADH mechanism aids the balance of body water in times of either

overhydration or dehydration. In cattle which produce voluminous feces of high water content the losses of water by this route can be large, averaging about 15 liters / day (Tasker, 1971). Water is also lost via the skin and lungs. Thus when abnormalities of sodium concentration occur in the ECF, they are usually the result of conditions which interfere with the regulation of both water and sodium. Hypernatremia can occur when salt intake is excessive and water intake is restricted.

It appears therefore, that abnormalities in the balance of body water, electrolytes and acid-base is mainly a question of intake and loss (Tasker, 1971). But because of the possible combinations and permutations of these abnormalities, which can occur as a result of the involvement of most of the major body systems through complex integration, fluid balance problems will usually reveal a broad spectrum of derangements.

f) Sodium and Acid-Base Balance

Four acid-base buffering systems are operant within the body. They are: (i) the bicarbonate-carbonic acid system which quantitatively is most important; (ii) the phosphate buffering system of the red blood cells and renal tubule cells; (iii) the plasma and tissue cell proteins; and (iv) hemoglobin (Tasker, 1971). The effects of renal regulation of acid-base balance on Na and K excretion is well illustrated in the bicarbonate-carbonic acid buffer system where sodium reabsorption

is linked to ion-exchange processes (Guyton, 1971). These processes are of great physiological significance in the maintenance of acid-base and ionic equilibria of the body's fluid compartment (Gans and Mercer, 1977; Guyton, 1971; Osbaldiston, 1977).

Unlike the urine normally produced by man and the dog, bovine urine is alkaline in reaction and contains a high concentration of bicarbonate (Anderson and Pickering, 1962). It is believed that sodium is reabsorbed in the distal tubule cells as part of an ion-exchange mechanism which pumps either H^+ or K^+ from the cells into the urine to replace the reabsorbed Na^+. In the bovine the high concentration of bicarbonate in urine is due to the competition between H^+ and K^+ for secretion in exchange for reabsorbed Na^+ (Berliner et al 1951). The kidney of the bovine appears to allow K^+ to take the greater share of the secretion mechanism than normally observed in the monogastric animal kidney. Such preferential secretion of K^+ along with a large dietary intake by the bovine may account for the common alkaline reaction of urine in this species. Pickering (1965) stated that the cow normally does not suffer from a permanent hyperkalaemia metabolic acidosis like the monogastric animal. He attributed this phenomenon to the fortunate coincidence of the natural herbivorous diet having large amounts of K which is part of the excess inorganic cations that underline the excretion

of alkaline urine so as to avoid metabolic alkalosis. This unique renal mechanism in ruminants, therefore, enables Na^+ excretion to be minimal while maintaining a high level of K^+ excretion in urine. This may have practical implication on the feeding of alkali treated roughages relative to K:Na ratios.

g) Sodium and Rumen Fermentation

Sodium and potassium added as bicarbonates to high grain rations of dairy cows have tended to change the rumen pH, molar ratios of short-chain fatty acids and milk fat percentage to values obtained when diets containing larger amounts of hay were fed (Davis et al 1964; Emery, 1965). The rationale for feeding the bicarbonates was that it increased the buffering capacity of rumen fluid which was lowered by the decreased salivary secretion and increased lactic acid associated with the fermentation of high-grain rations. Perhaps of equal importance is the addition of the cation which increases the osmotic pressure of the rumen fluid and tends to maintain a more nearly optimum moisture content in the rumen (Ward, 1966). He observed that proper K:Na ratio was essential for maintaining desirable in vivo medium for bacterial fermentation.

It is generally considered that ruminants requires somewhat less than 0.6% sodium (Morris and Gartner, 1971) and about 0.6% potassium (Devlin et al 1963) for satisfactory rumination and

performance. Cellulose digestion *in vitro* was depressed by an increase in sodium concentration when potassium concentration was low (Petchey and Mbatya, 1977). But digestibility was increased when potassium concentration was high. Hubbert *et al* (1958) showed that potassium was essential for improved *in vitro* cellulose digestion. The finding was further supported by the intake and growth of lambs. This led the authors to conclude that a certain ratio of sodium and potassium exists (unidentified) which should be maintained for maximum cellulose digestion. The relative importance of potassium in improving digestibility was also shown in data summarized by Chappell *et al* (1955) from a number of experiments with cattle and sheep. Maintenance of comparable rumen fluid osmolarity with plasma, which has been reported to be important to sustain desirable moisture content of the rumen fluid for cellulose digestion (Balch and Johnson, 1950; Nicholson *et al* 1960), appear to be the main function of the two ions.

It would appear from limited results that the ionic composition of rumen fluid, especially the K:Na ratio, does have an influence on fermentation in the rumen. As the standard nutritional requirements for sodium and potassium have been determined for animals fed predominantly on cereal diets (Devlin *et al* 1963; Morris and Gartner, 1971), the ruminant animals requirement may be different when fed high roughage diets.

Therefore, if the dietary K:Na ratio is found to be more relevant than the absolute level, the optimum ratio must be established and related to the roughage or fibre level of the diet which will promote better utilization of lignocellulosic materials.

2.12.4 METABOLIC DISORDERS AND ANIMAL PERFORMANCE ASSOCIATED WITH SODIUM STATUS

a) Effects of Sodium Deficiency

Sodium deficiency may develop as a result of inadequate intake, renal insufficiency, adrenocortical failure or due to excessive sweating. With dogs and young ruminants, sodium deficiency can also develop as a result of excessive losses from the GIT during diarrhea or vomiting (Church et al 1974).

Smith and Aines (1959) experimented with dairy cows and reported that the first clinical symptom of sodium deficiency was a craving for salt which developed within 2 weeks. After about two months cows showed signs of pica. A decrease in body weight was noted after 10-11 months and was correlated with a loss of appetite and complete anorexia. The sodium deficient cows also developed dry harsh skin and became restless. Some of the cows developed a staggered gait while others collapsed and died.

Work with twin dairy cows (Helfferich et al 1966, Bertzbach et al 1966; Pfeffer et al 1966) showed that cows on a low sodium

intake (3.2 g and 5.5 g/day) lost a total of 190 g of body sodium during the first seven weeks of lactation. In response to the sodium loss, milk production and body weight fell rapidly and a new sodium equilibrium was established.

b) Effects of Excess Sodium Intake and Accumulation

Excess sodium may accumulate within the animal's body either as a consequence of excessive intake or because of failure to excrete the excess sodium in the urine. The former situation can be brought about by over supplementation of diet with sodium salt or by presence of salt marshes and plants containing high salt concentration in grazing areas. The recent renewed interest in the treatment of lignocellulosic materials with sodium hydroxide (Jackson, 1977) to improve their feeding value is another potential source of increased sodium ingestion. Accumulation of high level of sodium in ECF above the normal range can influence animal health and performance.

Chapman and Gibbons (1959) provided a comprehensive review of the past history of dietary sodium and potassium and their relation to incidence of hypertensive blood pressure. Dustan (1974) pointed out that the retention of as little as 20 mEq/l of sodium per day added one litre of extracellular fluid each week. He further noted that one of the manifestations of chronic sodium chloride toxicity was expanded extracellular fluid volume.

(i) Genetic Influence

Clues regarding differences in susceptibility to excess sodium intake among and within species have existed for decades (Alexander et al, 1954, 1956 and Dahl et al, 1962). Variation of blood pressure among mice was found to be genetically determined and involved many genes (Schlager, 1965; 1968 and Schlager and Weibust, 1967). In earlier work sodium chloride sensitive and resistant strains of rats were developed to explore the genetic component of the variable response (Dahl et al, 1962) and later similar strains of rats were tested on various levels of salt intake (Louis et al, 1969, 1971). Hypertension in all rats was found to occur earlier in life and was worsened by extra dietary sodium chloride. Dahl et al (1963) experimented with rats grouped into four genetic categories. In contrast their clinical observation revealed a genetic dissociation of a number of independent noxious effects of excess NaCl ingestion. Nevertheless, from the comprehensive review (Henry and Cassel, 1969), it is apparent that the genetic factors which explain the phenomenon of individual sensitivity to excess sodium have been recorded in numerous epidomiological studies.

(ii) Ruminant Animals' Response

Numerous short-term experiments using sheep and cattle have been carried out to determine possible harmful effecto of excessive intake of sodium. Elam (1961) and Elam and Autry (1961)

experimented with cattle. They found that 8% NaCl intake decreased digestibility of organic nutrients. A lower level of NaCl (1 or 2%) increased calcium retention. In contrast Meyer et al (1966) fed NaCl at levels ranging from 0.66 to 12.3% of the ration to growing lambs and found no detrimental effect on digestibility or growth. Kidneys were, however, larger in lambs receiving 9.4 or 12.8% NaCl and carcass grades were depressed slightly. Pierce (1957, 1959) provided water containing 1 to 2% NaCl to sheep. He reported that the 1% NaCl level had no adverse effect but the 1.5% level was detrimental to some individuals and 2% was toxic to all the sheep. Decreased food consumption, loss of body weight , occasional diarrhea and increased water intake relative to the amount of NaCl ingested were observed. Similar results were reported by Musely and Jones (1974).

In another experiment to investigate the effect of water restriction on sheep fed diets containing from 7.5 to 15% added NaCl, Wilson and Hindley (1968) observed that restricting access to water once a day caused reduction in feed intake. The reduction was more severe with the more saline diets. However, there was variation in response between Merino and Border Leicester sheep. The former drank less water (5 1/day) than the latter (7.6 1/day). Potter (1963) found that sheep responded to ingestion of saline water (1.3% NaCl) by increased

urinary excretion of sodium and chloride. Urinary pH was increased and osmolarity reduced; but there was no change in kidney function. This was confirmed in subsequent experiments (Potter, 1968). He found that sheep could tolerate added sodium levels (10% NaCl solution) when adapted to saline water by stepping up excretion of sodium and chloride without exhibiting adverse signs.

Weeth et al (1960, 1961, 1962, and 1968) studied the effect of excess salt consumption by cattle under various conditions. They found 1% NaCl in water was tolerated very well by heifers but 2% was toxic and caused severe anorexia, weight loss and dehydration. During winter blood serum sodium and potassium were elevated. In summer 1.2% NaCl in water was toxic probably due to increased demand on water metabolism for cooling purposes. Water consumption was increased, 47 and 69% respectively, by the addition of 1% and 1.2% NaCl to drinking water. Blood hematocrit, pulse and respiration rates were also increased. Further work showed that water containing 1.5% NaCl resulted in increased urinary excretion of urea-N by 37% over animals receiving tap water. Plasma osmolarity increased from the control value of 291 to 332 mosm/kg.

According to Hemsley et al (1975) thirst was induced with increased drinking of up to 2 litres of water daily when sheep were given 150 g of NaCl per day. The increased water intake

caused increased flow of digesta through the rumen with resultant reduction in retention time in the rumen from 20 hrs. to 12 hrs. The consequences of the rapid flow were 24% reduction in organic matter digestibility and decrease in the number of protozoa. Long term effects of such rapid flow of digesta through the rumen have been reported by Walker et al (1971) on carcass composition. Increase in water content because of changes in osmolarity and reduction in fat content were observed. In addition the fat which is laid down tended to be of a less-saturated type due probably to less opportunity for the hydrogenation of the unsaturated fatty acids in the rumen.

It appears that sheep will adapt readily to 1.3% saline as drinking water but 2% is toxic (Payne, 1977). Cattle would tolerate 1% but 2% would cause anorexia, weight loss and dehydration. In hot weather the toxicity of saline is greater than in cold weather because of the greater strain on water metabolism to keep cool.

(iii) Monogastic Animals' Response

Ingestion of excess dietary sodium chloride over a period of time can cause changes in gastric secretion, permeability and morphology of stomach cells of monogastric animals. A concentration of about 0.5 molar NaCl solution in the stomach of a dog would be near the threshold for inhibition of acid secretion in the dog (Rehm et al 1953) and rat (Sernka and Jackson, 1975).

At slightly higher concentration sodium chloride produced an increased permeability to ions through the gastric mucosa of the cat (Frenning, 1974). The same wuthor through scanning electron microscopy observed that such sodium concentrations produced disruptions and intercellular openings in the surface epithelium of the cat gastric mucosa (Frenning, 1973).

However, dogs can consume an astonishing amount of salt without apparent ill effect provided its renal tissues are functioning normally (Meneely and Battarbee, 1976). Rats eating excess sodium chloride with extra potassium showed dramatically enhanced survival with resultant prolongation of their average life duration by two to eight months (Meneely and Ball, 1958). Ingestion of excess sodium has been reported to influence fat metabolism. Dahl (1960) reported that among rats and dogs fed excess sodium chloride, plasma cholesterol elevations were frequent. Increasing dietary sodium chloride from 4 g to 24 g per day significantly altered the clearance of intravenously administered fat from the blood stream of human volunteers (Talbott, 1961). It is suggested (Drori, 1976) that NaCl in the food produces hypodipsia (i.e. a failure to drink an optimal amount of water), causing changes in electrolyte balance which reduce food intake and progressively reduce the efficiency of fat synthesis.

Alkali treatment of diets containing 20% soybean protein was found to cause nephrocytomegalia in rats (DeGroot et al,

1976). The nephrotoxic properties were imparted to the protein by alkali treatment which caused destruction of amino acids and formation of new amino acids like lysinoalanine (LAL). The latter on complete hydrolysis induced considerable renal activity (DeGroot et al, 1976). But so long as such amino acids remain protein-bound, their toxic effect on the kidney was minimal.

There is an important syndrome of acute salt poisoning in pigs as well. The spontaneous disease is complicated and caused by an interrelationship between water availability, dietary salt, and dietary protein (Deutschlander, 1974). The clinical signs described by Osweiler and Hurd (1974) included thirst, blindness, deafness, constipation, and convulsive seizures. Serum sodium concentration rises above 105 mEq/1 and cerebrospinal fluid may rise even higher. Post mortem examinations showed evidence of fatty liver and cerebral edema. Mason and Scot (1974) reported that pigs are also tolerant to excess salt provided drinking water is freely available.

From these studies, it appears that the availability of fresh water and the extent to which the kidney can excrete urine containing the various concentrations of salt or sodium can influence the severity of toxicity. Young and light pigs (6.1 - 10 kg) are less resistant to salt toxicity than old ones (Adamesteanu et al, 1972).

(iv) Sodium-Potassium Interaction on Blood Pressure

Addison (1928) found that potassium salt regularly produced

a decline in blood pressure while sodium produced the opposite effect. Similar additional information was reported by Berghoff and Geraci (1929) and Thompson and McQuarrie (1933). In another experiment (McQuarrie et al, 1936) it was found that potassium lowered hypertensive blood pressure although the dietary salt intake remained high. A low incidence of apoplexy and comparatively low blood pressure were reported among a Japanese population whose diet was high in sodium chloride and who were also eating a high level of potassium in the form of fruit (Sasaki, 1962). These findings suggest further that the addition of extra potassium to a diet containing a high level of sodium could be beneficial; provided the extra potassium does not elevate its concentration to toxic levels to influence cardiac function. The results further indicate that K:Na ratio may be a more important factor than their individual absolute value.

3 EXPERIMENTAL

3.1 INTRODUCTION

The studies reported herein were conducted in three phases. The first phase consisted of three digestion and nitrogen balance experiments. Phase two involved measurement of feedlot performance. In the third phase three digestion and nitrogen balance experiments were again run. Prior to putting steers on the test diets and during the ad libitum intake period, blood samples were taken. At the end of each digestion and nitrogen balance experiment rumen fluid samples were obtained from each steer. After the third phase the steers were slaughtered for the purpose of measuring carcass characteristics and evaluating rumen papillae, liver and kidney tissues.

3.2 MATERIALS AND METHODS

a) Animals

Eighteen (F_1, Charlais x Hereford) crossbred steers averaging 216 kg were used for the studies. The steers were matched for age and weight and then randomly assigned to the dietary treatments. Each were individually penned during the adjustment phase and similarly confined to metabolism crates during restricted feeding and collection periods. Water was available ad libitum and feeding was done twice daily at 8:30 a.m. and 4:00 p.m.

During feedlot performance studies, the steers were group fed their respect diets and had access to water continuously. Weights

were taken at two weeks intervals in the morning before the steers were fed. Water was withdrawn for 12 hours pre-weighing.

b) Ration Formulation

Three experimental diets in pelleted form (15.5 mm in diameter) were used. The diets consisted of the following Neepawa wheat straw (NWS) treatments: (i) untreated, (ii) 5% NaOH treated or (iii) 3.5% NH_3 treated straw. A modification of the "Dry Method" described by Rexen and Thomsen (1976), was used for the sodium hydroxide treatment. During the experimental period, batches of Neepawa wheat straw with moisture content of 8-10% were hammermilled through a 1/4 screen and transferred to a feed mixer. Concentrated solution of commerical sodium hydroxide (50% W/W) was then sprayed onto the hammermilled straw (5 g NaOH/ 100 g straw DM) while being mixed. After 10 minutes of mixing the treated straw was steamed pelleted into 5/8 pellets so that the heat produced during pelleting process could complete the chemical reaction. The dense hard pellets were reground and 60% of the ground straw incorporated into the final diet. The ambient temperature ammoniation technique (Kernan et al, 1977) was used for the anhydrous ammonia treatment. This involved covering the stacks with a gas-tight plastic and injecting anhydrous ammonia (3.5 gNH_3/100 g straws DM) into the stacks. The treated materials were then left sealed for 30 days before opening the stacks. The ammoniated straw was left in the open for 9 months prior to start of the experiment. By this time the CP had declined from 9% to 6% and the in vitro organic matter digestibility (OMD) had also declined from 41% to 39%. The control straw was also

9 months old at start of the experiment. Both the ammoniated and untreated straws were hammermilled and 60% of each was included in the respective diets (Table 7). The OMD of the untreated straw at the start of the experiment was 32% and increased to 33% at end of the trial.

The percent composition of the three diets is shown in Table 7. Neepawa wheat straw constituted 60% of the diet. One percent urea was added to the control and NaOH diets to provide NPN source to balance that in the ammoniated straw. To improve the palatability, especially of the NaOH diet, 2% molasses was added to each diet. Chemical composition of the diets is given in Table 8. The three diets were similar in crude protein and gross energy as predicted by computation.

c) Digestion and Nitrogen Balance

Two series of digestion and nitrogen balance experiments were conducted. The first series ended at after 30 days on the test diets and the second series were run between 240 and 270 days on the test diets. Each digestion and nitrogen balance experiment consisted of 10 days adjustment phase and 10 days ad libitum intake in individual pens. This was followed by 5 days restricted feeding at 70% of ad libitum intake and 5 days total collection of feces and urine in individual metabolism crates.

d) Collection and Measurement

Daily feces voided by each steer was collected in a galvanized metal tray. The feces were weighed fresh every morning at 9:00 a.m. and a 10% sample taken. Urine was collected in properly covered plastic containers. Galvanized metal trays with narrow necks were used

TABLE 7 Percent Composition of Ration

Ingredients %	Treatment		
	Control	5%NaOH	3.5%NH_3
Wheat Straw	60	60	60
Barley	23	23	23
Soy bean	12	12	13
Urea (45%N)	1	1	-
Molasses	2	2	2
Ca-P source *	0.5	0.5	0.5
Vitamin Premix+	1.0	1.0	1.0
Salt (I + Co)	0.5	0.5	0.5

* Cy. Phos: 18.5% Calcium; 20.5% Phosphorus

+ Supply: (i) 4400 IU of vitamin A per kg of feed
(ii) 880 IU of vitamin D per kg of feed

TABLE 8. Chemical Composition of the Ration

Item	Treatment		
	Control	NaOH	NH_3
D M (%)	91.4	91.9	92.1
C P (%)	12.1	12.2	12.3
E. Ext. (%)	1.4	1.6	1.4
N.F.E. (%)	47.4	49.6	46.1
A D F (%)	34.9	30.1	34.5
Gross Energy (Mcal/kg DM)	4.1	4.1	4.2
pH	6.4	7.7	6.3

for draining urine into the plastic containers. Daily urine volumes were measured and a 10% sample taken. Urine samples intended for N analyses were placed in bottles containing 6N HCl as suggested by Martin (1966) and frozen until required for analyses. Neither NCl (Martin, 1966) or 85% orthophosphoric acid (Ross and Kitts, 1970) was added to the samples intended for electrolytes and osmolarity analyses.

Water consumption per day was measured using a Bedgar meter (Fig. 9). Rumen fluid was taken 3 - 4 hrs after feeding at the end of each digestion trial using a stomach tubing technique.

(e) Sampling and Preservation

The fresh samples of feces were weighed and dried in a forced draft oven at 65°C for 3 days. The dry samples were then weighed, ground and stored in the cold room for analyses. The urine samples were strained through layers of cheese cloth and their pH measured immediately before they were frozen until required for analyses. Rumen fluid samples were similarly strained and pH measured. This was followed by centrifugation of the rumen fluid for 20 minutes at 7,000 r.p.m. The supernatants were decanted and frozen for VFA analyses.

At the end of each ad libitum intake period, three blood samples were withdrawn from the jugular vein of each steer. Samples for baseline data were taken before putting the steers on their respective test diets. All of the samples were taken between 8:00 - 8:30 a.m. prior to the morning feeding. Eight ml of heparinized blood, for blood gas analyses, were withdrawn using a sterilized disposable monoject needles (18 GA, 1½A) and 12 ml syringes. Ten ml of blood samples without

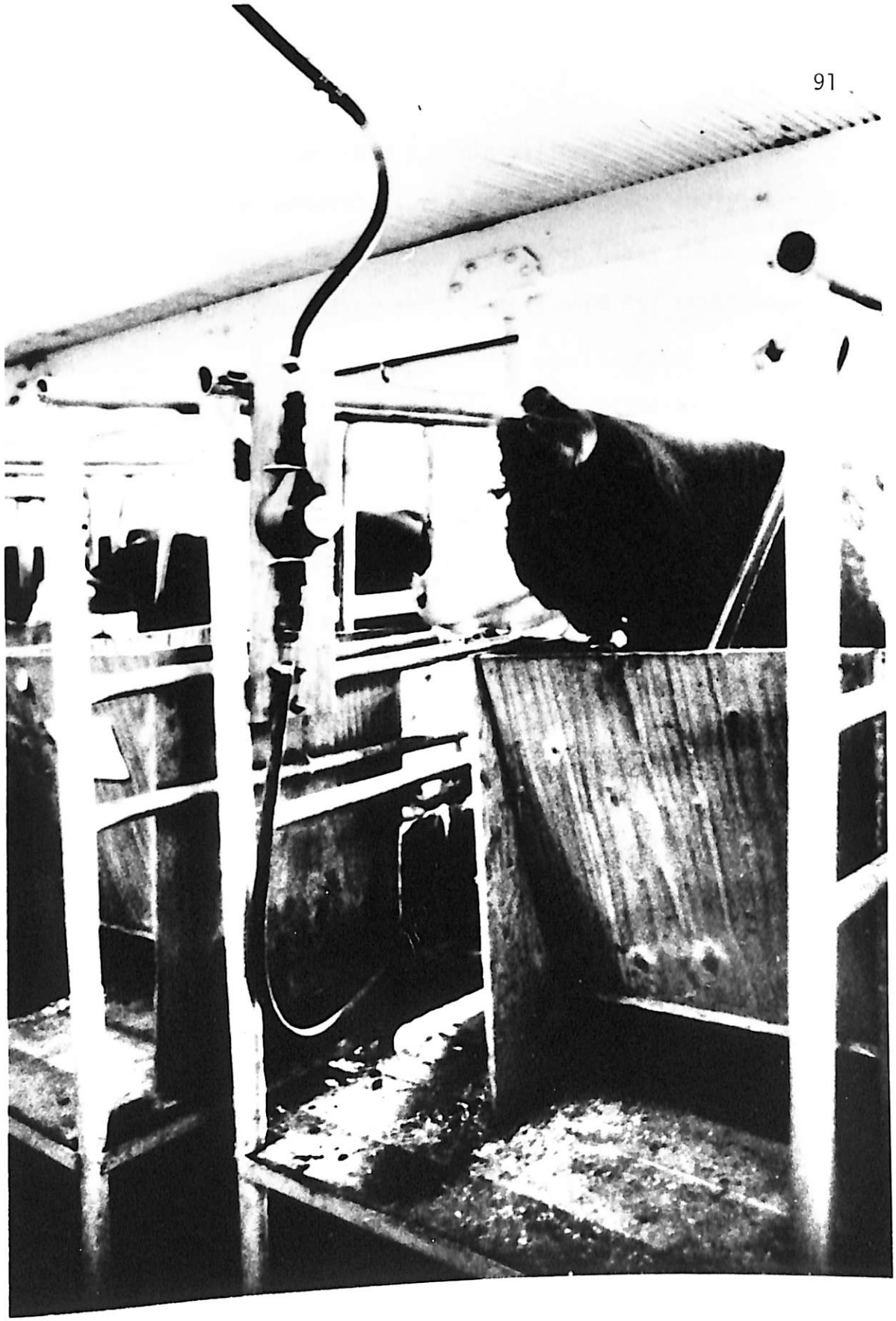

Figure 9. A Bedger meter used for recording water intake.

anticoagulant were withdrawn into a plain silicone coated vacuum venoject glass tube for mineral, total protein and BUN analyses. Five ml of blood was withdrawn into vacujm collection glass tubes containing 0.05 ml of EDTA. The latter samples were used for hematological determinations.

On the morning of slaughter at the Intercontinental Packers Ltd., representative samples of fresh rumen, liver and kidney tissues from each steer were taken and immediately fixed in 10% neutral buffered formalin in labelled jars. Following adequate fixation, all tissues were dehydrated, embedded in paraffin, sectioned at 6 μ and stained with hemotoxylin-easin for microscopy observations. Hot carcass weights were taken soon after slaughter. Ribeye areas and fat thickness were measured from the 12th rib after 24 hours of chilling carcass at 0 - 2°C.

f) Chemical Analyses

Chemical analyses were carried out using the following methods:

(i) Nitrogen content of the diets, urine, and feces were determined by the macro-Kjeldhal method of AOAC (1970).

(ii) Ether extract, NFE, ash and moisture in the feed and feces were also determined by the procedures outlined by AOAC (1970). Gross energy was determined by oxygen bomb calorimetry.

(iii) Acid-detergent fibre was determined according to the method of Van Soest (1967).

(iv) Total and individual VFA were analysed by the gas chromatography method described by Kellogg (1973).

(v) Blood gas analyses were carried out using the Corning pH/blood gas model 161 (Corning Scientific Instruments, 1976). Blood hematological parameters were determined using the Auto-Coulter Counter Model S (Coulter Electronic Inc., 1976).

(vi) Osmolarity of urine, rumen fluid and plasma were measured with an osmometer (Precision Systems Inc., 1976) by the freezing point depression procedure.

(vii) Urine specific gravity was determined with an American Optical TS refractometer (AO, 1976).

(viii) BUN was determined using A-Gent BUN Test based on hexokinase G.6PDH method (Abbott, L.D.D., 1976). Creatinine in the urine and blood was determined using the Abbott Biochromatic Analyses (ABA-100TM) procedure developed by Abbott Laboratories, 1976.

(ix) Minerals: Na and K were determined using the flame photometry method. P was determined by the Pierce's phosphorus Auto/Stat TM Kit. Mg was determined using the Pierce's magnesium Rapid Stat TM Kit (Pierce, 1974). Ca was determined by the Fluorometric method using Corning Model 940 Ca-analyser (Corning Scientific Instruments, 1973).

g) Experimental Design and Statistical Analyses

Randomized block design was used for digestion and N-balance experiments and related measurements.

Data from digestion, nitrogen balance, blood samples, feces and rumen fluid samples were statistically analysed using the two-way Model I ANOVA. One-way ANOVA was used for carcass characteristic data

as suggested by Steel and Torrie (1960). Repeated measurement split-plot and completely randomized analyses techniques (Gill and Hafs, 1971) were used for weight gain data. The IBM 370 computer was used for the statistical analyses and the results verified with Tl programmable 57 Texas instrument hand calculator. The level of significance was set at $P < 0.05$.

Bartlett's test for homogeneity of variance was done on the data prior to statistical analyses (Sokal and Rohlf, 1969). Tukey's test for nonadditivity was used to ascertain whether the interactions could be explained in terms of multiplicative main effects (Tukey, 1949). The Student-Newman-Keuls (SNK) procedure was used for the separation of the means (Sokal and Rohlf, 1969).

4. RESULTS

4.1 Intake and digestibility

The effects of dietary treatments on voluntary intake and apparent digestibility are presented in Table 9. Dry matter digestibility (DMD) improved slightly with chemical treatment and with time. These differences were not significant ($P \geq 0.05$). Both the DMD and organic matter digestibility (OMD) was not influenced by period ($P > 0.05$). The pooled means did however show that OMD was significantly ($P < 0.05$) higher for the NaOH diet compared to the other two diets. The digestibility of the nitrogen free extract (NFE) decreased with time ($P < 0.05$) and its value was significantly ($P < 0.05$) higher for the NaPH diet than for the NH_3 diet. No significant difference was found between the control and NaOH diets. Mean crude fiber digestibility (CFD) was significantly ($P < 0.05$) higher for NaOH diet than for the control or the NH_3 diet. Period x treatment interaction was signficant ($P < 0.05$). There was significant ($P < 0.05$) improvement in CFD in the long term for all treatments. Digestible energy declined with time ($P < 0.05$) and there was a significant ($P < 0.05$) difference between the NaOH diet and the NH_3 diet.

There was no significant ($P > 0.05$) treatment differences in voluntary intake when expressed as $g/kgw^{0.75}$ (Table 9). Period x treatment interaction and period effects were significant ($P < 0.05$). Intake expressed as a percentage of body weight was different ($P < 0.05$) between periods but there was no treatment difference

TABLE 9 Voluntary Intake and Apparent Digestibility

Item	Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
Digestibility					
Dry matter dig. %	30	56.6^{a}	58.0^{a}	56.2^{a}	56.9^{A}
	270	57.1^{b}	58.4^{b}	58.6^{b}	58.0^{A}
	Pooled mean	56.8^{x}	58.2^{x}	57.4^{x}	
Organic matter dig. %	30	57.5^{a}	59.7^{b}	57.4^{a}	58.2^{A}
	270	58.3^{bc}	60.5^{b}	57.1^{c}	58.6^{A}
	Pooled mean	57.9^{y}	60.1^{x}	57.2^{y}	
N F E dig. %	30	67.0^{a}	70.9^{b}	67.8^{a}	68.6^{A}
	270	66.8^{b}	66.3^{b}	63.3^{c}	65.6^{B}
	Pooled mean	66.9^{yx}	68.6^{x}	65.8^{y}	
Crude fibre dig. %	30	38.7^{a}	40.8^{b}	34.4^{c}	38.0^{A}
	270	42.5^{b}	48.7^{c}	46.7^{d}	46.0^{B}
	Pooled mean	40.6^{y}	44.7^{x}	40.5^{y}	
Digestible energy %	30	58.0^{a}	59.3^{a}	57.8^{a}	58.4^{A}
	270	56.6^{b}	59.0^{a}	54.5^{b}	56.7^{B}
	Pooled mean	57.3^{y}	59.2^{x}	56.2^{y}	
Voluntary Intake					
Dry matter intake $g/kgW^{0.75}$	30	129.7^{b}	144.7^{a}	136.0^{c}	136.8^{A}
	270	118.6^{c}	104.7^{b}	117.7^{c}	113.7^{B}
	Pooled mean	124.2^{x}	124.7^{x}	126.9^{x}	
Intake as % body wt.	30	3.2^{a}	3.5^{a}	3.3^{a}	3.3^{A}
	270	2.6^{b}	2.2^{b}	2.6^{b}	2.5^{B}
	Pooled mean	2.9^{x}	2.8^{x}	2.9^{x}	

1. ^{a,b,c,d} Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B} Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y} Pooled treatment means for each item with different superscript are significant ($P < 0.05$)

($P > 0.05$).

4.2 Nitrogen intake and metabolism

Daily nitrogen intake, excretion and balance are presented in Table 10. There was no significant ($P > 0.05$) treatment differences in pooled mean nitrogen intake but intake increased significantly ($P < 0.05$) between period for the control and NH_3 diets. Significant ($P < 0.05$) treatment differences were found within each period but were not consistent. Intake of nitrogen decreased on the NaOH diet in the long term. N intake expressed as $g/kgW^{0.75}$ showed no significant ($P > 0.05$) treatment effect. Urinary nitrogen was significantly ($P < 0.05$) low for the control diet compared to the values for the NaOH or the NH_3 diet. There was a significant ($P < 0.05$) period effect due mainly to the substantial reduction by urinary N for NaOH treatment in the long term. A similar trend was found when urinary N was expressed as $g/kgW^{0.75}$. Fecal nitrogen was significantly ($P < 0.05$) higher for the NH_3 diet as compared to the control or NaOH diet. Period effects on fecal nitrogen was significant ($P < 0.05$) for steers fed the control or NH_3 diet. Mean nitrogen balance was significantly ($P < 0.05$) different between treatments and between periods. There was significantly ($P < 0.05$) higher N retention by steers fed the control diet compared to those on the NaOH or NH_3 diet. N retention increased with time for all treatments.

The urinary expressed as a percentage of intake was significantly ($P < 0.05$) lower for the control diet compared to the alkali treated

TABLE 10 Nitrogen Intake, Excretion and Balance

Item	Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
N intake g/day	30	109.6^{b}	130.0^{a}	114.0^{ab}	117.9^{A}
	270	140.3^{bc}	122.0^{b}	146.0^{c}	136.2^{B}
Pooled mean		125.0^{x}	126.0^{x}	130.0^{x}	
N intake g/$Wkg^{0.75}$/day	30	1.60^{a}	1.89^{a}	1.69^{a}	1.73^{A}
	270	1.46^{a}	1.17^{a}	1.49^{a}	1.37^{A}
Pooled mean		1.53^{x}	1.53^{x}	1.59^{x}	
Urinary N g/day	30	58.8^{a}	80.8^{b}	65.1^{c}	68.1^{A}
	270	57.8^{b}	57.2^{b}	68.0^{c}	61.0^{B}
Pooled mean		58.2^{x}	68.9^{y}	66.6^{y}	
Urinary N g/$Wkg^{0.75}$ per day	30	0.86^{a}	1.17^{b}	0.96^{c}	1.00^{A}
	270	0.60^{d}	0.55^{d}	0.70^{e}	0.62^{B}
Pooled mean		0.73^{x}	0.86^{y}	0.83^{y}	
Fecal N g/day	30	34.8^{b}	33.8^{b}	40.4^{a}	36.1^{A}
	270	39.7^{a}	32.8^{b}	55.0^{c}	42.5^{B}
Pooled mean		36.8^{y}	33.3^{z}	47.7^{x}	
N balance g/day	30	16.0^{b}	15.4^{b}	8.5^{a}	13.3^{A}
	270	42.8^{b}	32.0^{c}	23.0^{d}	32.6^{B}
Pooled mean		29.4^{z}	23.7^{y}	15.7^{x}	
N balance g/$Wkg^{0.75}$ per day	30	0.23^{a}	0.22^{a}	0.13^{b}	0.19^{A}
	270	0.45^{c}	0.31^{d}	0.24^{e}	0.33^{B}
Pooled mean		0.34^{x}	0.27^{y}	0.18^{z}	
Urinary N as % intake	30	53.6^{b}	62.2^{a}	57.1^{c}	57.6^{A}
	270	41.2^{b}	46.9^{d}	46.6^{d}	44.9^{B}
Pooled mean		47.4^{x}	54.6^{y}	51.9^{y}	
Fecal N as % intake	30	31.8^{b}	26.0^{a}	35.4^{c}	31.1^{A}
	270	28.3^{a}	26.9^{a}	37.7^{b}	31.0^{A}
Pooled mean		30.1^{y}	26.5^{x}	36.6^{z}	
N digested %	30	68.2^{a}	74.0^{b}	64.6^{c}	68.9^{A}
	270	71.7^{a}	73.1^{a}	62.3^{b}	69.0^{A}
Pooled mean		69.9^{y}	73.5^{z}	63.5^{x}	
N retained as % intake	30	14.6^{a}	11.8^{b}	7.5^{c}	11.3^{A}
	270	30.5^{d}	26.2^{c}	15.8^{b}	22.2^{B}
Pooled mean		22.6^{y}	19.0^{z}	11.6^{x}	
N retained as % digested	30	21.4^{a}	16.0^{b}	11.5^{c}	16.3^{A}
	270	42.5^{d}	35.9^{a}	25.3^{b}	34.6^{B}
Pooled mean		31.9^{z}	25.9^{y}	18.4^{x}	

1. a,b,c,d,e, Means within a row for each item with different superscript are significant ($P < 0.05$).
2. A,B, Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. x,y,z, Pooled treatmtne means for each item with different superscript are significant ($P < 0.05$).

diets. Its values decreased ($P < 0.05$) with time for all treatments. Fecal nitrogen expressed as a percentage of intake was not affected by period ($P > 0.05$) but treatment differences were significant ($P < 0.05$). Pooled mean fecal nitrogen of steers fed NH_3 diet was higher than for the control or the NaOH diet. Digested nitrogen was significantly ($P < 0.05$) low for the NH_3 diet as compared to the control or the NaPH diet. The values for the control and the NaOH diets were also different ($P < 0.05$). Nitrogen retained expressed as a percentage of N-digested was similarly ($P < 0.05$) influenced by dietary treatments and periods. Period x treatment interaction effects were significant ($P < 0.05$) for nitrogen retained whether expressed as percentage of intake or of digested nitrogen.

4.3 Volatile fatty acids

The molar proportions of acetic, propionic, iso-butyric, n-butyric, iso-valeric and n-valeric and total VFA (mmole/liter) are presented in Table 11. The acetic acid molar proportion was significantly ($P < 0.05$) reduced in the long term but there was no significant ($P > 0.05$) treatment difference. Significantly ($P < 0.05$) higher molar proportions of propionic acid were obtained from rumen fluids in the short term but these values declined in the long term. Pooled means show relatively ($P \geq 0.05$) lower propionic acid for the control diet than for the other two diets. There were no significant ($P > 0.05$) treatment differences in iso-butyric, n-butryic, iso-valeric and n-valeric acids molar proportions. The molar proportion of n-butyric acid did however increase significantly ($P < 0.05$) in the long term

TABLE 11 Volatile Fatty Acids in Rumen Fluid

Item	Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
Molar proportions					
Acetic acid %	30	59.9^{b}	57.1^{a}	59.3^{b}	58.8^{A}
	270	56.6^{a}	56.7^{a}	54.4^{d}	55.9^{B}
	Pooled mean	58.3^{x}	56.9^{x}	56.9^{x}	
Propionic acid %	30	24.7^{a}	27.7^{b}	26.3^{b}	26.2^{A}
	270	21.6^{c}	23.2^{c}	26.2^{b}	23.7^{B}
	Pooled mean	23.2^{y}	25.5^{y}	26.3^{y}	
Iso-Butyric acid %	30	1.3^{a}	1.1^{b}	1.3^{a}	1.2^{A}
	270	1.8^{c}	1.0^{d}	1.5^{c}	1.4^{A}
	Pooled mean	1.6^{y}	1.1^{y}	1.4^{y}	
n-Butyric acid %	30	10.4^{a}	10.4^{a}	8.9^{b}	9.9^{A}
	270	16.0^{cd}	16.9^{c}	15.0^{d}	16.0^{B}
	Pooled mean	13.2^{x}	13.7^{x}	12.0^{x}	
Iso-Valeric acid %	30	2.2^{a}	2.1^{a}	2.3^{a}	2.2^{A}
	270	2.0^{b}	1.2^{c}	1.7^{b}	1.6^{B}
	Pooled mean	2.1^{x}	1.7^{x}	2.0^{x}	
n-Valeric acid %	30	1.5^{a}	1.6^{ab}	1.9^{b}	1.7^{A}
	270	1.6^{a}	1.5^{a}	1.3^{b}	1.4^{A}
	Pooled mean	2.1^{y}	1.7^{y}	2.0^{y}	
Total V F A conc. mmole/l	30	108.3^{b}	158.6^{a}	113.4^{b}	126.8^{A}
	270	109.9^{c}	147.0^{b}	100.9^{c}	119.2^{B}
	Pooled mean	109.0^{y}	152.8^{x}	107.2^{y}	

1. ^{a,b,c,d,e}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

for all treatments. The iso-butyric, iso-valeric, and n-valeric acids molar proportion tended to decrease in the long term especially for the NaOH diet. There was significantly ($P < 0.05$) higher total volatile fatty acid concentration in the rumen fluid of steers fed the NaOH diet than for the control or the NH_3 diets. Period and period x treatment effects were significant ($P < 0.05$) for all the parameters.

4.4 Rumen fluid electrolytes, pH and osmolarity

The rumen fluid electrolyte concentration, pH, osmolarity and potassium'sodium ratios are presented in Table 12. Sodium concentration was significantly ($P < 0.05$) reduced in the long term. There was no significant ($P > 0.05$) treatment difference in rumen fluid sodium concentration though the mean value for the NH_3 diet was relatively low. Potassium concentration was also reduced in the long term ($P < 0.05$). However K concentration was significantly ($P < 0.05$) higher in the rumen fluid of steers fed NaOH diet compared to the control or NH_3 diet. There was no significant ($P > 0.05$) treatment difference in the pooled mean of chloride concentration. However, chloride concentration in the rumen fluid was significantly ($P < 0.05$) reduced in the long term. Rumen osmolarity significantly ($P < 0.05$) declined in the long term for all treatments. Nevertheless, despite the decline, significantly ($P < 0.05$) higher rumen osmolarity was main ained in the rumen fluid from steers fed the NaOH diet compared to the control or the NH_3 diet. The pooled mean of rumen pH for NaOH approaches a significant level ($P > 0.05$). There was a lower K:Na ratio for the NaOH diet as compared to the control or the NH_3 diet.

TABLE 12 Rumen Fluid Electrolytes, pH and Osmolarity

Item	Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled Period Mean
Na^+ mEq/liter	30	176.2^{a}	168.2^{a}	173.0^{a}	173.4^{A}
	270	107.0^{b}	111.8^{b}	99.8^{a}	106.2^{B}
	Pooled mean	143.1^{y}	140.0^{y}	136.4^{y}	
K^+ mEq/liter	30	26.0^{a}	34.8^{b}	28.2^{a}	29.7^{A}
	270	19.5^{b}	24.2^{c}	17.5^{b}	20.4^{B}
	Pooled mean	22.8^{y}	29.5^{x}	22.8^{y}	
Cl^- mEq/liter	30	71.5^{b}	69.7^{ab}	64.0^{a}	68.4^{A}
	270	13.7^{b}	15.3^{b}	14.5^{b}	14.5^{B}
	Pooled mean	42.6^{x}	42.5^{x}	39.3^{x}	
Osmolarity mOsm/kg	30	388.7^{a}	446.0^{b}	400.8^{ab}	411.8^{A}
	270	281.8^{bc}	337.0^{c}	260.3^{b}	291.4^{B}
	Pooled mean	335.3^{x}	389.0^{y}	330.6^{x}	
pH	30	6.0^{a}	5.7^{a}	5.9^{a}	5.9^{A}
	270	6.2^{b}	5.9^{b}	6.2^{b}	6.1^{A}
	Pooled mean	6.1^{x}	5.8^{x}	6.1^{x}	
K:Na ratio	30	1:6.8	1:4.8	1:6.1	
	270	1:5.5	1:4.6	1:5.7	

1. ^{a,b,c}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

4.5 Water consumption and excretion

Water intake, urinary excretion and fecal water are presented in Table 13. Steers fed the NaOH diet drank significantly ($P < 0.05$) higher quantities of water per day and per kg of feed DM compared to those on the control or the NH_3 diet. They also excreted significantly ($P < 0.05$) larger volumes of urine (liters per day or ml per $kgW^{0.75}$) compared with the steers on the control or the NH_3 diet. Water intake of the steers fed the NaOH diet was positively correlated ($r = 0.84$) with DM feed intake. However, water intake and urine excretion by the steers fed the NaOH diet were significantly ($P < 0.05$) reduced by 270 days.

Fecal water loss was significantly ($P < 0.05$) reduced in the long term by steers fed the NaOH diet compared with those fed the control and NH_3 diets. Period and period x treatment interaction effects were significant ($P < 0.05$). Fecal water expressed in liters per kg feces DM was significantly ($P < 0.05$) reduced for all treatments in the long term. Analysis of the pooled data showed that significantly ($P < 0.05$) more water was lost per kg of fecal DM by the steers fed the NH_3 diet.

4.6 Urine composition

Urine electrolytes, urea, osmolarity, pH, creatinine and specific gravity are presented in Table 14. There was significant ($P < 0.05$) treatment differences in sodium concentration. Urine from the steers fed the high sodium diet contained significantly ($P < 0.05$) higher sodium as compared with urine from steers fed the control or NH_3 diet. The lowest urinary sodium concentration was obtained from

TABLE 13 Water Consumption and Excretion

Item	Days on test	Treatment: Control	5%NaOH	3.5NH_3	Pooled period mean
Water intake (liters/day)	30	21.6^{a}	30.4^{b}	23.9^{a}	25.3^{A}
	270	21.2^{b}	25.3^{c}	21.4^{b}	22.7^{B}
Pooled mean		21.4^{y}	27.8^{x}	22.7^{y}	
Water intake (liters/kg feed DM)	30	3.4^{a}	4.3^{b}	3.7^{a}	3.8^{A}
	270	2.4^{b}	3.8^{c}	2.5^{b}	2.9^{B}
Pooled mean		2.9^{y}	4.1^{x}	3.1^{y}	
Urine volume (liters/day)	30	5.2^{a}	16.4^{b}	4.5^{a}	8.7^{A}
	270	5.4^{b}	8.8^{c}	5.6^{b}	6.6^{B}
Pooled mean		5.3^{y}	12.6^{x}	5.1^{y}	
Urine volume (ml/kg$W^{0.75}$)	30	65.7^{a}	198.5^{b}	57.0^{c}	107.1^{A}
	270	56.2^{b}	84.5^{c}	57.3^{b}	66.0^{B}
Pooled mean		61.0^{y}	141.5^{x}	57.2^{y}	
Fecal water (liters/day)	30	12.7^{a}	12.4^{a}	14.0^{b}	13.0^{A}
	270	12.7^{a}	8.0^{c}	14.9^{b}	11.9^{B}
Pooled mean		12.7^{z}	10.2^{x}	14.5^{y}	
Fecal water (liters/kg feces DM)	30	4.7^{ab}	4.3^{a}	5.0^{b}	4.7^{A}
	270	3.5^{ab}	3.1^{a}	4.1^{b}	3.6^{B}
Pooled mean		4.1^{y}	3.7^{x}	4.5^{y}	

1. ^{a,b,c}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

the urine of steers fed the NH_3 diet. Period and period x treatment interaction effects were significant ($P < 0.05$). Urinary potassium concentration was significantly ($P < 0.05$) different between the treatments. Urine from the steers fed NH_3 lowest value ($P < 0.05$) was obtained from urine of steers fed NaOH diet with the control values in-ermediate. There was significant ($P < 0.05$) treatment differences in urinary chloride concentration. The lowest values ($P < 0.05$) were recorded from urine of steers fed the NaOH diet. The values for the control and the NH_3 diets were not significantly ($P > 0.05$) different. Period and period x treatment interaction effects were significant ($P < 0.05$).

There were significant ($P < 0.05$) treatment and period effects in urinary urea concentration. The lowest values were obtained from the urine of steers fed NaOH diet ($P < 0.05$) and the highest values were obtained from the urine of steers fed NH_3 diet. Creatinine concentrations in urine were significantly ($P < 0.05$) higher during the short term than in the long term. Treatment differences were also significant ($P < 0.05$). The lowest values were recorded from urine of steers fed NaOH diet. The pooled mean value of urinary osomolarity was signifi-cantly ($P < 0.05$) low for steers fed NaOH diet. Urinary osmolarity was also affected by period and period x treatment interactive effects ($P < 0.05$). The pH was significantly ($P < 0.05$) higher for urine obtained from steers fed NaOH diet. There was no significant ($P < 0.05$) treatment or period effects on urine specific gravity. Potassium/sodium ratios were low for urine from steers fed NaOH diet.

TABLE 14 Urinary Electrolytes, Urea, Osmolarity, pH Creatinine and Specific Gravity

Item		Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
Na^+	mEq/liter	30	40.3^{b}	168.5^{a}	3.8^{c}	70.8^{A}
		270	33.8^{a}	222.3^{b}	16.8^{d}	91.0^{B}
	Pooled mean		37.1^{x}	195.3^{y}	10.3^{z}	
K^+	mEq/liter	30	285.3^{a}	128.8^{b}	342.7^{c}	252.3^{A}
		270	294.3^{bc}	181.7^{ab}	312.8^{c}	262.9^{A}
	Pooled mean		289.8^{y}	155.3^{x}	327.8^{z}	
Cl^-	mEq/liter	30	126.1^{a}	46.3^{b}	66.6^{c}	79.7^{A}
		270	102.7^{b}	83.7^{c}	158.3^{d}	114.9^{B}
	Pooled mean		114.4^{y}	65.0^{x}	112.5^{y}	
Urea	g/100ml	30	9.9^{b}	2.5^{a}	11.1^{c}	7.8^{A}
		270	11.1^{a}	8.2^{b}	11.8^{a}	10.4^{B}
	Pooled mean		10.5^{y}	5.3^{x}	11.5^{z}	
Creatinine	mg/100ml	30	13.4^{a}	6.4^{b}	19.9^{c}	13.0^{A}
		270	0.9^{d}	0.7^{b}	0.6^{b}	0.7^{B}
	Pooled mean		7.2^{y}	3.5^{x}	10.3^{z}	
Osmolarity	Osm/kg	30	1.4^{a}	0.8^{b}	1.6^{a}	1.2^{A}
		270	2.3^{b}	2.0^{b}	2.7^{c}	2.3^{B}
	Pooled mean		1.9^{y}	1.4^{x}	2.1^{y}	
pH		30	7.2^{b}	8.9^{a}	6.8^{b}	7.6^{A}
		270	7.3^{a}	7.6^{a}	7.2^{a}	7.4^{A}
	Pooled mean		7.3^{y}	8.3^{x}	7.0^{y}	
Specific gravity		30	1.03^{a}	1.03^{a}	1.04^{a}	1.03^{A}
		270	1.04^{b}	1.03^{b}	1.04^{b}	1.04^{A}
	Pooled mean		1.03^{x}	1.03^{x}	1.04^{x}	
K:Na ratio		30	7.1:1	0.76:1	100:1	
		270	9.1:1	0.82:1	20:1	

1. ^{a,b,c,d}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y,z}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

4.7 Effect of sodium and potassium intake on their metabolisms

Daily calculated sodium and potassium intake, excretion and retention (g/day) are given in Table 15. There was significant ($P < 0.05$) intake of sodium by steers fed the high sodium diet. The pooled mean showed no significant ($P > 0.05$) treatment differences in potassium intake but period effect was significant ($P < 0.05$). Urinary sodium quantity was significantly ($P < 0.05$) higher for the NaOH diet and different between periods. The period x treatment interaction effect was significant ($P < 0.05$). Urinary potassium was significantly ($P < 0.05$) higher for the NaOH diet compared with the other two diets. Fecal sodium was not affected ($P > 0.05$) by treatment except by period ($P < 0.05$). Fecal potassium on the other hand was affected both by treatments and periods ($P < 0.05$). A significantly ($P < 0.05$) lower quantity of potassium was excreted via the feces by the steers fed the NaOH diet.

Sodium retained as a percentage of intake was significantly ($P < 0.05$) different between treatments. Steers fed NaOH diet retained the highest quantity of sodium ($P < 0.05$) compared with the other two treatments. In the short term there was negative retention of K with a significantly ($P < 0.05$) effect of NaOH treatment. But there was a signficiant ($P < 0.05$) positive retention of K in the long term for the control and the NaOH treatment compared with the NH_3 treatment.

4.8 Blood chemistry

Plasma electrolytes, BUN and total protein are presented in Table 16. There were no significant ($P > 0.05$) treatment differences

TABLE 15 Effect of Sodium and Potassium Intake on Excretion and Retention of Sodium and Potassium

Item	Days on test	Treatment			Pooled period mean
		Control	5%NaOH	3.5%NH_3	
Sodium intake g/day	30	21.1^{b}	152.3^{a}	20.5^{b}	64.6^{A}
	270	28.6^{c}	141.6^{b}	29.5	66.6^{A}
Pooled mean		24.8^{y}	146.9^{x}	25.0^{y}	
Potassium intake g/day	30	70.4^{b}	85.2^{a}	70.2^{b}	75.3^{A}
	270	95.7^{c}	79.2^{d}	90.7^{c}	88.5^{B}
Pooled mean		83.1^{x}	82.2^{x}	80.5^{x}	
Urinary sodium g/day	30	6.9^{a}	90.9^{b}	0.6^{c}	32.8^{A}
	270	6.0^{d}	64.3^{e}	3.1^{x}	24.5^{B}
Pooled mean		6.5^{x}	77.6^{y}	1.9^{z}	
Urinary potassium g/day	30	57.8^{a}	82.4^{b}	60.1^{a}	66.8^{A}
	270	62.0^{b}	62.4^{b}	68.3^{c}	64.2^{B}
Pooled mean		59.9^{y}	72.4^{x}	64.2^{z}	
Fecal sodium g/day	30	14.7^{b}	16.6^{a}	16.9^{a}	16.1^{A}
	270	21.2^{c}	24.6^{a}	25.7^{a}	23.8^{B}
Pooled mean		17.9^{y}	20.6^{x}	21.3^{x}	
Fecal potassium g/day	30	17.8^{a}	12.8^{b}	15.4^{c}	15.3^{A}
	270	24.8^{b}	8.8^{c}	19.4^{d}	17.7^{B}
Pooled mean		21.3^{x}	10.8^{y}	17.4^{z}	
Na retained as % intake	30	2.0^{a}	29.4^{b}	14.7^{c}	15.4^{A}
	270	3.3^{b}	37.2^{c}	2.1^{d}	14.2^{A}
Pooled mean		2.6^{x}	33.3^{y}	8.4^{z}	
K retained as % intake	30	-7.4^{a}	-11.7^{b}	-7.5^{a}	-8.9^{A}
	270	9.3^{b}	10.1^{b}	3.3^{c}	$+7.6^{B}$
Pooled mean		0.9^{x}	-0.8^{y}	-2.1^{z}	

1. ^{a,b,c,d,e}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y,z}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

in plasma concentration of sodium, potassium, chloride, bicarbonate, calcium, magnesium and phosphorus. Total protein level was not affected ($P > 0.05$) by treatments. Blood urea nitrogen level was significantly ($P < 0.05$) affected by period but there were no significant ($P > 0.05$) treatment differences except for the control diet in the long term.

Blood gas, creatinine, pH and osmolarity are presented in Table 17. The partial pressure of oxygen was significantly ($P < 0.05$) higher for blood obtained from steers fed NH_3 diet as compared with the other two treatments. The partial pressure of carbon dioxide was not significantly affected by treatments ($P > 0.05$) and period. Creatinine was significantly ($P < 0.05$) low for steers fed NaOH diet. Period pH were not significantly ($P > 0.05$) affected by treatments and period.

4.9 Hematology

Mean packed cell volume (PCV), hemoglobin (Hb), red blood cell (RBC), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), white blood cell (WBC) and fibrinogen are presented in Table 18. There were no significant ($P > 0.05$) treatment differences in any of these parameters. However, PCV, Hb, MCV, MCHC and fibrinogen were significantly ($P < 0.05$) affected by period. PCV, Hb, and MCV significantly ($P < 0.05$) increased in the long term while MCHC and fibrinogen decreased.

White blood cells (WBC) and the components are presented in Table 19. Neutrophils were significantly ($P < 0.05$) affected by period. Low value was obtained ($P < 0.05$) for NH_3 treatment. Period

TABLE 16 . Blood Electrolytes, BUN and Total Protein

Item		Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
Na^+	mEq/liter	30	146.3^a	143.8^a	144.7^a	144.9^A
		270	148.3^b	146.5^b	148.8^b	147.9^A
	Pooled mean		147.3^x	145.2^x	146.8^x	
K^+	mEq/liter	30	4.6^a	4.8^a	4.6^a	4.7^A
		270	4.0^b	4.5^b	4.8^b	4.4^A
	Pooled mean		4.3^x	4.7^x	4.7^x	
Cl^-	mEq/liter	30	101.5^a	99.2^a	100.7^a	100.5^A
		270	93.5^b	93.3^b	93.7^b	93.5^A
	Pooled mean		97.5^x	96.3^x	97.2^x	
HCO_3^-	mEq/liter	30	29.5^a	30.4^a	28.9^a	29.6^A
		270	30.5^b	31.3^b	31.0^b	30.9^A
	Pooled mean		30.0^x	30.9^x	30.0^x	
Ca^{++}	mg/100 ml	30	10.1^a	10.5^a	10.2^a	10.3^A
		270	9.9^b	10.0^b	10.0^b	10.0^A
	Pooled mean		10.0^x	10.3^x	10.1^x	
Mg^{++}	mg/100 ml	30	2.1^a	2.0^a	2.2^a	2.1^A
		270	2.3^b	2.2^b	2.2^b	2.2^A
	Pooled mean		2.2^x	2.1^x	2.2^x	
PO_4^{---}	mg/100 ml	30	8.2^a	8.2^a	7.9^a	8.1^A
		270	8.0^b	7.0^b	8.1^b	7.7^A
	Pooled mean		8.1^x	7.6^x	8.0^x	
BUN	mg/100 ml	30	16.4^a	15.3^a	15.3^a	15.7^A
		270	20.8^b	18.8^c	18.8^c	19.5^B
	Pooled mean		18.6^x	17.1^x	17.1^x	
Total protein	g/100 ml	30	6.9^a	7.0^a	6.9^a	6.9^A
		270	7.3^b	7.5^b	7.1^b	7.3^A
	Pooled mean		7.1^x	7.2^x	7.0^x	

1. ^{a,b,c}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x}Pooled treatment means for each item with the same superscript are not significant ($P > 0.05$).

TABLE 17 Blood Gas, Creatinine, pH and Osmolarity

Item		Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
PO_2	mmHg	30	42.8^{a}	35.9^{b}	37.4^{b}	38.7^{A}
		270	31.1^{c}	35.1^{c}	43.9^{b}	36.7^{A}
	Pooled mean		36.9^{y}	35.5^{y}	40.6^{x}	
PCO_2	mmHg	30	52.1^{a}	50.8^{a}	51.3^{a}	51.4^{A}
		270	47.2^{b}	49.9^{b}	47.0^{b}	48.0^{A}
	Pooled mean		49.6^{x}	50.4^{x}	49.2^{x}	
Creatinine	mg/100 ml	30	1.1^{a}	0.8^{b}	1.2^{a}	1.03^{A}
		270	1.3^{c}	1.0^{a}	1.3^{c}	1.20^{B}
	Pooled mean		1.2^{y}	0.9^{x}	1.3^{y}	
Osmolarity	mOsm/kg	30	296.8^{a}	299.9^{a}	301.1^{a}	299.3^{A}
		270	310.0^{b}	308.7^{b}	310.5^{b}	309.7^{A}
	Pooled mean		303.4^{x}	304.3^{x}	305.8^{x}	
pH		30	7.37^{a}	7.40^{a}	7.39^{a}	7.4^{A}
		270	7.42^{b}	7.42^{b}	7.42^{b}	7.4^{A}
	Pooled mean		7.40^{x}	7.41^{x}	7.4^{x}	

1. ^{a,b,c,}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

TABLE 18 Hematological Parameters

Item		Days on test	Treatment: Control	5%NaOH	3.5%NH_3	Pooled period mean
PCV	%	30	39.7^{a}	35.0^{b}	37.1^{a}	37.3^{A}
		270	45.8^{b}	44.4^{b}	44.7^{b}	44.9^{B}
	Pooled mean		42.7^{x}	39.7^{x}	40.9^{x}	
Hb	g/100 ml	30	13.8^{a}	13.2^{a}	13.6^{a}	13.5^{A}
		270	16.1^{b}	15.6^{b}	15.9^{b}	15.9^{B}
	Pooled mean		14.9^{x}	14.4^{x}	14.7^{x}	
RBC	$x10^{6}/mm^{3}$	30	9.2^{a}	8.6^{a}	9.1^{a}	9.0^{A}
		270	9.9^{b}	9.9^{b}	10.0^{b}	9.9^{A}
	Pooled mean		9.5^{x}	9.2^{x}	9.5^{x}	
MCV	μ^{3}	30	40.8^{a}	39.8^{a}	39.7^{a}	40.1^{A}
		270	46.8^{b}	45.3^{b}	45.5^{b}	45.9^{B}
	Pooled mean		43.8^{x}	42.6^{x}	42.6^{x}	
MCH	pg	30	15.4^{a}	15.7^{a}	15.2^{a}	15.4^{A}
		270	16.7^{b}	16.5^{b}	16.5^{b}	16.5^{A}
	Pooled mean		16.0^{x}	16.1^{x}	15.8^{x}	
MCHC	$x10^{3}/mm^{3}$	30	36.3^{a}	37.9^{a}	36.8^{a}	37.0^{A}
		270	35.4^{b}	35.4^{b}	35.7^{b}	35.5^{B}
	Pooled mean		35.9^{x}	36.7^{x}	36.2^{x}	
WBC	$x10^{3}/mm^{3}$	30	9.1^{a}	9.2^{a}	9.2^{a}	9.2^{A}
		270	9.4^{b}	10.1^{b}	9.7^{b}	9.4^{A}
	Pooled mean		9.3^{x}	9.4^{x}	9.4^{x}	
Fibrinogen	mg/100 ml	30	333.3^{a}	266.7^{b}	300.0^{a}	300.0^{A}
		270	183.3^{c}	200.0^{c}	200.0^{c}	194.4^{B}
	Pooled mean		258.3^{x}	233.3^{x}	250.0^{x}	

1. ^{a,b,c}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x}Pooled treatment means for each item with the same superscript are not significant ($P > 0.05$).

TABLE 19 White Blood Cells and the Components

Item		Days on test	Treatment: Control	5%NaOH	3.5NH$_3$	Pooled period mean
WBC	x10^3/mm^3	30	9.1^{a}	9.2^{a}	9.2^{a}	9.2^{A}
		270	9.4^{b}	10.0^{b}	9.7^{b}	9.4^{A}
	Pooled mean		9.3^{x}	9.4^{x}	9.4^{x}	
Neutrophils	x10^3/mm^3	30	2.2^{b}	1.7^{a}	2.2^{b}	2.0^{A}
		270	2.7^{c}	2.8^{c}	2.2^{d}	2.5^{B}
	Pooled mean		2.5^{x}	2.3^{x}	2.2^{x}	
Neutrophils	%	30	22.7^{a}	27.8^{b}	23.7^{a}	28.1^{A}
		270	29.5^{b}	25.5^{c}	22.0^{c}	25.7^{B}
	Pooled mean		26.1^{y}	26.6^{y}	22.8^{x}	
Monocyte	x10^3/mm^3	30	0.40^{a}	0.40^{a}	0.30^{a}	0.37^{A}
		270	0.40^{b}	0.50^{b}	0.40^{b}	0.43^{A}
	Pooled mean		0.40^{xy}	0.45^{x}	0.35^{y}	
Monocyte	%	30	5.6^{a}	4.0^{b}	2.3^{c}	3.9^{A}
		270	3.8^{a}	4.8^{c}	3.7^{a}	4.1^{A}
	Pooled mean		4.7^{y}	4.2^{y}	3.0^{x}	
Eosinophils	x10^3/mm^3	30	0.40^{a}	0.30^{a}	0.30^{a}	0.33^{A}
		270	0.30^{a}	0.30^{a}	0.30^{a}	0.30^{A}
	Pooled mean		0.35^{x}	0.30^{x}	0.30^{x}	
Eosinophils	%	30	4.8^{a}	2.8^{b}	3.4^{c}	3.7^{A}
		270	2.8^{b}	2.5^{b}	2.7^{b}	2.7^{B}
	Pooled mean		3.8^{y}	2.7^{x}	3.1^{y}	
Lymphocyte	x10^3/mm^3	30	6.2^{a}	6.8^{a}	6.6^{a}	6.5^{A}
		270	5.9^{a}	7.6^{b}	7.1^{b}	6.9^{A}
	Pooled mean		6.1^{x}	7.2^{y}	6.9^{x}	
Lymphocyte	%	30	68.3^{a}	73.5^{b}	71.5^{b}	71.1^{A}
		270	64.0^{c}	68.3^{d}	73.2^{e}	68.5^{B}
	Pooled mean		66.2^{x}	70.9^{y}	72.3^{y}	

1. ^{a,b,c,d}Means within a row for each item with different superscript are significant ($P < 0.05$).
2. ^{A,B}Pooled period means for each item with different superscript are significant ($P < 0.05$).
3. ^{x,y}Pooled treatment means for each item with different superscript are significant ($P < 0.05$).

x treatment interactive effects were also significant. Monocyle expressed in percentage was significantly ($P < 0.05$) low for NH_3 diet compared with the other two diets. Eosinophils expressed in percentage was significantly ($P < 0.05$) low for blood samples taken from steers fed NaOH diet.

4.10 Kidney, liver and rumen tissues

The microscopic examination of sections of the kidney, liver and rumen tissues taken from the steers immediately after slaughter showed no significant evidence of pathological changes in these organs. Only mild interstitial nephritis were found in the kidney sections from steers fed the control and NaOH diets. Some focal area of healing infarction were also observed. Mild cloudy swellings in the hepatic sections from steers fed the high sodium diet and those fed NH_3 diet were evident. Glomeruli in all the kidney sections examined appeared to be slightly hypercellular (i.e. increased number of cells). Sections of rumen tissue examined appeared normal.

4.11 Feedlot performance and carcass characteristics

The initial weight of steers when entering the feedlot phase of the experiment, final weight, voluntary intake, average daily gain and feed conversion are presented in Table 20. Steers fed the NaOH diet grew faster ($P < 0.05$) and were heavier compared to those fed the control diet. There was no significant ($P > 0.05$) treatment difference between the steers fed the control or NH_3 diet. The steers fed the NaOH diet significantly ($P < 0.05$) ate less and had higher

TABLE 20 Feedlot Performance

Item	Days on test	Control	NaOH	NH_3
Initial wt. (kg)	200	280.5	284.0	276.5
Final wt. (kg)	200	439.0^{b}	492.3^{a}	450.4^{ab}
Intake DM (kg/day)	200	12.6^{c}	10.9^{b}	11.6^{cb}
Intake DM ($g/kgW^{0.75}$)	200	131.1^{c}	104.7^{b}	118.7^{cb}
A D G (kg/day)	200	0.82^{d}	1.04^{c}	0.83^{d}
Feed/gain	200	15.2^{c}	10.5^{d}	14.0^{c}

^{a,b,c,d}Means within a row for each item with different superscript are significant ($P < 0.05$).

feed conversions compared with those fed the control diet. There was no significant ($P > 0.05$) difference between the control and NH_3 diets on these parameters. The cumulative mean live weight gains measured over eleven periods are shown in Figure 10. Pooled analysis showed significant ($P < 0.05$) treatment, period and interactive effects on the growth of steers. Analysis of weight gains for periods 1-5 showed similar significant ($P < 0.05$) treatment, period and interaction effects but the periods 6-11 only period effect was significant.

Carcass characteristics are presented in Table 21. Hot carcass weight was significantly ($P < 0.05$) heavier for steers fed NaOH diet compared with those fed the control diet. There were no significant ($P > 0.05$) treatment differences in dressing percentage and ribeye area. There was significantly ($P < 0.05$) more fat over rib on the carcasses of steers fed NaOH diet than those fed the control diet. Five carcasses from steers fed the control diet graded A_1 and B_1. Three carcasses from steers fed NaOH diet graded A_1, two A_2 and one B_1. Five carcasses from steers fed the NH_3 diet graded A_1 and one A_2 respectively.

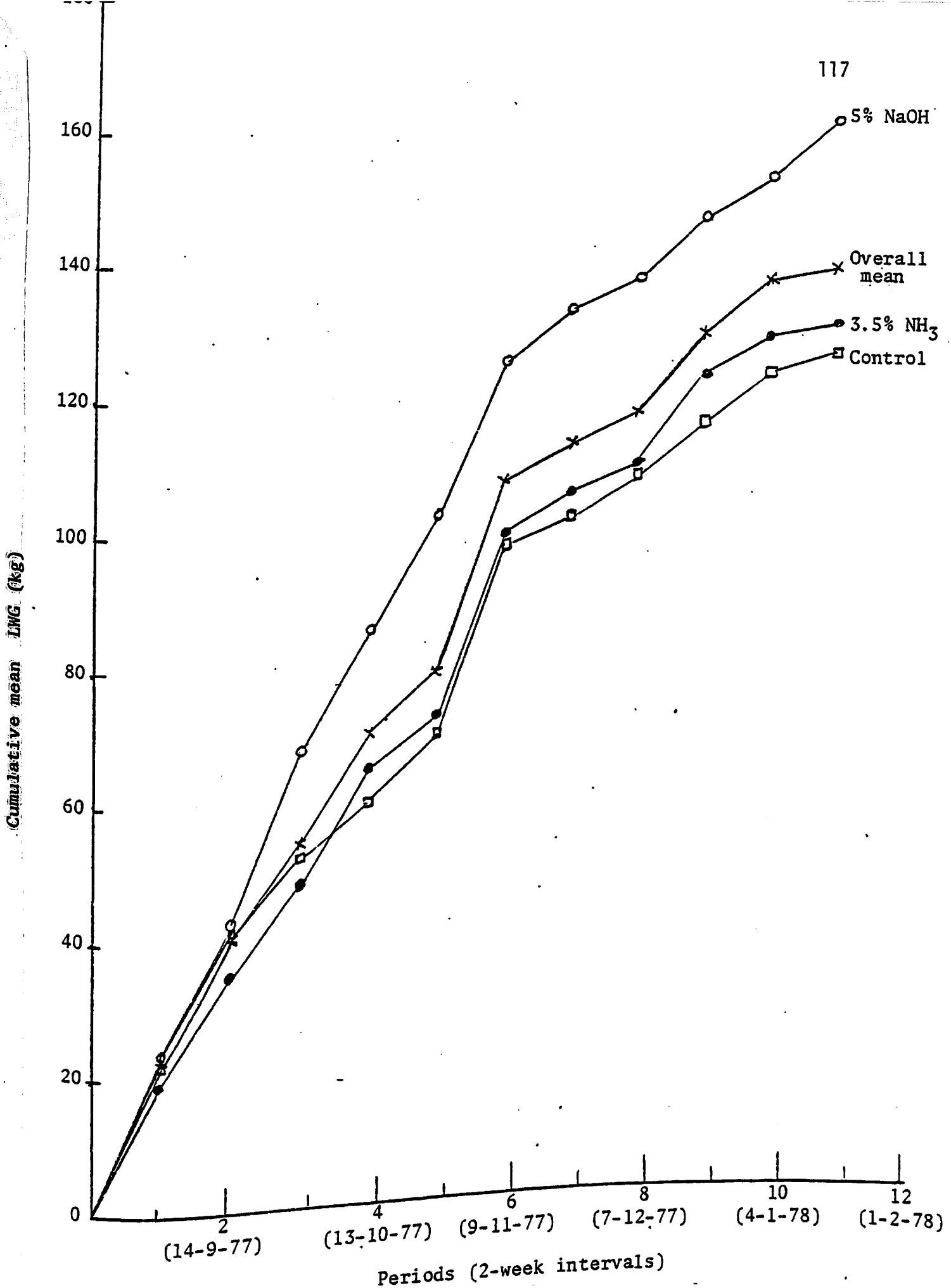

Fig. 10 Cumulative Mean Liveweight Gains

TABLE 21 Carcass Characteristics

Item	Control	NaOH	NH_3
Final weight (kg)	439.8^{b}	492.3^{a}	450.3^{ab}
Hot carcass wt (kg)	243.5^{c}	275.9^{b}	253.4^{bc}
Dressing %	55.4^{a}	56.6^{a}	56.3^{a}
Rib eye area (cm^2)	61.9^{b}	63.9^{b}	61.9^{b}
Fat over rib (cm)	1.2^{c}	1.6^{d}	1.4^{cd}
Carcass grade	$A_1(5)$	$A_1(3)$	$A_1(5)$
	$B_1(1)$	$A_2(2)$	$A_2(1)$
		$B_1(1)$	

a,b,c,d Means within a row for each item with different superscript are significant ($P < 0.05$).

5. DISCUSSION

5.1 Digestibility

The pooled mean dry matter digestibility of the straw based diets were 56.8, 58.2, 57.2 respectively for the control, NaOH treated and NH_3 treated diets. Treatment and period effect approached significance ($P \geq 0.05$). The NaOH treated diet was slightly higher in dry matter digestibility compared with the control and NH_3 treated diets. Organic matter digestibility for NaOH treated diet was significantly ($P < 0.05$) higher compared to the other two diets. Non-significant treatment difference was found between the control and NH_3 treated diets. The marginally improved dry matter digestibility within period and with time for NaOH and NH_3 diets could be attributed to a number of factors. These include the initial quality of the straw, the ration of which the straw was a component, the effect of processing and storage and the influence of the high sodium on the rate of passage of digesta through the reticulorumen and on micro-organism activity.

The mean *in vitro* digestibility of the untreated straw was 33% which is quite low for obtaining the maximum benefit from chemical treatment. (Kernan et al (1978) pointed out that crop residues with initial *in vitro* digestibility less than 36% may not be worthwhile to with chemical. This is because the digestibility of the materials would not be improved to a level (50% or above) required for effective utilization of the treated materials by ruminant animals. Many *in vivo* studies have demonstrated that the digestibility of most straws

reaches a maximum level with a treatment of 4-6% NaOH/100g DM (Mowat and Ololode, 1970; Klopfenstein et al 1972; Ololade et al 1973; Thomsen et al 1973). For ammonia treatment, 3-5% NH_3/100 g DM have been reported to be effective (Oji et al 1977; Kernan et al 1977; Sunstøl et al 1978). Thus it is unlikely that the level of chemical used for treating the Neepawa wheat straw was a factor on the marginal improvement in digestibility.

The composition of a ration in which straw is a component is known to influence the digestibility and intake of straw. - (Fishwick et al 1974). The diets used in the present experiment were iso-nitrogenous and fairly isocaloric (Table 8). Thus if the low initial digestibility of the straw rendered chemical treatments less effective, then the supplemental barley, soy bean, urea and molasses were the main substrates fermented in the diets at least in the short term, resulting in similar digestibility of the diets. Donefer, (1968) reported an increase in energy digestibility by 13.5 percentage units when no urea was included and an increase of 18.3 digestibility units with inclusion of 2.5% urea to alkali treated straw. These improvements are higher than the values obtained in the present experiment.

The slight improved digestibility (DM) of the NaOH diet over the control and NH_3 treated diets could have been due to the method of processing. The pelleting of chopped straw treated with NaOH and regrinding the pellets prior to incorporation into the final diet gave an advantage of the NaOH treated diet over the other two diets. The regrinding made the NaOH treated straw particle size smaller compared to those of the other two diets; thereby increasing surface area for

microbial attack. This was reflected in the dry matter bulk density which was 20% per unit volume greater for NaOH diet than the control and 1819% greater than the NH_3 treated diet. Arndt et al (1978) fed lambs a sorghum - soy bean meal in cubed rations containing 70% gin trash. They reported apparent DMD of 54.67 and 58.65% respectively for rations containing 4% NaOH treated chopped gin trash and 4% NaOH treated chopped and reground gin trash. This finding lends supportive evidence to the present results.

Storage duration could have also influenced the marginal treatment differences in digestibility. The author's unpublished data showed that the protein content of the ammoniated straw had decreased from 9% to 6%, a decline of 33.3%, after a year of standing uncovered in the open. Waagepetersen (1974) reported that about 24% of the ammonia nitrogen is very loosely held while the rest is more firmly bound. This implies that the 24% could volatilize or leach out as ammonia and ammonium salts respectively if exposed to weather for long periods. The remaining N fraction could probably not be utilized efficiently by rumen microbes. Nitrogen balance data (Table 10) from the present experiment tends to support this suggestion. Comparable improvement in digestibility coefficients have been obtained from wheat straw freshly treated with anhydnous ammonia or with NaOH (Coxworth, 1976). Thus the poor response of the NH_3 treated diet indicates that ammoniated straw left uncovered in the open could have deteriorated with time.

The one-year old Neepawa wheat straw used in the control diet was found, on close examinations, to be invaded by fungi Imperfecti species. These fungi through their growth pattern had ruptured the

epidermis of the straw as shown by the scanning electron micrographs (Fig. 11, 12, 13). These activities of the fungi increased surface area for microbial attack. Such physical change could have improved slightly the utilization of the untreated straw resulting in reduced treatment differences. There was no fungal growth on treated straw.

The increased sodium and water intake, together with the smaller particle size of the NaOH treated diet, would be expected to increase the rate of passage of the digesta. This would reduce the mean time for fermentation in the rumen and lead to relatively lower digestibility for the diet (Hemsley et al, 1975) This appears not to have been a major factor in the present experiment particularly in the long term because the mean digestibility of the NaOH diet was higher than those of the other two diets.

The decline in the digestibility of NFE with time and the corresponding increase in the digestibility of crude fibre could be attributed to adaptation effect related to change in micro-organisms population and composition in the rumen. It would be expected that initially amylolytic activity would be great hydrolyzing soluble substrates. But with time the population of cellulolytic bacteria would become dominant. Recent papers (Leng, 1973, Phillipson, 1977) emphasized that in the presence of readily soluble carbohydrates rumen micro-organisms are able to rapidly ferment the soluble carbohydrates before attacking the less digestible cellulose and hemicellulose. The significant improvement in the digestibility of crude fibre with time for all the three diets used in the present experiment is a supportive evidence. The significantly improved crude fibre digestibility of

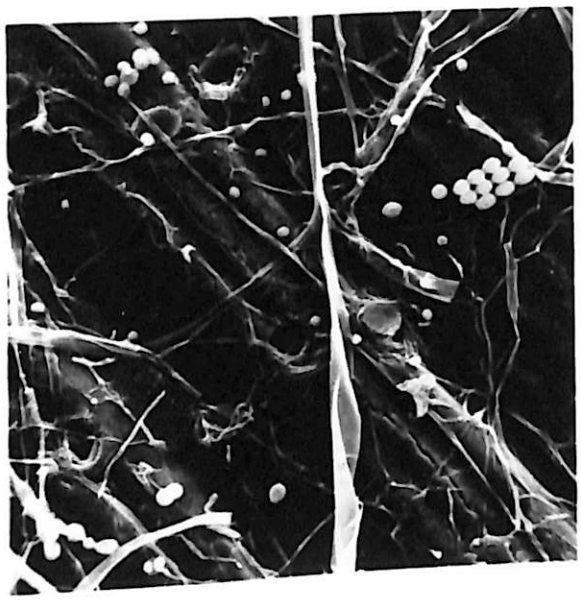

Figure 11. Electron micrograph of surface of untreated one-year old straw. X300
Note mycelia of Fungi Imperfecti lying along cracked ridges.

Figure 12. Longitudinal section of straw surface. X300
Note the growth of hyphal stylets.

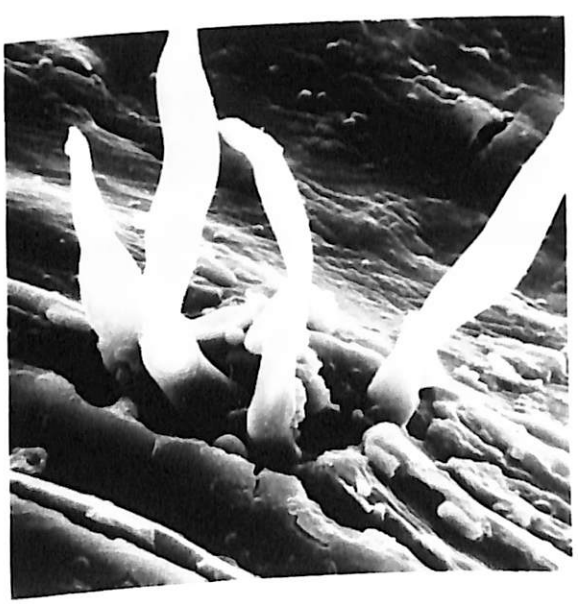

Figure 13. Close-up of growing hyphal stylets on straw surface. X600
Note the ruptured epidermis and the underlying tissues.

NaOH diet over the other two diets could be attributed to the NaOH treatmtne of hemicellulose and lignin of the straw and adaptation of rumen microflora to the diet. Sharma and Jackson (1975) obtained an increase in cellulose digestibility of 15-20% units with 15g NaOH/100 wheat straw. This would be equivalent to an increase of 5-7% with 5g NaOH/100g straw which is slightly higher than the increase of 2.1 - 6.2% units obtained for CF in the present experiment. Whistler and Teng (1970) suggested that alkali treatment reduces the strength of intermolecular hydrogen bonds which bind cellulose molecules together thus resulting in swelling of the fibres. Such swelling should make the treated material more easily penetrated by rumen microorganisms and this would account for the greater digestibility of the treated roughage. However, with the dry method of NaOH treatment of straws, the increases brought about in the digestibility of NaOH spray-treated straw over that of the untreated may not be due to improvement of cellulose per se. Fernandez, Carmona and Greenhalgh (1972) suggested that both materials solubilized by the alkali and the portion of the treated materials actually digested by the animals contribute to the final digestibility value. Thus solubilized hemicellulose, silica and lignin would contribute to the overall digestibility. Nevertheless, digestible energy (Table 9) for NaOH treated diet significantly increased with time as compared with the other two diets; indicating the beneficial effect of NaOH treatment.

Therefore, the digestibility data obtained in the present experiment indicate that in the mixed diets containing 60% straw and readily fermentable substrates, there were numerous associative

factors which might have interacted to reduce treatment differences. This has implication in the evaluation of the role of chemically treated crop residues in production diets.

5.2 Intake

Dry matter intake expressed in grams per kg metabolic body size shows significant treatment differences in the short-term; with the highest intake for the NaOH diet. In the long term intake declined significantly for NaOH diet as compared to the other two diets. However, there was a general reduction in food intake with time across the treatments. The pooled means show little treatment differences. Several factors could have influenced the pattern and variations in the dry matter intake. They include response of the steers to pelleted diets, then as time went on, the influence of season and the diets on the animals. The effect of body composition change could have been an additional factor.

Initially, as would be expected, the steers responded to the pelleted diets by increasing intake and at the same time interacted with the quality of the diets. The increased intake of NaOH diet in the short term could have been augmented by the effects of NaOH treatment on rate of passage of the digesta through the reticulo-rumen and on rumen pH (Ololade, 1972). Ingestion of large amounts of sodium chloride (150 g/day) was reported to have increased the rate of flow of fluid from the rumen and digesta from the abomasum increased by 5-6 kg/day (Hemsley *et al*, 1975). The high intake of sodium (152 g/day) during the first 30 days observed in the present experiment could have exerted similar influence thereby increasing intake. Recent studies

by Ali et al (1977) gave similar results regarding the effect of NaOH treatment on intake. Intake of low-quality roughage based diets is often strongly influenced by the physical form of the material offered (Ali et al, 1977). Milling and pelleting being particularly important in this regard (Moore, 1964; Greenhalgh and Reid, 1973). Both these effects is related to the rate of passage of the digesta (Jarrige, 1974). This could have contributed to the generally higher intake of the NaOH diets during the first 30 days as compared to the long term when steers were better adapted to handling such diet.

The decline with time in intake of all diets could have been influenced by adaptation of the steers to the diets and to slight extent by the cold winter temperature. Westra and Christopherson (1975) and Christopherson (1975) reported that cold winter temperature significantly reduced intake and digestibility of feed by sheep and steer calves. Such severe temperature effect would not apply to the present experiment because the steers were sheltered. The significant reduction in intake of NaOH diet cannot be accounted for by the above factors alone. A more likely explanation for the reduced intake could have been due to the high sodium intake of 2.23g Na per $kg^{0.75}$ per day during the short term. This level of sodium intake is within the threshold value of 2.2 - 2.4g Na per $kg^{0.75}$ per day reported by Potter (1963), Weeth et al (1968) and Ali et al (1977). At this level of sodium intake they suggested that the effect of sodium tended to push the mechanisms for the maintenance of homeostasis to the limit. This might have forced the animals in the present experiment to compromise by reducing intake of the high sodium diet to limit sodium intake (Table 15) in the long

term. The reduction in sodium excretion via urine with corresponding increase in sodium excretion via the feces would indicate the ability of the steers to adapt to the high sodium diet initially by evoking maximum kidney excretion of excess sodium. Then with time reducing sodium intake and altering the route for sodium excretion to avoid over working the kidney. Such capacity to adapt to high sodium diet may fail with more than 5.6% NaOH treatment (Ali et al, 1977). With lower level of NaOH treatment the capacity of animals to cope with excess sodium appears to depend on fresh water availability and functional kidney as indicated by the large water intake and excretion via the kidney (Potter, 1968). The effect of NaCl ingestion on intake have been suggested to be a result of hypodipsia (Drori, 1976).

Intakes expressed as a percentage body weight were similar between treatments. Feed conversation efficiency was significantly higher on NaOH diet as compared to the other two diets. This could be attributed to less degradation of protein in the rumen because of sodium effect (Hemsley, 1975). This would improve feed utilization. The importance of the hindgut in ruminant nutrition has been recently reported (Hoover, 1978). He stated that the volume of the hindgut contents, which is equivalent to 20% of that of rumen, together with a longer retention time, represent a sizeable capacity for fermentation. This accounts for as much as 27% of the cellulose and 40% of hemicellulose digested daily. The resultant volatile fatty acids production can account for 8 to 17% of the total daily production. Probably the effect of high sodium intake on rate of passage enhanced

digestion in the hindgut to give the overall superior digestibility and better utilization of the NaOH diet. The significant reduction in feed conversion in the long term could have been due to cold temperature which forced all the steers to channel some of the food energy to temperature regulating mechanism, resulting in the low average daily gain.

5.3 Nitrogen intake and metabolism

There was a significant intake of nitrogen by the steers fed the NaOH diet during the first 30 days as compared with the steers fed the control diet. In the long term the steers on the NaOH diet had reduced their nitrogen intake by 13% as compared with those on the control diet while those on the NH_3 diet had significantly increased their nitrogen intake by 19.7% over those on NaOH diet. When nitrogen intake was expressed as grams per metabolic body size ($g/kgW^{0.75}$) there was no treatment difference but season effect was still significant. The interaction between animals and the diet with time is suggested because of the consistent treatment x period interaction. Body size appear to have influenced the apparent significant higher intake of nitrogen by the steers fed NaOH diet.

Urinary nitrogen was 37.4% and 10.7% respectively higher for NaOH diet and NH_3, diets as compared to the control diet during the short term. However, in the long term there was no treatment difference between the control and NaOH diets. By 270 days the steers fed the NaOH diet had significantly reduced their urinary nitrogen by 41.3% over the 30 days value. This indicated a remarkable adjustment by the steers to the high sodium diet and suggests that NaOH influenced

nitrogen metabolism. There was a slight increase of 4.4% in urinary nitrogen of the steers fed NH_3 diets by 270 days. The values from this experiment is higher than the urinary nitrogen values reported by Braman and Abe (1977) probably because of low nitrogen intake by the steers they used and the low crude protein content of their test diets as compared to the ones used in the present experiment. McDonald (1968) recognized that dietary protein may undergo deaminative degradation in the rumen and that in the absence of sufficient energy the resulting ammonia may largely be absorbed and wasted. Tagari et al (1962) stated that protein with a high solubility are degraded in the rumen to ammonia at a rate too rapid for efficient utilization. The rumen micro-organisms in such a situation can utilize only a relatively small part of the liberated ammonia for synthetic purposes. Excess ammonia would diffuse into the blood through the rumen wall and is converted in the liver into urea most of which is then excreted in the urine and a small amount is returned to the rumen through saliva.

In the present experiment the solvent extracted soy bean used as supplement together with urea are all prone to rapid degradation to ammonia in the rumen. It has been demonstrated (Hemsley, et al, 1975) that ingestion of high sodium alters the osmolarity of the rumen and the activity of the rumen microflora during adaptation period. These previous findings might explain the abnormally high urinary nitrogen obtained in the short-term from the urine of steers fed the NaOH diet.

Fecal nitrogen was significantly higher in the feces of steers

fed NH_3 diet and the value increased with time compared to the other two diets. This might have been due to increased nitrogen intake by steers on NH_3 diet in the long term. However, the consistently higher fecal nitrogen for steers fed NH_3 diet compared to those on the other two diets indicates that the dietary nitrogen in NH_3 diet was poorly digested. This is reflected in the nitrogen digestibility and retention values which were found to be lowest for this treatment. There was no consistent difference between the control and NaOH diets in fecal nitrogen whether expressed as g/day or $g/kgW^{0.75}$. This result agees with that of Jackson et al (1971) who found little animal and treatment differences in fecal output of nitrogen. There was significant period x treatment interaction in the present experiment.

During the first 30 days there was little treatment difference between the control and NaOH diets in nitrogen retention; but N retention was significantly low for NH_3 diet regardless of whether nitrogen retention was expressed in g/day or $g/kgW^{0.75}$. For all treatments nitrogen retention increased with time at different rate thereby giving significant period x treatment interaction. Mosely and Jones (1974) showed that high intake of NaCl(80g/day) by sheep increased urinary nitrogen excretion and reduced nitrogen retention. Evidence from steers fed the NaOH diet in this experiment tend to agree with their results. The mean retention of nitrogen (g/day) by the steers fed the control diet was 24.1% and 87.3% respectively higher compared with those on NaOH and NH_3 diets. In contrast animal performance and empty body weight were superior for steers fed NaOH diet with slight difference between those fed the control and NH_3 diets. Hemsley (1975)

and Hemsley et al, 1975 reported improved protein utilization and wool growth when sheep were fed high salt diet. The higher nitrogen retention by the steers fed the control diet with corresponding lower rates of gain and empty body weight could mean that part of the retained nitrogen was metabolized for non synthetic purpose, possibly for gluconeogensis and only a small fraction was used for synthesis of protein. Lindsay (1973) stated that reactions have been demonstrated which show that amino acids like alanine, glutamate, asparte , phenylalanine and tryptophan can be converted to intermediates such a pyruvate, oxalo-acetate, α-oxo glutarate or propionyl-CoA; all of which are known to be convertible to glucose.

Urinary N expressed as a precentage of intake was significantly higher for the NaOH and NH_3 diets compared to the control. Fecal N expressed as a percentage of nitrogen intake was significantly low for NaOH and highest for NH_3 diet. Nitrogen digested was significantly higher for NaOH diet compared to that of control and NH_3 diet. The improved digested nitrogen for NaOH diet with the corresponding high urinary excretion and low nitrogen retention suggest that most of the digested N ended as urea in urine particularly during the short term. The pooled nitrogen retained as a percentage of intake and as a percentage of nitrogen digested followed the same pattern as nitrogen retained (g/day) though there were some significant treatment differences within periods resulting in significant period x treatment effect.

It appears therefore, that NaOH treatment had some effect on nitrogen metabolism in the short run but this effect declined with time indicating the adaptive capacity of the steers to the diet. On

the other hand the poor nitrogen utilization by steers fed NH_3 diet tended to agree with the result of Nicholson et al (1977). The low digestibility of nitrogen would indicate that considerable fraction of nitrogen source in the NH_3 diet was not easily digestible as shown by the high fecal loss. The low performance and the empty body weight of steers fed the control diet in spite of the high nitrogen retention suggested that sizeable fraction of the retained nitrogen was metabolized possibly for gluceneogensis to meet synthetic energy requirements.

5.4 Rumen fluid parameters

5.4.1 Volatile fatty acids (VFA)

Rumen total VFA concentration was significantly higher in the rumen fluid from steers fed NaOH diet during the short and long terms compared to those for the control or NH_3 diet. For all treatments total VFA concentrations declined with time (Table 12) and period x treatment interaction was significant. The significant increase in rumen total VFA concentration for NaOH diet in the present experiment agrees with the results of Ololade and Mowat (1975) and Ali et al (1977) where rumen total VFA increased with NaOH treatment. The decline in total VFA concentration with time could not be attributed much to the winter temperature as observed by Westra and Christopherson (1975) and Christopherson (1975) because the steers were sheltered in heated stone barn.

In the short-term the molar proportion of acetic acid for NaOH diet was lower than the values for the control and NH_3 diets. There was no significant treatment differences in the molar proportion of

acetic acid in the long term. Period x treatment interaction was significant. Wilkie and Merwe (1976) reported that high levels of concentrate in the diet could result in high molar proportion of propionic acid at the expense of acetic acid proportion. The relatively low level of concentrate supplements used in the experimental diets would indicate that other factors were involved in reducing the proportion of acetic acid. Moore (1964) summarized that one of the effect of grinding and pelleting is a decrease in ratio of acetate to propionate in the rumen. The regrinding of pelleted straw treated with NaOH and re-pelleting could probably explain partly the decreased proportion of acetic acid with corresponding increase of proportion of propionic acid observed in the short term. In contrast, Jackson et al (1971) reported that the effect of the physical form of the diet on the composition of the short-chain fatty acids of the rumen fluid were not consistent. Kromann and Ray (1967) and Jackson et al (1971) showed that excess sodium ions in the rumen decreased acetic acid and elevated butyric and propionic acid levels. In the present experiment the concentration of sodium ions in the rumen was in fact slightly lower for the NaOH diet. This sodium ion level in the rumen seems not to account for the similar observations obtained in this experiment. Thus it appears that there is a dynamic interaction between the animal and its diet which cannot be adequately explained.

N-Butyric acid proportion increased with time for all treatment. There was no significant treatment difference. Iso-butyric, iso-valeric and n-valeric were low for the NaOH diet and their proportions declined with time. The control and NH_3 diets gave similar values but the

pooled mean value of n-valeric showed little treatment difference. Annison (1954) reported an increase in branched-chain (C_4 and C_5) acids with supplementary protein feeding. These acids are derived from branched-chain amino acids (El-Shazly, 1952a, 1952b). The work of El-Shazly (1952a, 1952b) and Annison (1954) showed that iso-butyric, iso-valeric and D-2-methyl-n-butyric acids are produced in response to protein and amino acid catabolism. However, Bryant (1977) pointed out that the mounts of total dietary amino acids metabolized in the rumen that are catabolized to these and products are not well known. With the variable values of these branched-chain fatty acids within and between periods and among treatments obtained in the present experiment it is difficult to ascribe the pattern to protein and amino acid catabolism per se. The tendency of iso-butyric, iso-valeric and n-valeric acids to decline with time for NaOH diet indicates the influence of sodium hydroxide on their proportions in rumen fluid. Ololade and Mowat (1975) suggested that the decrease in iso-valeric acid concentration with NaOH treatment might be due to impairment of proteolytic rumen bacteria by this alkali.

5.4.2 Electrolyte, osmolarity and pH

Sodium, potassium and chloride concentrations in the rumen fluid decreased with time for all treatments. However, sodium was the most abundant mineral and cation, which agrees with the results of McCullough and Smart (1968) and those of Bennink et al (1978). The non-significant treatment difference in Na concentrations could have been due to salivery additions, high dilution rate for NaOH treatment or potassium stimulated active transport of sodium from the rumen of

steer fed NaOH diet. Scott (1966) indicated that high K concentration affects electrical potential between rumen fluid and blood and may stimulate active transport of Na from the rumen. In the present experiment K concentration in the rumen fluid from steers fed NaOH diet was significantly higher than those of the control or NH_3 diet. Bailey (1961) reported that the principal source of Na in rumen fluid is from saliva and tend to increase with coarse feed. The coarse pellets of the control and NH_3 diets relative to NaOH treatment could have influence salivary flow. The higher water intake by steers fed NaOH diet could have been a factor in dilution rate.

The ingestion of NaOH diet significantly increased osmolarity of the rumen fluid as compared to those of the control and NH_3 diets. This is in agreement with the results of Potter et al (1972). The steers fed the control or NH_3 diet produced rumen fluids which in the long term, were hypotonic compared with blood plasma. The rumen fluid of steers fed the high sodium diet remained hypertonic throughout the experimental period. The variation of osmolarity between treatments in the long term is in agreement with the reports of Potter et al (1972).

The observed changes in rumen osmotic pressure might be expected to result from the concentrations of electrolytes in the rumen particularly that of sodium and potassium (Warner and Stacy, 1965)) and increased VFA concentration (Bennink et al, 1978). This was the case with the steers consuming the NaOH diet which was significantly higher in rumen fluid electrolytes and VFA.

In terms of changes in rumen function, the effect of electro-

lytes through osmotic effect were related to alteration in fermentation pattern. Adaptation of rumen micro-organisms was postulated by Peirce (1957) to account for the increased food consumption which often accompanied salt-water ingestion in sheep. Potter et al, (1972) found the total metabolic activity of the rumen flora significantly altered when sheep drinking salt water was consuming ground and pelleted ration. Hogan and Weston (1971) found the rumen liquor from sheep consuming NaOH-treated wheat straw was devoid of protozoa. Similar report was given by Hemsley et al (1977) suspected that the reduction in voluntary intake of the diet containing 5.6% NaOH was due to high osmolarity of the rumen liquor which pushed the physiological mechanisms to the limit. Hemsley et al (1975) suggested that the high osmotic pressure in the rumen was unfavourable to rumen microflora and reduced their activity. Bergen, (1972) reported that cellulose digestion was not impaired until the osmotic pressure was greater than 350 mosm/kg. In the short term of the present experiment, the rumen fluids osmolarities were greater than 350 mosm/kg. This might explain the low crude fibre digestibility in the short term and higher digestibility in the long term.

There was no treatment differences in rumen fluid pH was relatively low in thefluid from the steers fed the NaOH diet. This might have been due to increased VFA concentration in the rumen fluid of steers fed NaOH diet. Hodgson et al 1976 reported that as VFA concentration increased, the rumen pH decreased. Church (1975) and Moore, (1964)

concluded that grinding and pelleting of roughage will normally increase microbial activity, resulting in greater VFA production and lower pH of the rumen.

5.5 Water consumption and excretion

5.5.1 Consumption

Steers fed NaOH diet drank significantly higher quantity of fresh water whether expressed as liters per day or liters per kg feed dry matter. The mean daily intakes (liters per day) for the entire experiment being 21.4, 27.8, and 22.7 liters for the control, NaOH and NH_3 diets respectively. Between periods water intake decline with time particularly for steers fed NaOH diet and the decline was related to decline in sodium intake (Table 15) in the latter. These results are in agreement with several previous reports (Potter et al, 1972). Pierce (1957) reported increased water intake of sheep with increase in concentration of NaCl in drinking water. Increased water intake was associated with salt treatments in the experiment carried out by Hemsley (1975) and Hemsley et al (1975). Drori (1976) reported that NaCl increased the fluid intake of rats by 23 - 44% if the salt was provided in food and by 44 - 229% if NaCl was included in drinking water. More recently (Ali et al, 1977) it has been observed that growing lamb fed diets containing 4.1% or 5.6% NaOH drank alot of water and had their rumens distended with liquid. In the present experiment similar observations were made. The steers on the high sodium diet increased their water intake 19.3 - 40.7% over the control when intake was expressed in liters per day and by 26.5 - 58.3% when intake was expressed in liters/kg feed DM. There was a high correlation between kg

feed DM and Water consumption (r = 0.84). The steers drank alot of water and shortly after feeding their stomach were distended to the size of bloating animals. However, the distention disappeared with time post-feeding without apparent ill effect on the steers. This indicated rapid movement of fluid through the rumen. Engelhardt (1970) pointed out that little net movement of water across the rumen epithelium has been observed when rumen osmolarities are 260 to 340 mosm/kg. This would imply that most water was absorbed into the body from the hindgut in the present experiment.

5.5.2 Water Excretion

Daily urine output expressed either as liters/day or ml/kg$W^{0.75}$ was significantly larger for steers fed NaOH diet compared to those from steers fed the control or NH_3 diet. Urine excretion by steers on NaOH treatment increased by 63 - 215% over the control. The mean urine volumes for the entire experiment were 5.2, 12.6 and 5.1 liters per day respectively from steers fed control, NaOH and NH_3 diets. The increased water intake and large urine volume output by the steers has been reported to be associated with the excretion of excess sodium and maintenance of body fluid osmolarity (Potter, 1963). A number of studies by Potter (1961, 1963, 1966, 1968) have shown that there is an adaptive mechanism involving kidney function which allowed the sheep he experimented with to deal with large quantities of ingested or infused salt. He suggested that this mechanism may be related to conditions within the rumen. Stacy and Warner (1966) reported that the absorption of sodium is stimualted by hypertonic conditions in the rumen. The possible involvement and mechanism by which the kidney

enabled the steers to cope up with the high sodium intake in the present experiment is discussed in subsection 5.5.3.

Fecal water expressed either as liters per day or liters per kg feces DM was significantly higher for NH_3 diet as compared with the control and NaOH diets. However, there was a marked reduction in fecal water loss and urine output by steers on the high sodium diet in the long term. A decline of 86.4% in urine volume and 55% in fecal water were observed. Although this tended to related to reduced water intake, it is also suggestive that the steers were conserving water in their body in the long term (Table 13) possibly to balance the osmotic effect of the slightly elevated plasma sodium.

5.5.3 Urinary composition

The urinary sodium concentrations differed significantly between treatment and between periods. Significantly higher concentration of sodium was obtained from the urine of steers fed NaOH diet as expected. The urine of steers fed NH_3 diet surprisingly contained very low concentration of sodium. No explanation could be given for the very low values except indication of high sodium conservation (Table 14). Expressed as g/day, urinary sodium concentration declined with time by 41.4% for the steers fed NaOH diet, indicating that the apparent increase in sodium concentration (mEq/liter) in the long term was due to changes in urine volumes (Table 13.). The concentration of urinary potassium and chloride were the reverse of that of sodium. Steers fed the control and NH_3 diets excreted in their urine significantly higher potassium and chloride (mEq/liter) than those on the high sodium diet. There was period x treatment interaction for chloride excretion (Table

14). When potassium concentration was expressed as g/day the pattern was different. Steers on NaOH diet excreted significantly higher quantity of potassium in urine in the short term as compared to the steers on the other two diets (Table 15). In the long term there was no difference in the quantity of urinary potassium between the group of steers that were fed the control or NaOH diet.

No detailed measurements were made to obtain information which would explain the manner of renal response of the steers fed the high sodium diet over the prolonged period. However, the increased water intake and urine excretion together with the pattern of electrolytes excretion agree with several previous work involving high salt ingestion (Potter, 1960, 1963, 1968; Ali et al 1977). According to Potter (1961) renal adjustments associated with ingestion of salt were due to increases in glomerular filtration rate and filtration fraction without any pronounced change in renal plasma flow. In another experiment involving tubular study (Potter, 1963), evidence was given which showed that the amount of functional tubular tissue remained the same even when sheep consumed salt over long periods. This contrasted with his previous results. But he confirmed the pattern of excretion of the three electrolytes (Na, K, Cl) in urine of sheep which consumed NaCl. As expected the increase in sodium excretion was considerable. He also found that less sodium, potassium and chloride were re-absorbed in the kidney tubules after filtration at the glomeruli. Thus he concluded that the elimination of additional salt is accomplished by a reduction of re-absorption in individual nephron rather than by an increase in the tubular mass of the sheep kidney. This result was

subsequently confirmed (Potter, 1968). His experiment (Potter, 1968) with sheep adpated to salt intake demonstrated that sheep which have become accustomed to drinking salt water, developed some adaptive mechanism which enabled them to withstand sodium chloride loading. Results from the present experiment show that the steers adapted well to the high sodium diet with time, thus agreeing with Potter's finding. He suggested that the stimulus for this adaptation remains in doubt but may be elicited from the rumen. Stigsen (1975) suggested that with high intakes of NaOH, base excretion in cattle is mainly regulated by changes in diuresis, which tend to agree with results from the present experiment. The present evidence indicates that steers maintained homeostasis by excreting more urine and by concentrating sodium in urine while maintaining inverse relationship with potassium probably to maintain electrical neutrality. The negative potassium balance (Table 15) in the short terms and the positive balance in the long term in response to sodium ingestion and metabolism indicates that the metabolism of these two electrolytes is variable. The substantial increase of 15 - 27% in fecal sodium with time (Table 15) for steers fed NaOH diet would tend to suggest that the steers have the capacity of varying the route of excretion of sodium possibly to alleviate the kidney from overload of excreting sodium.

Osmolarity of the urine of steers fed NaOH was 45.7% and 50% respectively less than that of the urine from steers fed the control on NH_3 diet. Nevertheless, all urine remained hyperosmotic with respect to plasma. According to Potter (1963) this would enable the osmotic concentration of body fluids to be maintained. The specific gravity

of the urine showed no treatment difference and the range of 1.03 - 1.04 was in agreement with the values reported by Potter (1963). The average pH of the urine of steers fed NaOH diet was higher than that of steers fed the control or NH_3 diets as expected. Urea was significantly higher in the urine obtained from steers fed the control or NH_3 diet compared with those fed NaOH diet. The high level of urea for the two diets was considered to be due to extensive protein and amino acids catabolism for purposes other than synthesis of protein.

5.6 Blood chemistry and hematology

5.6.1 Blood chemistry

Despite the great increase in sodium intake by steers fed NaOH diet throughout the experiment, they were able to maintain the level of plasma sodium relatively constant within normal values. The lack of no apparent detrimental effects of NaOH treatment on sodium level and body fluid homeostasis, could be attributed primarily to renal mechanisms which were able to excrete the increased sodium load (Potter, 1963, 1968; Thomas *et al* 1973). The observation that substantial amounts of sodium can be absorbed into the body fluid against a concentration gradient under conditions of high rumen osmolarity (Warner and Stacy, 1972; Hemsley *et al* 1975) could probably explain the large urinary sodium excretion by steers fed the high sodium diet.

There were little treatment differences in plasma potassium, calcium, magnesium, phosphorus, chloride and bicarbonate thus in accord with the observations of Potter, (1963) and Peirce, (1963). However, chloride level decreased with time. Bicarbonate level in plasma were relatively high for all the treatments indicating that the steers were

alkalotic. This could have been induced by excitement of steers during blood withdrawal as all steers appeared healthy. Blood gas were also higher in value above normal average figure especially for partial pressure of CO_2. These deviations could also be attributed to steers excitement during sampling of blood. Peirce, (1963) reported inconsistent results of blood carbon dioxide and cound not attribute it to salt effect. Blood urea nitrogen increased with time on all treatments and were associated with increased urinary urea nitrogen. This result is in contrast with that reported by Ololade and Mowat, (1975) and tend to contradict the N-balance results. Lesperance (1965) found that consumption of saline water instead of tap water decreased plasma urea but increased urinary urea. Total protein, pH and plasma osmolarity were little affected by NaOH or NH_3 treatments. Blood cretinine concentration was significantly low for steers fed NaOH diet compared to the steers fed the other two diets and its value decreased with time on all treatments.

Thus in general NaOH or NH_3 treatments did not have serious effects on blood chemistry both in the short and long terms. This would indicate that the steers were able to adapt and maintain homeostosis inspite of high sodium intake.

5.6.2 Hematology

Pooled means (Table 18) show no significant treatment differences and the values of the parameters measured were within the normal range for healthy bovine. However, period x treatment effects were significant ($P < 0.05$) for PCV, Hb, MCV and MCHC with MCH approaching

significant level ($P \geq 0.05$). Non significant differences among treatments were also found for white blood cell differences among treatments were also found for white blood cell components with the exception of neutrophils and lympocytes which were influenced by period. But they did not show any particular trend. High intake of NaOH, therefore, did not appear to have influenced these parameters to affect the health of the animals.

5.6.3 Health of the animals

All the steers remained in good health throughout the experimental period, but gonitis (inflamation of the stiffe joint) did occur in one of the steers fed NaOH treated diet. This was not attributed to NaOH treatment because the causes of gonitis are many. The microscopic examination of sections of kidney, liver and rumen tissues of all steers showed little evidence of pathological changes in these organs. Only mild interstitial nephritis were found in the kidney sections of the steers fed NaOH and the control diets. Glomeruli in all kidney sections examined appeared to be slightly hypercellular. Sections of rumen tissues examined all appeared normal.

Thus although an intake of sodium of 2.23g/kgW$^{0.75}$ per day during the short term was within the threshold values, the renal mechanisms and related organs were able to maintain the steers in electrolytes balance to ensure good health. This was achieved mainly: (a) through active excretion of excess sodium by the kidney and fecal loss, coupled with high water consumption (b) through decreased sodium intake in the long term (1.36g/kgW$^{0.75}$/day) with a mean of 1.80g/kgW$^{0.75}$ for the experimental period.

It appears therefore, that abnormalities in the balance of body water, electrolytes and acid-base under high sodium intake can be brought about if fresh water intake is restricted or when renal mechanisms fail to excrete excess sodium.

5.7 Feedlot performance and carcass characteristics

Steers fed the NaOH diet grew faster and were heavier at the end of the experiment compared to those fed the control or NH_3 diet. There was little difference in performance between the steers fed the control and those fed NH_3 diets (Fig. 12). Statistical analyses showed that maximum rate of growth and treatment differences occurred during the first five periods which happened to be in summer and fall. During the last six periods which covered winter time, rates of growth were reduced and there was no significant treatment differences though cumulative live weight gain contained to be superior for NaOH diet over the other two diets. Change in body compsoition with age could have been another factor which influenced the steer's performance.

The average daily gain and feed conversion in the feedlot obtained in this experiment for all diets are higher than previously reported (Nicholson et al 1978). The proportion of straw in the diet, level and type of supplementation and the breed of cattle used could have contributed to the differences in steers performance. Garret et al (1976) reported that at 36% straw in the diet no significant treatment differences were observed in intake and rate of gain of lambs. However, at 72% straw in the ration there were significant treatment differences between untreated and ammoniated straw-based diets. These authors concluded that in order to achieve the beneficial effects of

ammoniation and improve animal performance economically, large amounts of straw must be included in the ration. The 60% straw used in dietary treatments in the present experiment was high enough to effect treatment differences. The non-significant difference between the control and NH_3 cannot therefore be attributed to low level of straw in the diets.

The surprisingly high performance by steers fed the control diet is difficult to explain but it could be due to the quality of the straw, processing and storage effects. Grimson (1978), observed apparent improvement in average daily gain, feed intake and feed conversion when Hereford and Angus-Hereford crossbred steers were fed pelleted NaOH treated barley straw. The steers fed the NaOH treated straw gained 13.5% faster and had 12.2% better feed conversion than the control. In the present experiment the steers fed NaOH diet gained 25.3% faster and had 36.9% better feed conversion than the control. There was little difference between the control and NH_3 diets. This could be due to reported poor response of old straw to ammonia treatment (Nicholson et al 1977).

The carcass weight was heavier for steers fed NaOH diet compared to those fed the control and NH_3 diets. No significant treatment differences were found in dressing percentage and rib-eye area. The similarity in dressing percentage would suggest that the liveweight of the steers fed NaOH diet might have been exaggerated a bit by increased rumen fluid due to high conservation of water. The caracass of steers fed NaOH diet had significantly more fat over rib compared with caracass from steers fed the control and NH_3 diet. This was reflected in the grade of the caracasses. (Table 21).

6. SUMMARY

Diets containing 60% of untreated, 5% NaOH treated or 3.5% NH_3 treated Neepawa wheat straw were used in experiments designed to determine the long term effects of feeding high sodium diet to steers. Feedlot performance and carcass characteristics of the steers fed the three diets were also investigated. The various parameters measured included the following: intake, digestibility, nitrogen balance, rumen fluid parameters (VFA, electrolytes, osmolarity and pH), water consumption and excretion, urinary composition, blood chemistry and hematology, performance and carcass characteristics.

The dry matter digestibility of the diets for the entire experiment were 56.8, 58.2 and 57.2% respectively for the control, NaOH and NH_3 diets. Treatment differences approached significant level ($P \geq 0.05$). Factors involving the straw quality, the ration of which the straw was a component, the effects of processing and storage and the influence of high sodium intake were considered to have affected treatment differences. Organic matter digestibility was significantly ($P < 0.05$) higher for NaOH diet compared with the NH_3 diet. NFE digestibility declined with time while crude fibers digestibility especially for NaOH diet increased significantly ($P < 0.05$) in the long term. Digestible energy was significantly ($P < 0.05$) higher for NaOH diet than for the control or NH_3 diet.

Dry matter intake of the feed expressed in $g/kgW^{0.75}$ was not

significant ($P > 0.05$) between treatments when overall means were considered. Intake of feed decreased with time for all treatments, particularly for NaOH diet where intake decreased by 38.2% in the long term. Intakes expressed as a percentage of body weight was affected by period only. Feed conversion efficiency was significantly ($P < 0.05$) high for NaOH diet compared with either the control or NH_3 diet.

Differences in nitrogen intake between treatments were apparently due to body size because there was no significant ($P > 0.05$) treatment effect when intake was expressed in $g/kgW^{0.75}/day$. Urinary nitrogen (g/day) was similar between the control and NaOH treatment in the long term. In the short term it was significantly ($P < 0.05$) higher for NaOH than for the control. Significantly ($P < 0.05$) higher urinary nitrogen was also recorded for NH_3 diet compared with the control. Fecal nitrogen was significantly ($P < 0.05$) higher for the NH_3 diet compared to the control or NaOH diet. N retention was significantly ($P < 0.05$) higher for the control than for the alkali treated diets.

Urinary N expressed as a percentage of intake was significantly low for the control compared to the alkali treated diets. Fecal nitrogen as a percentage of intake was significantly ($P < 0.05$) high for NH_3 diet compared to the other two diets. N digested was significantly ($P < 0.05$) high for the NaOH diet compared with the control or NH_3 diet respectively. N retention as a percentage of intake or N digested was higher for the control than for NaOH or NH_3 diet.

Rumen total VFA concentration significantly ($P < 0.05$) in-

creased with NaOH treatment over the control or NH_3 diet. The molar proportion of acetic acid was generally low for the alkali treatments while the molar proportion of propionic acid was high. These differences were not significant ($P > 0.05$). Iso-butyric acid increased with time and were slightly higher for the control and NH_3 diets than for NaOH diet. N-butyric acid increased with time on all treatments. Iso-valeric and n-valeric did not show any consistent trend but tended to decrease with time for NaOH treatment.

Sodium concentration in the rumen fluid did not differ ($P > 0.05$) between treatments but the value declined with time. Potassium concentration also declined in the long term but it was significantly ($P < 0.05$) higher for NaOH treatment compared to the control or NH_3 diet. There was no significant ($P > 0.05$) treatment difference in chloride concentration. Rumen fluid osmolarity and pH were significantly ($P < 0.05$) higher for NaOH diet compared with either the control or NH_3. In the short term the rumen fluid osmolarity for each treatment was hyperosmotic to that of plasma. However, in the long term only the rumen fluid from steers fed NaOH diet was hyperosmotic.

The steers fed the high sodium diet increased their water intake (liters/day) by 19.3 - 40.7% over the control in the long and short terms respectively and by 26.5 - 58.3% when water intake was expressed as liters/kg of feed DM. Urine excretion by the steers fed NaOH diet increased by 63 - 215% over the control diet in the long and short terms respectively. Fecal water was significantly ($P < 0.05$) low for NaOH diet.

Urinary concentration of sodium was significantly ($P < 0.05$) higher for steers fed NaOH diet compared to the control or NH_3 diet. Steers fed NH_3 diet surprisingly conserved sodium and excreted a lot of potassium. Potassium and chloride were significantly ($P < 0.05$) low in the urine of steers fed NaOH diet. Steers fed the control or NH_3 diet excreted significantly higher urine urea compared to those fed NaOH diet. Creatinine and osmolarity were significantly low for the urine from steers fed the high sodium diet. Urine pH was signifi- cantly ($P < 0.05$) higher for NaOH diet compared to the control or NH_3 diet. There was no significant treatment difference in urine specific gravity. Potassium to sodium ratios were quite low for urine from steers fed NaOH diet, Sodium intake and excretion had negative effect on potassium balance in the short term and positive effect in the long term.

Despite the great increase in sodium intake, the steers fed NaOH diet were able to maintain plasma sodium level relatively con- stant. There was also no significant treatment differences in plasma potassium, calcium, magnesium phosphorus, chloride and bicarbonate. There was no consistent results with blood gas.

The hematological parameters measured appeared normal and there were no significant ($P > 0.05$) treatment differences. But PCV, Hb, MCV and MCHC significantly ($P < 0.05$) increased with time for all treat- ments.

Steers remained in good health throughout the experimental period except for one steer which had gonitis at the time of slaughter.

The microscopic examination of the kidney, liver, and rumen tissues showed little evidence of pathological changes.

The steers fed NaOH diet frew faster and were heavier at the end of the trial compared to those fed the control or NH_3 diet. The rate of gain was 25.3% faster for the steers fed NaOH diet and their feed conversion was better by 36.9% over the control.

Carcass weight was heavier for those steers fed NaOH diet compared to carcasses from steers fed the other two diets. There was little difference in dressing percentage and ribeye area for all treatments. Fat over rib was significantly ($P < 0.05$) for carcasses from steers fed NaOH diet compared with carcasses from steers fed the control or NH_3 diet.

7. CONCLUSIONS

1. There was no significant treatment difference in dry matter digestibility.

2. Organic matter, NFE, CF and energy digestibilities were significantly higher for the NaOH treated diet.

3. NaOH treatment significantly increased urinary nitrogen in the short term but its concentration decreased by 41.3% in the long term indicating adaptation by the steers to NaOH diet.

4. Fecal nitrogen was significantly higher for steers fed NH_3 treated diet compared to NaOH or control diet indicating poor N digestibility.

5. Mean nitrogen retention (29.4, 23.7 and 15.7 g/day respectively for the control, NaOH and NH_3 diets) shows improved nitrogen retention by steers fed the control diet compared to those fed alkali treated diets.

6. Digestible nitrogen was significantly higher for NaOH treated diet compared to the control or NH_3 diet but the relatively low N retention by the steers fed NaOH diet suggest some wastage of N urea.

7. NaOH treatment resulted in decreased feed intake in the long term.

8. Higher feed conversion efficiency was obtained from steers fed NaOH diet than from those fed the control or NH_3 diet.

9. NaOH treatment increased VFA concentration in the rumen fluid by an average of 40.2% over the control. However, VFA concentration in rumen fluids decreased with time for all treatments.

10. The molar proportions of acetic and propionic acids decreased with time while that for n-butyric acid increased in the long term. Iso-butyric, iso-valeric and n-valeric acids tended to decrease with time for NaOH diet.

11. There was no significant treatment difference in rumen fluid sodium and chloride concentrations. Potassium was significantly higher in the rumen fluid of steers fed NaOH diet compared to the other two diets.

12. Rumen fluid osmolarity was significantly increased by NaOH treatment; though it decreased with time. pH was lower in the fluid from steers fed NaOH diet.

13. Steers fed NaOH treated diet increased their water intake (liters/day) by 40.7% in the short term and by 19.3% in the long term over the control group. When water consumption was expressed as liters/kg feed DM, the increase in water intake was 58.3% in the short term and 26.5% in the long term.

14. Urine volume (liters/day) excreted by steers fed NaOH diet increased by 215% and 63% respectively during the short term and long term compared with that of the control group indicating osmotic diuresis in the former.

15. Fecal water and urine volumes (liters/day) excreted by steers fed NaOH diet significantly declined with time, suggestive

of long term adjustment to sodium load by the steers.

16. Urinary sodium concentration was significantly higher for steers fed NaOH diet compared with values for the control or NH_3 diet. In terms of g/day, steers fed NaOH diet excreted 84 and 58.3 g respectively more sodium during the short and long terms compared to those fed the control diet.

17. Urinary potassium was significantly higher for the control and NH_3 groups compared with that from the steers fed NaOH diet. Chloride concentration followed similar pattern.

18. High sodium intake had more negative effect on K retention in the short term.

19. Urinary urea, creatinine and osmolarity were significantly low for steers fed NaOH diet compared to the values for the other two diets.

20. There was no significant change in urine specific gravity.

21. Despite the great increase in sodium intake, steers fed NaOH diet were able to maintain plasma sodium level relatively constant. High intake of sodium also had little effect on the level of plasma potassium, calcium, magnesium, phosphorus and chloride. Bicarbonate level was slightly elevated for all treatments. No consistent results was obtained with blood gas.

22. Hematological parameters measured were not significantly different between treatments. But PCV, Hb, MCV and MCHC were significantly increased with time for all treatments.

23. Steers fed NaOH diet remained in good health like those

on the control or NH_3 diet. Microscopic examination of the kidney, liver, and rumen tissues showed little evidence of pathological changes.

24. Steers fed NaOH diet gained 25.3% faster and had 36.9% better feed conversion compared with the control. No significant difference in performance was found between the control and NH_3 groups.

25. Heavier carcasses were obtained from steers fed NaOH diet compared with the control. However, there was little treatment differences in dressing percentage and ribeye area. Carcasses from steers fed NaOH diet had more fat over rib.

26. Although the availability of fresh water has been shown to be important in the excretion of excess sodium, there appear to be an important relationship between sodium and potassium. This might be important in the feeding of NaOH treated diets. Research along this line might be worthwhile. Further work is also required to test the value of old ammoniated straw. The variability in response to NaOH diet by the steers during the present experiment would suggest the need for further test with different animals or breeds. The role of fungi in old straw also need further investigation.

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A P P E.N D I C E S

APPENDIX A

HEMATOLOGY

Baseline Data on Alfalfa/Brome Hay

Item		Treatment		
		Control	5%NaOH	3.5%NH_3
PCV	%	37.70	36.28	35.13
Hb	g/100 ml	13.35	13.07	13.03
RBC	x $10^6/mm^3$	9.23	8.68	8.75
MCV	μ^3	40.00	40.67	39.00
MCH	$\mu\mu g$	14.77	15.32	15.20
MCHC	x $10^3/mm^3$	35.72	36.02	37.15
WBC	x $10^3/mm^3$	9.40	9.02	8.90
Neutrophils	%	25.33	24.60	22.83
Neutrophils	x $10^3/mm^3$	2,276.67	2,267.67	2,125.83
Lymphocyte	%	69.50	69.67	72.00
Lymphocyte	x $10^3/mm^3$	6,421.17	6,252.83	6,485.57
Monocyte	%	3.60	3.50	3.17
Monocyte	x $10^3/mm^3$	395.60	307.00	274.50
Eosinophils	%	2.25	2.00	2.75
Eosinophils	x $10^3/mm^3$	212.75	159.75	231.25
Fibrinogen	mg/100 ml	216.67	226.67	250.00

APPENDIX B

BLOOD CHEMISTRY

Base Line Data on Alfalfa/Brome Hay

Plasma Composition		Treatment		
		Control	5%naOH	3.5%NH_3
Na^+	m Eq/l	140.50	140.83	141.33
K^+	m Eq/l	4.43	4.50	4.65
Cl^-	m Eq/l	99.67	98.17	98.83
HCO_3^-	m Eq/l	26.17	28.45	26.17
Ca^{++}	mg/100 ml	10.52	10.52	10.58
Mg^{++}	mg/100 ml	2.28	2.17	2.37
$PO_4^{\equiv}$	mg/100 ml	7.30	7.62	7.47
BUN	mg/100 ml	11.65	12.18	12.03
Total Protein	g/100 ml	6.97	7.05	6.82
PO_2	mmHg	37.55	33.73	36.87
PCO_2	mmHg	44.87	44.12	49.23
pH		7.38	7.40	7.37