STUDIES IN RUMINANT NUTRITION WITH PARTICULAR REFERENCE TO THE USE OF A CONCENTRATED LIQUID PROTEIN, MINERAL AND VITAMIN SOLUTION

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SUMMARY

The work in this thesis investigates the use of a novel concentrated feed supplement (LS) which contains urea, calcium, phosphorus, sodium, trace elements and vitamins in a fully soluble liquid form with principally 1100 g crude protein, 30 g Ca and 15 g P/kg. Such a concentrated liquid supplement might have advantages over a solid in that it could have a wide range of possible means of application to feeds for both large and small farm units. Considerable reliance is presently placed on providing supplementary nutrients in the form of free-access blocks or liquids in an effort to save labour on farms. Experimental studies are discussed that show that for these materials intake by ruminants in groups is far from uniform, many consume none of the materials offered. Methods of incorporating the liquid supplement into ruminant diets are examined in relation to the voluntary intake of oat straw, digestibility and animal performance and their subsequent use in production trials are investigated.

In Section 1, LS supplementation was assessed in conjunction with alkali treatment of straw. Recent work has indicated that the addition of alkali to straw increases its digestibility. However, when alkali treatment is used to improve the energy value of straw to allow a greater consumption there should in turn be a reduced requirement for cereals. This results in a reduced protein and mineral content in the diet and therefore the need for additional protein, mineral and vitamin supplementation. It was shown that LS supplementation of straw (at chopping) was both practical and nutritionally advantageous and when the straw was simultaneously treated with NaOH the effect was additive, in terms of improved intake rather than improved digestibility. However, because on-farm treatment of straw with NaOH using existing machinery and equipment currently available is relatively expensive

and presents some safety hazards to the operator, $Ca(OH)_2$ treatments were investigated as an alternative. $Ca(CH)_2$ treatment had no effect on straw digestibility, probably as a consequence of its relatively low solubility. Subsequently the ensiling of $Ca(OH)_2$ treated straw was examined. The results were not promising and the treated materials were completely unsuited for animal feeding.

In Section 2 various methods of presenting LS to ruminants were studied in relation to the voluntary intake and digestibility of straw-based diets (these included : LS, in the drinking water; in a barley cube; in a molasses lick and sprayed on to oat straw). All methods of supplementation except LS via the water were found to be satisfactory in increasing intake or improving the digestibility of oat straw. In terms of animal acceptance, response and practical application the most practicable method of giving LS to ruminants was on the straw.

In Section 3 the effect of LS supplementation on given production parameters was examined. LS supplementation of whole oats given to lactating ewes (suckling twin lambs) produced equivalent growth rates of lambs to that recorded when soya bean meal was the supplementary nitrogen source. The rate of use of LS was governed by the amount of supplementary nitrogen required in a given particular circumstance. Therefore the diet plus the LS addition may not provide the full amounts of calcium and phosphorus to meet current A.R.C. (1965) recommendations. The adequacy of LS was examined when given to ruminants receiving less Ca and/or P than the recommended intakes. It was found that LS was a convenient and adequate method of supplementation, when given on bruised barley and sugar beet pulp and that in general, although mineral intakes were lower than the current A.R.C. (1965) recommendations no deleterious affects were noted in the given production parameters that were investigated over extended periods with both pregnant and lactating

and growing ruminants.

It is concluded that the use of this fully soluble liquid containing urea, minerals and vitamins is a convenient and adequate method of supplementing ruminant diets and has a wide range of uses with regard to both nutrient content and method of incorporation.

GENERAL INTRODUCTION

This thesis is primarily concerned with the use of a novel, concentrated feed supplement, which contains urea, calcium, phosphorus, sodium, trace elements and vitamins in a fully soluble liquid form.

A feed supplement is a material which is included in the diet at less than 5% of the total ration. It supplies those dietary materials which are inadequate in farm-mixed diets. To include a supplement at 5% or less, adequate mixing is essential to achieve uniformity of intake of the supplement by animals within a group. This is especially important with urea, for example, because of its possible toxic affects at high intakes. It is also important for phosphorus compounds due to their rising costs.

Ideally, the composition of a feed supplement should be such that it correctly compensates for the inaedquacies of the whole diet. Manufacturers of feed supplements can only reasonably provide a restricted range of products considered suitable for use in the more common husbandry systems. For unusual diets, additional supplementary materials may be required. A product having a wide range of uses with regard to both nutrient content and method of incorporation (e.g. into cereals or into straw) has obvious advantages.

In the present context it is assumed that the main purpose of a feed supplement is to increase the supply of protein in the form of urea to ruminants. Additionally, the supplementary product may contain calcium, phosphorus, salt, trace elements and vitamins. Whilst, commonly, mineral/vitamin mixtures may be offered free-choice, urea-containing products should preferably be presented in a controlled manner and incorporated within a larger amount of other feed to prevent over-consumption.

Under present legislation (The Fertilisers and Feeding Stuffs (Amendment) Regulations 1976) the presence of urea in animal feed stuffs must be declared. A value of the crude protein equivalent of this may be claimed using the normal factor of 6·25 which assumes 16% N in crude protein . On this basis the crude protein equivalent of urea is 46 x 6·25 = 287·5% and this value has been used throughout this thesis.

There are currently three principal methods for providing feed supplements containing urea with or without varying proportions of minerals, trace elements and vitamins to ruminants.

The first method is by the provision of urea in the form of urea/mineral/vitamin mixture as a blend of powdered and crystalline materials. Examples of the composition of these products are given in Table 1.

Within this range of products the urea concentration varies from about 300-500 g/kg. The use of these mixtures for free-access feeding is not recommended due to the high urea content. The most desirable method of inclusion of these materials would be by thoroughly mixing the chosen product with rolled or ground cereal or similar substance to increase the crude protein content from say about 100 to 135 g/kg.

The rate of use is governed by the urea content. Taking, as an example a 450 kg suckler cow given poor roughage and limited cereals requiring an additional say, 250 g CP from the given supplement the amounts of associated minerals and vitamins provided will vary greatly. For example, the amounts of calcium provided could range from about 13 to about 41 g/day and the amounts of phosphorus from about 4 to about 10 g/day.

The second method of providing urea to ruminants is by way of high density feed blocks, offered on a free-access basis to cattle and sheep. Use is normally restricted to animals grazing poor quality roughage (e.g. in hill areas in Britain during winter or on range vegetation in

more arid countries), but they may be given in other circumstances. Blocks contain up to 250 g/kg crude protein containing 80-190 g CP/kg present as urea. The high salt content of many blocks may make them unsuitable for feeding indoors, due to the effects of increased water intake on the wetness of the bedding.

Table 1. Examples of commercial urea/mineral/vitamin mixtures supplied as powders.

	per kg	A	B	C	D
Crude protein as urea	g	1000	1450	960	1400
Calcium	g	165	77	153	71
Phosphorus	g	42	25	26	25
Salt	g	128	100	100	200
Magnesium	g	8	25	14	16
Iron	mg	1000	1500	1900	3300
Copper	mg	150	1000	250	360
Cobalt	mg	60	140	70	220
Manganese	mg	770	3000	605	3500
Iodine	mg	60	300	75	250
Zinc	mg	700	2000	1100	1680
Selenium	mg	-	5	-	-
Sulphur	mg	-	-	8900	12500
Vitamin A	1000 iu	165	360	400	236
Vitamin D_3	1000 iu	41	90	57	59
Vitamin E	iu	-	500	-	-
Intakes when product supplies 250 g crude protein/day					
Ca	g	41·3	13·3	39·8	12·7
P	g	10·5	4·3	6·8	4·5

Table 2. Examples of the composition of some feed blocks for ruminants.

	per kg	A	B	C	D
Crude protein total	g	243	176	170	204
as urea	g	176	90	87	190
Ether extract	g	7	12	60	61
Salt	g	169	123	145	142
Calcium	g	22·0	24·0	20·1	23·5
Phosphorus	g	2·8	3·8	4·8	3·2
Magnesium	g	17·8	49·2	31·0	39·8
Estimated ME	MJ	8·9	9·1	11·1	10·2
Intakes when product supplies 250 g crude protein/day					
Ca	g	22·6	34·0	29·6	28·8
P	g	2·9	5·4	7·1	3·9

Examples of four block products are given in Table 2. When each block is consumed to provide a total of 250 g CP/day, there is as wide a range of additional phosphorus provided as there is with the mineral supplements.

Blocks must be designed to be weather resistant. One important property is their hardness which results from the inclusion of a binding agent within their cereal base and/or pressure during manufacture. Their salt content may be at such a high level of inclusion that it is an unpalatable ingredient, thus limiting consumption. This is an advantage because it provides a safe method of limiting urea intake on an ad libitum basis, but a disadvantage in that it reduces the energy intake from the block. Due to the cereal inclusion not all the protein in the blocks is in the form of urea. Mineral inclusion, especially phosphorus is frequently very small and the energy supplied is also small relative to cereals and many compound feeds and may be expensive.

Kendall (1977) recorded a wide variety of difficulties associated with block feeding to a range of cattle and sheep at grass. Intake was effected by several variables. Stocking rate greatly altered block intake, a much higher proportion of sheep consumed no block when grazed at 1 ewe/ha than 1 ewe/0.5 ha. Likewise the number of blocks on offer at any one time, and/or the provision of alternative feeds effected intake. Consumption was increased by 50% with continuous rain. Snow cover also increased block consumption (when fresh blocks were provided). Cold weather decreased consumption, probably because the blocks became very hard. High winds causing livestock to seek shelter, also reduced intake.

Kendall (1977) also found a wide day-to-day variation in group intake. For both cattle and sheep individual consumption was always more variable than when the animals were provided with a similar amount of dry matter (DM) given as a cubed concentrate in troughs. A high proportion ($\sim$20%) of sheep in hill conditions consumed no block

and equally a high proportion (~20%) consumed very large amounts in relation to the overall mean intake.

The third principal method for providing supplementary urea is in a molasses-containing liquid. These products normally contain about 120-140 g/kg urea and about 500 g/kg molasses to give a crude protein content of 340-400 g/kg. These products may also contain small amounts of phosphoric acid (providing less than 3 g/kg phosphorus) to reduce possible fermentation. Vitamins A and D are also commonly included in the products. A major problem with such products is that sedimentation of sludge like materials may occur in the farm storage tanks. Calcium is specifically omitted because of serious precipitation problems. There is no mineral inclusion and the additional provision of free-access mineral/vitamin mixtures is generally recommended. These products are usually delivered by bulk-tank to farms. They are generally made available to animals on a free—access basis. The molasses liquid is made available via liquid feed dispensers. These are covered troughs into which at least two rotating balls or rollers are fixed, so that the ball is half covered with the viscous solution and the other half is uncovered protruding through an opening in the trough cover. Intake is controlled by the licking action of the animal on the rotating ball. Although the product is theoretically available on a free-access basis this is seldom the case. In practice the ball-licker is filled up once daily, and competition between animals for the lick is high. The daily allocation is usually consumed within a few hours. Individual consumption of these licks is as varied as with feed blocks. Nolan, Ball, Murray, Norton and Leng (1974) have recorded that in a situation where the mean intake of such a product by a group of 48 Hereford heifers at grass was 850 ml, eight animals

had an intake of nil and individual intakes ranged from 30 ml to 2·4 l/day. Nolan, Norton, Murray, Ball, Roseby, Rohan-Jones, Hill and Leng (1975) showed similarly with sheep that 97 out of a total of 200 consumed none of the liquid. Mean overall intake was 105 ml, with a range of consumption for individual sheep from 5 - 550 ml.

The major disadvantage of both feed blocks and liquid feeds is the lack of uniformity of intake of these products. Another important point is the relatively high cost of the energy content of these products, which is low in relation to cereals. The relatively high cost arises partly from the manufacturing process, from the packaging (blocks) and from the distribution cost of relatively low concentrations of protein and energy in liquid feeds.

There are few systems of animal husbandry that do not need another form of energy additional to that supplied by feed blocks or liquid feeds especially in winter grazing and poorer roughage systems. They may generally increase the intake of poor quality roughage but by only about 10-15%. It would seem reasonable to give a urea/mineral/vitamin supplement that contained no appreciable energy, leaving the additional energy required to be supplied (e.g.) from barley on the farm. There are potential advantages in using a non-viscous liquid supplement instead of a solid. A solid supplement is limited to the addition of cereals. In contrast, a free-flowing concentrated liquid has a wide range of possible methods of application.

1. For application to straw.

Straw production in Britain is about 9 million tonnes/year. It is estimated that 3·5 million tonnes is burned during the autumn (NFU, 1973) and about 3 million tonnes are fed. A report organised by The Agricultural Development and Advisory Service (ADAS) (Anon, 1974) recommended that the most effective way of using straw was to feed it to ruminants. High straw diets are low in protein and phosphorus. Supplementation with a liquid urea/mineral/trace element/vitamin product would increase the feed value of the straw. The liquid could be included at baling using existing applicators used for hay preservatives. It could be poured over conventional or large bales at or prior to feeding. The liquid could be easily incorporated into existing straw chopping systems or used with on farm cereal/straw mixing machines. It could also be added separately at the same time as sodium hydroxide treatment of straw.

2. For application to cereals.

On British farms there are approximately 40,000 roller crushers and 30,000 hammer or other grinding mills (A proportion of these grinding mills may be associated with pig farms). In contrast, there are only 11,000 mixers and 12,000 combined milling and mixing plants (Compound Animal Feeding Stuffs Manufacturers National Association Ltd., 1975). From this information it can be concluded that a large proportion of cereals are processed on farms, but there may often be no mixing facilities available. In this situation solid supplements could not be mixed into processed grains other than by shovelling. However, a liquid supplement could be added to cereals as they leave the roller or bruiser by gravity or by a spray method. Dust would also be suppressed by addition of such a liquid.

3. A liquid supplement could be used with whole unground cereals for sheep.

4. Other feeds.

The liquid could be poured over and adhere to turnips, potatoes, or molassed beet pulp. Maize silage is deficient in protein and phosphorus and a liquid supplement could be added at the chopping stage as is already the case with acids used for silage preservation.

5. Drinking water.

A liquid supplement might be incorporated in the drinking water at an appropriate level. This method would ensure that all animals received the supplement unless it had a detrimental effect on taste.

6. Home-mix liquid supplements.

The liquid supplement could be diluted with molasses and water to form a free-access liquid for stock, of comparable urea concentration to existing urea/molasses feeds.

However, to be capable of such a wide possible range of uses the liquid must be concentrated so that it neither runs off straw before it is absorbed and so that it does not make cereal grains too moist that they stick together.

An extensive review on liquid supplements for livestock feeding has been published by Wornick (1969). America was the fore-runner in the use of liquid feed supplements, but there have been problems in finding suitable liquid vehicles for the appropriate additives. The first supplements contained urea and molasses, then came the further addition of phosphoric acid. Almost every liquid supplement now contains vitamins A and D and trace elements, and some include vitamin E. In addition to the phosphorus content (principally from phosphoric acid and ammonium polyphosphates) it would be desirable to add calcium to liquid supplements. However, at the rate of addition

of calcium required, it has been impossible to keep it in solution, massive precipitation occurs. More soluble forms of calcium (e.g. calcium chloride and calcium hydroxide) or chelating agents have been tried but the problem has not been overcome. Some supplements were developed in America, where the desired calcium required was added resulting in a liquid supplement with calcium as a suspension. One drawback is that agitation is required during transport and storage. Frequently, the addition of calcium to molasses-containing liquids may result in the formation of hard, almost concrete-type precipitates. More generally there is extensive production of gelatinous-type flocculations in the presence of phosphorus added as ammonium polyphosphate.

Previous to this experimental work, Hemingway, Parkins, Fishwick and Ritchie had developed and formulated a liquid supplement (Hemingway, Parkins and Fishwick, 1977; Fishwick, Parkins, Hemingway and Ritchie, 1978; Fishwick and Parkins, 1979) that fulfilled the following desirable objectives.

1. It should be free-flowing to aid mixing, store well, and be stable and free of sedimentation over a long period and range of temperatures.
2. It should be concentrated to reduce handling and application rates.
3. It should contain a high proportion of non-protein-nitrogen (NPN) as supplementary protein is the most important additive to the supplement.
4. It should be palatable, for this reason a proportion of molasses is generally desirable.
5. A degree of acidity is necessary to stabilize the urea when in contact with other feeds, and to minimise any problems of palatability and toxicity if urea were converted to ammonia.

6. It should contain phosphorus, essential in straw-based diets, poor hay and root diets where phosphorus is deficient.

7. It should contain calcium in a fully soluble form as this is a major inadequacy in diets containing a high proportion of cereals.

8. It should contain salt, trace elements, and vitamins in a fully stable form.

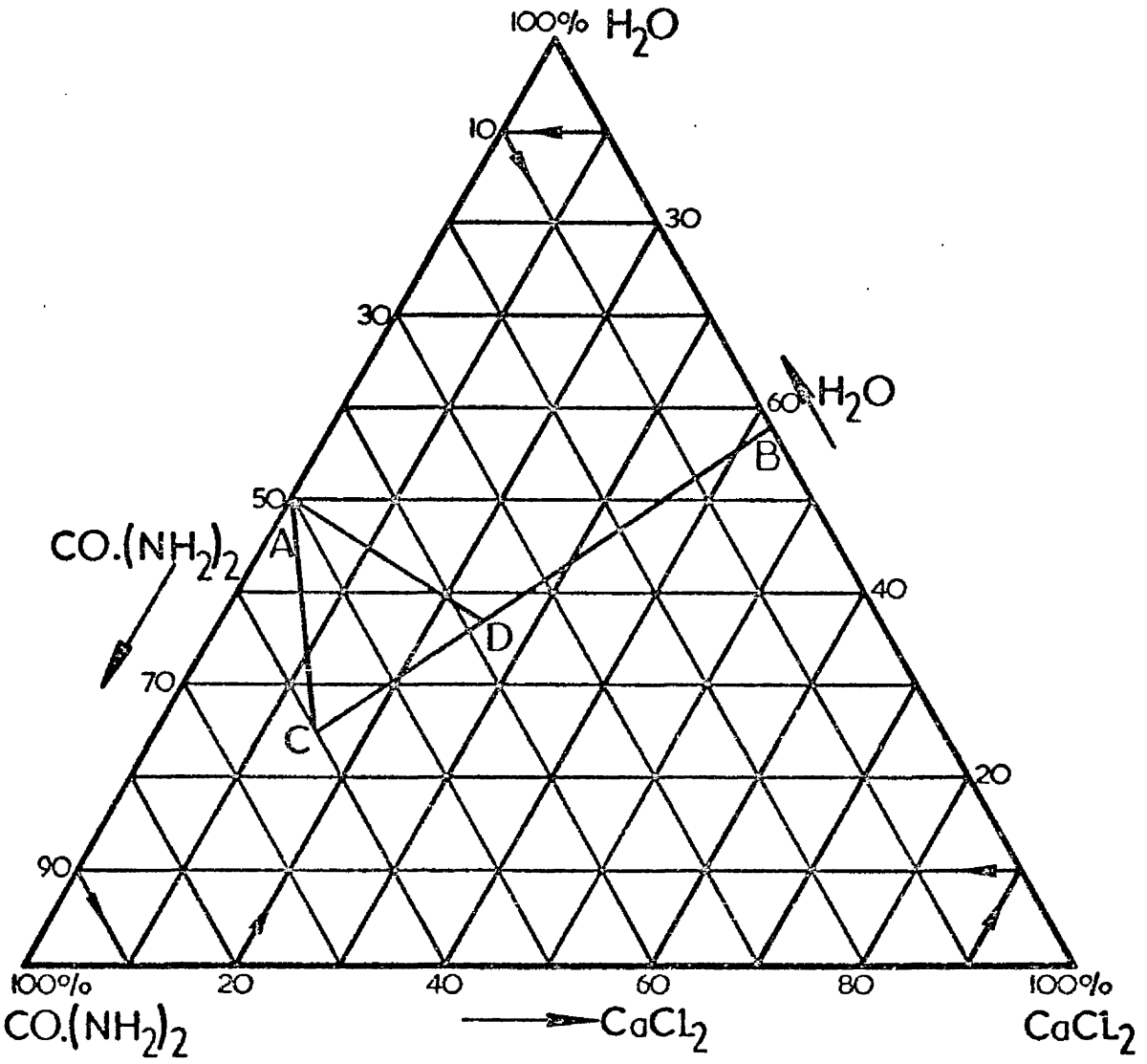
Construction of a concentrated fully soluble product containing urea, calcium and phosphorus.

Under normal atmospheric pressure the content of urea in saturated solutions is positively related to temperature i.e.

Temperature (^{o}C) of saturated solution	8	17	26	36	46	56	68	79	90
% urea by weight	45	50	55	60	65	70	75	80	85

At normal environmental temperatures of 8-17^{o}C only 45-50% of urea may be contained in a saturated solution. It was demonstrated by Hemingway, Parkins and Fishwick (personal communication) that increased solubility of urea (to saturation) was evident when calcium chloride was present in solution. Fig.1 shows the phase diagram at a normal ambient temperature of about 15^{o}C for urea, water and calcium chloride (described as the anhydrous salt). All the proportions represented by that part of the diagram (tending towards 100% water) above the line A-C-B refer to the proportions which can form a solution free of undissolved material. Below that line, undissolved material is present. The highest proportion of urea for minimum water is at C with the composition 60% urea, 15% anhydrous calcium chloride and 25% water. D represents the lowest point for urea inclusion with 38% urea, 25% anhydrous calcium chloride and 37% water, i.e. there is still a greater amount of urea than the water which would have been needed to dissolve it, if the calcium chloride had not been present.

Fig.1. Phase equilibrium diagram of water/urea/anhydrous calcium chloride compositions at 15°C and normal atmospheric pressure.


100% H_2O
10
30
30
60
H_2O
B
50
$CO.(NH_2)_2$
A
40
D
70
C
20
90
100%
20
40
60
80
100%
$CO.(NH_2)_2$
$CaCl_2$
$CaCl_2$

The amount of phosphoric acid which may be added to a urea/calcium chloride/water complex without the formation of a precipitate was found to be dependant upon the urea and calcium chloride contents. Below 5% calcium chloride the amount of phosphoric acid which may be added becomes asymptotic with concentrations of phosphoric acid approaching infinity. Between 21 and 25% calcium chloride the amounts of phosphoric acid which can be added is practically too small (i.e. for ruminant nutrition purposes).

On a percentage by weight basis the maximum amount of phosphoric acid which may be present in a phosphoric acid/urea/calcium chloride/water composition is given by:-

maximum % H_3PO_4 included =

$$\frac{90}{A} \text{ anti log } (1{\cdot}8782 - 1{\cdot}5652\ UC \times 10^{-3})$$

where A is the % phosphoric acid by weight in the phosphoric acid solution used. (e.g. if 90% H_3PO_4 ; A = 90).

U is the % by weight of urea in the final composition.

C is the % by weight of calcium chloride in the final composition.

On a basis of many considerations (primary amongst which was to obtain the most suitable amounts of urea, calcium and phosphorus to supplement a range of practical diets) the following proportions were adopted to form a suitable fully soluble composition. This is described as the urea/calcium chloride/phosphoric acid/water "mother liquor". It has the composition (% by weight) urea, 47; calcium chloride (anhydrous), 11; phosphoric acid (88-90%), 7; and water, 35.

Subsequently, for practical nutritional use it was found desirable to add molasses (10%), sodium chloride (5%), magnesium and a comprehensive range of trace elements (as their chlorides), iodine and

vitamins A, D and E.

The final fully soluble product has the declared composition

	%
Protein equivalent of urea	110
Calcium	3·0
Phosphorus	1·5
Salt	5·0
Sugars from molasses	5·0

Trace elements	mg/kg
Magnesium	680
Manganese	638
Zinc	800
Copper	152
Cobalt	1·6
Iodine	12·6
Selenium	0·1

Vitamins	iu's/kg (3 months after manufacture)
A	100,000
D	10,000
E	40

The material is free flowing acidic (pH about 1·6) and has a specific gravity of 1·3.

It is currently manufactured in 20-50 tonne quantities in a plant used for the manufacture of concentrated liquid fertilisers. Delivery to farms is normally by bulk tank into 200 litre polypropylène drums. Dispension from the drum is either by tap or hand pump. The product stores well in both cold and warm conditions and is not hazardous to handle.

The product is currently marketed by Imperial Chemical Industries Ltd. (Agricultural Division), Billingham, Cleveland, under the trade-name "Granstock". In the majority of the experimental work described in this thesis the liquid protein supplement (LS) used was manufactured in bulk. For experimental purposes the amounts of nitrogen, calcium, and phosphorus present in particular batches were analysed before use in the appropriate experiment. The other values were taken as being present as declared by calculation from the amounts of contained ingredients.

The objectives of this thesis were to evaluate the uses of LS in terms of animal acceptance, response and to investigate the most practicable method of supplying the liquid supplement to animal diets. The essential details of the experimental designs in respect of proceedures, livestock and dietary treatments are described separately for each experiment. The details of all the analytical techniques, time lapse photography studies, nylon-bag techniques and the daily routines for balance trials for sheep housed in metabolism cages are given in a separate Appendix at the end of this thesis.

In general, only mean values together with their statistical errors are presented in the thesis. Individual data are only quoted where they seem to be of unusual interest. Details of the individual values appropriate to their quoted means are lodged in the Animal Husbandry Department, Glasgow University.

LITERATURE REVIEW

The literature reviewed is divided into three main sections: (i) Urea as a NPN source; (ii) Nutritional deficiencies in relation to voluntary intake of food and (iii) Methods of processing low quality roughages to improve their nutritive value. These topics cover the area in which LS is investigated.

The first, urea as a NPN source, discusses the principals and uses of NPN in relation to animal metabolism and utilization.

The second, nutritional deficiencies in relation to voluntary intake of food, summarizes the effect on protein inadequacy and mineral and vitamin deficiencies on voluntary food intake.

The third, methods of processing low quality roughages to improve their nutritive value, reviews various methods of improving the nutritive value of roughages with particular reference to chemical treatments and their effect on rumen function/physiology and animal performance.

UREA AS A NON PROTEIN NITROGEN SOURCE

The ability of ruminal bacteria to utilize NPN has been studied and exploited for nearly a century. There are several reviews on the history, development and acceptance of NPN as a protein replacer in ruminant nutrition (Reid, 1953; Stangel, 1964; Briggs, 1967; Waldo, 1968; Conrad and Hibbs, 1968; Helmer and Bartley, 1971; Anon, 1977). For this reason it is the intention to review only the literature more directly involved with the experimental work of this thesis.

Historical background.

Weiske, Schrodt and Danger (1879) were probably one of the first group of workers to suggest using NPN compounds as protein replacers in ruminant diets. During the next fifty years numerous experiments were reported, mainly from Germany, on urea utilization and feeding to ruminants. By the early 1940s urea was being produced on a commercial scale in Europe (Curtis, 1932) and in America. Research on urea subsequently revealed that a readily available energy source was essential for effective NPN utilization by the ruminant. Both the total protein and level of natural protein in the ration were demonstrated to influence urea utilization (Wegner, Booth, Bohstedt and Hart, 1940, 1941a, 1941b). It was in the late 1940s that urea became acceptable in the commercial rearing of livestock, since then research work has concentrated on increasing the efficiency of urea utilization and minimising any potential risk of toxicity.

Helmer and Bartley (1971) have reviewed the use of urea in ruminant diets. Urea is used in systems either to supplement poor quality roughages or to replace a proportion of a costly vegetable protein. Several factors are important in obtaining the optimal utilization of urea to ruminants in different feeding and production regimes. The factors include (i), the solubility or degredation of

the feed protein by rumen micro-organisms; (ii), the proportion of protein in the ration; (iii), the source of energy, (iv), microbial protein synthesis and (v), the level of milk yield in lactating animals. Many experiments have investigated the effect of different levels of substitution of urea for crude protein in the production of milk by dairy cows. The results are conflicting, however, as the amino acid nutrition of high yielding dairy cows is critical. At high levels of milk production lysine, methionine and tryptophan may become limiting. This suggests that rumen micro-organisms cannot supply the requirements for certain amino acids. It is in these circumstances that supplements of NPN are not fully effective.

Reid (1953) reviewed the use of urea in calf rations. However, in practice giving urea is generally delayed until the calf becomes fully ruminant.

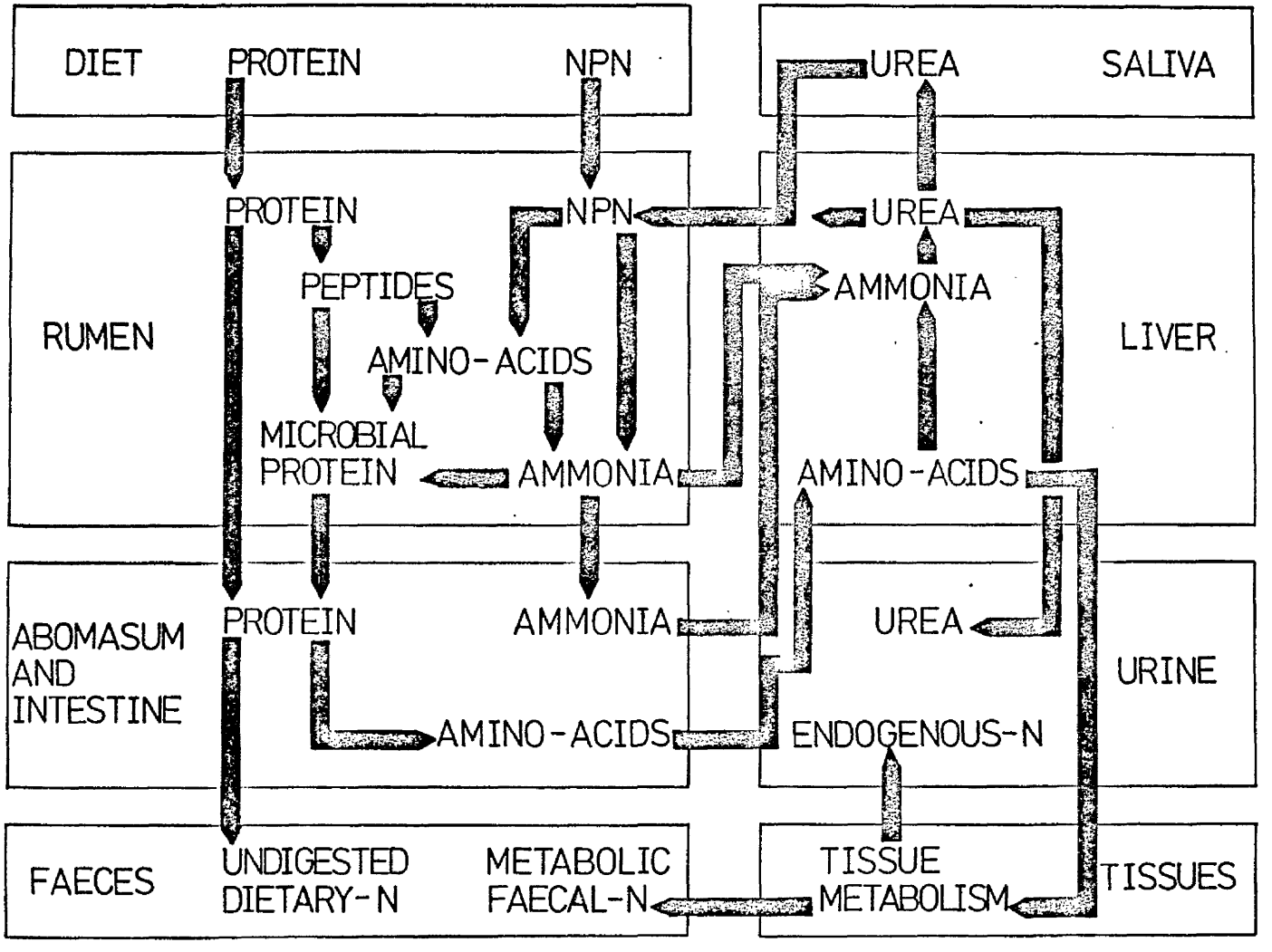
Urea is of use for suckler cows, growing heifers and store beef cattle given straw or poor quality hay and for supplementing vegetable protein for fattening beef cattle rations.

Nitrogen metabolism in the rumen.

A schematic summary of nitrogen utilization by the ruminant is presented in Fig.2. The primary source of nitrogen to the rumen is from the dietary constituents. Ammonia is produced in the rumen by the metabolism of proteins, peptides, amino acids, urea, nitrates and other NPN compounds. McDonald (1948) showed that large quantities of ammonia were produced in the rumen under normal feeding regimes. Ammonia concentration was shown to be dependant upon the type of protein and carbohydrate present.

The second source of rumen N is urea which is known to enter the rumen endogenously by salivary recirculation. The presence of salivary urea was demonstrated by McDonald (1948). The concentration of salivary

Fig.2. Nitrogen metabolism in the ruminant (Adapted from Annison and Lewis (1959)).


DIET
PROTEIN
NPN
UREA
SALIVA
RUMEN
PROTEIN
NPN
UREA
PEPTIDES
AMMONIA
AMINO-ACIDS
LIVER
MICROBIAL
PROTEIN
AMMONIA
AMINO-ACIDS
ABOMASUM
AND
INTESTINE
PROTEIN
AMMONIA
UREA
URINE
AMINO-ACIDS
ENDOGENOUS-N
FAECES
UNDIGESTED
DIETARY-N
METABOLIC
FAECAL-N
TISSUE
METABOLISM
TISSUES

urea was shown to be increased when higher rumen ammonia concentrations occurred (Lewis, 1957).

The third method of entry of N into the rumen is by diffusion across the rumen wall (Houpt, 1959). Cocimano and Leng (1966) showed that entry of total endogenous urea into the rumen was a function of blood urea concentration.

Urease activity.

Proteins are hydrolysed in the rumen to varying degrees depending upon their individual solubilities and physical form (El-Shazly, 1958). Pearson and Smith (1943a) using in vitro techniques demonstrated that rumen fluid has a high urease activity at all times. As urease activity was minimal in the dietary constituents and it was not secreted into the rumen, they concluded that urea was hydrolysed in the rumen by bacterial urease producing ammonia and carbon dioxide. Most of the work indicates that urea is rapidly hydrolysed, making urea utilization almost synonymous with ammonia utilization. However, Farlin, Brown and Garrigus (1968) have found evidence to suggest that not all urea is converted to ammonia before utilization. They infused either ^{14}C-labelled urea or sodium bicarbonate into the rumen and found that the carbon of urea did not equilibrate with the carbon dioxide pool, suggesting that urea is metabolized in the rumen without complete hydrolysis to carbon dioxide and ammonia, and that it need not be hydrolysed for utilization of the contained N.

Ammonia absorption.

Ammonia absorption through the rumen wall is one pathway of N disappearance from the rumen. McDonald (1948) was the first to demonstrate this phenomenon. Lewis (1957) later demonstrated that portal blood ammonia concentration increased as a curvilinear function

of rumen ammonia content. Ammonia absorption across the rumen wall is governed by rumen pH (Hogan, 1961), and the concentration gradient (Lewis, Hill and Annison, 1957; Hogan, 1961). Hogan (1961) found that ammonia absorption was dependant on concentration gradient at pH 6·5, but ammonia loss was nil at pH 4·5.

The absorbed ammonia is carried via the portal circulation to the liver where conversion to urea occurs. Lewis et al. (1957) found that changes in rumen ammonia concentration of sheep on different diets were paralleled by changes in portal blood ammonia concentration. On the given dietary regime a maximum of 60 mM ammonia/l in the rumen was observed. When the ammonia concentration in portal blood exceeded 0·8 mM/l the peripheral blood ammonia concentration increases as the liver was unable to complete the conversion to urea effectively and toxic symptoms developed. A major problem concerned with the efficient utilization of urea is the rapid release of ammonia. Coombe, Tribe and Morrison (1960) have expressed concern about the important relation of the increased rate of absorption of ammonia with increased pH to urea toxicity.

Part of the beneficial effect of feeding a readily available carbohydrate with urea may be due to the fact that acids produced by microbial fermentation prevent a rise in rumen pH and thus reduce the rate at which ammonia is absorbed. Hence the reason for the practical use of urea in molasses solutions. Molasses not only serves as a readily available carbohydrate, but also as an excellent carrier.

Increased acidity may reduce the activity of urease and thus reduce the rate of ammonia release from urea. Ritchie, Parkins and Hemingway (1972) administered urea phosphate or equivalent amounts of nitrogen and phosphorus in the form of urea and dicalcium phosphate orally to overnight-starved sheep and cattle. Results showed that the

administration of urea phosphate produced lower concentrations of blood ammonia, rumen ammonia and potential toxicity was less than with urea. These results were associated with the acidic properties of urea phosphate which affected the rate and amount of ammonia produced in the rumen. Similar results were reported by Hemingway, Parkins and Ritchie (1972). Urea-phosphate contains about 17% nitrogen and 20% phosphorus. The results of Perez, Warner and Loosli (1967) indicated that urea-phosphate can be used effectively as a nitrogen and phosphorus supplement for ruminants.

Recycling of urea.

Urine is the major pathway for loss of urea in the ruminant, but not all blood urea is eliminated by the kidney. However, 70% of the total urinary N is from urea (Livingston, Payne and Friend, 1962). When urea was injected intravenously into sheep receiving a low protein, carbohydrate-supplemented ration, 52% of the urea was not recovered in the urine, or in body fluids (Houpt, 1959) and was presumably utilized by rumen micro-organisms. In cattle 77% of the total N in mixed cattle saliva is attributable to urea (Bailey and Balch, 1961). Likewise Somers (1961) estimated that under normal conditions urea represented 60-70% of the total N in sheep saliva, and the concentrations of urea N in blood and in saliva were well correlated. Blood urea concentration is also influenced by the N intake of the sheep. A number of workers have shown that endogenous urea enters the rumen by saliva (Houpt, 1959; Packet and Groves, 1965; Cocimano and Leng, 1967; Houpt and Houpt, 1968).

However, urea also enters the rumen by diffusion across the ruminal epithelium, Houpt (1959) estimated that transport of urea across the rumen epithelium could account for up to 95% of the total transfer.

Urea also enters the rumen by transference from the blood to sites of microbial degradation in the digestive tract of sheep (Cocimano and Leng, 1967). Houpt (1959) exchanged the rumen contents of sheep with saline and measured the return of urea N to the rumen; 5·2 m moles urea N returned per hour to the rumen. Of this only 0·3 m moles/h was in the saliva. Thus he attributed the remaining 4·9 m moles/h to absorption of urea through the rumen wall. Allen and Miller (1976) have queried the extent to which urea is transferred to the rumen and the means by which it is transferred. A maximum transfer of blood urea to the rumen of sheep of approximately 5g N/day has been suggested by Weston and Hogan (1967). However Nolan and Leng (1972) concluded that only 1·2 g N/day was transferred in sheep given lucerne hay. Somers (1961) found that the secretions of urea in saliva contributes to the transfer of blood urea to the rumen. While Nolan and Leng (1972) suggest that virtually all urea transfer occurred in the saliva. Kennedy and Milligan (1978) found that with sheep given brome grass, the rate of transfer of urea in the rumen was not significantly correlated with plasma urea concentration in the range 145-250 mg N/l.

Similar plasma urea concentrations associated with maximal urea transfer have been found by various workers (Weston and Hogan, 1967; Vercoe, 1969; Thornton, 1970). From the evidence to date, urea transport is dependent on rumen ammonia concentration. However, the mechanism by which ammonia inhibits urea transport is uncertain. Kennedy and Milligan (1978) postulate that this inhibition could be an effect on diffusion, or active transport in the rumen epithelium, changes of blood flow to the epithelium, or factors associated with dietary differences.

Recycled urea is hydrolyzed by ruminal urease to ammonia, which may be used to maintain an active microbial population (Moir and Harris,

1962). Easily fermentable dietary carbohydrates improved the utilization of recycled urea (Houpt, 1959; Packet and Groves, 1965).

Urea which is not utilized in the rumen passes into the abomasum and the intestine. However, this urea is not totally inaccessible to the ruminant as urease activity has been found to be present in the intestinal fluids (Sidhu, Jones and Tillman, 1968) and ammonia can be absorbed from the intestine (Hecker, 1971).

Factors influencing urea utilization.

The balance between the amount and availabilities of N and energy to the rumen microbial population has an important effect on the utilization of nitrogen and energy. Schwartz (1967) reviewed the factors affecting urea utilization. Low utilization of N and carbohydrate results when N is limiting in the rumen. Campling, Freer and Balch (1962) infused 75 or 150 g urea solution daily into the rumen of cows given oat straw containing 0.46-0.53% N and increased the feed intake, rate and extent of fibre digestion and rate of particle passage. The amount of urea which can be utilized, by the ruminant and the amount of protein which it can replace depends upon the amount and nature of the dietary protein, the amount and type of carbohydrate in the ration, and the concentration of urea liable to cause toxicity. Pearson and Smith (1943b) found that certain amino acids promoted while others depressed the *in vitro* synthesis of protein from urea by micro-organisms.

Goodrich (1965) has emphasised the importance of evaluating the mineral contribution of rations that are supplemented with urea, since the replaced high protein feeds are often excellent mineral sources. Burroughs, Latona, De Paul, Gerlaugh and Bethke (1951) found sodium, potassium, calcium, magnesium, sulphur, chlorine, phosphorus and iron to be essential for optimum cellulose digestion and urea utilization *in vitro*.

Other factors influencing urea utilization include the extent of rumen development and its microbial population.

Methods of improving urea utilization.

The limiting factor in the utilization of urea by ruminants is the rapid hydrolysis of urea by microbial urease. A quantity of ammonia may be absorbed from the rumen before microbial synthesis. It is perhaps for this reason that most performance studies conducted with animals have indicated that urea N is inferior to that of vegetable protein supplements when given in iso-nitrogenous quantities.

Much research has been conducted to minimize ammonia N loss by attempting to reduce the rate of urea hydrolysis, to convert urea to less soluble forms, to increase the ability of micro-organisms to utilize ammonia N, or to increase the amount of urea N recycled to the rumen. Some feeding trials with NPN have shown poor NPN utilization. Repp, Hale and Burroughs (1955) observed that NPN - supplemented rations improved in value after a 2-3 weeks adaptation period. Since then numerous studies have observed this adaptation response (Campbell, Loosli, Warner and Tasaki, 1963; Schaadt, Johnson and McClure, 1966; Caffrey, Hatfield, Norton and Garrigus, 1967). It is for this reason that NPN compounds should be introduced to the feeding regime gradually to allow the rumen micro-organism population to adapt to the increased rumen ammonia concentration and to allow the liver to adjust to the consequent increase in blood ammonia concentration which may in fact be quite rapid i.e. within one hour of feeding.

Bloomfield, Garner and Muhrer (1960) reported that the rate of urea hydrolysis was nearly four times greater than the corresponsing uptake of ammonia by rumen micro-organisms suggesting that it might be possible to improve urea utilization by decreasing rumen urease activity. There has been only limited work on improving urea utilization by reducing the rate of urea hydrolysis by inhibiting rumen urease. Tillman and Sidu (1969) have reviewed the work on inhibition of ureolysis and proteolysis by chemical inhibitors, antibiotics and by producing

circulating antibodies to urea.

Several attempts have been made to reduce the rate of ammonia release from urea by altering its physical form. Deyoe, Bartley, Pfost, Boren, Perry, Anstaett, Helmer, Stiles, Snug and Meyer (1968) developed a product "Starea" by cooking urea with maize, wheat or barley at a high temperature and extruding the gelatanized product in pellet form. Subsequent growth trials showed "Starea" to be superior to urea as a protein supplement. Johnson, Bentley and Hershberger (1962) coated urea prills with 20 different fat and wax type materials and succeeded in reducing the rate of ammonia release with some of the materials. Ward and Cullison (1970) compared urea with urea coated with ethyl cellulose. The coated material was less toxic, more palatable, but in nitrogen balance studies it did not increase nitrogen retention. Hemingway and Law (1975) coated urea phosphate and urea with urea-formaldehyde to reduce their rate of water solubility. Coating with urea-formaldehyde resulted in slightly lower rumen ammonia concentrations (non significant). Fishwick (1978) coated urea prills with sulphur or wax, and showed both methods to be effective in reducing the rate of hydrolysis of urea to ammonia.

Other slow release compounds include isobutylidene diurea (IBDU), a sparingly water soluble material containing 32% nitrogen. Parkins, Ritchie and Hemingway (1971a) have shown that the addition (via a rumen fistula) of IBDU, produced negligible increases in rumen and blood ammonia relative to equivalent amounts of nitrogen in the form of urea. In a feeding trial with lambs a growth rate response equivalent to using soya bean meal was obtained by IBDU supplementation (Parkins, Ritchie and Hemingway, 1971b). Komatsu and Sakali (1971) suggested that during the release of urea from this compound, isobutyraldehyde is formed which in turn is converted to isobutyric acid, which is an important energy substrate for microbial growth.

Biuret is another slow release compound, therefore it is a possible substitute for urea. Many workers have reported that biuret is less toxic to animals than urea (Hatfield, Garrigus, Forbes, Neumann and Gaither, 1959). Biuret is slowly hydrolyzed in the rumen (Bauriedel, Craig, Ramsey and Camehl, 1971), this appears to result from low biuretase activity in the rumen. Ammonia is the end product of biuret hydrolysis, urease is only involved in the hydrolysis of biruet if urea is an intermediate product.

Although these slow release materials effect the production of rumen ammonia, animal production parameters are not appreciably influenced and they are not widely used in ruminant nutrition because of their expense relative to urea.

After Bloomfield et al. (1960) reported that urea hydrolysis was four times more rapid than the uptake of ammonia N, Bloomfield, Welsch, Garner and Muhrer (1961) studied the effect of more frequent feeding of less urea at one time to keep rumen NPN at a minimum. Using wether sheep they found that urea utilization, nitrogen balance and whole blood albumin were increased and blood urea concentration was lowered when the animals were given a diet containing 32 g urea/kg offered given 16 times a day compared with 2 times a day. One of the supposed advantages of giving urea on a free access basis (e.g. in liquid form or in a block to be licked) is that urea may be utilized more efficiently when consumed little and often compared with once daily. Campbell, Howe, Martz and Merilan (1963) showed similar findings using dairy heifers given a diet containing 33 g urea/kg either 6 or 2 times daily. Heifers receiving the supplement 6 times daily attained a 25% greater daily liveweight gain than those animals receiving the supplement twice a day. Other workers (e.g.) Goodrich, Meiske and Gharib (1972) have found no advantage in giving urea frequently in

terms of increased utilization. Kendall (1977) using beef cows compared oat straw supplemented with urea containing blocks given once or ten times daily with a barley/urea concentrate and barley given once a day. He found no response to the frequent intake of NPN, measured in terms of increased voluntary intake of straw and/or improved digestibility compared with the block or barley urea given once a day.

If the benefit of NPN supplementation to the diet is derived primarily from the incorporation of ammonia into rumen micro-organisms, it is essential to establish the concentration above which rumen ammonia ceases to enhance microbial growth (Slyter, Satter and Dinus, 1979). Satter and Slyter (1974) found that at the concentration of rumen ammonia-nitrogen of 5 mg/100 ml of rumen fluid that ammonia-nitrogen became limiting for microbial growth. Slyter et al. (1979) using rumen fistulated steers weighing 183 to 226 kg studied the effect of rumen ammonia concentration on nitrogen utilization. Increasing the ammonia-nitrogen content above 2·2 mg/100 ml of rumen fluid had no effect on digestion in the rumen. Increasing the ammonia-nitrogen content beyond 4·5 mg/100 ml had no significant effect on the total volatile fatty acid (VFA) concentration and nitrogen retention increased as urea infusion increased until the rumen ammonia-nitrogen concentration was 4·5 mg/100 ml. Their results support the view that maximum microbial growth will occur at a concentration ranging from 2 to 5 mg ammonia-nitrogen/100 ml rumen fluid.

NUTRITIONAL DEFICIENCIES IN RELATION TO VOLUNTARY INTAKE OF FOOD

As already discussed, control of voluntary intake in the ruminant is governed by complex interactions of various regulatory systems. It is the intention to review only the literature related to nutritional deficiencies and their influence on limiting voluntary intake.

Protein inadequacy.

In ruminants there is considerable evidence that shows that the intake of low protein content rations is reduced. Various workers have conducted experiments in which feed intake was specifically studied. For sheep (Egan and Moir, 1965; Elliot, 1967b; Weston and Hogan, 1968) and for cattle (Campling et al., 1962; Elliot, 1967a; Lyons, Caffrey and O'Connell, 1970), were shown to consume less of diets deficient in protein than of the same diets with supplementary protein or urea. The decrease in voluntary food intake may have been due to decreased ruminal fermentation (Campling et al., 1962) and partly to the metabolic effect on the animal (Masters, 1963; Egan, 1965). Egan and coworkers in a series of experiments have endeavoured to establish the manner by which low protein diets depress the voluntary feed intake by sheep. Egan (1970) concluded that the regulation of feed intake is limited at the lower end of the digestibility scale by mechanisms other than reticulorumen fill, and that casein supplementation resulted in increased intake that could be attributed to more rapid removal of digesta from the rumen and an alteration of the "setting" of the fill mechanism. Therefore protein metabolism could override the fill mechanism or permit "resetting" at a higher level. Kempton and Leng (1979) demonstrated that in lambs given a low-protein cellulose-based diet, responses in food intake and growth were obtained to supplementation with urea and casein, both of which are rapidly degraded to ammonia in the rumen. However greater responses were

obtained when protein was given in a form which escaped rumen fermentation (e.g. formaldehyde-treated casein). In a further study Kempton, Nolan and Leng (1979) concluded that the primary factor limiting voluntary food intake and growth of lambs given low-protein cellulose-based diets appeared to be the availability of amino acids for absorption from the small intestine. The results of Kempton et al. (1979) and Egan (1977) suggest that intake of low quality lignified roughages may be stimulated by supplementing with rumen undegraded protein.

Protein, NPN, mineral or vitamin supplementation will enhance the utilization of poor quality roughages if they form an inadequate diet in these respects. Poor quality roughages are deficient in nitrogen, are low in mineral content and high in crude fibre (e.g. barley straw about 40 g CP, 500 g CF, 4 g Ca and 1 g P/kg DM) and are of low digestibility. Any improvement in the quality and acceptability of roughages resulting in increased voluntary intake by the ruminant and higher performance is important from the nutritional point of view. Due to the high cost of energy rich cereals the practicality of utilizing these materials for protein requirements of ruminants is limited. The alternative is to use NPN and/or mineral, vitamin supplements. Nitrogen is the major limiting nutrient in low quality roughages, supplementation with NPN to supply ammonia to the rumen microflora is appealing economically and ecologically. Many experiments on urea utilization with low quality roughage diets have been conducted. Increases in voluntary intake have been reported with urea supplementation given to ruminants on low protein roughage diets (Morris, 1958; Beams, 1959; Williams. Pearce, Delany and Tribe, 1959; Campling et al. 1962; Coombe and Tribe, 1963; Hemsley and Moir, 1963; Fishwick, Hemingway, Parkins and Ritchie, 1973; Fishwick, Fraser,

Hemingway, Parkins and Ritchie, 1974; Kendall, 1977; Innes and Kay, 1979; Mbatya, Smart and Kennedy, 1979). Not all workers have reported increases in voluntary intake with urea supplementation. Kay, Andrews, MacLeod and Walker (1968) found a slight depression with urea supplementation of barley straw when given to pregnant beef cows, however, the barley straw contained as much as 50-70 g CP/kg DM.

However, efficient utilization of urea N requires a higher level of available energy than is found in most roughage diets. (Bloomfield, Wilson and Thompson, 1964; McLaren, Anderson, Tsai and Barth, 1965; Williams, Whiteman and Tillman, 1969). Substitution of NPN materials for the normal energy and protein sources in conventional production diets at levels greater than 30% has generally led to substantial decreases in productivity, (Conrad and Hibbs, 1968; Swan and Lambing, 1968), while diets based on low quality roughages plus NPN, mineral supplements barley provide maintenance requirements for ruminants (Coombe and Tribe, 1962; Coombe, Christian and Holgate, 1971).

Mineral and vitamin deficiencies.

Mineral and vitamin status in the ruminant is also important and unless an adequate supply of minerals and vitamins are available biochemical conditions in the rumen are not conducive to efficient microbial protein synthesis and various deficiency symptoms may arise. Various workers have reported that feed intake in ruminants was decreased with diets deficient in, calcium (Underwood, 1966), manganese (Maynard and Loosli, 1962), potassium (Telle, Preston, Kintner and Pfander, 1964), phosphorus (Preston and Pfander, 1964; Playne, 1969), cobalt, copper, vitamin A and vitamin D (NRC, 1976), zinc (Miller, Blackmon, Powell, Gentry and Hiers, 1966), riboflavin (Weise, Johnson, Mitchell and Nevens, 1947) and vitamin B_{12} (Somers, 1969).

Minerals and vitamins are involved in many important physiological functions in the body. However, for the purpose of this thesis the review will be restricted to the influence of phosphorus in the diet.

Phosphorus is associated with the normal function of all animal tissue, due to its role in the energy exchange processes. Therefore any limitation in the phosphorus supply will be reflected in general impairment of body function. Symptoms of phosphorus deficiency in ruminant animals include loss of appetite, reduced production, depressed inorganic phosphorus in the blood serum and reduced reproductive performance. Continued depletion results in skeletal disorders and pica. Phosphorus in the ruminant diet has been studied by Theiler, Green, and Dutoit (1928); Eckles, Palmer, Gullickson, Fitch, Boyd, Bishop and Nelson (1935); Kleiber, Goss and Guilbert (1936); Hemingway (1967); Little (1970); Hemingway and Fishwick (1976) and Hemingway (1977). The initial effect of phosphorus deficiency is a depression of feed intake. Kleiber et al. (1936) reported that growing heifers given a diet containing 0·8 g P/kg had 60% of the voluntary appetite of those given a diet with 4·0 g P/kg. Little (1968) demonstrated a significant linear response in voluntary intake of phosphorus deficient cattle when these were given graded supplements of phosphorus to a diet adequate in other respects. Fishwick and Hemingway (1973a,b) reported that additional phosphorus increased the voluntary intake by growing sheep of urea supplemented molassed sugar beet pulp (8 g/kg P). Fishwick, Fraser, Hemingway, Parkins and Ritchie (1974) reported that increasing the total intake of phosphorus from about 6 to 17gP/day did not increase the voluntary intake of straw by pregnant beef heifers on a short term basis. However, Fishwick, Fraser, Hemingway, Parkins and Ritchie (1977) showed that over a longer period of 22 weeks using cows in late pregnancy and early

lactation the voluntary intake of oat straw was reduced to 3·4 kg/day compared to 6.2kg/day when the phosphorus intake was about 12 g compared to 28 g P/day. Theiler, Green and Du Toit (1924) observed reduced efficiency of feed utilization by phosphorus deficient animals. Riddell, Hughes and Fitch (1934) and Kleiber et al. (1936) reported that the digestibility of feed was not impaired by phosphorus deficiency. However, phosphorus deficiency has an adverse effect on the utilization of energy (Kleiber et al. 1936) and nitrogen (Stewart, 1934; Morris and Ray, 1939).

METHODS OF PROCESSING LOW QUALITY ROUGHAGES TO IMPROVE THEIR NUTRITIVE VALUE

Introduction.

Although this is a wide subject, for the purpose of this thesis the discussion will be mainly confined to the processing of cereal straw for ruminant feeding. Straws have a low crude protein content (e.g. oat straw 20-50 g/kg DM, barley straw 20-65 g/kg DM and wheat straw 20-30 g/kg DM (Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries for Scotland and Department of Agriculture for Northern Ireland, 1975 (M.A.F.F. et al. 1975))) and are mainly composed of structural carbohydrates. Generally they have low DM digestibility coefficients (c. 0.40) when fed to ruminants owing to the high content of cell wall materials. Approximately 75% of straw is cellulose and hemicellulose which together should apparently constitute an excellent energy source for ruminants. However, lignocellulose is a complex of lignin, cellulose and hemicellulose and accounts for most of the cell wall constituent of plants (Pigden and Heaney 1969). As a proportion of total DM, the lignocellulose content of forages varies widely depending on the stage of maturity of the plant and the species. Cellulose and hemicellulose materials are important components of the diet to the ruminant animal, because they can provide tactile stimulation necessary for rumen function (without any particular regard to any nutritive contribution from lignocellulose) (Baumgardt, 1969) and can be utilized as an energy source by rumen microflora. As the plant matures the physical and chemical properties of the lignocellulose complex alter rendering these and the other carbohydrate constituent increasingly unavailable to the rumen microflora.

Guggolz, Kohler and Kloppenstein (1971) have defined the factors which affect carbohydrate digestion in the rumen. (i) The lignin acts as an inert barrier between the carbohydrate sources of straw and the digesting enzymes of ruminants. (ii) Cellulose is too highly crystalline and structured to be quickly available to enzyme action. (iii) Silica inhibits carbohydrate digestibility.

The voluntary intake of straw is low due to the poor digestibility of straw. Biological, mechanical and/or chemical treatment may increase digestibility and voluntary intake. Supplementing straw with protein, minerals and vitamins may be necessary to improve dietary utilization. However, supplementation alone does not overcome the problems of low intake and the resultant low metabolisable energy (ME) provided.

Wood (1974) and Palmer (1976a) have reviewed the feeding value of straw to ruminants. However, untreated straw has its limitations. Biological treatment of straw is based on the use of fungi that degrade lignin. The following section, however, only reviews the physical and chemical methods of improving poor quality roughages with particular reference to the alkali treatment of straws as they are currently the only methods used in practice.

PHYSICAL TREATMENTS

Grinding and pelleting.

There are numerous substantial reviews on the effect of grinding and pelleting roughages (Minson, 1963; Beardsley, 1964; Moore, 1964; Campling and Milne, 1972; National Academy of Sciences, 1973; Owen, 1978). Physical processing of roughages may affect the following parameters, intake, digestibility, ME and efficiency of utilization of ME. Reduction in forage particle size usually results in improved animal performance which is mainly due to the increase in voluntary intake of the animals (Moore, 1964). However, apparent digestibility

can be reduced due to the reduction in retention time in the alimentary tract. Gharib, Goodrich, Meiske and El Serafy (1975a) found no increase in digestibility (DM) from grinding poplar bark. Improvement of roughage intake is affected by the quality of the roughage, the poorer the roughage the greater the response to grinding and pelleting. Campling and Freer (1966) found no increase in voluntary intake from grinding and pelleting a good quality grass, but with oat straw the voluntary intake increased by 26%. Levy, Amir, Holzer and Newmark (1972) using Israeli-Friesian male calves found that although grinding and pelleting straw decreased the apparent digestibility, the ME was used with greater efficiency. Dehority and Johnson (1961) achieved extreme reductions in the particle size of forages by ball-milling and recorded large increases in in vitro digestion of cellulose.

Chopping, grinding and pelleting of straw are necessarily power consuming processes. On the farm scale they also take a considerable time and some of the machines may require tractor power beyond that found on many predominantly livestock farms.

Steam and pressure.

Waiss, Guggolz, Kohler, Walker and Garrett (1972) found that the in vitro digestibility of rice straw was improved by heating with steam at 160°C. Garrett, Walker, Kholer, Waiss, Graham, East and Hart (1974) compared rice straw diets treated with NaOH or steam under pressure given to lambs. They found that rice straw steamed under 28 kg/cm^2 of pressure for 90 s was not consumed in sufficient quantity for lambs to maintain body weight, and that steam pressure treatments were detrimental to digestibility.

Irradiation

High levels of electron irradiation have been suggested for increasing the in vitro dry matter digestibility (IVDMD) of straw (Lawton, Bellamy, Hungate, Bryant and Hall, 1951; Pigden, Pritchard and Heaney, 1966; Huffamn, Kitts and Krishnamurti, 1971; Yu Yu and Emery, 1975) Lawton et al. (1951) found that high levels of irradiation could produce delignification, depolymerization and destruction of the crystalline structure of cellulose. Yu Yu and Emery (1975) found that irradiation reduced all fibrous constituents of straw at dose levels of 7·66 log rads and above. High levels, (8·66 log rads) increased total in vitro cell wall digestibility mainly due to the increase in solubility of the DM and not to an increase in microbial digestion. Pritchard, Pigden and Minson (1962) used gamma radiation to treat wheat straw with 5-9 log rads and found an increase in IVDMD. They also found a sharp reduction in VFA production in vitro with 8 log rads treatment and above, indicating a disintegration of nutrients. McManus, Manta, Mcfarlane and Gray (1972) using in vivo methods suggested that there was a formation of microbial inhibitory compounds in samples irradiated at high dosages. Yu Yu and Emery (1975) found that rumen micro-organism cell wall digestion was dramatically decreased at high levels of irradiation. Huffman et al. (1971) irradiated different wood products, finding in vitro cellulose digestion to be similar to those obtained as a result of NaOH treatment. However, Millett, Baker, Feist, Mellenberger and Satter (1970) concluded that irradiation costs were too high for commercial application.

CHEMICAL TREATMENT

Historical Background.

The treatment of straw with chemicals to remove the factors inhibiting digestion has been attempted since about 1900, and was based on

delignification processes used for manufacture of paper from wood and straw. Most of the early work was conducted in Germany and as early as 1890 Henneberg and Lehmann (cited by Archibald 1924) reported feeding trials in which crude fibre was prepared from rye straw by the action of sodium hydroxide. Godden (1920) soaked straw in NaOH solution (2 - 3% by weight) and then washed it with water. Archibald (1924) reviewed the early work which culminated in the wide acceptance of the Beckmann process for treating straw. The process (Beckman, 1921) involved soaking chopped straw in a 1·5% aqueous solution of NaOH at a ratio of 8 parts solution to 1 part straw at atmospheric pressure and temperature for at least 24 hours. The straw was then drained and washed with water to remove residual alkali. Processing costs, by this method are expensive mainly due to the loss of nutrients (20-25%) by leaching during the washing operation. However, the digestibility of the straw is increased from about 40 to 60-70% and the straw becomes more acceptable to the animal. The limiting factors affecting the Beckmann method are the large amounts of water needed for washing the straw and the subsequent pollution problem, the labour involved, the storage as the product is quite wet and the cost of the alkali treatment compared with the low protein content of the product. The effectiveness of the Beckmann process was subsequently confirmed by Archibald (1924), Ferguson (1942), McNally (1942), Sen, Ray and Talapatra (1942), Woodman and Evans (1947). In recent years there has been a revival of interest in the Beckmann process (Stone, Mossir, Glenn and Keller, 1966; Ololade, Mowat and Winch, 1970; Saxena, Otterby, Donker and Good, 1971; Carmona and Greenhalgh, 1972). Lampila (1963) developed a method which would simultaneously decrease the amount of water, alkali and labour required. The total water consumption for both treatment and washing was only 7 kg per kg of straw, which was considerably less than that

required by the normal Beckmann process. Hart, Graham, Hanni, Rockwell, Walker, Kohler, Waiss and Garrett (1975) have improved the Beckmann process by separating the liquor from the straw by pressure and recycling it into the soaking bath.

However, all these methods require washing to remove the unreacted alkali, resulting in a loss of water- and alkali-soluble nutrients. More recent work has centred on the use of spray or soaking with more concentrated alkali solutions and with or without subsequent neutralization of any residual alkali with either mineral or organic acids.

A simpler, cheaper and more effective method was a "dry" process developed by Wilson and Pigden (1964). Roughage was sprayed with a relatively small volume of a concentrated solution of NaOH (9 g NaOH in 30 ml H_2O per 100 g straw) and the excess alkali was neutralized with an organic acid. The moist product can then be fed immediately to animals, without being washed. Other investigators have since increased the digestibility of straw to about 60% by spraying it with a concentrated solution of NaOH with or without neutralization of any residual alkali (Wilson and O'Shea, 1964; Donefer, 1968; Donefer, Adeleye and Jones 1969; Singh and Jackson, 1971; Guggolz, et al., 1971; Carmona and Greenhalgh, 1972). Following the work by Wilson and Pigden (1964) there has been a world-wide revival in alkali treatment of poor quality roughages. Over the last fifteen years numerous experiments and research reviews have been published (Donefer, 1972; Rexen and Moller, 1974; Greenhalgh, 1976; Palmer, 1976b; Rexen, Stigsen and Kristensen, 1976; Jackson, 1977; Jackson, 1978; Owen, 1978).

Effect of alkali on digestibility and chemical composition of treated roughages.

Alkali treatment of roughages disrupts the cell wall lignocellulose complex by partially dissolving hemicellulose, lignin and silica by hydrolysing uronic and acetic acid esters (Feist, Baker and Tarkow, 1970) and by swelling cellulose (Whistler and Teng, 1970). Cellulose is not dissolved, as can be seen from Table 3 taken from Jackson (1977). Tarkow and Feist (1969) showed that alkalis exerted their effect on roughages by altering the binding between lignin and carbohydrates (i.e. by breaking the esteric ties in the xylene chains that bar water absorption) thus rendering the carbohydrates more accessible to enzyme digestion in the rumen.

Table 3. The mean recovery of dry-matter cell contents and cell wall components from paddy, wheat and oat straws treated with 12-16 g NaOH/100 g straw. (g/100 g original untreated straw DM).

(adapted from Jackson, 1977).

	Treated	Untreated
Dry matter	73	100
Cell contents	13	23
Cell-walls	60	77
Hemicellulose	12	26
Cellulose	38	38
Lignin	6	9
Silica	4	7

Hence the major effect of alkali treatment on roughages is to increase the digestibility (Beckmann, 1921).

It has been shown that treatment of roughages with alkali increases solubilization of hemicellulose (Ololade et al., 1970; Summers and Sherrod, 1975). Alkali may also exert its effects through swelling of the cell (Tarkow and Feist, 1969) and possibly through altering certain lignin-carbohydrate bondages.

When the alkali treatment is followed by washing with water to remove the residual alkali, large losses of DM occur (Sen et al., 1942; Ololade et al., 1970; Saxena et al., 1971; Chandra and Jackson, 1971; Carmona and Greenhalgh, 1972). Saxena et al., (1971) found that at high levels of NaCH treatment followed by washing, that crude protein and lignin decreased and acid detergent fibre (ADF) content (cellulose and lignin) increased. However, if alkali treatment is not followed by washing there is no change in ADF content (Ololade et al., 1970; Rexen and Thomsen, 1976). A decreased concentration of cell wall constituents occurs following NaOH treatment (Ololade et al., 1970; Rexen and Thomsen, 1976). This may be due largely to loss of hemicellulose because both workers found no significant changes in ADF content. At high levels of alkali treatment lignin content tends to decrease (Saxena et. al., 1971; Chandra and Jackson, 1971; Gharib, Meiske and Goodrich, 1972a). At concentrations of NaOH lower than 8% of roughage DM, the lignin content does not change.

Factors affecting the action of alkali on the composition and digestibility of straw.

(i) Amount and concentration of alkali used

Since the Beckmann process there have been many experiments conducted to improve the efficiency of this process, largely by reducing the volume of water applied and increasing the alkali concentration. Work has been carried out to find the concentration of alkali to use to treat straw to achieve maximum animal performance and minimum labour and costs.

The Beckmann process requires large amounts of alkali (8 to 10 g/100 g straw) and water. Jayasuria and Owen (1975) examined the effect of volume and concentration of NaOH solution treatment of barley straw on the digestibility and voluntary intake by sheep (68 kg body weight). NaOH was applied at 45 or 90 g/kg straw in 2 or 8 litres of water and then neutralized with hydrochloric acid. The results indicated that the volume of water in which the NaOH was dissolved did not affect the efficiency of treatment over the range 60 to 800 ml/100 g chopped straw. However, by reducing the volume to 30 ml digestibility decreased. Similar results were obtained by Donefer et al. (1969). Jayasuria and Owen (1975) also found by in vitro experimentation that the efficiency is improved by increasing the volume of solution from 60 to 120 ml/100 g straw. They found that when solution volumes were not limiting that increases in digestibility were small when the NaOH concentration was increased above 4·5 g/100 g straw. Singh and Jackson (1971) also found that above 3·3 g NaOH in 100 ml water/100 g straw digestibility of the straw was not significantly increased. Carmona and Greenhalgh (1972) compared the Beckmann process with a spraying process. The spraying method was found to be poorer, and this was attributed to the difficulty of adequate mixing of the straw with the NaOH solution. Donefer et al. (1969) suggested that the more efficient mixing of alkali and straw obtained by using larger volumes of solution was the principal explanation for the increased response to using increased amounts of liquid. Accordingly, when the volume of water is large enough to ensure adequate mixing the efficiency of the alkali treatment will be independent of volume of the alkali solution. A number of workers (Wilson and Pigden, 1964; Ololade et al., 1970; Chandra and Jackson, 1971) have found that with 12-15 g NaOH/100 g straw the maximum increases in in vitro digestibility (~40% units)

are obtained. An increase in in vitro digestibility occurs with increasing amounts of NaOH up to 10 g NaOH/100 g straw and a levelling off thereafter occurs (Carmona and Greenhalgh, 1972; Rexen et al., 1975; Levy, Holzer, Neumark and Folman, 1977).

(ii) Reaction time

The time for the alkali to completely react is important, depending upon whether the treated roughage is to be fed immediately, stored loose or processed (e.g. pelleted). In a commercial situation it is expensive to extend the time of reaction. Chandra and Jackson (1971) and Agrawal (1975) have found that the amount of residual alkali continues to react at a slow rate after treatment. However, the in vitro digestibility of roughages sprayed with NaOH was shown not to increase with time over a period of up to 5 days. (Agrawal, 1975) or up to 150 days (Gharib, Meiske, Goodrich and El Serafy, 1975b). Chandra and Jackson (1971) suggested that the benefit from longer reaction times (10-15 min) would be marginal and probably not economical on a commercial scale. However, Ololade et al. (1970) found that over a period of 24 h that the digestibility of sprayed barley straw was significantly higher than when the straw had been treated for one hour. Similar results were obtained by Rexen et al. (1976), a reaction time of 24 h increased the digestibility of treated roughage.

(iii) Temperature and pressure

Alkali treatment is enhanced by heat and pressure (Klopfenstein, Bartling and Wood, 1967; Ololade et al., 1970; Guggolz, et al., 1971; Gharib, Meiske and Goodrich, 1972b; Umunna and Klopfenstein, 1972; Klopfenstein, Graham, Walker and Kohler, 1974). Chandra and Jackson (1971) found that increasing the temperature to 100°C without alkali increased the digestibility of maize cobs, but not wheat or paddy straw.

Ololade et al. (1970) found that temperature affected the rate as well as extent of the response to NaOH treatment of roughages.

The combined effects of temperature and pressure have been studied by Rexen et al. (1976) on ground straw subsequently treated with NaOH and subjected to a high pressure and temperature rise during pelleting. Applying pressure for 1 min at room temperature, or raising the temperature only had little effect. However, when the temperature was increased and pressure raised to 50 atm, organic matter digestibility (OMD) increased from 53% to 60% with 30 g NaOH/kg straw and 62% to 73% when using 60 g NaOH/kg straw. Such a process is currently in use commercially in both Great Britain and elsewhere.

RESPONSES BY THE ANIMAL

Differences between *in vitro* and *in vivo* results.

Discrepancies have been shown between the digestibility coefficients obtained by methods *in vitro* and *in vivo* when the rate of addition of NaOH increases above 40 g/kg of roughage (Guggolz, Saunders, Kohler and Klopfenstein, 1971; Ololade and Mowat, 1975; Rexen et al., 1976; Levy et al., 1977). Digestibility coefficients obtained from *in vivo* methods are generally lower than expected from *in vitro* values (e.g. Coombe, Dinius and Wheeler, 1979; Acock, Ward, Rush and Klopfenstein, 1979).

Chandra and Jackson (1971) found that the amount of residual alkali increased with increasing concentration of alkali treatment. Wilson and Pigden (1964) showed that after 21 days wheat straw treated with 6% NaOH still had 30% unreacted NaOH present. Donefer et al. (1959) neutralized the unreacted alkali with acetic acid. Chandra and Jackson (1971) showed that wheat straw treated with 3% NaOH had only 8% of the alkali unreacted and they postulated that there is no need to neutralize the unreacted alkali unless more than 2-3% of alkali is used in the

treatment. Maeng, Mowat and Bilanski (1971) found that the digestibility of energy in NaOH-treated straw was increased when the treated straw was fed in combination with alfalfa silage thus reducing the concentration of alkali fed.

Although the necessity or benefit of neutralization of unreacted alkali has clearly been established, it can be seen that from work on alkali-treated roughages the discrepancy between *in vitro* and *in vivo* results is marked especially at high rates of addition of alkali. From this it may be concluded that the residual alkali might interfere with microbial fermentation (either an effect of hydroxide or sodium ions) and prove potentially detrimental to livestock health at high concentrations of alkali treatment. Residual alkali may effect the osmotic pressure of rumen fluid or increase the rate of passage of feed through the rumen due to increased water intake (these points are to be discussed later).

Water intake.

NaOH treated straw contains high levels of sodium (up to 60 g/kg DM). Although the ruminant has adequate mechanisms to deal with high sodium intakes at higher concentrations of alkali treatment voluntary intake is depressed indicating that the animals are under physiological stress. Various workers have reported an increase in water intake with animals given alkali treated rations (Donefer *et al.*, 1969; Maeng *et al.*, 1971; Jayasuria and Owen, 1975; Rexen *et al.*, 1976; Choung and McManus, 1976; Rees, 1977; Pirie and Greenhalgh, 1978).

Jayasuria and Owen (1975) have found that treated straw significantly increased the total water intake of wether sheep. Faecal moisture contents were not affected by alkali treatment. Urine pH was 9·09 when consuming straw treated with 4·5 g NaCH/100 g straw and was significantly reduced to 8·9 when consuming straw treated with

9.0 g NaOH/100 g straw. Present evidence indicates that the extra sodium is excreted entirely in urine (without retention) and that excretion in the faeces is not increased (Maeng et al., 1971; Choung and McManus, 1976). Not only does water intake increase, but as a result so does urine volume (Singh and Jackson, 1975; Pirie and Greenhalgh, 1978). Rexen et al. (1976) reported increased water intakes on diets containing NaOH, but as there were only minor differences between the neutralized and unneutralized rations this indicated that it is more the amount of sodium rather than the amount of hydroxide consumed that determines the water intake.

Most reports agree that giving NaOH-treated straw increases water consumption by about 30% per unit of straw intake. This would mean that under practical farming conditions despite the greater efficiency in the untilization of straw being fed a greater amount would be required for bedding (where used) due to the increased urinary output.

The high content of sodium in treated straws could cause alkalosis in cattle. If no signs of alkalosis are obvious, the acid-base regularity mechanism has been able to excrete the amount of base ingested. Bhattacharya and Warner (1968) did not record a change in blood pH.

There is need for long term experimentation on the effects of prolonged high intakes of sodium. Singh and Jackson (1975) fed Sahiwal - Jersey cattle straw treated with up to 100 g NaOH/kg of straw for 13 months and no adverse effects on animal health were observed. Weeth and Haverland (1961) studied the sodium tolerance limits in cattle and found that if sodium was given in the drinking water the limit was 240 g/day or 3.0 g/kg metabolic body weight. Jackson (1977) in concluding his review on the alkali treatment of straws makes the interesting remark that if a herd of 100 animals were fed treated straw for one year at a rate of 6-8 kg/day each would consume 300 g of sodium

per day. Collectively, they would excrete 10 tonnes of sodium per year. This could pose a serious pollution threat.

Effect of alkali on rumen function and physiology.

(i) Rumen pH.

The pH of alkali-treated straw is about 12. Ingestion of large quantities of treated straw could effect rumen pH and subsequently effect metabolic pathways.

A rise in rumen pH has generally been found when animals ingest alkali treated straw (Bharracharya and Warner, 1968; Donefer et al., 1969; Rexen et al., 1976; Miller, Johnson, Briggs and Kempsey, 1977). However other workers (Levy et al., 1977; Garrett, Walker, Kohler and Hart, 1979) have found no difference in rumen pH due to NaOH treatment of roughages. Ololade and Mowat (1975) found rumen pH decreased with alkali treatment of the diets. It is possible that high rumen pH might give rise to urea toxicity if large quantities of NPN are fed at the same time (Rees, 1977). NPN sources are rapidly fermented in the rumen to ammonia which is quickly absorbed into the blood. The rate of absorption of ammonia is partly governed by rumen pH and at a high rumen pH toxicity may occur.

(ii) Rumination.

Piatkowski and Nagel (1975) examined the chewing and ruminating activity of cows on rations with cereal straw after chemical treatment. Rumination was measured electronically by monitoring chewing and regurgitation. They found that after NaCH treatment rumination was reduced by 56% for each kg crude fibre consumed.

(iii) Rumen ammonia and blood urea.

Rumen ammonia concentrations have generally been found to be lower with animals given alkali treated rations (Saxena et al., 1971;

Miller et al., 1971; Levy et al., 1977). Ololade and Mowat (1975) found that the decrease in rumen ammonia was highly correlated with the decrease in rumen pH. Lewis (1955) indicated that production of ammonia declines as pH decreases. Blood urea concentrations have been found to be lower when the straw was treated with NaOH. (Saxena et al., 1971; Ololade and Mowat, 1975). Part of the reason for reduced ammonia concentrations would be due to increased microbial synthesis made possible by the provision of increased energy available in the alkali treated materials. Reduced blood urea concentrations suggest that alkali treatment was effective in enhancing incorporation of ruminal NPN into bacterial protein.

(iv) Volatile fatty acids.

In general, giving alkali-treated straw results in a higher concentration of total volatile fatty acids in the rumen. (Klopfenstein, Krause, Jones and Woods, 1972; Ololade and Mowat, 1975; Choung and McManus, 1976). This would indicate that rumen activity had increased and consequently increased the availability of energy in the treated materials. The effect on the concentration of individual VFAs in the rumen varies between reports, but in general propionic acid concentration increases and isovaleric and acetic acid concentrations decrease with increasing levels of alkali. Saxena et al. (1971) only found small changes in the concentration of individual VFAs with alkali treatment. Ololade and Mowat (1975) found that the plasma concentrations of total VFA were quite variable with no significant difference due to NaOH treatment. However Bhattacharya and Warner (1968) found that the total blood VFA concentrations were significantly lower on alkali treated group. When urea was added to NaOH-treated straw, the concentration of propionate was reduced and the concentration of butyrate was increased (Bolduan, Voigt and Piatkowski, 1974).

(v) Osmotic pressure.

Ololade and Mowat (1975) have reported that the osmolality of rumen fluid showed a significant linear increase with increasing concentration of NaOH treatment. NaOH in treated roughages may increase the osmotic pressure in the rumen fluid (Ololade, Mowat, Yao, Smith and Ashton, 1972), and hence reduce microbial activity (Bergen, 1970). Bergen (1970) reported that the feed intake by sheep was depressed when rumen osmotic pressure was increased. High rumen osmolality either increases water movement into the rumen or increases the net digesta outflow, in turn adversely affecting microbial activity. Cellulose digestibility may also be limited by a restriction of microbial activity due to increased rumen osmolality (Bergen, 1972).

(vi) Nitrogen retention.

A number of workers have found that nitrogen retention is higher for animals on diets treated with NaOH (Koers, Klopfenstein and Wood, 1969; Klopfenstein et al., 1972; Shultz and Ralston, 1974). However, Levy et al. (1977) has reported that with animals given roughages treated with 80 g NaOH/kg roughage the isovaleric acid and ammonia concentrations in rumen fluid were high, indicating a more extensive deamination process in the rumen and consequently lower nitrogen retention.

(vii) Achieving maximum digestibility.

Table 4 shows the level of alkali required to produce the maximum increase in digestibility for a range of forages (adapted from Palmer, 1976b). The data substantiates the conclusions that the digestibility of untreated straws should be considered before deciding whether to use alkali treatment (Jayasuria and Owen, 1975). There is, however, a limited amount of published data involving treated straw in production

situations. In general reported live-weight gains of animals given treated straw diet have been low, suggesting that the level of intake and/or the crude protein and overall energy intake were limiting potential performance.

Table 4. The amount of alkali required to produce the maximum increase in digestibility on a range of forages. (Palmer, 1976b).

Straw type	Organic matter digestibility values (%) Untreated	Treated	Alkali rate (g/kg straw as fed)
Oat	46	69	108+
Barley, milled	44	74	99++
Barley, milled	45	64	90++
Barley, milled	56	67	90+
Barley, chopped	45	71	90+
Barley, chopped	45	61	80++
Wheat, ground	53	62	33+
Wheat, milled	53	71	33+

+ Soaked

++ Sprayed

Voluntary intake of treated roughage.

The voluntary food intake by ruminants is controlled by interactions of complex regulatory systems. These include physical regulation and the rate of disappearance of digesta from the reticulo-rumen (reviewed by Balch and Campling, 1962; Conrad, 1966 and Campling, 1970). The role of physiological regulation has been reviewed by Baile and Mayer (1970), Baumgart (1970). More general reviews of the subject have been by Jones (1972), Baile and Forbes (1974).

The voluntary intake of diets consisting mainly of roughages is related to the amount of digesta in the reticulo-rumen and is a function of the rate of digestion of food and the rate of passage out of the rumen (Balch and Campling, 1962). The rate and extent of digestion of straw are increased by alkali treatment (Rexen and Thomsen, 1976); hence voluntary intake is increased (Singh and Jackson, 1971; Carmona and Greenhalgh, 1972; Garrett et al., 1974; Jayasuriya and Owen, 1975). The optimum amount of NaOH to maximize voluntary food intake of treated straw lies between 50-70 g NaOH/kg DM straw (Jayasuriya and Owen, 1975). The amount of sodium ion left in the treated material may be important to the voluntary intake of feed by ruminants. Jayasuria and Owen (1975) found that as rate of addition of NaOH increased, so was the voluntary intake of animals. Singh and Jackson (1971) also found that the voluntary DM intake increased with treatment to 3·3% NaOH then decreased with further additions of NaOH. Levy et al. (1977) reported that DM intake (relative to body weight) on 40 g and 80 g NaOH/kg roughage was 8 and 21% lower respectively than for rations containing untreated roughages. They attributed the reduced intake to an affect on palatability. Other workers have reported a similar reduction in intake (Singh and Jackson, 1971; Rexen et al., 1975). However, when the taste of alkali-treated roughage was masked by other feeds in a complete ration (Garrett et al., 1974) or when the residual alkali was neutralized or washed out (Mowat, 1971; Carmona and Greenhalgh, 1972; Rexen et al., 1975) voluntary intake was increased compared with untreated roughage. Terry, Spooner and Osbourn (1975) found that the DM intake by calves of a neutral mixture of straw, treated with NaOH at 7% of the straw fresh weight, and a highly digestible grass silage was 15% greater than that of grass silage alone. Similarly, Petchey and Mbatya (1977) fed grass silage alone or mixed

with untreated or NaOH treated straw to supply 20 or 40% of the total DM to steers. Their results differed from Terry et al. (1975) in that addition of 20% straw to the diet significantly reduced DM intake and 40% addition caused a further reduction. NaOH treatment however increased the digestible OM intake. The differences between these two experiments may have been caused by differences in the grass silages or the class of livestock used.

Published responses in voluntary intake and digestibility resulting from NaOH treatment are variable owing to different experimental conditions. Some workers when undertaking digestibility studies on straw treated with NaOH have either used milled or chopped straw. Carmona and Greenhalgh (1972) found a small improvement in digestibility and intake on treating coarsley milled (20 mm screen) straw (Table 5). However, Pirie and Greenhalgh (1977) did not find any further improvement by milling treated straw.

Table 5. Digestibility and intake by sheep of barley straw given various mechanical and chemical treatments. (Carmona and Greenhalgh, 1972).

	Untreated straw		Treated straw	
	C^{+}	M^{++}	C^{+}	M^{++}
OM digestibility (%)	45·4	44·9	60·8	63·5
Dry matter intake g/kg $W^{0.75}$/day	26·7	36·2	48·4	53·6

$^{+}$ Chopped $^{++}$ Milled.

Nitrogen supplementation.

Nitrogen supplementation of low quality roughages will increase digestibility and increase voluntary intake (Campling et al., 1962). The increased rate of disappearance of food substances from the reticulo-rumen resulted from an improved cellulolytic activity when given increased supplementary nitrogen. However, Weston (1967) suggests that an increase in voluntary intake of low protein roughages by ruminants given supplementary nitrogen may also be due to an improved protein status. When an adequate substrate is present, protein synthesis is determined by the quantity of energy released during organic matter fermentation in the rumen (Walker, 1965). Also the quantity of bacterial protein that passes from the rumen may be increased by reducing the mean time spent by bacteria in the rumen (Hobson and Summers, 1967). As already stated NaOH treatment increases the rate of passage of digesta. Supplementing straws with various nutrients in which they are deficient is in itself a method of improving digestibility and voluntary intake. It is postulated that the effects of supplementation and chemical treatment are additive. Therefore improving the nutritive value of low quality roughages by chemical treatment should provide higher intakes, higher levels of organic matter digestion in the rumen and shorter residence times for exposure to micro-organisms.

Donefer et al. (1969) confirmed the postulation that the effects of urea supplementation and NaOH treatment were additive. However, treated straw for production rations or long term experiments must always be supplemented with other energy sources to provide an adequate ration. Donefer et al. (1969) showed that urea supplementation increased voluntary intake of both untreated and alkali-treated straw. However, voluntary intake decreased when only alkali treatment was applied. Although the delignification effect of NaOH resulted in increased energy

digestibility, the low nitrogen content of straw was a limiting nutrient. An adequate supply of nitrogen was necessary to increase the rate of microbial protein synthesis and consequently the voluntary intake of the animals.

Saxena et al. (1971) obtained similar results, the intake of lambs fed diets based on treated straw supplemented with urea was 35% higher than those on untreated straw. Miller et al. (1977) (Table 6) found that both alkali treatment and urea increased DM digestibility of all-straw diets when given to sheep and the combined effects were additive. However, alkali treatment only increased DM intake in the presence of urea, suggesting that nitrogen was limiting.

Table 6. The DM intake (g/day), DM digestibility and digestible DM intake (g/day) (Miller et al., 1977) of all-straw diets given to sheep.

	A	B	C	D		
Treatment	Nil	Nil+ urea	Alkali	Alkali+ urea	SEM	Significance
DM intake	568	870	429	1143	71·8	B>A***; D>A*
DM digestibility	0·30	0·46	0·51	0·64	0·035	B,C>A***
Digestible DM intake	158	385	197	734	57·1	B>A***; C>A**; D>A*

Various workers have supplemented alkali treated roughages with soya bean meal (SBM) and obtained greater increases in voluntary intake than with urea supplementation (Hasimoglu, Klopfenstein and Doane, 1969; Saxena et al., 1971). Saxena et al. (1971) attempted to explain the difference between SBM and urea by suggesting that it was possible that SBM supplied precusors for branched chain VFA needed for maximum synthesis of bacterial protein. Saxena et al. (1971) found that live-weight gain was significantly increased by alkali treatment when

supplemented with SBM and urea. The results in Table 7 suggest that for lambs, treating straw with alkali can have a significant effect on live-weight gains, but performance is much greater if supplemented with a source of true protein. Ørskov and Grubb (1978) when evaluating the effect of urea supplementation on intake and digestibility of straw with or without sodium hydroxide treatment have illustrated that in order for the animal to benefit from making the carbohydrate of a feed more fermentable by the rumen microbes, sufficient nitrogen for the bacterial growth potential of the increased fermentation must be available.

Table 7. Performance of lambs given oat straw or alkali-treated oat straw supplemented with different nitrogen sources (Saxena et al., 1971).

Diet	Untreated straw		Alakli-treated straw	
	Soya	Urea	Soya	Urea
Feed intake (kg DM/day)	0·87	0·87	1·29	1·11
Live-weight gain (g/day)	61·5	53·1	177·1	125·0

Animal performance.

A few trials have been conducted with dairy cows. They have involved a wide range of inclusion rates, but even at the higher concentrations of NaOH application no adverse physiological effects have been noted. The present emphasis in dairy feeding regimes is to feed high concentrate/restricted roughage diets in early lactation to obtain the highest possible peak yield. Therefore it is probable that alkali-treated straws might be fed to dairy cattle only in late lactation and during the dry period. Greenhalgh, Pirie and Reid (1976) fed diets (ad libitum) consisting of 50% barley straw, either treated with 8% NaOH or untreated and 50% concentrate mix treated with propionic acid (3·6%)

to high yielding dairy cows. DM intakes were 13·4 and 10·8 kg/day and milk yield 19·0 and 17·6 kg/day respectively for treated and untreated diets. Milk composition was improved by alkali treatment of straw, milk butterfat was 3·74 and 3·54% and total solids 12·82 and 12·27% respectively for treated and untreated diets. As already stated ingestion of alkali straw could increase rumen pH. Armstrong and Prescott (1970) have found that for dairy cows a mean daily pH greater than 6·0 could increase butterfat concentrations. Under normal conditions rumen pH for an animal on a high cereal or finely ground straw diet would fall rapidly after ingestion to about 5·5, 30 min after feeding, depending upon the quantity eaten. However, Rexen et al. (1976) using mature, dry cows found that when alkali-treated straw was fed at either 50 or 95% of the diet, the initial reduction of pH did not occur. This may be of benefit in maintaining butterfat levels in high yielding dairy cows.

Braman and Abe (1976) gave 264 kg steers diets containing 50% wheat straw treated (4% NaOH) or untreated. Steers given the treated straw diet grew faster ($P<0·05$) and had greater ($P<0·05$) DM intakes than untreated diets. The rate of gain of animals offered roughages treated with 30 g NaOH/kg straw was not significantly increased and that of animals offered roughages treated with 60 g NaOH/kg straw was reduced significantly compared with the control. However, animals given NaOH-treated straw had a significantly higher dressing-out percentage and a greater fat trim than the control animals. Efficiency of conversion of ME into live weight or carcass weight was improved only with the neutralized 30 g NaOH/kg treatment. Garrett et al. (1979) conducted a comparative slaughter feeding trial with cattle and sheep fed NaOH treated rice straw in a complete diet containing 72 or 36% treated straw. The diet containing 72% treated straw had larger

intakes and less feed was required per unit of gain when compared to untreated straw diets. The treated straw diets had higher net energy values.

Shin, Garrigus and Owen (1975) fed wether sheep (52 kg) various NaOH-treated straws as 60% of the ration. NaOH at 3g/100 g straw increased daily gains from 43·8 to 153·4 g/day. However, at 9 g NaOH/100 g straw daily gain was -4·0 g/day, and as NaOH concentration increased urine volume increased. Javed and Donefer (1970) gave wether lambs NaOH-treated oat straw at inclusion rate of 77·5 to 85% of the diet with molasses (7 to 10%) plus protein and mineral supplements. The initial group of wethers offered the untreated straw ration were not able to maintain body weight. The treated straw had a higher digestibility and intake and growth results approached those of a control group of wethers given an alfalfa ration.

Experiments involving beef cattle have been reported by Cuthbert, Thickett, Wilson and Brigstocke (1977). They included 0-30% of treated straw in beef cattle rations. However, treatments did not differ significantly with live-weight gains ranging from 0·94 kg/day (control) to 0·97 kg/day 30% inclusion of treated straw in diet. In another trial, treated straw at an inclusion of 60% in the diet reduced voluntary intake. Pirie and Greenhalgh (1978) fed cattle (300 kg) for a 12-week period a complete diet containing 60% chopped or coarse-milled straw either treated or untreated. The cattle given the treated straw gained 1·18 kg/day (chopped) and 1·09 kg/day (milled). With the untreated straw the gains were 0·71 kg/day and 0·70 kg/day for chopped and coarse-milled respectively. Holzer, Levy and Folamn (1978) gave cattle wheat straw either untreated or treated with 30 g/kg or 60 g/kg of NaOH and residual NaOH was either left or neutralized with sulphuric acid. The treated materials were then pelleted. Increasing the concentration

of NaOH to 60 g/kg straw reduced intake, digestibility increased at both concentrations and neutralization had no effect.

Treated straws have a role as partial replacers of cereals in farm mixed concentrate diets for fattening both cattle and lambs. However, the major role would be as a replacer for medium quality roughages (e.g. hay and poor grass silages) with suitable NPN/protein and mineral/vitamin supplementation.

PROCESSES FOR CHEMICAL TREATMENT OF STRAW.

Since the revival of interest in alkali treatment of poor quality roughages, several procedures for the chemical treatment of straw have been developed. The first are industrial processes involving large amounts of fixed equipment and machinery to produce a dry pelleted product, usually employing heat and pressure. The second are on-farm processes, either involving adapted or a range of purpose built machinery. The material produced is usually compact and dry enough to store.

The development of industrial processes has been discussed by Rexen and Moller (1974), Rexen et al. (1976), Robb (1976), Palmer (1976), Walsh (1976), Arnason (1978) and Thomsen, Moller and Vibe (1978). Over the past few years straw processing plants have been built in the U.K. Unitrition International Ltd. and B.P. Nutrition Ltd. (for example) operates several plants each processing about 25,000 tonne/year (Wilson and Brigstocke, 1977). Most of the processed straw is then used in the manufacture of compound feeds for ruminants as a partial replacement for cereals.

Various purpose-built machines have been produced which have become available for on-farm processing of straw. The machines are available from Farmhand (UK) Ltd., J.F. Farm Machines and Taarup, for sale or hire. Baled straw is brought to the machine which chops and shreds the straw as a continuous process and applies the concentrated alkali solution by a pump through a flow meter at very low volumes.

On-farm treatments have been discussed by Jackson (1978), Greenhalgh (1976), Owen (1978) and Arnason (1978).

The efficiency of on-farm treatments has not yet been assessed. Disadvantages include their high cost as most machines require large tractors to drive them. Some may produce only a little over 1 tonne/h. The high concentrations of alkali and consequent low water volumes used may possibly result in a fire risk due to the heat liberated during the exothermic reaction between the alkali and straw. NaOH is potentially a very dangerous chemical and elaborate safety precautions are necessary during handling and application. Protective clothing and goggles must be worn during the operation.

Wide spread use of the on-farm processing has not been accepted due to the high cost and safety factors. The use of low cost machinery has been investigated by adapting existing farm machinery. Greenhalgh (1976) and Wilkinson and Gonzalez Santillana (1978b) have described the use of mixer-trailers and Taylor, Lewis, Langley and Yates (1979) the use of dump boxes. Greenhalgh, Pirie, Shin and Stewart (1978) used a Lister Bearcat straw grinder. Alkali was applied to the chopped straw via the water jets on the machine originally invented for dust control. The jet was enlarged to 6 mm and alkali was fed by a peristaltic pump. Kellaway, Crofts, Thiago, Redman, Leibholz and Graham (1978) have described a new technique for alkali treatment under field conditions. Alkali solution was sprayed into the chute of a forage harvester during the harvesting operation.

Both industrial processes and on-farm treatments involve a double handling of materials. The straw is baled then transported to the processing plants or on-farm machinery. Kellaway *et al.* (1978) described a process involving only one operation. Whether the process involves one or two operations, deficient nutrients can be supplied at the same time of alkali treatment, to obtain a medium quality

roughage from a nutrient-deficient low quality roughage.

TYPES OF ALKALI.

Various chemicals other than NaOH have been investigated, but none have proved as effective in increasing the digestibility of roughages. These chemicals include calcium hydroxide, calcium carbonate, ammonia, sodium sulphide, sodium sulphite, sodium bicarbonate, calcium hydrochlorite, hydrogen peroxide, sodium chloride, potassium hydroxide and combinations of some of these chemicals (Bhattacharya and Warner, 1968; Nath, Sahai and Kehar, 1969; Chandra and Jackson, 1970; Waiss et. al., 1972; Anderson and Ralston, 1973; Barton, Amos, Albrecht and Burdick, 1974; Gharib, et al., 1975b; Waller and Klopfenstein, 1975; Oji, Mowat and Winch, 1977; Garrett et al., 1979; Horton, 1979; Rounds, Klopfenstein, Waller and Messersmith 1979).

However, it is the intention of this thesis to review only the effect of calcium hydroxide on roughages. Verma and Jackson (1975) and Gharib et al. (1976) found Ca $(OH)_2$ treatment to be less effective than NaOH. If the $Ca(OH)_2$ treated materials were allowed to stand for 150 days in vitro digestibility was increased and comparable to that of the NaOH treated material. Cellulose, hemicellulose and lignin contents were also decreased. Nath et al. (1969) gave Kumaoni bullocks paddy straw rations after $Ca(OH)_2$ or $CaCO_3$ treatment. The DM digestibility coefficients were not affected. However, more protein was ingested from the $Ca(OH)_2$ - treated straw and nitrogen balance was significantly higher and calcium retention was improved. This experiment was not conducted to physically improve digestibility, but to determine if the treatments could combat the negative calcium balances often encountered on paddy straw rations. Similarly Bhattacharya and Warner (1968) investigated the voluntary food intake

of pelleted diets as affected by alkali supplements to see if slightly raising the low rumen pH of animals given high concentrate diets would increase feed intake (Table 8). In this experiment the $Ca(OH)_2$ was presumed to be acting as an alkaline buffer in the rumen.

Table 8. Effect of alkali supplements fed with pelleted feeds on the daily feed and water intake of wether sheep and heifers (Bhattacharya and Warner, 1968).

Kind of pellets	Feed intake (kg)		Water intake (kg)
	Wether Sheep	Heifers	Wether sheep
Control	0·92	14·1	1.89
Control + 2·5% $Ca(OH)_2$ by weight	1·12**	16·3**	2·39**

$Ca(OH)_2$ appears to have promise as a partial replacement to NaOH. Waller and Klopfenstein (1975) found a mixture of NaOH(3%) and $Ca(OH)_2$ (1%) to be more effective than NaOH (4%) alone in terms of daily gain and feed efficiency of lambs and yearling heifers. However, $Ca(OH)_2$ treatment can be as effective as NaOH, as it is less soluble it reacts more slowly. Therefore it must be allowed to remain in contact with the straw for some time to react. From this it can be seen the next step would be to ensile $Ca(OH)_2$-treated straw for possibly several months. The other advantages of $Ca(OH)_2$ are that as a chemical it is not as hazardous as NaOH it is less expensive and has the advantage of supplying extra calcium and buffering the ration. However, the very fine powder form may make it unpleasant to use.

ENSILING ALKALI TREATED STRAW

The most common material for ensiling in the U.K. is grass. On ensiling, the water-soluble carbohydrates of the ensiled material are fermented by lactobacilli under anaerobic conditions to produce organic acids, mainly lactic acid. Acid production creates a preserving medium of low pH (3·8 to 4·3). This low pH silage will remain stable as long as anaerobic conditions are maintained. However, good preservation does not occur when a wet crop with a low concentration of sugars is ensiled, especially if the silage making is prolonged and the silo is not airtight. Additives can be used in these situations, to assist the inhibition of undesirable micro-organisms. Crawshaw (1977) has reviewed the use of additives in silage making.

However when straw is ensiled with alkali the pH is increased therefore the mechanism by which alkali preserves straw is of interest. Various workers have reported that the addition of water will increase the alkali reaction when treating roughages (Donefer et al., 1969; Jayasuriya and Owen 1975). Large amounts of water are not desirable, sufficient should only be used to ensure adequate mixing of the alkali. Producing large amounts of relatively wet material present storage problems. On a far scale alkali-treated straw would lend itself to ensiling. Ensiling treated straw would result in an extension of the reaction time, which in the case of $Ca(OH)_2$ has led to an increase in alkali effect (Gharib et al., 1975b; Rounds et al., 1976; Oji et al., 1977). Combinations of $Ca(OH)_2$ and NaOH may be effective; $Ca(OH)_2$ may render the NaOH more effective by reducing its conversion to sodium carbonate (Mowat, 1974).

Greenhalgh et al., (1978) have found that a high silage pH can be maintained during storage with low microbial activity. However, with materials treated with low levels of alkali or supplemented with soluble

carbohydrate or that are very wet, the pH will decrease during storage to pH 4 - 5 (Shultz, Ralston and Shultz, 1974). The microbial population of silos have not been estimated by many workers. However, some have reported the presence of organic acids (Shultz et al., 1974; Wilkinson and Gonzalez Santillana, 1978a) from this it can be assumed fermentation has occurred.

Work to date, on the effect of alkali treatment and subsequent ensiling has produced silages of varying quality. On-farm ensilement of alkali-treated straw cannot be recommended until research has been reported on the effect of alkali on microbial growth, on soluble carbohydrates, the water content and degree of anaerobiosis in the silo.

Level of alkali and volume of solution on the composition of ensiled straw.

Wilkinson and Gonzalez Santillana (1978a) compared the effect of NaOH, $Ca(OH)_2$ and KOH treatments on chopped (~5 cm particle length) barley straw when ensiled in laboratory silos for 90 days. NaOH was added at 0, 1·05, 2·10, 3·15 or 4·20 g per 100 g straw DM or at 0, 2·5, 5·0, 7·5 and 10·0 g per 100 g straw DM in two experiments in solution either 60 ml or 120 ml per 100 g straw DM. Straw composition was comparable for each volume of solution and type of alkali applied. The content of neutral detergent fibre decreased as the concentration of NaOH increased with little effect in the contents of acid detergent fibre or lignin. Lactate and acetate were detected in all silages. However, butyrate was present in silages made from straws treated with less than 5 g NaOH/100 g straw DM. Nitrogen content decreased as the concentration of alkali increased. Wilkinson and Santillana (1978b) ensiled 2 tonnes NaOH-treated straw (application 7·5 g/100 g straw DM in 120 ml water) which was stored for 76 days. They found the composition to be similar to that for laboratory silos. Manda, Izumi

and Tarkano (1976) found that the addition of water at ensiling to a low-moisture rice straw increased the production of organic acid, decreased pH and water soluble carbohydrates.

Type of alkali and digestibility after storage.

Mowat (1971) has demonstrated that the *in vivo* digestions of low quality roughages can be improved by ensiling with hydroxide. Wilkinson and Gonzalez Santillana (1978a) found that digestibility of organic matter in the DM (DOMD) increases with increasing concentration of NaOH. Volume of solution had little effect on digestibility. KOH mixed with NaOH gave levels of DOMD *in vitro* similar to those obtained with NaOH. $Ca(OH)_2$ improved DOMD, but was less effective than the other alkalis (NaOH and KOH).

Silo characteristics.

(i) Acidity.

Shultz *et al.* (1974) treated ryegrass straw with 45 kg alkali (NaOH + KOH)/t and ensiled it with molasses. The pH was initially 11·6. After 4 days it fell to 6·9 and after 2-3 weeks stabalized in the pH range 4 - 5. However some of the silages contained up to 13% butyric acid in the dry matter. Wilkinson and Gonzalez Santillana (1978a) found that during storage pH decreased. This was associated with the presence of organic acids as Filpot, Mowat, Parkins and Buchanan-Smith (1976) also found. Greenhalgh *et al.* (1978) found that the pH of the straw immediately after treatment was 11·4. After 8 weeks of storage the pH of straw stored in open sacks fell to approximately 10. However, straw stored anaerobically remained above 11. After 12 months storage the pH of the ensiled straw had decreased to 10 and after exposure to air for 24 hours it fell to 9·6.

Various types of Bacillus are able to grow at such a high pH ranges of 9-11 (Ohata, Kiyomiya, Koyama and Nosh, 1975). Similarly, Lie and Marth (1968) have found that Aspergillus flavus and A. parasiticus can grow in pH 9·3 and 9·9 respectively and form aflatoxins, growth being accompanied by a drop in pH.

(ii) Microbial and mould growth.

Wilkinson and Gonzalez Santillana (1978a) found that alkali-treated straw silages were well preserved. Surface mould growth was slight, and was more obvious in silos containing treatments involving higher volumes of solution than for lower. Greenhalgh et al. (1978) found that fungal counts increased during storage to reach a maximum of 3×10^8 propagules (water alone treated straw silage), 2×10^5 propagules (alkali-treated, sacks open) or 3×10^4 (alkali treated, sealed sacks). In a second experiment NaOH-treated straw was allowed to settle into a compact heap and loosely covered with a canvas sheet. On opening there were dark patches of straw that were wetter, whereas the rest had $1{\cdot}2 \times 10^5$ aerobic bacteria/g of straw and fungal counts at lower limits 6×10^2 propagules/g.

(iii) Temperature.

The slight elevation in temperature which often occurs early in the ensiling process should increase the effectiveness of the alkali (Ololade et al., 1970). Greenhalgh et al. (1978) found that immediately after treatment with alkali the temperature of the straw rose to 32°C (16°C above ambient). When the treated straw was put into the open sack the temperature increased to 35°C returning to ambient temperature within 48 h. The maximum temperature reached by treated straw in sealed sacks was 32°C. The temperature of water-treated straw stored in an open sack rose to 33°C after 36 hours of storage.

Animal production from ensiled straws.

Wilkinson and Gonzalez Santillana (1978b) fed NaOH-treated barley straw which had been ensiled for 76 days and grass silage plus supplements mixed together in different proportions to young beef cattle. Intake of ME and weight gain decreased with increasing levels of straw in the diet, averaging 889 g/head per day for the control diet of grass silage (91·7% of the total diet DM) and 749, 550 and 150 g/head per day when the proportion of straw DM to grass silage DM was 33 : 66, 66 : 33 and 100 : 0 respectively. They concluded that grass silage and NaOH-treated barley straw silage when both adequately supplemented with protein are not comparable in nutritional effeciency when given to young growing beef cattle. However, weight gains greater than 500 g/day can be reached if the proportion of ensiled treated straw is less than half the total DM. Greenhalgh et al. (1978) fed diets containing 60% of an ensiled alkali-treated straw and 40% of a concentrate mixture (DM basis) to cattle and wether sheep. They recorded the intake and growth rate of cattle and the intake and digestibility of the sheep (Table 9). The results suggest that the large differences in the digestibility of the diets fed to sheep could be due to the ensiling process having enhanced the effect of the alkali.

Owen, Herrod-Taylor, Tetlow and Wilkinson (1978) gave ensiled alkali-treated straw and concentrates to pregnant sheep and found no differences in ewe weight changes or in lamb birth weights when the treated straw was replaced up to 75% of grass hay in iso-caloric iso-nitrogenous diets.

Table 9. Intake and Growth rate of cattle, and intake and digestibility for sheep, with diets containing 60% alkali-treated straw. (Greenhalgh et al. 1978).

	Type of straw		SE and significance of difference
Cattle	Ensiled	Freshly-treated	
Initial liveweight (kg)	369	374	-
DM intake (kg/day)	10·23	9·06	0·556
($kg/kg_W^{0·75}$/day)	114	100	-
Liveweight gain (kg/day)	1·08	1·00	0·128
Sheep			
DM intake (kg/day)	1.56	1·77	-
($kg/kg_W^{0·75}$/day)	80	90	-
DM digestibility (%)	69·7	62·5	$0·73^{***}$
Energy digestibility (%)	65·9	60·1	$0·73^{***}$

SECTION 1

CHEMICAL TREATMENT OF OAT STRAW WITH OR WITHOUT LS SUPPLEMENTATION

Introduction.

There is considerable current interest in improving the digestibility of poorer quality roughages such as cereal straws by alkali treatment as already discussed in the literature review. Many workers have shown marked improvements in digestibility when NaOH treatment is in the order 4 to 6% of the DM (e.g. Wilson and Pigden, 1964; Ololade and Mowat, 1975), and excellent reviews by Palmer (1976b) and Jackson (1977) have discussed the topic in detail. Similarly NPN supplements have increased both the voluntary intake and digestibility of straw-based diets. (Campling et al., 1962; Fishwick et al., 1973; Mbatya, Kay and Smart, 1978; Ørskov and Grubb, 1978).

The novel LS solution described by Hemingway et al., (1977) suitable for such N supplementation of straws and initial trials (Fishwick et al., 1978 and Fishwick and Parkins, 1979) demonstrated the potential improvement in digestibility of straw. When the LS (Fishwick et al., 1978) was injected into baled oat straw and given to beef cows the resulting digestibility (0·572) of a diet of about 6·3 kg straw and 1·5 kg barley DM was significantly greater than when comparable amounts of urea and normal mineral products (i.e. dicalcium phosphate and calcium carbonate) were included in the barley (0·502). If by alkali treatment of straw the additional energy input from the straw (containing only about 20 g crude protein (CP)/kg) is used to reduce the amount of cereal or other energy-rich source there will be a relatively increased need for supplementary nitrogen as cereals contain about 100 g CP/kg. Various workers (Donefer et al., 1969; Miller et al., 1977) have indicated that the improvements in digestibility for combined alkali and urea treatments for low protein diets were additive. Miller et al. (1977) have indicated

that the voluntary intake of digestible dry matter from straw by wether sheep was increased from 158 to 197 g/day by a sodium hydroxide treatment. It was, however, increased to 385 g/day by urea supplementation and to 734 g/day by a combination of both sodium hydroxide and urea additions.

On a farm scale the incorporation of NaOH solution into straw is most practically and safely achieved if it is sprayed onto straw in a closed container as it is chopped or ground. It would be convenient if a NPN source (for cheapness) and minerals and vitamins could be admixed with the straw at the time of NaOH treatment.

Although NaOH treatment of chopped straw has been shown to significantly increase the digestibility of the organic matter of straw levels of addition of NaOH have varied between 1·5 to 10% with the resulting mixtures having very considerable variation in the amounts of associated water applied. However, NaOH is a hazardous chemical to handle. $Ca(OH)_2$, although less effective in the improvement of digestibility (e.g. Verma and Jackson, 1975) is less hazardous, less expensive and has the advantage of supplying extra calcium to the diet.

This section of the thesis examines the use of LS with or without NaOH treatment on the digestibility of the ration and performance of pregnant beef cows. It examines $Ca(OH)_2$ as an alternative alkali to NaOH and methods of improving the reaction of $Ca(OH)_2$ on straw with the subsequent addition of LS.

Experiment 1.1. An assessment of the digestibility of an oat straw plus ground barley diet by pregnant suckler cows as affected by sodium hydroxide and/or LS treatment of the straw.

Introduction.

The objective of Expt 1.1 was to treat straw on a farm scale with NaOH and to admix LS with the straw at the time of NaOH treatment, keeping the amount of water added in the NaOH and LS solutions to a minimum to avoid possible micro-organism spoilage and to make practical handling of the final material acceptable. Expt 1.1 investigates the separate and combined effects of a concentrated solution of NaOH and LS applied to oat straw at chopping on the digestibility of the resulting diets composed of about 3 straw : 1 barley given to housed, pregnant beef cows.

Materials and methods.

Eight adult pregnant beef cows, mainly Hereford cross, of mean live weight 472 kg and mean body condition score 2·3 (Lowman, Scott and Somerville, 1973) were individually housed in a byre. The cows were 3 to 4 months from calving at the onset of the experiment. There were also four adult non-pregnant rumen-fistulated Ayrshire cows of mean live weight 600 kg. The pregnant cows were arranged in two groups each of four animals on a basis of live weight, body condition score and expected calving date. Each group and the group of fistulated cows formed a separate 4 x 4 Latin square, each treatment being given in appropriate sequence in 21-day periods (84 days in total).

Chopped oat straw was supplemented in four different ways. The treatments were (a) nil, (b) sodium hydroxide (NaOH), (c) LS or (d) sodium hydroxide + LS (NaOH + LS). Baled oat straw was chopped using a Farmhand machine (operated by Mill Feed Services Ltd., Kirriemuir, Scotland Plate 1) powered by a farm tractor. The rate of chopping of

Plate 1a. Expt 1.1. Farmhand machine for chopping straw shown with pipes in position to blow the straw into the loose box.

Plate 1b. Expt 1.1. Farmhand machine with operator in protective garments necessary for applying NaOH, but not LS.


MILL FEED SERVICES


MILL
Granstoc

the straw by the machine was calculated by first processing the straw for the nil treatment (about 1·7 tonne/h). Sodium hydroxide as a 272 g/kg solution and/or LS were applied during the chopping process from pre-weighed barrels, by two separate electrically powered pumps and their rate of flow monitored by two flow meters. The amounts of the two products actually added to the weighed amounts of straw were calculated by re-weighing the barrels after treatment. It had been intended that diets B and D should have the same NaOH additions and that diets C and D should both have received the same additions of LS. However, due to very cold weather on the date of application, which altered the previously ascertained flow rates, and to somewhat variable outputs of straw by the machine, the actual rates of application were as given in Table 10.

Table 10. Expt 1.1. The amounts of sodium hydroxide and/or LS actually added to oat straw and the amounts of treated straw given to each cow/day and final sodium hydroxide additions as determined by laboratory analyses.

Treatment	A	B	C	D
Addition	Nil	NaOH	LS	NaOH + LS
NaOH (g NaOH/kg straw DM)	-	27	-	23
LS (g liquid/kg straw DM)	-	-	41	38
Straw given/cow/day kg FM	6·5	6·6	6·8	6·9
NaOH addition (g NaOH/kg straw DM) by analysis	-	26·8	-	22·5

As the straw was treated it was blown from the machine into separate compartments in weather proof buildings. The vigorous blowing action of the Farmhand machine ensured that the treated straw was thoroughly mixed. Sufficient quantities of each treatment were prepared at one time for half the experiment (i.e. 6 weeks). Table 10 details the mean amounts of NaOH DM and LS solution actually applied to the chopped straw at the two treatment times and the amounts of each of the treated straws (fresh matter (FM) basis) given to each cow/day. The rates of application of NaOH to the straw were checked by analyses of sixteen samples of treated material taken over the whole period of the experiment. The mean rates of addition were thus determined to be 26·8 (NaOH) and 22·5 (NaOH + LS) g/kg straw DM respectively (Table 10).

The rates of feeding of each of the four treated straws (Table 10) were such that each provided 6·5 kg/day fresh straw (i.e. equivalent of 5·1 kg straw DM/day). This amount was chosen on the basis of previous experience with these cows in the expectation that it represented slightly less than the full voluntary appetite so that there would be little, if any, residues of uneaten material. The amounts of contained NaOH and/or LS solutions were additional to this. The straw was weighed out for each cow daily into separate polypropylene bins and given in two approximately equal portions at 08.00 and 16.00 h.

Additionally each animal received 2·0 kg ground and cubed barley containing 15 g chromic oxide each day (07.30 h). Prior to the commencement of the experiment it was calculated that these amounts of straw (untreated) and barley, if fully consumed, would provide about 55 MJ ME and 200 g DCP/day. When LS was given this would provide an additional 200 g DCP/day.

Samples of the oat straw were taken for chemical analysis once every week and daily throughout each of the four collection periods

(days 15 to 21). The compositions of the oat straw and barley cubes are given in Table 11.

Table 11. Expt 1.1. The mean composition of the untreated oat straw, barley cubes (g/kg DM) and LS (g/kg FM).

	Oat straw	Barley cubes	LS
Dry matter	785	837	-
Crude protein	22	125	1076
Crude fibre	442	43	-
Ether extract	12	15	-
N-free extract	456	785	-
Ash	68	32	-
Na	1·8	0·5	20·5
Ca	2·5	1·3	27·7
P	0·6	2·9	16·0
pH	-	-	1·5

During the collection period straw residues (if any) were collected once daily. At the end of each collection period the residues were weighed and a separate DM determination was carried out on a subsample of the residue from each animal. During days 15-21 of each of the four feeding periods rectal grab samples of faeces were obtained from all the cows at 08.00, 12.00 and 16.00 h. The faecal samples were bulked for analysis for chromium, crude protein, ash, crude fibre and ether extract. The results of the analyses were used to calculate the digestibility of the diets, chromic oxide being used as a faecal indicator. A sample of straw from each treatment was also taken to test for loss of ammonia. The ammonia was determined by drawing air for 24 h through a known weight

(10 kg) of straw contained in a large sealed polythene bag and passed into acid, ammonia being determined by back titration.

On the last day of each feeding period (day 21) blood samples were obtained from each of the pregnant cows (10.00 h) and from the fistulated cows at 07.30, 10.00, 12.00, 14.00 and 16.00 h. All the blood samples were analysed for urea, calcium and phosphorus. At the same times, samples of rumen liquor were obtained from the four fistulated cows for the determination of ammonia, volatile fatty acids and pH. On the days that rumen liquor samples were taken from the fistulated cows, the straw ration was weighed into two equal halves for the 08.00 and 16.00 h feeds.

Throughout the experiment two spare cows were kept, one on the LS and the other on the NaOH + LS treated straws but these were not required.

The body condition score and live weight of the cows were recorded at the start and end of the experiment.

Results.

Over the total 84 days of the experiment the mean live weight of the eight pregnant cows increased from 472 to 495 kg, but there was a mean loss in body condition score from 2·3 to 1·6 by the end of the experiment. Most of the apparent increase in live weight must have been due to the increasing size of the foetus. In contrast, the mean live-weight change of the four fistulated cows was from 600 to 604 kg, with no change in body condition.

The treatments which included NaOH caused an immediate yellowing of the straw, and a slight smell of ammonia could be detected from the stored straw. The amount of ammonia was very small, only 3 mg of ammonia being detected/kg straw when air was drawn through a sample for 24 h.

Treatment with NaOH and/or LS altered the pH of the straw. The pH of the NaCH and NaOH + LS (10·43 + 10·38) treated straws was significantly

($P<0.01$) more alkaline than the nil (9.3) treatment. The LS-treated straw was significantly more acid than both the nil ($P<0.05$) and the NaOH ($P<0.001$) treatments. The pH of the NaOH + LS (10.38) was significantly ($P<0.001$) more alkaline than the LS treatment (9.02).

The barley/chromic oxide concentrate was readily and completely consumed by all the cows. The rate of consumption of the straw varied between treatments. Those cows which consumed the straw completely, ate each half-daily allocation ($\simeq 3.25$ kg) within 2 h. Eleven of the twelve cows left some of the untreated straw and seven of the twelve cows left some of the NaOH-treated straw (Table 12).

Table 12. Expt 1.1. Individual straw residues (mean kg DM/day - over day 15 - 21 of each period).

Period	Nil	NaOH	LS	NaOH + LS
Pregnant cows				
Square 1				
1	0.61	-	-	-
2	0.14	0.16	-	-
3	0.12	0.79	-	-
4	0.22	0.86	0.06	--
Square 2				
1	-	-	-	-
2	0.96	-	-	-
3	0.50	-	-	-
4	0.20	1.83	0.08	-
Fistulated cows				
1	0.82	0.34	-	-
2	0.93	0.21	0.20	-
3	1.29	0.43	0.64	0.29
4	1.30	-	0.10	-

In contrast, six cows left residues when the straw was treated with either LS or NaOH + LS. Three of these six cows left quite trivial amounts ($\leq$ 0·1 kg/day) during period 4. This may have been associated with very severe winter conditions, when problems arose with frozen drinking water although water was supplied adlibitum by bucket. The four fistulated cows left larger residues than the pregnant cows.

At each change of diet the pattern of consumption altered. Cows going onto the nil or the NaOH treatment started to leave residues within five days. In contrast, cows changing from the nil or the NaOH to the LS or NaOH + LS treatment fully consumed the straw within five days. It must be noted that by observation of their feeding habits that the cows when given LS or NaOH + LS treated straw might almost certainly have consumed more, if it had been offered.

The straw DM consumed and the digestibility coefficients of the total diet DM, OM, CF and N and straw alone OM, in vitro OM, the calculated ME (MJ/kg) of the straw, and ME intake (MJ/day) from the straw consumed are presented in Table 13. In all these calculations, as for the intakes of straw given in Table 13 the amounts of added NaOH and LS have been excluded, so that all the data refer to the original untreated straw alone to ensure proper comparability.

The effect of the four treatments on each of the digestibilities for total diet DM and OM and for the straw alone OM followed the same general pattern, for both the pregnant and fistulated cows. The lowest value for the digestibility of the untreated straw was recorded in the fistulated cows and the combined addition of NaOH + LS markedly and significantly increased the digestibility.

Table 13. Expt 1.1. The mean amounts of straw given and consumed (DM kg/day), the digestibility coefficients of the total diet dry matter and organic matter and for straw alone organic matter, and the amounts of metabolizable energy consumed as straw.

Treatment	A Nil	B NaOH	C LS	D NaOH +LS	SE of mean	Significance
Straw DM given (kg)	5·10	5·10	5·10	5·10	-	-
Straw DM consumed (kg)						
8 pregnant cows	4·76	4·65	5·09	5·10	0·126	C,D > A,B**
4 fistulated cows	4·02	4·86	4·87	5·03	0·077	B,C,D > A*
All 12 cows	4·51	4·72	5·01	5·08	0·088	C,D > A***; D,C > B*
Total diet DM digestibility						
8 pregnant cows	0·56	0·59	0·55	0·59	0·014	NS
4 fistulated cows	0·52	0·57	0·56	0·62	0·021	D > A*
All 12 cows	0·54	0·58	0·55	0·60	0·012	D > A**, C*; B > A*
Total diet OM digestibility						
8 pregnant cows	0·57	0·60	0·57	0·61	0·013	NS
4 fistulated cows	0·53	0·59	0·57	0·64	0·022	D > A*
All 12 cows	0·56	0·60	0·57	0·62	0·012	D > A**, C*; B > A*
Straw alone OM digestibility						
8 pregnant cows	0·47	0·51	0·47	0·52	0·018	NS
4 fistulated cows	0·43	0·49	0·47	0·56	0·023	D > A**, C*
All 12 cows	0·46	0·50	0·47	0·53	0·014	D > A, C**; B > A*

Total diet CF digestibility						
8 pregnant cows	0·81	0·83	0·80	0·85	0·012	D>A,C*
4 fistulated cows	0·74	0·81	0·81	0·87	0·030	D>A*
All 12 cows	0·78	0·82	0·81	0·85	0·013	B>A*;D>A***,C*
Total diet N digestibility						
8 pregnant cows	0·70	0·75	0·85	0·84	0·015	B>A*;C,D>A***;C>B***; D>B**
4 fistulated cows	0·68	0·71	0·84	0·86	0·071	NS
all 12 cows	0·69	0·73	0·85	0·84	0·016	CD>AB***
Calculated ME of straw DM (MJ/kg)						
8 pregnant cows	7·0	7·6	7·1	7·8	0·28	NS
4 fistulated cows	6·5	7·4	7·0	8·4	0·34	D>A**;D>C*
All 12 cows	6·9	7·4	7·1	8·0	0·22	D>A,C**,B*
ME intake from straw (MJ/day)						
8 pregnant cows	33·3	35·3	36·0	39·7	1·77	D>A*
4 fistulated cows	26·4	36·0	34·5	42·6	1·63	D>A***,B,C*;B>A**;C>A*
All 12 cows	31·0	35·5	35·5	40·7	1·30	BC>A*;D>A***
<u>In vitro</u> OM digestibility	0·45	0·53	0·43	0·51		

Statistical analyses of the results showed that the squares x treatment effect for the 2 Latin squares of pregnant cows, and for the Latin square of fistulated cows was non-significant for all comparisons. For this reason and the fact that both the NaOH and NaOH+LS treatments increased the digestibilities, but by amounts which were non-significant for the pregnant cows, the results have also been presented for all 12 cows given the experimental diets.

For the eight pregnant cows, the straw DM consumed when given the LS and NaOH+ LS (5·09 and 5·10 kg/day) treated straws was significantly ($P < 0.05$) greater than for the nil (4·76 kg) and NaOH (4·65 kg) treated straws and represents the full intake of the amount given. For the four fistulated cows the straw DM consumed when given the three treated straws was significantly ($P < 0.01$) greater than for the nil treatment. When the results for the 8 pregnant and 4 fistulated cows were combined the consumption of the LS and NaOH+ LS treated straws was significantly greater than both nil ($P < 0.001$) and NaOH ($P < 0.05$) treatments.

For the eight pregnant cows, the differences in total diet DM digestibility coefficients between treatments were not significant all being about 0·56 - 0·59. For the four fistulated cows, the total diet DM digestibility coefficient of the NaOH+ LS treated straw (0·62) was significantly ($P < 0.05$) greater than that for the nil treatment (0·52). For all 12 cows considered together, the total diet DM digestibility coefficient of the NaOH+ LS treated straw was significantly greater than both nil ($P < 0.01$) and LS ($P < 0.05$) treatments. The total diet DM digestibility coefficient of the NaOH-treated straw was also significantly ($P < 0.05$) greater than the nil treatment.

For both the eight pregnant cows and the four fistulated cows, when considered separately and together, the total diet DM digestibility coefficients for the four diets follow the same significance trends as for the total diet DM digestibility coefficients.

The digestibility coefficients for the straw alone have been calculated assuming that the DOMD of the barley given was 0·86 (M.A.F.F. et al., 1975). For the eight pregnant cows OM digestibility coefficient between treatments for the straw alone was not significant. For the four fistulated cows, the OM digestibility coefficient of the straw alone for the NaOH+LS treated straw was significantly greater than both the nil ($P<0·01$) and LS ($P<0·05$) treatments. When the three Latin squares were combined OM digestibility coefficient for the straw alone for the NaOH+LS (0·53) treated straw was significantly greater ($P<0·01$) than both the nil (0·46) and LS (0·47) treatments, and the NaOH treatment (0·50) was significantly ($P<0·05$) greater than the nil treatment.

For the eight pregnant cows CF digestibility coefficient of the total diet for the NaOH+LS treated straw (0·85) was significantly greater ($P<0·05$) than for both the nil (0·81) and LS (0·80) treated straws. For the fistulated cows only the nil treated straw (0·74) was significantly different ($P<0·05$) from the NaOH+LS treated straw (0·87). When all 12 cows were considered the differences in the total diet CF digestibility coefficients were similar to that of the eight pregnant cows. However, the NaOH treatment became significantly greater than the nil treated straw.

For the eight pregnant cows, the N digestibility coefficients of the total diet for the three treated straws were significantly greater than the nil treated straw. While the NaOH treated straw was significantly less than both the LS and NaOH+LS treated straws. The N digestibility coefficients of the total diet for the four fistulated cows were not significant between treatments. When all the 12 cows were considered both the total diet N digestibility coefficients of the LS (0·85) and NaOH+LS (0·84) were significantly greater ($P<0·001$) than both the nil (0·69) and the NaOH (0·73) treated straws.

The data obtained for the digestibility of the OM in the straw given in each treatment has been used to calculate (a) the apparent ME of the straw DM (ME = 0·15 x DOMD%, M.A.F.F. et al., 1975) and (b) the amounts of ME provided by the actual amount of straw DM consumed. For the eight pregnant cows there were no significant differences between treatments for the calculated ME value of straw. For the four fistulated cows, the calculated ME of the straw given the NaOH + LS treatment was significantly greater than both the nil ($P < 0.01$) and LS ($P < 0.05$) treatments. When the three Latin squares were combined, the calculated ME of straw given the NaOH+ LS treatment was significantly greater than the nil ($P < 0.01$), NaOH ($P < 0.05$) and LS ($P < 0.01$) treatments.

The combined effects of changes in straw consumption and OM digestibility resulting from the treatments are reflected in the calculated values for the ME intake obtained by the cows from straw alone. For the pregnant cows, the ME intake from straw consumed was significantly increased from 33·3 (nil treatment) to 39·7 MJ ME by the NaOH+ LS treatment, the values for the NaOH (35·3) and the LS (36·0) being greater than the nil treatment, but not significantly different. The values of the calculated ME intake reflect the combined effects of changes in straw consumption and OM digestibility resulting from the treatments. For the fistulated cows, the ME intake from the straw consumed was significantly greater for all the three straws than for the nil treatment (NaOH < 0.01; LS < 0.05; NaOH+ LS < 0.001). The ME intake from the NaOH+ LS treated straw consumed was significantly ($P < 0.005$) greater than for the straw treated with either NaOH or LS separately. For all twelve cows the ME intake when given the untreated straw (31·0 MJ) was increased to 35·5 when treated with NaOH+ LS ($P < 0.05$) and to 40·7 MJ ($P < 0.001$) when both treatments were applied together.

Table 13 details the *in vitro* OMD of straw for the four treatments (*in vitro* analyses undertaken by Alexander, R.H. The West of Scotland Agricultural College).

Rumen pH was not influenced by treatment. At any given time the rumen pH between treatments was not significant. Fig. 3 represents the changes in rumen pH during the day.

The mean VFA and total nitrogen concentrations are detailed in Tables 14 and 15. Concentrations of individual VFA in rumen fluid were not significantly affected until 4.5 h post feeding. At 12.00 h the n-butyric acid concentration for the NaOH treatment was significantly ($P<0.05$) greater than for the nil treatment. At 14.00 h the concentration of acetic acid was depressed for the NaOH treatment (299 mg/dl), being significantly depressed compared with the NaOH+LS (384 mg/dl) treatment ($P<0.05$). At 14.00 h the concentration of n-butyric acid for both the NaOH and NaOH+LS treatments was significantly ($P<0.05$) greater than both the nil and LS treatments. At 16.00 h the concentration of n-butyric acid for the nil treatment was significantly less than for the NaOH ($P<0.001$), LS ($P<0.05$) and NaOH+LS ($P<0.01$) treatments. The NaOH treatment had a significantly ($P<0.01$) greater concentration of n-butyric acid than the LS treatment.

Total VFA concentrations (Table 15) were similar for each of the treatments, except at the sample time of 14.00 h, when the NaCH+LS treatment gave a significantly ($P<0.05$) greater concentration than the NaOH treatment. The value for the total VFA concentrations appeared to increase steadily from 07.30 h to about 12.00 h, but the increases were not significant. However, the values tended to be lowest when the NaOH treated straw was given and highest for the NaCH + LS treatment. When the mean values for each of the 5 sampling occasions were considered, there were no significant differences in the concentration of acetic acid, but the concentration of propionic acid tended to be lowest when untreated

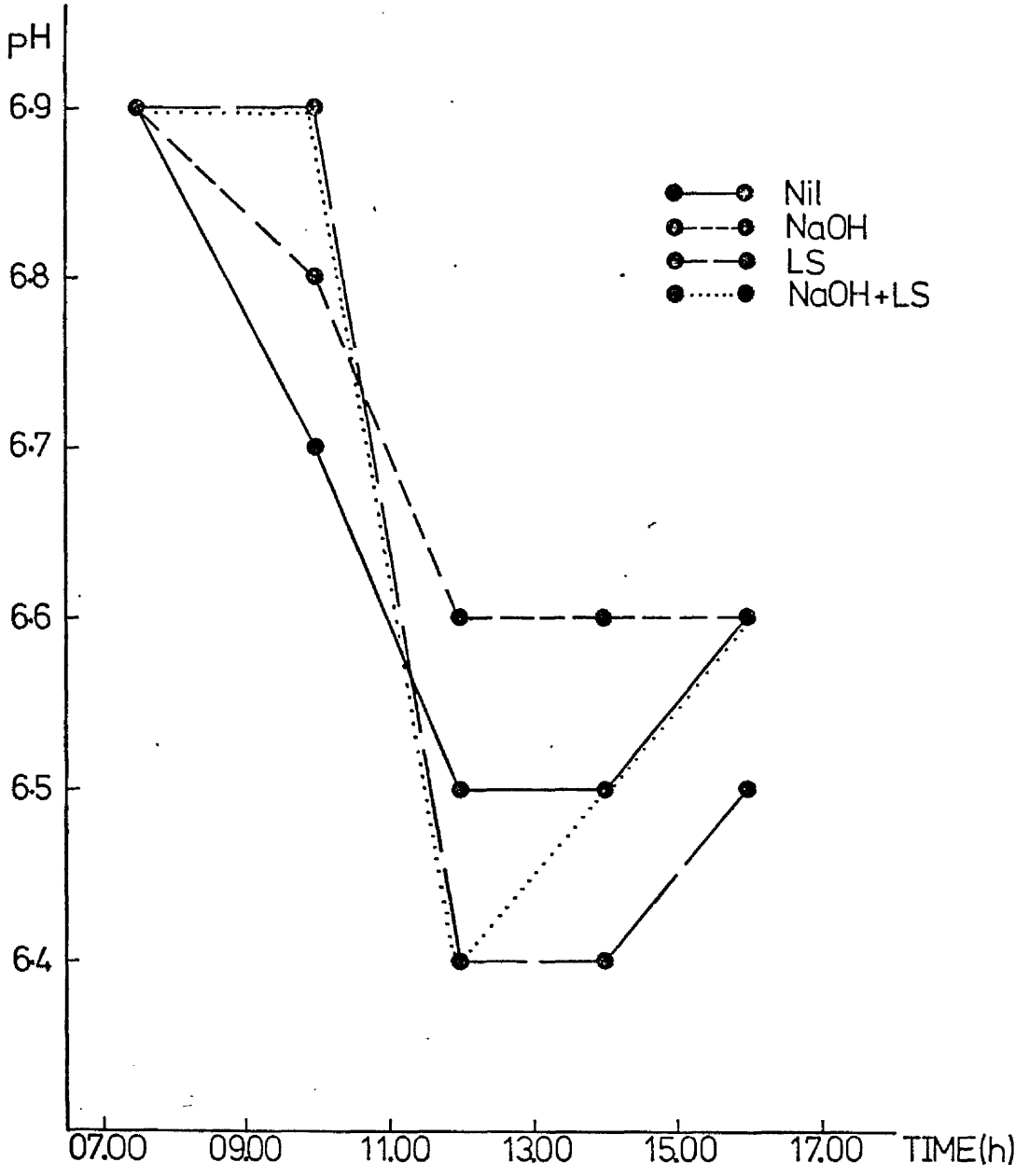

pH
6·9
6·8
6·7
6·6
6·5
6·4
Nil
NaOH
LS
NaOH+LS
07.00
09.00
11.00
13.00
15.00
17.00
TIME(h)

Table 14. Expt 1.1. The mean concentrations of volatile fatty acids (mg/dl) at five samplings between 07.30 and 16.00 h in the rumen liquor of the fistulated cows.

Treatment	A Nil	B NaOH	C LS	D NaOH + LS	SE of mean	Significance
Time of sampling (h)						
Acetic						
07.30	315	266	316	325	30·3	NS
10.00	338	308	324	355	32·7	NS
12.00	389	343	387	375	21·7	NS
14.00	383	299	360	384	24·2	D>B*
16.00	341	323	336	341	27·4	NS
Propionic						
07.30	80	92	91	91	3·4	NS
10.00	102	102	104	111	8·0	NS
12.00	104	111	133	130	11.3	NS
14.00	109	114	125	130	9·0	NS
16.00	96	110	110	108	6·2	NS
n-Butyric						
07.30	43	64	44	56	7·5	NS
10.00	54	70	47	61	7·6	NS
12.00	51	79	59	64	5·8	B>A*
14.00	53	70	57	71	3·9	D,B>A,C*
16.00	40	68	53	61	2·3	B***,C*,D**> A
iso-Butyric						
07.30	8	11	9	10	2·1	NS
10.00	6	8	9	10	2·1	NS
12.00	12	14	8	10	3·1	NS
14.00	7	10	10	12	1·9	NS
16.00	7	9	9	13	1·7	NS

Table 15. Expt 1.1. The mean concentrations of total volatile fatty acids (mg/dl) at five samplings between 07.30 and 16.00 h, the overall mean concentrations (mg/dl) of the constituent volatile fatty acids and the total nitrogen (g/litre) in the rumen liquor of the fistulated cows.

Treatment	A Nil	B NaOH	C LS	D NaOH + LS	SE of mean	Significance
Time of sampling (h)						
Total VFA						
07.30	447	433	460	482	40·7	NS
10.00	500	488	483	537	46·5	NS
12.00	556	546	588	578	33·0	NS
14.00	552	494	553	597	28·6	D > B*
16.00	484	510	509	522	31·5	NS
Overall mean+						
Acetic	353	314	345	356	12·2	NS
Propionic	98	106	105	114	3·4	D > A*
n-Butyric	48	68	52	63	2·4	BD > AC*
iso-Butyric	8	10	9	11	0·9	D > A*
Total VFA	507	498	511	544	16·1	NS
Total N						
07.30	5·5	6·0	8·7	9·0	1·16	NS
10.00	5·7	5·0	21·4	15·8	1·23	C***, D** > A C, D > B***
12.00	3·9	3·9	9·1	5·7	1·08	C > AB*
14.00	5·2	3·1	7·0	4·8	1·07	C > B*
16.00	3·2	2·8	5·7	5·5	0·60	CD > A*, B**

+Five sampling occasions/day.

straw was given and highest for the combined NaOH + LS treatment. There were, however, marked changes in the n-butyric and iso-butyric acid concentrations. Both appeared to be increased by the NaOH + LS and NaOH treatments.

Preprandial total nitrogen concentrations were similar for all treatments. However, at 10.00 h total nitrogen concentrations for LS (21·4 g/litre) and NaOH+LS (15·8 g/litre) treatments were significantly greater ($P<0·001$) than for the NaOH (5·0 g/litre) treatment. Total nitrogen concentrations for the nil treatment (5·7 g/litre) were significantly less than for both the LS ($P<0·001$) and NaOH + LS ($P<0·01$) treatments. At 12.00 h only the LS treatment was significantly ($P<0·05$) greater than the nil and NaOH treatments. At 14.00 h the total nitrogen concentration for the LS (7 g/litre) treatment was significantly ($P<0·05$) greater than for the NaOH (3·1 g/litre) treatment. At 16.00 h (pre second feed) concentrations of total nitrogen had dropped for all treatments, but the LS and NaOH+LS treatments still had significantly higher concentrations of total nitrogen than both the nil ($P<0·05$) and NaOH ($P<0·01$) treatments.

Table 16 details the mean blood concentrations of urea, calcium and phosphorus.

For the eight pregnant cows plasma urea (10.00 h) concentrations for both the LS and NaOH+LS treatments were significantly ($P<0·001$) greater than both the nil and NaOH treatments. This trend occurred with the fistulated cows. At all sampling times the plasma urea concentrations of the two treatments with the LS addition were significantly greater than the treatments with no LS addition.

Both blood phosphorus and calcium concentrations remained unaffected by treatment in the eight pregnant cows. For the four fistulated cows the concentrations of blood phosphorus and calcium remained unaffected by treatment at all the sample times except at 12.00 h when

Table 16. Expt 1.1. The mean concentrations of blood urea, calcium and phosphorus (mmol/litre).

Treatment	A Nil	B NaOH	C LS	D NaOH+ LS	SE of mean	Significance
Fistulated cows						
Urea						
07.30 (h)	1·4	1·3	3·1	2·9	0·25	C,D > A,B**
10.00	1·4	1·6	3·2	3·0	0·17	C,D > A***; D > B**; C > B***
12.00	1·4	1·4	3·4	3·2	0·25	C,D > A,B**
14.00	1·2	1·3	3·4	2·7	0·28	C,D > A**; D B*; C>B**
16.00	1·2	1·2	2·9	2·1	0·22	C > A**; D > A*; D > B*; C > B**
Calcium						
07·30	2·8	2·8	2·9	2·9	0·04	NS
10.00	2·7	2·8	2·8	2·8	0·05	NS
12.00	2·9	2·8	2·7	2·8	0·03	NS
14.00	2·8	2·7	2·8	2·8	0·05	NS
16.00	2·8	2·9	2·9	2·9	0·04	NS
Phosphorus						
07.30	1·9	1·9	2.0	1·7	0·07	NS
10.00	1·9	1·9	2·0	1·9	0·07	NS
12.00	1·9	1·7	2·0	1.8	0·06	C > D,B*
14.00	1·8	1·8	1·8	1·8	0·04	NS
16.00	1·7	1·7	1·8	1·7	0·06	NS
Pregnant cows						
Urea (10.00)	1·7	1.2	4·1	4·1	0·23	C,D > A,B***
Calcium (10.00)	2·7	2·6	2·7	2·6	0·06	NS
Phosphorus (10.00)	2·1	2·2	2.1	2·0	0·06	NS

the mean concentration for blood calcium for the LS treatment was significantly lower than both the nil ($P < 0.01$) and NaOH+ LS ($P < 0.05$) treatments. At 12.00 h also the mean concentration of blood phosphorus for the LS treatment was significantly ($P < 0.05$) greater than for both the NaOH and NaOH+ LS treatments. There were no differences in blood phosphorus or calcium concentrations between periods. For the pregnant cows concentrations were about 2·7 mmol Ca/litre and about 2·1 mmol P/litre and for the fistulated cows 2·8 mmol Ca/litre and 1·9 mmol P/litre.

The mean intake of dietary constituents by the pregnant cows from the diets consumed are summarized in Table 17.

Table 17. Expt 1.1. The mean intake of dietary constituents (per day) by the pregnant cows from diets consumed and the current recommended requirements for 450 kg cows in late pregnancy.

Treatment	A Nil	B NaOH	C LS	D NaOH + LS	Requirements
ME (MJ)	56	58	59	63	72
Crude protein (g)	314	311	546	530	-
DCP (g)	217	233	466	444	400
Ca (g)	14·1	13·8	20·7	20·3	31
P (g)	7·6	7·5	11·1	10·9	31
Na (g)	9·4	81·3	14·3	81·3	9

The recommended daily intakes for a 450 kg cow in late pregnancy are 72 MJ ME (M.A.F.F., et al., 1975). 400 g DCP (ADAS, 1976), 31 g P, 31 g Ca and 9 g Na (A.R.C., 1965). All the diets supplied insufficient ME and both the diets with no LS supplement supplied insufficient digestible crude protein. All the diets supplied adequate sodium, but only one-third of the phosphorus and one-third to two-thirds of the calcium requirements.

Discussion.

The cows were given a fixed daily allocation of 5·1 kg straw DM, which was lower than they were expected to be capable of consuming based on previous experience with the same cows given similar diets by Fishwick et al. (1978). Even so, there were residues of 0·4 kg (mean) straw DM/day by the pregnant cows when given straw not treated with LS irrespective of any NaOH treatment. The residues for the fistulated cows were 0·24 kg (mean) straw DM/day when either NaOH or LS were applied and over 1·0 kg straw DM/day when untreated straw was given.

From observations of the cows at feeding time it was inferred that all the pregnant cows and 3 of the 4 fistulated cows would have readily consumed more of the NaOH + LS-treated straw and that the pregnant cows would also have consumed more of the LS treated straw. In Expt 1.2 conducted at the same time using the same treated straws and concentrate feeds two groups each of four comparable pregnant cows were group-fed 7·8 and 7·9 kg FM/head of the LS and NaOH+LS-treated materials respectively. The whole of both treated straws in this trial were readily consumed, showing that the cows given these two treatments might reasonably have consumed about 1 kg straw FM more than was offered.

Levy et al. (1977) reported that the voluntary intake of NaOH-treated roughage was considerably reduced, being directly related to the amount of NaOH used. This may have been caused by a reduction in palatability. In this current experiment the NaOH treatment ($\pm$ LS) significantly ($P < 0.001$) increased the pH of the straw, while LS treatment alone significantly ($P < 0.05$) decreased the pH of the straw. This phenomena may have affected palatability. Singh and Jackson (1971) and Rexen et al., (1976) have also reported similar reductions in intake with NaOH treated roughages. If the taste of alkali-treated roughage was masked by inclusion with other feeds in a complete ration (Garrett et al., 1974), or if the residual alkali was neutralized or washed out

(Carmona and Greenhalgh, 1972; Rexen et al. 1976) the voluntary intake was increased compared with untreated roughages. However, Pirie and Greenhalgh (1978) found that alkali treatment of straw significantly increased straw intake by 12%.

Both NaOH and NaOH + LS treatments increased the digestibility, but by amounts which were non-significant for the pregnant cows. The digestibility of the NaCH + LS-treated straw was significantly greater than the nil treated straw when given to the fistulated cows. When all 12 cows were considered together the NaOH straw treatment significantly ($P<0.05$) increased digestibility, but the LS treatment did not. For the combined NaOH + LS treatment the digestibilities were generally significantly ($P<0.01$) greater than either the nil or the LS treated straws.

The effect of the NaOH and the LS treatments on the straw appeared to be additive in respect of the effective amounts of ME provided by the straw consumed (Table 13), but only for the fistulated cows when the increases due to the NaCH, LS and NaOH+ LS treatments were 9·6, 8·1 and 16·2 respectively. For the pregnant cows there were no significant effects on the OM digestibility and consequently the improvement in ME intakes for the LS and NaOH+ LS treatments was largely a reflection of the higher straw intake. The differences in increases in ME intake with treatment would have been greater if the animals had been allowed to consume their full voluntary intake of straw.

These results, indicating a considerable potential further response in energy intake resulting from the addition of a urea-containing solution to sodium hydroxide treated straw are consistent with the results for all-straw diets given to sheep previously reported by Miller et al. (1977). Since this present work commenced Ørskov and Grubb (1978) have also indicated that whereas the addition of urea in solution increased

the intake of digestible organic matter from straw by sheep from 180 to 211 g/day, a similar addition of urea to sodium hydroxide treated straw increased intake from 134 to 301 g/day.

None of the treatments markedly altered the concentration of total VFA or propionic acid concentrations in the rumen (Tables 14 and 15), but acetic acid concentrations tended to be lower with the NaOH treatment (not significant). When the overall mean values of the 5 sampling occasions during the day were considered the concentration of propionic acid tended to be lowest when untreated straw was given and highest when NaOH + LS treated straw was given.

Alkali treatment has been found to increase the total VFA concentration in rumen fluid (Koers, Woods and Klopfenstein, 1970; Ololade and Mowat, 1975). Levy et al. (1977) found the total VFA in rumen liquor to be 6 and 11% higher when given diets of roughages treated with 40 and 80 g NaOH/kg than when given untreated roughages (not significant). However, not all workers have found an increase in total VFA concentration with alkali treatment (Verma, 1975). Ololade and Mowat (1975) found that molar proportions of propionic acid increased and acetic acid decreased when NaCH treated straw was given, but Levy et al. (1977) found no differences in the concentration of individual VFA in rumen liquor due to NaOH treatment.

NaOH ($\pm$ LS) treatment increased the concentration of both n-butyric and iso-butyric acids by as much as 25%. Other workers (Kromann and Ray, 1967; Jackson, Kromann and Ray, 1971) have shown that excess sodium ions in the rumen elevate butyric and propionic acid levels. Saxena et al. (1971) investigated the effect of alkali treatment of oat straw on energy and nitrogen utilization for lamb growth when nitrogen was supplied from soya bean meal, urea or diammonium phosphate. Butyric acid concentration in the rumen was higher only when SBM was included with either the

treated or untreated straw. It is possible that SEM supplied precursors for branched-chain VFA needed for maximum synthesis of bacterial protein (Cline, Garrigus and Hatfield, 1966).

Allison, Bryant, Katz and Keeney (1962) have indicated that some rumen micro-organisms have a specific requirement for branched chain fatty acids such as 2-methyl butyric and iso-butyric acid. The increase in whole diet DMD (Table 13) was from 0·54 to 0·58 (nil vs. NaOH treatment) and from 0·55 to 0·60% (LS vs. NaOH + LS treatments) i.e. a mean increase of 4·5 digestibility units due to NaOH. In a previous communication (Fishwick et al., 1978) when the same cows voluntarily consumed about 6·4 kg oat straw DM and where a fixed allocation of 2.0 kg barley was supplemented with either 60 g urea (450g N/kg) or 92 g diureido-isobutane (DUIB 310 g N/kg) the significant increase in whole diet DMD was a similar 4·0 units i.e. 0·50 (urea) to 0·54 (DUIB). Unfortunately Fishwick et al. (1978) did not determine the concentration of rumen VFA in that experiment, but the similarity of these results suggests that the effect of NaOH treatment of straw on concentration of branched chain fatty acids might be of interest.

Although rumen pH was not influenced by treatment at any given time the fall in rumen pH post-feeding tended to be greater when the treatments containing LS were given and remained at a lower level for longer than the NaOH and nil treatments (Fig.3).

Ololade and Mowat (1975) found that with increasing levels of NaOH treatment the pH of the rumen fluid tended to decrease, but other workers (Levy et al., 1977) found that rumen pH was not affected by NaOH treatment of roughages.

Rexen et al. (1976) reported an experiment with mature dry cows which were given a series of diets of treated straw (with or without neutralization) supplemented with urea and minerals. For an animal given a high cereal or finely ground straw diet the rumen pH would normally fall

quickly after ingestion to a level of around 5·5 about 30 min later, depending on the intake. It would then gradually rise to a normal level of 6·5 to 7·0 after 3 - 4 h assuming no more feed was eaten. The results of Rexen et al. (1976) showed that when alkali treated straw was fed at either 50 or 95% of the diet, the initial depression of pH does not occur. This phenomena may be a benefit in maintaining butter fat levels in high yielding dairy cows.

In this trial when NaOH-treated straw was given the depression in pH was not as great as the nil treatment, but in both the treatments containing LS the depression in pH was greater than that with the nil treatment.

Addition of LS to straw ($\pm$ NaOH) increased rumen nitrogen and blood urea concentrations, the values for which were otherwise low. Both the LS and NaOH+ LS straw treatments caused large and significant increases in the total nitrogen content of the rumen fluid but only for a restricted period of about 2 - 3 h after the straw being given, thereafter values declined rapidly, but were generally about 30% higher than when no LS was applied to the straw (Table 15).

Saxena et al. (1971) measured rumen ammonia nitrogen 4 h after feeding. The rumen ammonia N levels were significantly higher with untreated straw (ground before treatment) than treated, and those from the urea-supplemented diets were significantly higher than those containing soya bean meal. Saxena et al. (1971) noted lower rumen ammonia and blood urea levels for the cattle given NaOH-treated straw. The reduced ammonia levels could be due in part to increased microbial synthesis made possible by increased energy availability in treated materials. Shin et al. (1975) and Ololade and Mowat (1975) have also reported reduced plasma urea levels due to alkali treatment.

Satter and Slyter (1974) have found that levels of rumen ammonia greater than 5 mg/100 ml indicate a quicker release of N than energy from the diet to allow maximum microbial growth, and as a result the N is inefficiently used (Satter and Roffler 1975).

As already discussed feeding alkali straw may arrest the initial depression of rumen pH post-feeding, which may be an advantage in dairy cow management. If treated straw was fed in a beef system and a NPN source such as urea was used, "urea" toxicity may possibly arise because NPN sources are rapidly fermented in the rumen to form ammonia, which is quickly absorbed into the blood stream.

The rate of absorption is in part reliant on the rumen pH and at high levels (as in alkali treated straw) could be fast enough to cause toxicity symptoms. However, Miller et al. (1976) found that alkali treatment only increased pH in the absence of urea.

Ololade and Mowat (1975) found that a decrease in rumen ammonia was highly correlated with a decrease in rumen pH. While studies by Lewis (1955) and Warner (1956) have indicated that production of ammonia declines as pH decreases. This present experiment does not give any results to suggest a possible ammonia hazard at the rates of NaOH and LS used.

Owen, Jayasuriya and Mwakatudu (1973) have suggested that the determination of digestibility by an in vitro method is liable to over estimate animal responses to alkali treated straws. In this experiment only the digestibility of the NaOH treated straw was found to be slightly higher by an in vitro technique, the digestibilities of the nil, LS and NaOH + LS treated straws were all slightly lower compared with in vivo measurement (Table 13). There is limited information on the accuracy of the in vitro techniques for predicting in vivo digestibility of alkali treated roughages. Many reports (Klopfenstein et al., 1972; Thomsen, Rexen and Kristensen, 1973; Jayasuriya and Owen, 1975) suggest

over-estimation of the response to treatment by *in vitro* determination. Donefer *et al.* (1969) noted that cellulose digestion *in vivo* was higher than that observed *in vitro* for untreated straw, but the *in vivo* and *in vitro* values obtained for NaOH-treated straw were similar. The prediction of *in vivo* results from *in vitro* determinations are discussed more fully in the literature review.

Table 17 shows the actual intakes of dietary constituents/day. It is interesting to note that although in the two diets containing LS the intakes of Ca and P are nearly twice those of the nil and NaOH treated diets, they are still not as high as the currently (A.R.C. 1965) recommended intakes. However blood calcium and phosphorus concentrations remained normal throughout the experiment.

Sodium intake was about equal to the A.R.C. (1965) recommended intake for both the nil and LS treatments, but abnormally high for both the treatments containing NaOH. This could have a serious physiological affect on the animal. There is conflicting data on the effects of a high dietary load of sodium. Singh and Jackson (1971) fed straw treated with 3·3% to 10% NaOH to cattle 8 to 18 months old over a 6 month period; water intake did not increase significantly and no ill effects were observed. However, other workers (Jayasuriya and Owen, 1975; Rees, 1977) have reported increases in total intake of water up to 30% and consequently a greater output of urine.

Jayasuriya and Owen (1975) noted that with increasing levels of NaCH urine pH was significantly reduced, the urine pH being 9·09 when consuming straw treated at 4·5 g NaOH/100 g straw and 8·9 when treated at 9·0 g NaCH/100 g straw. In most observations where no ill effects were observed no detailed observations on urine were made. One consequence of feeding high levels of sodium is that with increased urinary output this will result in cattle requiring more bedding material.

Table 17 details the total DCP (g/day) supplied by the four treatment diets, in comparison with the highest published DCP requirement 400 g DCP/day it can be seen that by adding LS to the diet the DCP intake is increased to above the published requirement. While the ME intake from all the four diets is below that recommended, no adverse affects in cow performance were observed, but each diet was, of course given for only a 3 week period and fixed allocations of feed were given to minimise residue problems.

Subsequent to the experiment all the cows calved normally. The cows continued on a diet of barley (3 kg/day) plus oat straw supplemented with LS until transfer to grass with a bull about 8 weeks after calving. Calf growth rate and the reproductive performance of the cows were both satisfactory.

In practice if sodium hydroxide treatment is used to improve the energy value to straw to allow greater consumption, there should in turn, be a reduced requirement for cereals. This results in a reduced protein and mineral content in the diet and increases the need for supplementary protein, mineral and vitamin supplementation. From this experiment it can be concluded that the LS supplementation of oat straw at the same time of chopping, is both practical and nutritionally advantageous, and when oat straw is simultaneously treated with sodium hydroxide the affect is additive with respect to improved intake rather than due to improvements in digestibility.

Experiment 1.2. Performance of pregnant beef cows given oat straw treated with NaOH+LS or LS and two levels of ground barley to give equal metabolisable energy allowmaces.

Introduction.

The objective of Expt 1.2 was, firstly, to observe the long-term effect of feeding NaOH treated straw on animal health and bedding requirements. Secondly, to compensate for the lowered requirement for ME from barley due to NaOH treatment increasing the ME of the straw and observe animal performance. However, as only a small number of animals (4/treatment) were used it is an "observation" rather than an experiment.

Materials and methods.

Eight pregnant beef cows, principally Hereford cross of mean liveweight 515 kg and body condition score 2·4 (Lowman, et al., 1973) were grouped on a basis of anticipated calving date, body condition score and liveweight, into two balanced groups each of four animals. The cows were housed in a dutch barn in pens of equal size. At the start of the experiment the cows were on average ten weeks from calving. For a preliminary period of 19 days the two groups were each given 25 kg of a mixture of the four treated straws used in Expt 1.1. The animals were given the dietary treatments for 6 weeks.

One group was given NaOH+LS the other LS treated oat straw (treatments as described for Expt 1.1) together with barley cubes (DM 805, Crude protein 124, Ca 1·38 and P 2·31 g/kg) at one of two levels (Table 18).

Studies by various investigators to date have not involved direct determinations of the ME content of treated straw. Thus the values available would have to be estimated from digestibility data. Effective chemical treatment of straw with sodium hydroxide generally increases the digestibility coefficient from 0·40-0·45 to 0·55-0·60. An increase in digestibility would be accompanied by an increase in ME. Both parameters

would be related to the original digestibility of the straw. For the purpose of this experiment it was assumed that the NaOH addition would increase the ME by 20% and that the addition of LS alone would not affect the ME of the straw. On the assumption that the NaOH treatment increases the ME of the straw, to enable both dietary treatments to have equal ME contents the amount of barley cubes provided in the NaOH treated straw diet would have to be reduced. Table 18 shows the quantity of treated straw and barley cubes given per head per day. The concentrates were given at 08.00 h on a group basis. The straw was group fed in ring feeders twice daily at 08.00 and 16.00 h. The cows were weighed and their body condition score assessed at the start and at 4 and 6 weeks. Blood samples were taken from the jugular vein at 4 and 6 weeks from the beginning of the experiment. The samples were analysed for calcium, phosphorus and urea.

Table 18. Expt 1.2. Dietary treatments.

	Diet	
	NaOH + LS	LS
Barley cube (kg/head/day)	1·55	2·30
Treated oat straw (kg/head/day)	7·9+	7·8+
Total estimated ME (MJ/kg/head/day)	70.7	70·6

+each animal received 7·5 kg fresh straw plus an allowance for the additions of NaOH and LS.

Results.

The mean liveweights, live-weight changes, blood urea, calcium and phosphorus concentrations are presented in Table 19.

Table 19. Expt 1.2. The mean live weight, live-weight changes (kg), blood urea, calcium and phosphorus concentrations (mmol/litre)

	NaOH + LS	LS	Pooled SE of mean	Significance
Live weight				
start	513	517		
4 weeks	522	535		
6 weeks	533	541		
Live-weight change				
4 weeks	+ 7·4	+18	4·56	NS
6 weeks	+20·3	+24	7·72	NS
Urea				
4 weeks	3·02	3·96	0·25	LS > NaOH+ LS *
6 weeks	3·92	4·95	0·55	NS
Calcium				
4 weeks	2·73	2·75	0·06	NS
6 weeks	2·73	2·78	0·04	NS
Phosphorus				
4 weeks	1·54	1.39	0·11	NS
6 weeks	1·58	1.46	0·17	NS

At the end of the experiment the mean liveweight of the cows was 537 kg and the mean body condition score 1·9. The mean increase in body weight was 22 kg over the 6 weeks of the experiment, this would largely

be due to the increase in size of the foetus as they lost body condition (2·4 to 1·9). The increase in body weight for the cows on each treatment was similar an average increase of 24·0 kg and 20·3 kg for the LS and NaOH + LS treatments respectively (not significantly different).

Both the barley cubes and treated straw were readily and totally consumed by all the cows. Both blood calcium and phosphorus concentrations were satisfactory an average of 2·76 mmol/litre calcium and 1·52 mmol/litre phosphorus. Blood urea concentrations for the animals given the LS treated straw tended to be higher than the concentration for the animals given NaCH + LS straw, but only significantly ($P < 0.05$) different at the 4 week recording.

Throughout the experiment the amount of bedding (barley straw) required by each group of animals was recorded. The amounts given in total were 780 and 730 kg for the NaOH + LS and LS treatments respectively.

Discussion.

Over a 6-week period no signs of animal ill health were noted for the cattle given either of the dietary treatments. However, the bedding requirements of the animals on the NaCH + LS treatment diet were increased by 7%, indicating that their urinary output was greater. The effect of NaOH on water intake and urinary output has been discussed previously in the literature review. Pal and Negi (1976) have studied the kidney function in rams maintained on alkali-sprayed paddy/wheat straw rations, supplemented with urea as the sole nitrogen supplement, for a period of 10 months. They found no evidence of impairment of kidney efficiency under the conditions of the experiment.

Over the 6 week period live-weight changes and blood calcium and phosphorus concentrations were all satisfactory. Blood urea concentrations were lower on the NaOH + LS treated diet, but this would be as a consequence of the lower barley intake for this diet. The two groups of

animals performed equally well on each diet, demonstrating the use of a NaOH treatment in lowering the requirement of ME from a relatively expensive cereal feed. However there are limits to how much ME can be replaced by NaOH-treated straws. An adequate supply of nitrogen is necessary on poor quality roughage diets to maintain and increase the rate of microbial protein synthesis and consequently the voluntary intake. Although NaOH treatment causes delignification of the oat straw resulting in increased digestibility and available energy, unless nitrogen is supplemented the low nitrogen content of straw would be the limiting nutrient. Therefore as the barley content of the ration is lowered an additional requirement for a protein supplement is created.

Following the experiment the cows calved normally. They continued to receive increased amounts of barley plus oat straw supplemented with LS until the transfer to grass with a bull about 8 weeks after calving. Subsequent calf growth rate and reproductive performance of the cows were both satisfactory.

Experiment 1.3. The effect of calcium hydroxide on the digestibility of LS-treated chopped oat straw by non-productive Greyface ewes.

Introduction.

Much current research work is in progress regarding alkali treatments of straws with specific emphasis on NaOH treatment. However, much less published data is available on the effectiveness of $Ca(OH)_2$ as a chemical treatment of straws. Work by Verma and Jackson (1975) and Gharib et al. (1975b) showed $Ca(OH)_2$ to be much less effective in increasing digestibility, probably as a consequence of the relatively low solubility of $Ca(OH)_2$. On-farm treatment of straw with NaOH using existing machinery and equipment currently available is relatively expensive and presents some safety hazards to the operator. This experiment examines the digestibility of oat straw treated with LS, with and without the addition of $Ca(OH)_2$ (Limbux, I.C.I. Ltd.) and the effect of added water.

Materials and methods.

Diet preparation.

Three oat straw treatments were prepared using a Mill-Feed Services Feedmobile machine. The basal treatment for all three diets was milling oat straw through a $\frac{1}{2}$ inch screen and mixing it with 4 kg LS per 100 kg fresh oat straw. For diet A there was no addition of $Ca(OH)_2$. For diet B there was a further addition of 5 kg $Ca(CH)_2$. For diet C the addition of 5 kg $Ca(OH)_2$ was followed by an extra 10 kg water per 100 kg oat straw. The addition of LS raised the nitrogen content of the oat straw from 26 to about 73 g CP/kg DM. Each diet was bagged in hessian sacks and stored for 21 days before the digestibility trial commenced.

Animals and ration allowances.

Twenty-one non-productive Greyface ewes (mean live weight 70 kg) were individually penned and assigned at random to one of three dietary treatments A, B or C for a 14-day preliminary feeding period.

The daily ration allowances were;

A:- (LS alone treatment) 750 g fresh treated straw plus 200 g bruised barley FM (mixed in with the treated straw);

B:- (LS plus $Ca(OH)_2$)788 g fresh treated straw plus 200 g bruised barley FM;

C:- (LS plus $Ca(OH)_2$ and water) 863 g treated straw plus 200 g bruised barley FM.

The daily allowances of the treated straws were such that the total dry matter intake of straw (minus any addition of LS or $Ca(OH)_2$) was almost equal in each treatment, at about 630 g/day.

During the preliminary feeding period, diet B proved to be unpalatable (because of the presence of dry powdered $Ca(OH)_2$ or $Ca\ CO_3$ formed therefrom), large daily residues accumulated and the treatment had to be abandoned.

The remaining 14 ewes given dietary treatments A and C were housed in standard metabolism cages (Duthie, 1959) and fitted with body harnesses and nylon-mesh faecal collection bags. A further 5 days run-in were allowed to accustom the animals to the metabolism cages before faecal collection commenced. In a trial of this kind it is important to adopt a standard procedure for the daily routine of feeding and collection of faecal samples, the procedure is described in the chapter on experimental techniques. The sheep were fed three times/day in order to minimise spillage. Feed intakes and faecal outputs were measured during a 7-day experimental period. Faeces were bulked for the week and subsamples taken for dry matter, ash and calcium determination. Faecal

slurries were prepared for nitrogen analyses. Table 20 details the analyses of the barley, LS and straw (before treatment).

The results were calculated for digestibility of DM, OM, N, Ca for the complete diet of straw plus barley and separately for the DOMD for straw alone.

Table 20. Expt 1.3. The mean composition of the untreated oat straw, barley (g/kg DM) and LS (g/kg FM).

	Dry matter	Crude protein	Ash	Ca
Oat straw	876	26	63	1·7
Barley	854	106	22	0·5
LS	-	1023	-	21·8

Results.

After milling and mixing the $Ca(OH)_2$ addition to diets B and C caused a yellowing of the straw. After bagging, the bags containing diets B and C heated up (particularly diet C with added water) to such an extent that the risk of spontaneous combustion was imminent. For this reason the sacks were stored spaced apart. Both the physical effects of heating and yellowing of the straw, confirm that a reaction had taken place between the straw (and/or its contained water) and the $Ca(OH)_2$.

Both diets A and C were readily consumed. Only one animal given diet A left a trivial straw residue of 28 g DM/day.

The digestibility coefficients for DM, OM, N and Ca in the complete diet and OM for straw alone are presented in Table 21. The total diet DM digestibility coefficient of diet A was significantly ($P< 0.01$) greater than that for diet C. However, when the DM of the LS $\pm$ $Ca(CH)_2$

additions are included in the total DM input, the differences in the total DM digestibility coefficients between treatments are no longer significant. The differences in the total diet OM and N digestibility coefficients between treatments were not significant. The Ca digestibility coefficient of diet C was significantly ($P < 0.001$) greater than diet A.

The digestibility coefficients for the straw alone have been calculated assuming that the DOMD of the barley given was 0·86 (M.A.F.F. et al., 1975). There was no difference between diets.

Table 21. Expt 1.3. The mean digestibility coefficients of the total diet dry matter, organic matter and for straw alone organic matter and nitrogen and calcium.

	Diet A LS	Diet C LS + $Ca(OH)_2$ + water	SED	Significance
DM digestibility				
Straw + barley	0·538	0·480	0·0169	A > C**
DM digestibility				
Straw + Barley + $Ca(OH)_2$ + LS	0·549	0·523	0·0146	NS
OM	0·563	0·533	0·0169	NS
N	0·463	0·424	0·0416	NS
Ca	-0·031	0·190	0·0449	C > A***
OM of straw alone	0·478	0·440	0·0215	NS

Discussion.

Other workers (Verma and Jackson 1975; Gharib et al., 1975b) have found $Ca(OH)_2$ to be less effective than NaOH in its ability to increase the digestibility of roughages. Gharib et al. (1975b) found that if

$Ca(OH)_2$ treated poplar bark was allowed to stand for 150 days its digestibility was increased as much as the poplar bark treated with NaOH. This phenomenon is probably attributable to the low solubility of $Ca(OH)_2$ and it was with this in mind diet C had a 10% inclusion of added water above the 14% already present in the straw.

Diet B was abandoned in the run-in period of the trial due to its unpalatibility, which was probably due to the very dusty nature of the diet.

$Ca(OH)_2$ plus the additional water did not increase the digestibility of the total diet DM, N and OM of straw alone. The digestibility of the DM (straw and barley) of diet A was shown to be 0·058 units higher than that of diet C. This result is an anomaly as when the extra DM attributable to the additions of LS and/or $Ca(OH)_2$ are taken into consideration, the DM digestibility coefficients of the two diets were not significantly different.

The results of the Ca digestibility are due to the vastly differing amounts of Ca in diets A and C. The digestibility coefficient of Ca in diet A (-0·031) is to be expected as there was no additional Ca in the diet (compared with diet C) and it reflects the endogenous loss of Ca. The increase in the digestibility coefficient of Ca in diet C reflects the increased input of Ca in the diet due to $Ca(OH)_2/CaCO_3$.

Although $Ca(OH)_2$ reacted with the straw, as observed by the physical effects this was not sufficient to be reflected by any increase in digestibility of the straw by the sheep. These results, and the results of other works (Verma and Jackson, 1975; Gharib et al. 1975b) suggest that $Ca(OH)_2$ treatment of roughages would be aided if it was allowed to stand for a longer period of time.

Experiment 1.4. The effect of ensiling chopped oat straw with added water and/or calcium hydroxide with subsequent additions of LS on its digestibility.

Introduction.

In the previous experiment Expt 1.3, it was found that the addition of $Ca(OH)_2$ alone to chopped straw produced a dusty, unpalatable material. When 10% water (by weight) was added to the straw together with 5% $Ca(OH)_2$ and the material stored in hessian sacks, there was a noticeable short-term rise in temperature together with a distinct yellowing in colour of the straw, confirming that some reaction had occurred. However, in a digestibility trial using sheep in metabolism cages it was found that there was no improvement in the digestibility of the treated straw. As already discussed, there are advantages in leaving the $Ca(OH)_2$ in contact with the straw over an extended period to allow for a longer reaction time. As $Ca(OH)_2$ is less soluble than NaOH it reacts more slowly, therefore additions of water to ensure adequate mixing of the alkali with straw would be desirable. The next step in $Ca(OH)_2$ treatment would be to ensile the treated straw resulting in an extension of the reaction time. The objective of Expt 1.4 was to examine the effect of ensiling chopped oat straw with added water and/or calcium hydroxide with subsequent additions of LS on its digestibility.

Materials and methods.

Three oat straw treatments were prepared using a Mill-Feed Services Feedmobile machine. The straw was passed through a half-inch screen in the feed processor unit and any additions were added through the top of the mixing compartment of the machine. The treatments for each silo were as follows:-

1. Oat straw + an equal weight of water (100%) alone.
2. Oat straw + 100% water + 5% $Ca(OH)_2$.

3. Oat straw + 60% water + 5% $Ca(OH)_2$.

4. (Oat straw with no additions, chopped and stored dry).

Each of the treatments 1 - 3 were stored in an insulated model silo in 300 kg straw quantities. The silos were built with thermally insulated boards in a loose box. Each silo was 1·5 m by 2·0 m and 2 m high being enclosed on three sides. The treated straw was packed and covered with polythene sheeting. The front of the silos were built up with bales, which also were placed over the top of the silo in an attempt to exclude the air. After settling the silos were on average 1·0 m high. The temperature was recorded (daily for the first 30 days and twice daily thereafter) at the centre of each silo using a long probe grass silage thermometer. The pH values of the materials were measured weekly. Sixty days after ensiling, samples were taken from each silo for mycological and bacteriological examination.

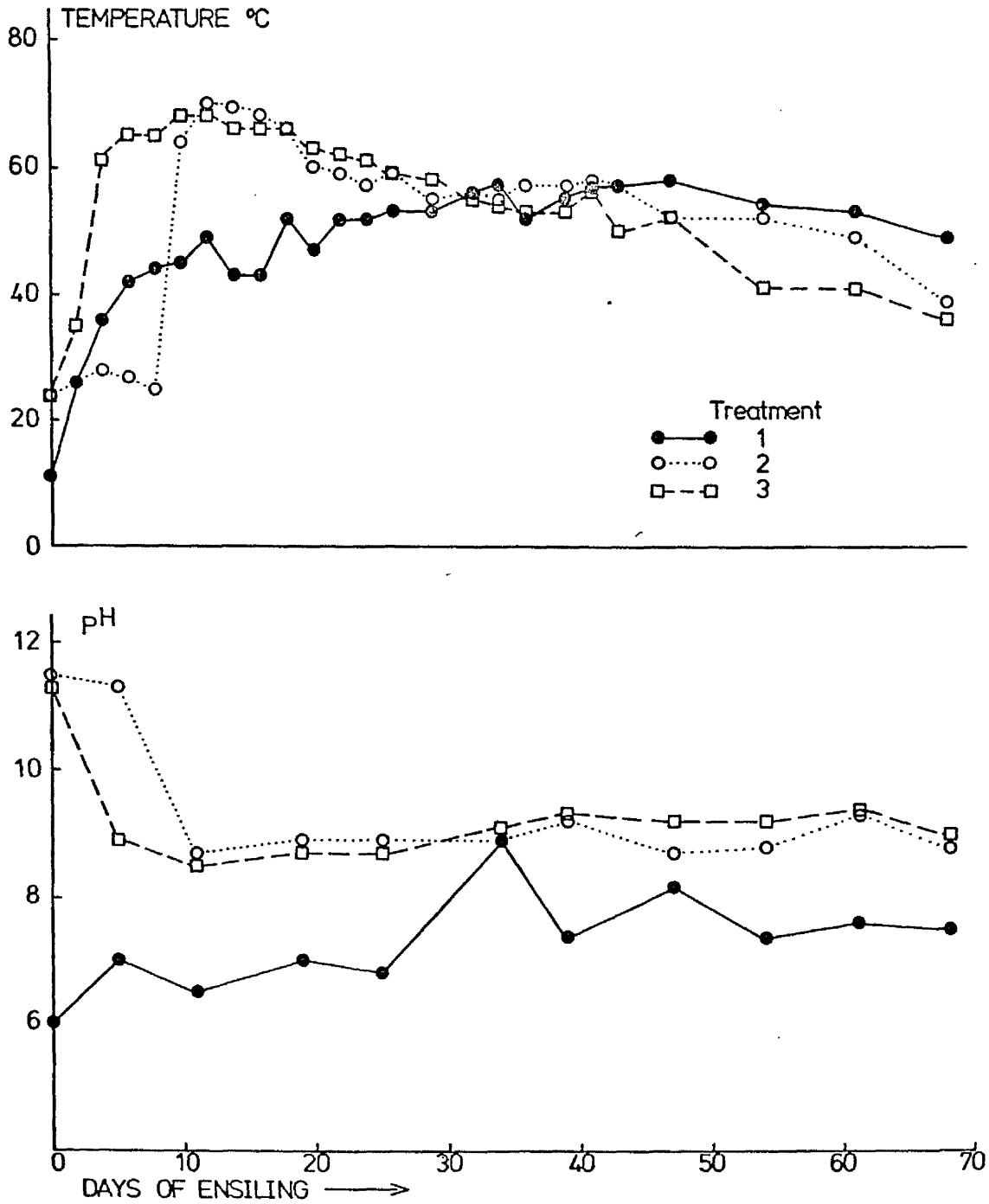
Results.

The $Ca(OH)_2$-treated straws (treatments 2 - 3) showed an immediate and marked colour change compared to the straw which had added water only (treatment 1). The colour became yellow-green and there was a distinctly noticeable, but not unpleasant "soapy" smell. The marked changes in colour and smell were subjectively much greater than those observed during Expt 1.3 when only 10% of water was added to the fresh straw.

The temperatures recorded over a 20 week storage period in each silo are given in Fig.4 and pH changes are shown in Fig.5. The temperature in the wetted straw (treatment 1) rose comparatively steadily to about 55°C after about 3 weeks of storage. In contrast, both treatments 2 and 3 with added $Ca(OH)_2$ had marked and rapid rises in temperature to 70°C after 10 days of storage. Treatment 2 with the higher water content (100% vs. 60%) had an initial lag phase of some 8 days before an extremely rapid temperature rise to 70°C, thereafter the temperatures of treatments 2 and 3 were

Fig.4. Expt 1.4. Temperature at centre of treatment silos 1(100% water), 2(100% water + 5% $Ca(OH)_2$) and 3(60% water + 5% $Ca(OH)_2$).

Fig.5. Expt 1.4. pH changes observed in treatments 1(100% water), 2(100% water + 5% $Ca(OH)_2$) and 3(60% water + 5% $Ca(OH)_2$).


TEMPERATURE °C
80
60
40
20
0
Treatment
1
2
3
pH
12
10
8
6
0
10
20
30
40
50
60
70
DAYS OF ENSILING ⟶

essentially similar.

Further distinct colour changes again occurred in the treated straws. Treatment 1 (water only added) became visibly browny-green and clearly heavily moulded by 21 days after treatment. Treatment 3 became dark brown by day 12 and treatment 2 became similarly very dark brown 25 days after storage began. Effluent appeared from both treatments 1 and 2 after 40 days (but not from treatment 3).

By day 50 it was apparent that all treatments were becoming heavily moulded. The materials had an unpleasant smell and were clearly quite unpalatable. Samples were taken from each treatment after 60 days of storage for mycological and bacteriological examination, the results are presented in Table 22.

All the treatments had extremely heavy mould presence, Humicola lanuginosa being the predominant type. This is a thermophilic mould found in heated decaying vegetation and can thrive in quite alkaline pH conditions. Very heavy bacterial contamination was found in the N+A plates, although this was not typed, it would have been thermophilic and an alkaline medium survivor. On an empirical basis treatment 1 (water alone) was by far the most heavily contaminated. Treatment 2 was carrying roughly 50% of the contamination of treatment 1, but treatment 2 (60% water, 5% $ca(OH)_2$) was appreciably the cleanest sample (mycologist's report). Further tests using greater plate dilutions would have been necessary to identify more types. However, due to circumstances beyond control, these tests were not performed. The mycologist's report states that more "Actinomycete colonies would have become evident as probably would have Polysporium faeni (Farmers' lung) moulds."

Discussion.

The treated materials were completely unsuited for animal feeding owing to the mould and bacterial contamination and severe spoilage. If

Table 22. Expt 1.4. Mycological and bacteriological analyses of ensiled treatments.

Medium	Glucose peptone + chloroampherical	Nutrient + actidione	2% malt nutrient + chloramphenical	Czapek-Dox + C
Treatment				
1 (100% water)	∞Hl mould	100% bacteria	mould	mould + bacteria 100%
2 (100% water + 5% $Ca(OH)_2$)	∞Hl mould	100% bacteria	50 colonies	mould+20% bacteria
3 (60% water + 5% $Ca(OH)_2$)	> 70 colonies Hl mould >1 colony Actinomycete	heavy bacterial contamination	17 colonies Hl	thin growth Hl

Hl = Humicola lanuginosa

this had not occurred it was the intention of this experiment to supplement the ensiled straw with LS prior to feeding and perform a digestibility trial with non productive Greyface ewes housed in metabolism cages.

It was not unexpected that treatment 1 should have decayed under such storage conditions, but treatments 2 and 3 with 5% $Ca(OH)_2$ added, giving a material with an initial pH of over 11 might have been expected to have stored well. However, this did not occur, initially aerobic bacterial fermentation must have occurred with some acid production as might be concluded from the lowered pH to about 9 in both treatments 2 and 3 by day 12 and 4 respectively. Thereafter anaerobic mould and bacterial colonies flourished under conditions of temperatures of 60-70°C and a pH of about 9.

The rise to alkaline pH of treatment 1 may be the result of some ammonia release as some thermophilic bacteria destroy protein material. Considerable gross energy was lost as heat from all three treatments in store due to micro-organism activities and was manifested in the large temperature elevations which occurred.

From the mycological examination it was clear that the wettest materials were the worst contaminated, however, $Ca(OH)_2$ had some effect on reducing colony numbers. As Expt 1.3 showed that 10% water addition + 5% $Ca(OH)_2$ under aerobic conditions produced a material with no improved digestibility further work is needed to ascertain the minimum amount of water to add to obtain the maximum effect of the $Ca(CH)_2$ addition. This would probably be best done on a laboratory scale, examining additions of 15, 20, 25 and 30% water + 5% $Ca(CH)_2$ to chopped straw to examine the extent of spoilage which may occur. Work (by previous workers) to date on the effect of alkali treatment and subsequent ensiling has produced silages of varying quality (as already discussed in the literature review).

Chopping and processing straw on a farm scale produces large volumes of material from which it can never be possible to fully exclude entrapped air. Subsequent storage conditions will almost inevitably allow entrance of air. In the present experiment all reasonable attempts (short of using sealed metal or concrete containers or vacuum packing) were used to exclude air. Spoilage was probably initiated by either the entrapped air or air which gained access and subsequent heat generation probably accelerated this. The prospects for a satisfactory treatment on a farm scale do not appear to be very promising.

SECTION 2

METHODS OF PRESENTING LS TO RUMINANTS

Introduction.

This section of the thesis examines the effect of different methods of presenting LS to animals on their voluntary intake of high straw diets. One advantage of a concentrated liquid supplement is that it can be applied to numerous base materials. This section attempts to determine if any particular method of presentation is more desirable in terms of practical application, convenience, animal acceptance and animal performance. The methods investigated for the presentation of LS were (a) in the drinking water, (b) in a barley cube, (c) in a molasses lick and (d) sprayed onto straw.

Supplying LS to animals through the drinking water would appear to be an easy and labour saving method. One advantage is that as all animals drink water, therefore unlike other free-access situations all the animals would receive an amount of the supplement perhaps in proportion to their dry matter intake. However, this method of supplementation will depend on the following facts:-

(i) The factors affecting total water intake.

- a. Dry matter eaten.
- b. Nature of the food.
- c. Individual variation.
- d. Frequency of drinking.
- e. Physiological condition of the animal.
- f. Ambient temperature and temperature of the water.
- g. Live weight of the animal.
- h. Distance between feed and trough.
- i. Trough size : animal number.

(ii) Class of stock to be supplied.

(iii) Whether different types of stock at different stages of growth and/or production are to be supplied from the same water supply.

(iv) Type of water supply on the farm.

The factors affecting water intake and water requirements have been reviewed by various workers: e.g. Leitch and Thomson (1944-45); Winchester and Morris (1956); A.R.C. (1965); Forbes (1968); Church (1979). Andersson (1978) has reviewed the physiological mechanisms governing the regulation of water intake. A large proportion of the work on water intake has been associated with dairy cattle: e.g. Craplet (1963); Paquay, De Baere and Lousse (1970 a,b); Thomas (1971); Castle (1972); Castle and Watson (1973); Castle (1975); Thomas and Castle (1974); Castle and Macdaid (1975); Little and Shaw (1978).

The knowledge of water requirements of sheep is not as critical in Britain as the majority of grazing animals would obtain a high proportion of their water requirements from water in the food. However, in arid areas where animals have to drink from piped supplies the water requirement is important. Squires and Wilson (1971) examined the distance between the food and water supply and its effect on drinking frequency and food and water intake of Merino and Border Leicester sheep. Water intake and feed intake was affected by the distance of the water supply from the food supply, both food intake and frequency of visits decreased as the distance from the water increased. In these arid areas, where ruminants are restricted to dry, mature herbage which is deficient in protein, provision of a NPN supplement in the water would be an efficient method. Snook (1958) and Von la Chevallerie and Coetzee (1964) have added urea to the drinking water. However, there were frequent cases of poisoning due to the urea concentration gradually increasing in the water in the trough over a period of time as a result of evaporation. It appeared that the

water which contained toxic levels was not sufficiently unpalatable to prevent consumption in fatal amounts. Holzer and Levy (1971) provided urea in the drinking water for beef cattle given poor quality roughage under controlled experimental conditions. The daily allowance of urea was divided into 3 parts which were introduced 3 times per day into a quantity of water that was judged to be approximately one-third of their voluntary consumption. There were, however, no significant increases in straw intake due to urea supplementation through the water.

Toxicity resulting from the consumption of large amounts of urea and other NPN compounds is characterized by an elevated concentration of rumen ammonia and subsequent high concentrations of ammonia in peripheral blood. The elevation of rumen pH has been shown to increase the rate of ammonia absorption from the rumen and therefore increases the susceptibility to toxicity. When urea is supplied via the water system, there is a potential risk of urea poisoning and because of this several workers have examined the use of ammonium acetate as an alternative to urea. Dilute acetic acid is often used in ammonia toxicity therapy to neutralize ammonia and therefore reduce its rate of abosrption. Webb, Bartley and Meyer (1972) studied the nitrogen metabolism and ammonia toxicity from ammonium acetate and urea in cattle. Ammonium acetate administered through the drinking water has been found to increase the content of butterfat in milk (e.g. from 2.76 to 3·12, not significant, (Kay, Walker and McKiddie, 1967)). Various workers have successfully given ammonium salts of short-chain fatty acids in the drinking water to dairy cows (Jackson, Hodgson and Rook, 1968; Hutton, Prescott, Seeley and Armstrong, 1969; Prescott, El-Shobokshy and Armstrong 1969). Other materials have been added to the drinking water: e.g. ammonium polyphosphate (Hemingway and Fishwick, 1975) and VFAs and vitamins (Kay, Andrews, MacLeod and Walker, 1968). Various commercial enterprises market magnesium supplements for use through the water supply. These

involve a proportioner pump which automatically adds the concentrated supplement (at a pre-set rate) to the drinking water in the trough as the water level falls on consumption.

The addition of LS through the drinking water is a possible method of presentation to animals provided that the problems already discussed are taken into account. However, for the purpose of experimental design all the dietary treatments in this section have a fixed intake of the supplement LS. Therefore in all the experiments in this section, LS given in the drinking water is allocated in a fixed concentration in a fixed amount of water that the animals are known to be able to consume.

Supplying LS to animals in a home-made free access liquid is another possible method of presentation. A LS/molasses/water lick has been formulated to the following proportions:- molasses 3, LS 2 and water 1. Throughout this section it will be referred to ás LS lick (LL).

The molasses serves as an excellent carrier for urea in self-feeding liquid systems. It increases further the palatability of urea-containing diets and is a readily available source of sulphur and energy which is necessary for optimal urea utilization. Webb et al. (1972) have found that by simultaneously administering molasses with urea reduced rumen ammonia concentrations, rumen pH and blood ammonia were obtained. Blood urea concentrations were also reduced. Molasses apparently increases nitrogen utilization by rumen micro organisms and decreases rumen pH thus reducing the rate of absorption of ammonia from the rumen.

Horton, Morris, Bierwirth and Ragland (1962) have reviewed the use of liquid urea/molasses preparations in roughage diets. Karalazos and Swan (1976) have reviewed the use of molasses and the effect of the inclusion of molasses on digestibility, microbial protein synthesis and the utilization of energy and food intake. Urea/molasses liquid supplements have been used to increase the intake and digestibility (Beames, 1959) of pastures by grazing ruminants.

In an attempt to ensure that urea/molasses solutions are not over consumed by individual animals nor consumed at too rapid a rate they are generally offered to groups of live stock via a ball-licking device. However, the individual intake of liquid supplements from ball-lickers by animals in a group is very variable. For example Nolan et al. (1974) presented such a supplement to 48 Hereford heifers (2-3 years old) at grass. Eight individuals consumed none and the intake of the others ranged from under 500 to over 2500 ml/day. The overall mean consumption was 854 ml, but only 35% of the animals consumed within $\pm$ 50% of this figure. Langlands and Bowles (1976) and Langlands and Donald (1978) have similarly found with 2 year old Hereford heifers at grass that some 5% consume none and some 10% consume excessive amounts. Nolan et al. (1975) have also recorded that 97 of 200 Merino wethers at grass consumed none of a urea/molasses lick, 12 consumed under 100 ml/day and 70 consumed 50% more than the mean intake of 105 ml.

It is generally indicated that giving urea frequently in small amounts may help to reduce the production of perhaps excessive amounts of ammonia in the rumen (e.g. Armstrong and Trinder, 1966). As discussed in the literature review some workers have found no advantage in giving urea frequently (in terms of increased utilization or voluntary intake of straw) while others have found a response. However, giving concentrates containing urea to beef cows more than once per day is not normally practical.

LS given once daily in a barley cube and LS sprayed on the straw available for the majority of the day are the other methods of presentation investigated.

WATER INTAKE

Introduction.

The objectives of the following experiments were to study patterns of water intake and LS palatability by housed wether sheep. They were also conducted to gain experience in the experimental techniques involved in measuring water intake.

Experiment 2.1. The effect of dry matter intake on water consumption by wether sheep.

Materials and methods.

Nineteen wether lambs (mean live weight 40 kg) were individually housed in metabolism cages. One group of 7 animals was given 1·0 kg grass nuts (870 g/kg DM, 174 g/kg crude protein and 224 g/kg crude fibre) at 08.00 h and the other group of 12 animals was given 1·5 kg grass nuts at 08.00 h. Water was constantly available in buckets and intake was recorded daily for one week at the time of the morning feed.

Results.

All the animals completely consumed their daily allocation of grass nuts. The group receiving 1·5 kg of grass nuts drank significantly ($P < 0·05$) more water (3·9 litres) compared with 3·2 litres for the group receiving 1·0 kg of grass nuts (SED 0.30). Table 23 details the mean individual daily water intakes of the sheep on both treatment groups. There was considerable variation in daily water intake for individual animals. This was expressed in the coefficient of variation of individual mean water intakes, which ranged from 5·3 to 29·3%.

Table 23. Expt 2.1. The mean daily water intakes over a 7 day period (litres/day).

Sheep no.	Mean water intake	SD	CV %
Group 1 (1·0 kg grass nuts/day)			
1	3·9	0·83	21·3
2	2·7	0·40	14·6
3	4·2	1·00	23·8
4	3·7	0·81	21·9
5	2·5	0·33	13·3
6	2·9	0·52	17·8
7	2·3	0·56	24·4
Group 2 (1·5 kg grass nuts/day)			
8	4·3	1·26	29·3
9	3·8	0·50	13·2
10	4·2	0·54	12·9
11	3·9	0·62	15·9
12	3·9	0·81	20·6
13	3·2	0·64	20·0
14	4·0	0·68	16·8
15	4·1	0·65	15·8
16	4·2	0·47	11·2
17	4·2	0·71	17·0
18	3·9	0·20	5·3
19	3·4	0·72	21·5

Experiment 2.2. The effect of dry matter intake and the time of consumption of feed on water intake by sheep.

Materials and methods.

The animals and housing conditions used in this experiment were identical to those in Expt 2.1. The animals were divided into 3 groups and given grass nuts of the same composition as for Expt 2.1.

Group 1:- 7 animals given 0·5 kg grass nuts at 08.00 h and 0·5 kg grass nuts at 16.30 h.

Group 2:- 6 animals given 0·75 kg grass nuts at 08.00 h and 0·75 kg grass nuts at 16.30 h.

Group 3:- 6 animals given 0·75 kg grass nuts at 08.00 h and 0·75 grass nuts at 13.00 h.

Daily water intakes were recorded for a period of one week. In the second period the dietary treatments were reversed for group 2 and 3 and after a change-over period of 4 days the daily water intakes were recorded for a further week.

Results.

All the animals completely consumed their daily allocation of grass nuts. The mean individual and group water intakes are given in Table 24. The two groups of animals receiving 1·5 kg of grass nuts drank significantly more water than the group receiving 1·0 kg grass nuts/day for both periods. Giving the feed at 13.00 h instead of 16.30 h had no effect on the total daily water intake, either between group 2 and 3 or between the same group for different periods. A large variation in daily water intake for individual animals was also recorded for this trial. The coefficients of variation of the individual mean daily water intakes ranged from 4·9 to 35·4%.

Table 24. Expt 2.2. Mean daily water intakes over a 7 day period (litres/day).

	Period 1			Period 2		
Sheep no. Group 1	Mean intake	SD	CV%	Mean intake	SD	CV%
1	3·7	0·52	14·1	3·8	0·85	22·4
2	2·5	0·32	12·7	2·3	0·32	13·9
3	3·7	0·66	17·9	3·6	1·20	33·2
4	3·2	0·40	12·5	3·4	0·49	14·4
5	2·8	0·48	17·1	2·3	0·26	11·3
6	3·1	0·39	12·6	2·7	0·26	9·7
7	3·2	1·13	35·4	2·2	0·44	20·2
Group 1	$3·2^{ac}$	0·44		$2·90^{bd}$	0·68	
Group 2						
8	6·0	0·91	15·2	4·9	0·53	10·9
9	4·0	0·61	15·2	3·6	0·64	17·9
10	4·1	0·41	10·1	3·9	0·19	4·9
11	4·2	0·36	8·5	4·2	0·49	11·6
12	3·8	0·90	23·7	3·7	0·25	6·7
13	3·5	0·45	12·7	3·0	0·62	20·7
Group 2	$4·3^{a}$	0·89		$3·9^{b}$	0·64	
Group 3						
14	4·1	0·37	9·1	3·9	0·62	15·9
15	4·0	0·73	18·2	4·0	0·43	10·8
16	4·5	0·94	20·8	4·4	0·38	8·7
17	4·3	0·40	9·4	4·4	0·52	11·7
18	3·8	0·31	8·1	3·5	0·41	11·8
19	3·5	0·45	12·9	3·3	0·29	8·8
Group 3	$4·0^{c}$	0·36		$3·9^{d}$	0·45	

Means followed by the same letter are significantly different a,b ($P < 0·05$) c,d ($P < 0·01$).

Experiment 2.3. The effect of time of eating on water intake.

Materials and methods.

In Expt 2.2 giving the second feed of grass nuts at 13.00 h instead of 16.00 h had no effect on the total daily water intake. It was therefore decided to investigate different feeding patterns on water intake during the day.

Five wether lambs, mean live weight 38 kg were individually penned indoors. For the first week, the animals received 0·5 kg bruised barley at 08.00 h and 0·75 kg hay at 15.00 h (hay 822 g/kg DM, 87 g/kg crude protein and 366 g/kg crude fibre, barley 855 g/kg DM, 103 g/kg crude protein and 25 g/kg crude fibre). Water was continually available in buckets and intake was measured at 08.00, 10.00, 15.00, 17.00 and 19.30 h, for a period of one week. After this period the hay was given at 08.00 h and the barley at 15.00 h. Following a change-over period of 4 days the water intake was measured for a further week.

Results.

All the animals completely consumed the hay and bruised barley. The mean daily water intakes are given in Table 25.

Table 25. Expt 2.3. The mean daily water intakes over a 7-day period (litres/day).

Barley given at 08.00 h and hay at 15.00 h.

Sheep no.	4	6	7	9	10	Significance
mean intake	2·2	1·9	2·5	2·1	1·8	$7>9^{*}, 9>10^{*}, 4>10^{**}, 7>6^{**}, 7>10^{***}$
SD	0·28	0·26	0·37	0·24	0·26	
CV%	12·5	13·4	14·9	11·3	14·3	

Hay given at 08.00 h and barley at 15.00 h.

mean intake	2·1	2·0	2·2	2·0	1·9	NS
SD	0·22	0·36	0·27	0·30	0·34	
CV%	10·3	18·1	12·3	15·2	17·9	

The total water intake/day of the same sheep did not differ significantly when the feeding regimes were inter-changed. Considered individually, the mean daily intakes of the sheep were not consistent (sheep no. $7>9^{*}$, $9>10^{*}$, $4>10^{**}$, $7>6^{**}$ and $7>10^{***}$) when the barley was given at 08.00h. The water intake of the individual sheep was more uniform when the barley was given at 15.00 h. The mean daily water intakes expressed as water intake/h as a percentage of the total (between the periods recorded) are given in Fig.6. Over 20% of the total water was drunk in the first 2 h after giving hay irrespective of the time of day when it was offered.

Experiment 2.4. The palatability of LS given in the water to wether sheep.

Materials and methods.

Seventeen wether lambs (mean live weight 40 kg) were individually housed in metabolism cages. One group of six animals was given 1·0 kg grass nuts and another group of 11 animals was given 1·5 kg grass nuts (of the same composition as for Expt 2.1). Each animal was offered ad libitum water or water containing 0·5 or 1·0% LS. Two animals were allocated to each treatment from the group receiving 1·0 kg grass nuts/day. Four animals were allocated to the water and 0·5% treatment and 3 animals to the 1·0% LS treatment from the group receiving 1·5 kg grass nuts/day. After an initial treatment acclimatization period of 7 days, the individual water intakes were recorded for a period of 3-days.

Results.

The mean daily group water intakes over a 3-day period are presented in Table 26. There was no difference in daily water intake between the treatments for those animals given 1·5 kg grass nuts/day (mean intake c. 3·1 litres/day). However, for those animals receiving 1·0 kg grass nuts the addition of LS (of either 1.0 or 0·5%) to the water significantly increased the water consumption.

Fig 6. Expt 2.3. The pattern of water intake throughout the day (% of total) of wether sheep. The unshaded area represents the mean water intake of animals given hay at 08.00 h and barley at 15.00 h. The shaded area represents the mean water intake of animals given barley at 08.00 h and hay at 15.00 h.

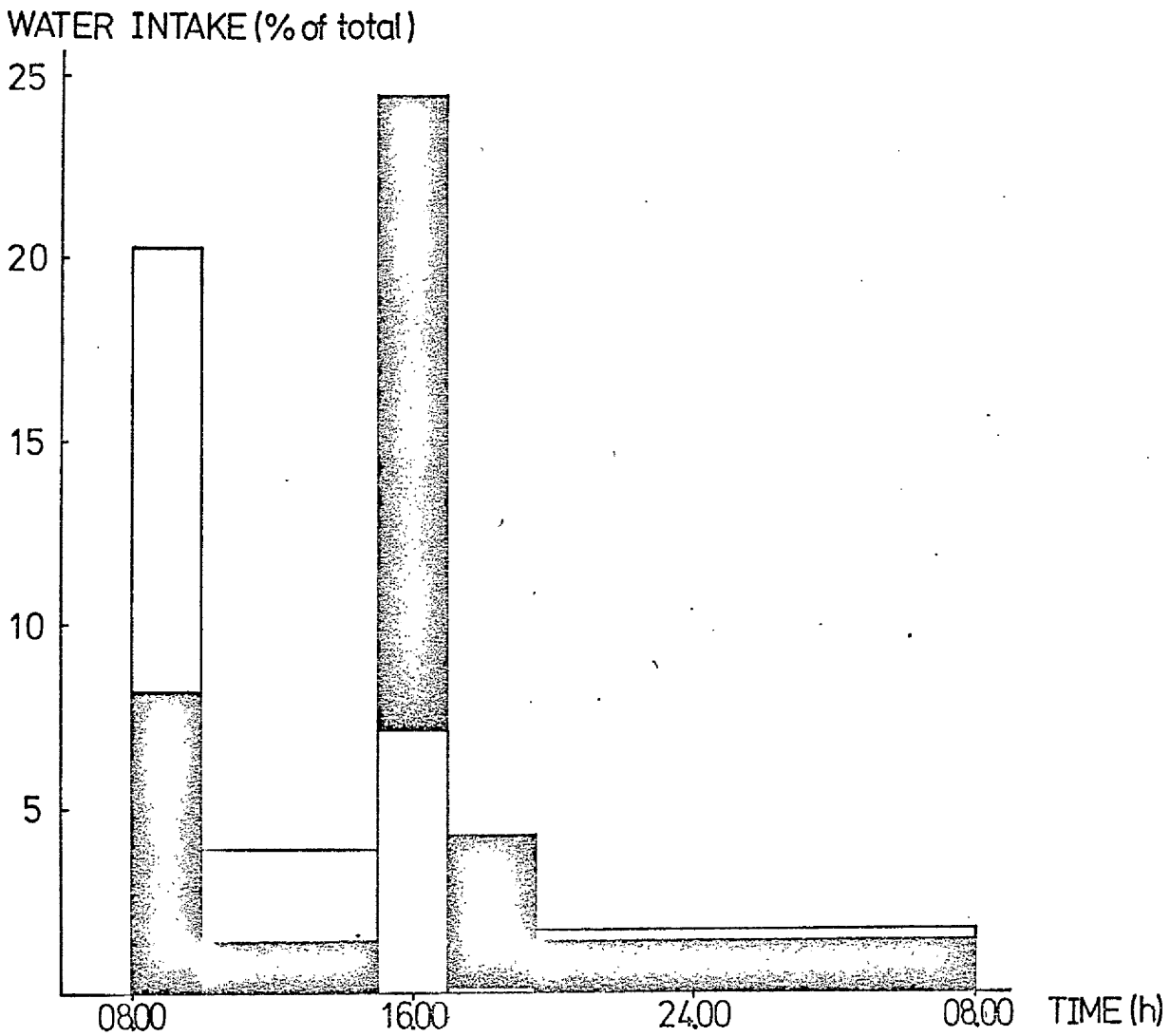

WATER INTAKE (% of total)
25
20
15
10
5
08.00
16.00
24.00
08.00
TIME (h)

Table 26. Expt 2.4. The mean daily group water intakes over a 3-day period (litres/day).

Group	1 Water	2 0·5% LS	3 1·0% LS	Significance
Animals receiving 1·0 kg grass nuts/day				
mean intake	2·3	3·6	2·9	$2>3^{**};3>1^{**};2>1^{***}$
SD	0·29	0·52	0·60	
Animals receiving 1·5 kg grass nuts/day				
mean intake	3·4	3·1	3·1	NS
SD	0·86	0·91	1·59	

Experiment 2.5. The palatability of LS given in the water to wether sheep.

Materials and methods.

Ten wether lambs (mean live weight 40 kg) were individually penned indoors. The animals received the same diet as in Expt 2.3, the barley being given at 08.00 h. In Expt 2.3 the mean daily water intake of similar animals on the same dietary regime was 2·0 litres/day. It was decided to restrict the water intake of the animals to a volume that would be completely consumed. Each animal was offered 1·5 litres of either water or water containing 1·3, 2·7 or 4·0% LS. Two animals were allocated to the water and 4·0% LS treatments, and 3 animals were allocated to the 1·3 and 2·7% LS treatments. Intakes were recorded daily for one week.

Results.

The two animals receiving water alone consumed their daily allocation of water. However, as the concentration of LS increased in the water, water intake decreased. The mean water intakes are given in

Table 27. At all concentrations of LS the water intake was depressed significantly. However, drastic reductions were not recorded until the LS concentration reached 2·7%.

Table 27. Expt 2.5. The mean daily group water intakes over a 7-day period (litres/day).

Group	1 Water	2 1·3% LS	3 2·7% LS	4 4·0% LS	Significance
mean intake	1·5	1·2	0·5	0·2	1>2,3,4***; 2>3,4***
SD	0·00	0·28	0·57	0·33	
CV%	0	23·1	112·7	141·1	

General discussion.

Water intake was affected by the total DM intake. The higher the DM intake the higher the water intake. Giving the feed at different times of the day did not alter the total daily water intake. It did, however, affect the pattern of water intake during the day. More data is required before drawing positive conclusions on the palatability of LS/water. It can be said that up to 1·0% LS addition in the water does not decrease water consumption, but above 1·3% LS water intake is impaired. However, not until LS was added at a concentration equal to or greater than 2·7% did water intake appreciably decrease.

Experiment 2.6. The effect of method of provision of LS on the voluntary intake of oat straw by 260 kg Hereford-cross cattle.

Introduction.

The objective of Expt 2.6 was to examine the effect of giving LS, (i) included in a barley cube, (ii) in the drinking water and (iii) in a molasses/water mixture (LL) on the voluntary intake of oat straw. LS was supplied at the rate of 100 g/head/day to housed 260 kg beef cross cattle being over-wintered with a minimum quantity of cereals and a maximum amount of straw.

Materials and methods.

Sixteen beef cattle (9 heifers and 7 steers), principally Hereford cross of mean live weight 263 kg were housed on a group basis. Following an initial acclimatization period of 28 days when the cattle were given oat straw ad libitum and 1·5 kg of barley cubes from diet B, (to be described) the cattle were arranged into four balanced groups each of four animals. The groups formed a 4 x 4 Latin square.

There were four dietary treatments

(A) 1·5 kg barley - no supplement

(B) 1·6 barley including LS (100 g/d in 1·5 kg = 6·6%)

(C) 1·5 kg barley plus LS in the drinking water available throughout the day (400 g LS in 60 litres water supplied to the group)

(D) 1·5 kg barley plus LL (1·2 kg/four cattle in a ball-licker (2 balls) given as the cattle finished consuming barley at 08.00 h).

The barley was ground and cubed and included chromic oxide to give about 10 g for every 1·5 kg cubes. The concentrate ration was given individually in locking feeders at 07.30 h.

Diets B, C and D gave the cattle a possible mean daily allocation of 100 g LS/head. The animals on diet B were given 1·6 kg barley cubes, to allow for the LS supplementation.

Oat straw was given ad libitum on a group basis, being replinished in the ring feeders twice daily (08.00 and 16.00 h).

In the preliminary period it was found that a group of four cattle consistently consumed about 60 litres/day of water. On this basis LS was offered at 400 g LS in 60 litres to the group/day (i.e. a 0·67% solution). If at any time the trough was emptied, fresh water was made available for the rest of the day. This ensured that their water intake (and hence possibly their straw intake) was not restricted.

Time lapse photography was used to examine both the pattern of water intake and consumption of LL. To supplement the data obtained from the time lapse photography, water intake was recorded during the day by means of a calibrated dip stick. The time for the LL to be totally consumed was recorded.

The four feeding periods were each of 21 days and straw intake was recorded separately for days 8-14 and days 15-21.

Blood samples were taken at 07.30 h from the jugular vein on day 21 of each period and analysed for blood urea.

Rectal grab samples of faeces were taken once daily over days 15-21 of each period for chromium determination. Faecal samples were obtained because a reduced chromic oxide content might imply that an individual animal in a group was eating more straw. This in turn might be related to the blood urea concentration of the animals indicating more than normal consumption of LS (especially for the treatments where LS intake was available on a group basis (i.e. in water or as LL)). Daily maximum and minimum temperatures were recorded.

The animals were weighed at the beginning of the experiment and at the end.

Samples of the oat straw and barley cubes were taken daily over days 8-21, of each feeding period, bulked and analysed for DM, crude protein, crude fibre, ether extract, ash, calcium, phosphorus and chromium.

Samples of LS were analysed for crude protein, calcium, phosphorus and pH. The results of the analyses are presented in Table 28.

Table 28. Expt 2.6. The mean compositions of oat straw, barley cubes (g/kg DM), LS and molasses (g/kg FM).

	Oat straw	Barley cubes	LS	Molasses
Dry matter	789	838	-	-
Crude protein	19	118	1090	32
Crude fibre	437	38	-	-
Ether extract	15	15	-	-
N-free extract	469	802	-	-
Ash	60	27	-	-
Ca	2·4	0·8	28·0	6·1
P	0·4	2·7	16·0	0·5
pH	-	-	1·5	5·4

Results.

Over the total 84 days of the experiment the mean live weight of the 16 animals remained constant being 263 kg at the start 262 kg at the end.

No difficulties occurred with adaptation to LS in the water and LL in the ball licker at each change of feeding period. However, ten of the sixteen cattle left some of the barley/LS cubes offered. These animals consumed the barley/LS cubes more slowly than the unsupplemented barley cubes. On days 8-14 of the periods nine animals left residues. Three left quite trivial amounts (mean, 51 g/day); four left a mean 282 g/day and two left a mean 840 g/day. On days 15-21 of the periods ten of the cattle left residues. Four left very small amounts (mean 52 g/day) and six left a mean 163 g/day. The overall mean residue for days 8-14 was 310 g/day (mean of 9) and for days 15-21 was 118 g/day (mean of 10).

In a comparable experiment by Fishwick et al. (1973) it was found that when measuring the voluntary intake of straw it was not necessary to have the customary 14 days run-in period and valid results were obtained when straw was measured during days 8-14 of each period. For this reason straw intake was measured separately during days 8-14 and days 15-21 of each period. The voluntary intake of the cattle and mean blood urea concentrations are presented in Table 29.

Table 29. Expt 2.6. Voluntary straw intake (kg DM/day), mean blood urea (mmol/litre) and faecal chromium concentrations (g/kg DM).

Treatment	A Nil	B LS in barley	C LS in water	D LL	SE of mean	Significance
Straw intake						
Days 8-14	2·86	3·26	3·03	3·26	0·132	NS
Days 15-21	2·90	3·29	3·41	3·15	0·103	B,C > A*
Days 8-21 combined	2·88	3·28	3·22	3·21	0·066	D > A*; B,C > A**
Blood urea						
(day 21)	1·0	2·2	1·9	1·8	0·13	B > A***; C,D > A**
CV%	50·7	31·6	38·6	36·4		
Faecal chromium	2·77	–+	2·59	2·48		
CV%	13·1	–	8·8	16·0		

+ barley/LS residues, therefore chromium concentration incorrect.

The voluntary intake of straw for days 8-14 was not significantly affected by treatment. For days 15-21 barley/LS cubes and LS in the water significantly ($P < 0·05$) increased the voluntary intake of the cattle from

2·90 kg/day (nil) to 3·29 kg/day (barley/LS cubes) and to 3·41 kg/day (LS in the water). When the combined results over days 8-21 are taken into consideration the LL treatment significantly ($P < 0.05$) increased straw intake compared to the nil, and the significance for barley/LS cubes and LS in the water was then $P < 0.01$.

The blood urea concentrations when the supplemented diets were given were all significantly higher than the nil treatment (1·0 mmol/ litre); barley/LS cubes (2·2 mmol/litre) $P < 0.001$; LS in water (1·9 mmol/litre) $P < 0.01$ and LL (1·8 mmol/litre) $P < 0.01$.

The mean faecal chromium concentrations were 2·77, 2·59 and 2·48 g/kg for the nil, LS in water and LL treatments respectively. The mean chromium concentration of the faeces when the cattle were given the barley/LS cubes is not quoted, as the variation between cattle was large due to the animals leaving barley/LS residues and thus not receiving their full complement of chromic oxide.

The data from the time lapse photography was analysed manually with a fixed frame film projector. It became obvious after examining the films, that although an animal may be in the frame with its head directly above the water trough it was not necessarily drinking (nor had been drinking). Therefore, for the purpose of analysing the film, the frames were divided into the number of positive drinks or number of possible drinks per visit (a visit = 1 frame = 65 sec.). Using this information and the data recorded for water intake it was possible to obtain data for both (a) litres consumed/per/hour and (b) the cumulative consumption per group of four animals.

The data obtained from the water intake films was so immense that only a proportion of the data has been presented (Figs. 7,8,9 and 10).

However, the results indicate that for the cattle in this current experiment, there was no consistent pattern in the intake of water. The total time spent at the drinking trough for one animal varied from day-to-

day (e.g. Fig.7). In comparing the average drinking patterns of different groups of cattle at 3-week intervals the drinking patterns for particular 2 hour periods varied considerably (Fig.8). In any given 2 hour period on two consecutive days the frequency of drinking for given animals was variable (Fig.7). In any 2 hour period on a given day there was considerable variation between the frequency of drinking of the individual cattle in one pen (Fig.7). Fig.9 details an example of the cumulative consumption (litres/group of 4 animals) and litres consumed per group of 4 animals per hour. It can be noted that although drinking activity occurs during the night the majority of water is consumed during day-light hours.

Competition for LL at the ball licker was quite high. However, there was no set pattern of intake. LL intake was largely governed by the pecking order in the group. Usually the strongest amongst the animals obtained and kept access until satisfied. The LL was generally consumed within 2 hours. Fig.10 details the total number of frames that each animal was recorded as licking/day for different groups and days. The frequency of visits by individual animals to the ball-licker varies from day to day. Demonstrating that although on each day the same amount of LL was available the LL was consumed in less total licks on one day than another.

Fig.11 details the daily maximum and minimum temperatures for each period.

Discussion.

Palatability problems occurred with the barley/LS cube dietary treatment. A large proportion (63%) of the animals left residues and the animals consumed the barley/LS cubes more slowly. With the small amount of cereals given, to supply 100 g LS/head/day means that the LS addition in the barley is as much as 6.6%. At this high concentration

Fig.7. Expt 2.6. The total number of visits to the water trough undertaken by individual animals over two consecutive days. The shaded area represents the number of visits that the animal was recorded as positively drinking from the trough.

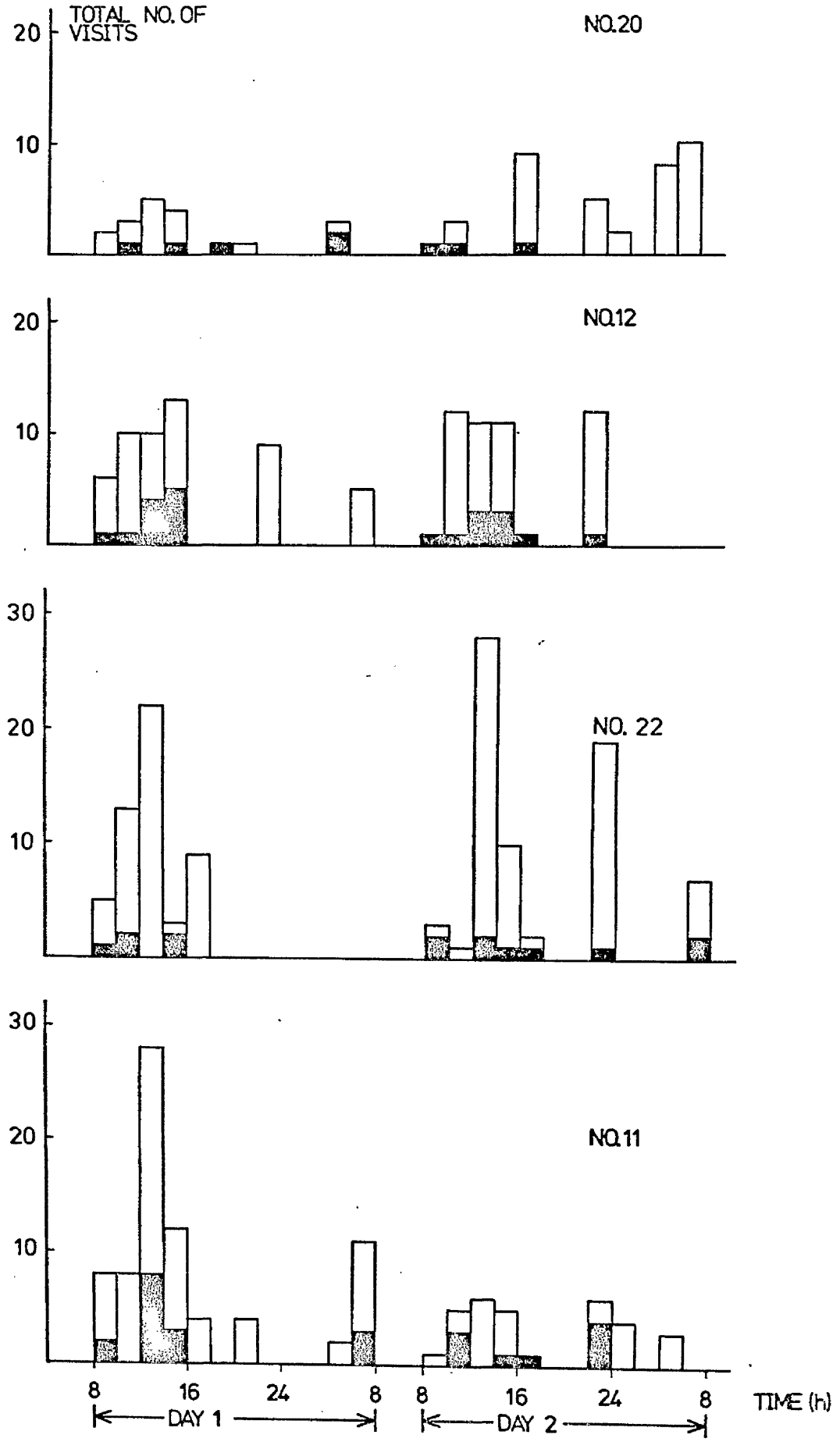

TOTAL NO. OF VISITS
NO.20
NO.12
NO. 22
NO.11
20
10
30
8
16
24
DAY 1
DAY 2
TIME (h)

Fig.8. Expt 2.6. The mean total number of visits/group of four cattle to the water trough over two consecutive days. The shaded area represents the mean number of visits that the group was recorded as positively drinking from the trough.

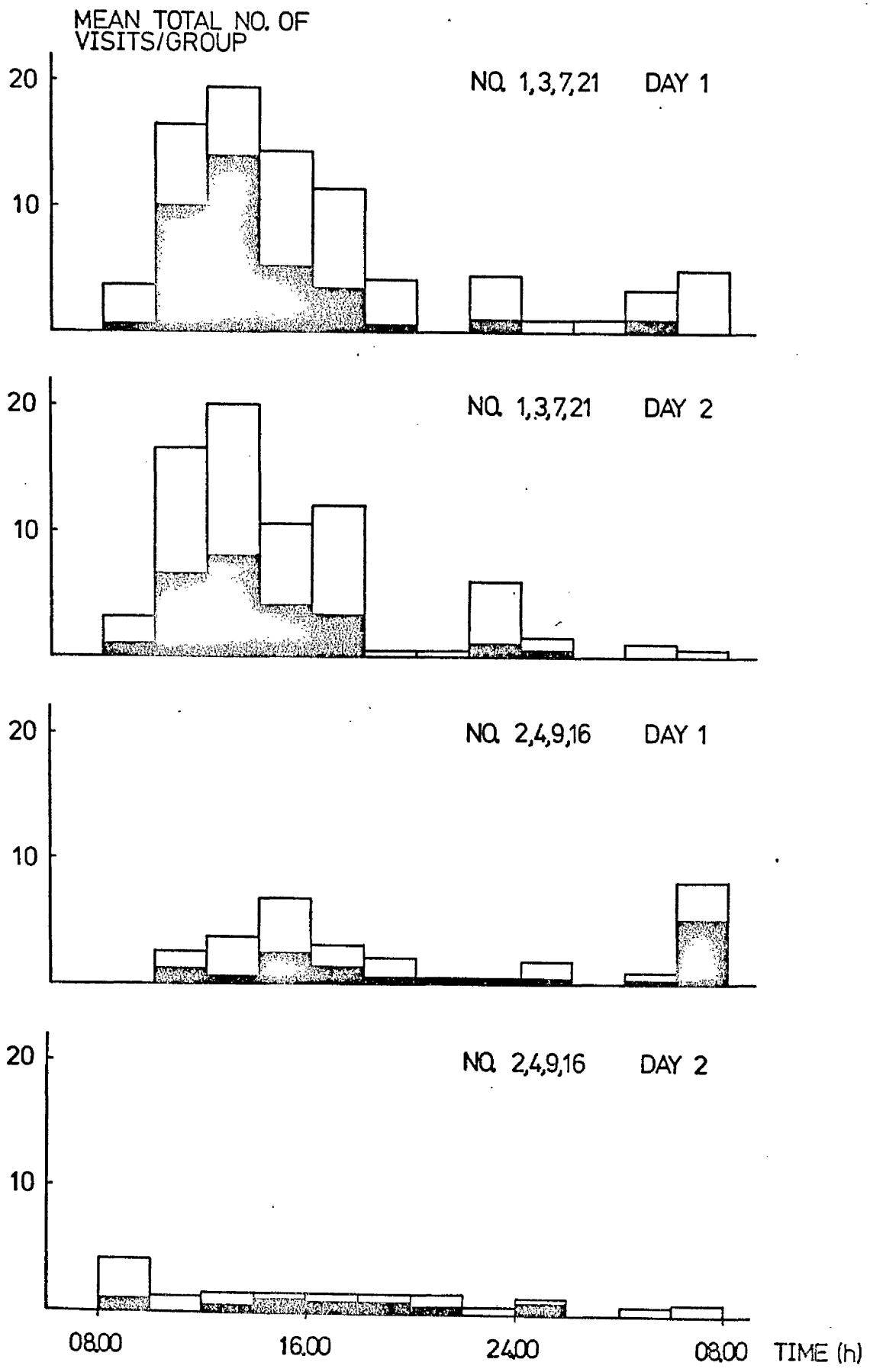

MEAN TOTAL NO. OF VISITS/GROUP
20
10
NO. 1,3,7,21 DAY 1
20
10
NO. 1,3,7,21 DAY 2
20
10
NO. 2,4,9,16 DAY 1
20
10
NO. 2,4,9,16 DAY 2
08.00
16.00
24.00
08.00
TIME (h)

Fig.9. Expt 2.6. The pattern of water intake during the day (litres/pen/h and litres/pen) (4 animals/pen).

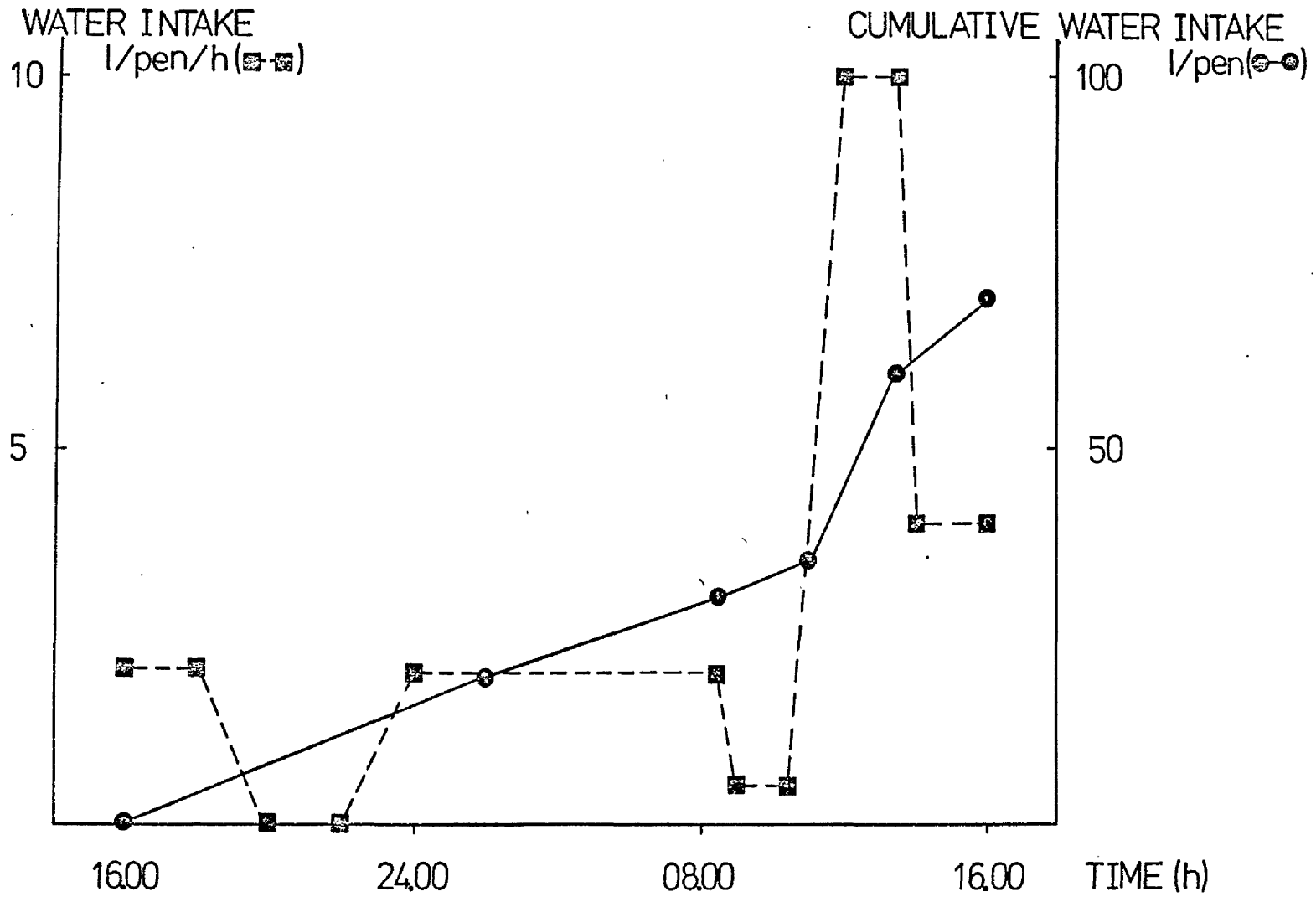

WATER INTAKE
l/pen/h
10
5
CUMULATIVE WATER INTAKE
l/pen
100
50
16.00
24.00
08.00
16.00
TIME (h)

Fig.10. Expt 2.6. Frequency of visits by individual animals to the ball-licker (no. of frames licking).

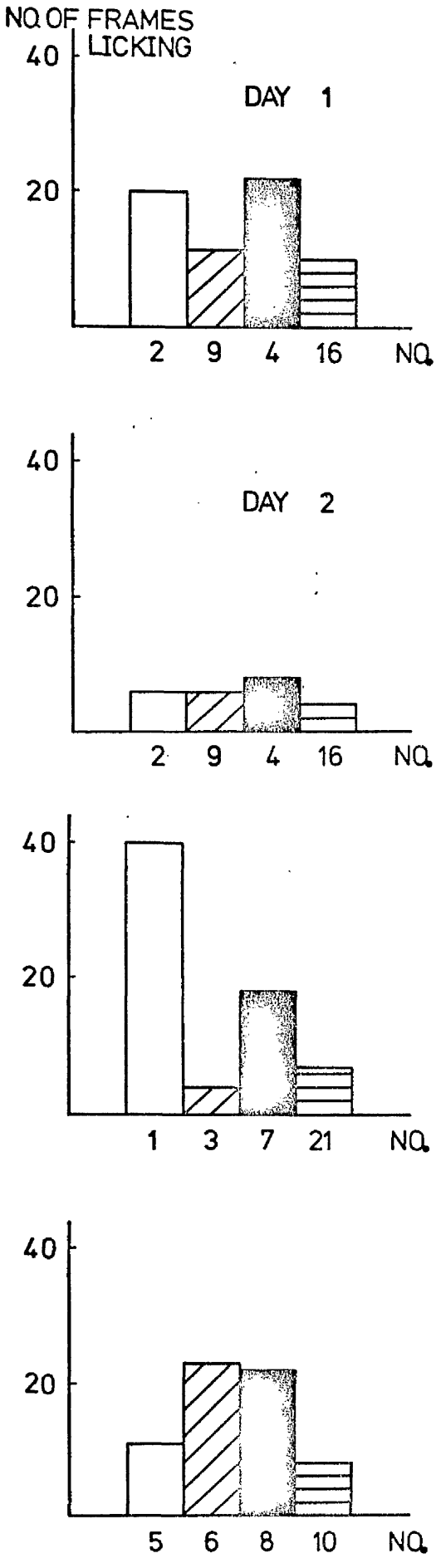
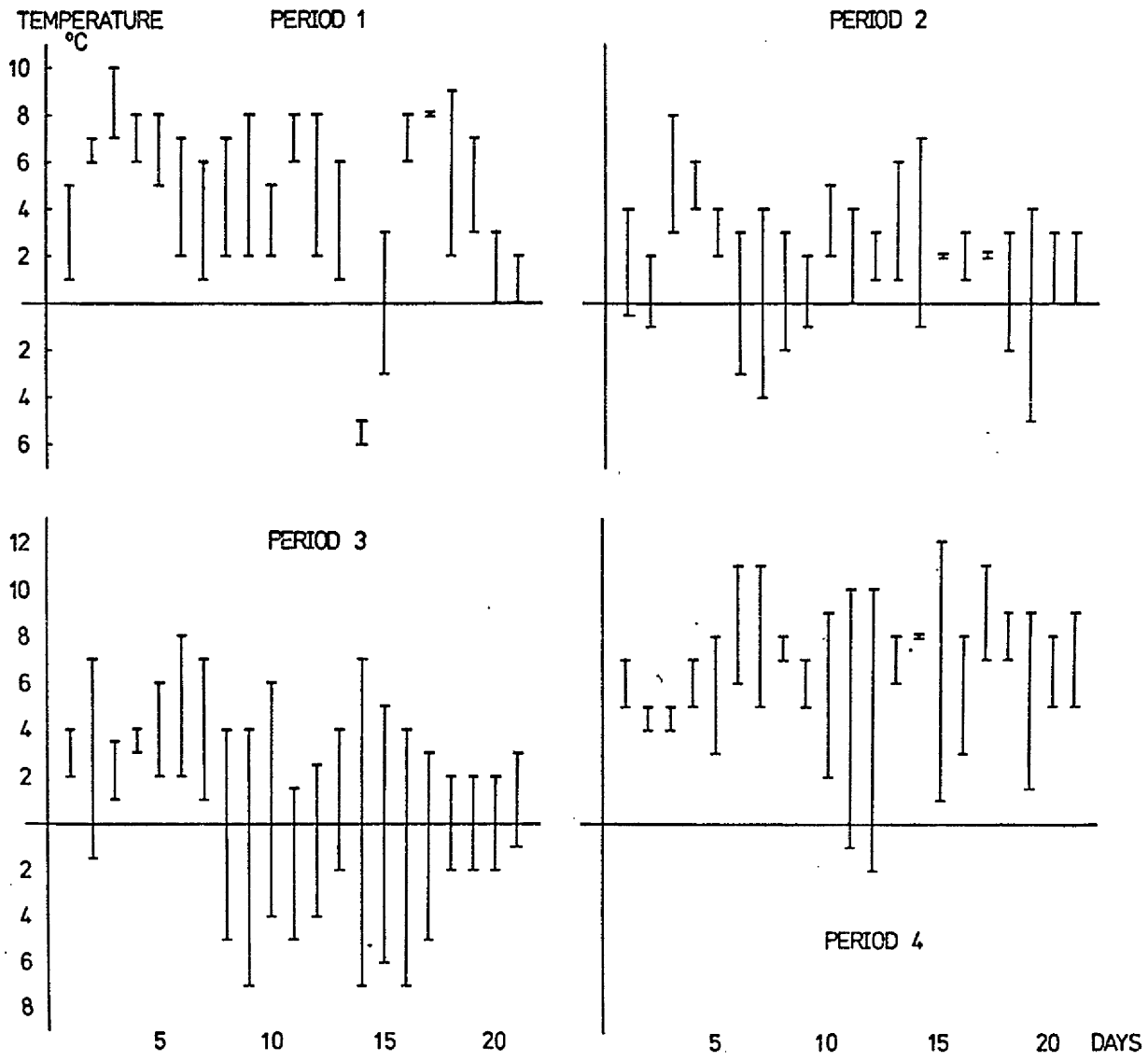

NO OF FRAMES LICKING
40
20
DAY 1
2 9 4 16 NO.
40
20
DAY 2
2 9 4 16 NO.
40
20
1 3 7 21 NO.
40
20
5 6 8 10 NO.

Fig.11. Expt 2.6. Daily temperature variation for periods 1, 2, 3 and 4 expressed as maximum and minimum temperature (^{o}C).


TEMPERATURE
°C
PERIOD 1
PERIOD 2
PERIOD 3
PERIOD 4
10
8
6
4
2
2
4
6
12
10
8
6
4
2
2
4
6
8
5
10
15
20
5
10
15
20
DAYS

it appears that the barley/LS cube is less palatable than a straight barley cube. One advantage of applying LS to the barley at grinding and subsequently cubing the mixture is that it produced a firm cube which stored well. However, the effect of LS in reducing the rate of consumption may be an advantage in other production systems where much more cereal is provided. It could reduce the hazards of rapid over-eating.

All methods of supplementation were equally effective for these small groups kept indoors in small pens. From the results of straw intake it can be seen that it was necessary in this trial to have a run-in period of 14 days before differences between treatments could be recognised. When analysing the data between days 15-21, the dietary treatment LL was not significantly better than the nil treatment. However, when days 8-21 are considered the straw intake with the LL treatment became significantly greater for the nil treatment. This occurred because the nil treatment intake was lower and the LL treatment was higher for days 8-14 compared with days 15-21.

It was anticipated that a reduced individual faecal chromium content might imply that an individual animal was eating more straw. However, both the mean faecal chromium concentrations and the coefficients of variation were similar for each treatment and thus no conclusions can be drawn from the data. It can, however, be inferred that the lower coefficient of variation (8·8) of faecal chromium for the LS in the water treatment may indicate that the animals in the group had a more uniform intake of LS. The coefficient of variation for the LL treatment was slightly higher than for the nil treatment. It may therefore be inferred that the LL treatment gave a less uniform intake. For blood urea, the mean values for all the supplemented diets were significantly higher than the nil treatment. The coefficients of variation were similar for blood urea concentrations, therefore no relationship can be drawn between the

urea and chromium concentrations (i.e. high blood urea concentration did not correlate with low chromium). Due to ease of handling the blood samples were taken preprandial. If however, they had been taken at 12.00h when most of the animals had consumed all or some LS supplement the results may have been different.

The results of the time lapse photography showed that calves kept indoors on high straw diets do not have a set pattern of drinking. On a group basis daily water intake was constant at approximately 60 litres/day. Temperature had no effect on water intake. Period 3 was markedly colder (Fig.11, the mean minimum temperatures for Periods 1,2,3 and 4 were + 1·0, + 0·0, - 2·2 and + 4·1 respectively) than the other periods yet intake remained relatively constant, this contradicts the work of Bailey, Hironaka and Slen (1962) and Cunningham, Martz and Merilan (1964). Their data indicated that a reduction in environmental temperature reduced water intake.

The cattle did however, when drinking remain at the trough for quite a period of time. Part of this time was spent drinking and part apparently playing with the water. Their behaviour would probably be quite different if fed at a set time of the day or if they were not housed.

The drinking habits of various ruminant species have been investigated, to only a limited extent. Castle, Foot and Halley (1950) observed that when water was readily available to dairy cows, they usually drank from 2-7 X/day with an average of 3·8 X/day. However, the observations of numerous investigators indicate that confined cattle tend to drink frequently if water is readily available (Church, 1979). Bond, Rumsey and Weinland (1976) found that confined steers on different types of diets spent 60-65% of the total daily time at the water between 06.00 and 18.00 h.

Although supplementation of LS by the molasses/water mixture increased the straw intake, the design of the experiment portrayed an artificial

situation under the housing conditions that the animals were kept. This was not comparable to the stiuation where a ball-licker is positioned in a field. In the experiment the four animals in each group could share 2 balls to lick and were always in close proximity to the licker. They obviously also noticed the LL being replenished each morning. These conditions are totally artificial and in a field situation not all the animals would obtain any supplement, especially if a restricted amount was supplied daily. However, this experiment does show that if animals do consume LL it can increase straw intake.

Experiment 2.7. Comparison between LS given in the drinking water and as LL on the voluntary intake of oat straw by groups of lactating beef cows and yearling beef cattle.

Introduction.

In Expt 2.6 LL supplementation increased straw intake between days 15 and 21 by an amount which just failed to be significant whereas LS given in the water significantly increased straw intake. This present experiment was designed to compare the two methods of giving LS to two classes of animal, lactating beef cows (suckling single calves) and yearling beef cattle.

Materials and methods.

The same sixteen beef cattle were housed in the same four groups of four animals as for Expt 2.6. Their mean live weight was 262 kg at the beginning of the experiment. Twelve lactating beef cows (principally Hereford cross mean live weight 470 kg) with their twelve suckling calves of mean live weight 53 kg were housed on a group basis in two balanced groups each of six cows and their calves. Both types of cattle had previously been given diets high in straw, hence the initial acclimatization period to the new diet was relatively short (7 days).

There were two dietary treatments for both cows and beef cattle (dietary treatments replicated). Over successive 21-day feeding periods (using a crossover design) LS was given either in the drinking water or as LL presented to the cattle in a ball-licker at 08.00 h after their feed of barley. The barley was gound and cubed and given as follows:-

Yearling cattle 1·5 kg/head barley given in individual locking feeders.

Lactating cows 3·0 kg/head barley given as a group in a trough with ample feeding space.

The amounts of LS provided were:-

	Amount (g/day/animal)	Total water/group(litres)		LL/group(kg)
4 yearling cattle	100	60	(0·67% LS)	1·2
6 lactating cows	250	250	(0·60% LS)	4·5

Oat straw was given ad libitum on a group basis, being replenished in the ring feeders at 08.00 and 16.00 h for the cattle and at 08.00, 12.00 and 16.00 h for the cows.

In a preliminary period it was found that a group of 6 lactating beef cattle consistently consumed about 250 litres/day of water. On this basis LS was offered at 1·5 kg in 250 litres to the group of 6 cows/day and 400 g in 60 litres to the group of 4 cattle/day. If at any time the trough was emptied fresh water was made available for the rest of the day.

Time lapse photography was used to examine the pattern of water intake and consumption of LL. To supplement the data obtained from the time lapse photography water intake was recorded during the day by means of a calibrated dip stick and the time when the LL was totally consumed was also recorded.

The two feeding periods were each of 21 days and straw intake was recorded between days 15-21. Blood samples were taken from the jugular vein on day 21 of each period (10.00 h) and analysed for blood urea.

The animals were weighed at the beginning and end of the experiment.

Samples of the oat straw and barley cubes were taken daily over days 15-21 and analysed for DM, crude protein, crude fibre, ether extract, ash, calcium and phosphorus. Samples of LS were analysed for crude protein, calcium, phosphorus and pH. The results of analyses are presented in Table 30.

Table 30. Expt 2.7. The mean compositions of oat straw, barley cubes (g/kgDM), LS and molasses (g/kg FM).

	Oat straw	Barley cubes	LS	Molasses
Dry matter	806	843	-	-
Crude protein	15	105	1076	62
Crude fibre	438	32	-	-
Ether extract	8	9	-	-
N-free extract	482	821	-	-
Ash	57	33	-	-
Ca	2·8	1·2	27·7	6·1
P	0·6	3·4	16·0	0·5
pH	-	-	1·5	5·2

Results.

Over the 6 weeks of the experiment the mean live weight of the 16 yearling cattle increased from 262 to 277 kg. The mean live weight of the suckling calves increased from 53 to 87 kg (a mean daily gain of 0·8 kg) and the lactating cows decreased from 470 to 426 kg (a loss of 1 kg/day). All these weight changes were considered to be appropriate to the diets given. The barley cubes were readily and completely consumed by both the yearling cattle and the cows. Although the cows were group fed, the troughs were sufficiently long to allow all 6 cows to feed at once and their appetite was such that the feed was cleaned up in 10 min by all cows.

At the change-over no difficulties occurred with adaptation to the new dietary treatments.

The voluntary straw intakes of the cows and yearling cattle and mean blood urea concentrations are presented in Table 31.

Table 31. Expt 2.7. The mean voluntary straw intake (kg DM/day) and blood urea concentration (mmol/litre).

Treatment	A LS in water	B LL	SE of Mean and SED	Significance
Straw intake				
Yearling cattle	3·74	3·74		
Cows	7·55	7·31		
Mean of both groups	5·01	4·93	0·269	NS
Blood urea (10.00 h)				
Yearling cattle	1·7	1·3	0·14	A > B*
SD	0·58	0·40		
CV%	34·1	30·8		
Cows	1·4	1·1	0·18	NS
SD	0·40	0·31		
CV%	28·6	28·2		

There was no difference in voluntary straw intakes resulting from the different methods of LS presentation. The blood urea concentrations were equally variable for both treatment diets (CV c. 30%). The blood urea concentrations for the yearling cattle were significantly higher when they received LS in the water than when given as LL. The data obtained from the time lapse photography was comparable with that for Expt 2.6. Due to the vast amount of information produced from the time lapse photography studies for this present experiment and Expt 2.6, no figures are presented for this present experiment, but a general conclusion will be given in the discussion.

Discussion.

The performance of both the cows and the yearling cattle was satisfactory. There was no difference between treatments, both LS in the water and LL produced similar voluntary straw intakes and mean blood urea concentrations.

A striking difference in the drinking behaviour between the yearling cattle and the cows was recorded. While a yearling animal would "play" around when drinking this was not the case with the cows. When a cow drank it took one long gulp and then left the trough. An example to illustrate this is that on examining one film in two consecutive frames, the first frame showed the trough and water and the second the trough with the water level about 10 cm lower, indicating that between the frames (65 s) a cow had been and consumed a very large amount of water. In contrast, when a yearling animal was recorded at the trough it could have been present in up to 10 consecutive frames although not necessarily positively drinking. However, a cow was never seen for more than 2 consecutive frames and 9 times out of 10 was obviously positively drinking.

Experiment 2.8. The effect of method of provision of LS on the voluntary intake of oat straw by 240 kg Hereford cross cattle.

Introduction.

In Expt 2.6 three methods of presenting LS were investigated, (i) in a barley cube, (ii) in the drinking water and (iii) as LL. Expt 2.6 had shown that LS in the water and LL were satisfactory methods of giving LS. However, although LS in the barley increased voluntary straw consumption, palatability problems occurred. It was decided to repeat the former two methods and to investigate applying LS onto the straw.

The objective of Expt 2.8 was to examine the effect of giving LS either (i) in the drinking water or (ii) as LL or (iii) on the straw on the voluntary intake of oat straw. LS was provided at the rate of 100 g/head/day to housed 240 kg beef cross cattle being over-wintered with a minimum quantity of cereals and a maximum amount of straw.

Materials and methods.

Sixteen beef cattle (8 heifers and 8 steers), principally Hereford cross of mean live weight 243 kg and mean body condition score 2·1 (Lowman et al., 1973) were housed on a group basis. Following an initial acclimatization period of 14 days when the cattle were given oat straw ad libitum and barley in amounts gradually increasing to 1·5 kg of barley/head/day, the cattle were arranged into four balanced groups each of four animals on a basis of live weight, body condition and sex. The groups formed a 4 x 4 Latin square.

There were four dietary treatments

(A) 1·5 kg barley - no supplement

(B) 1·5 kg barley plus LS on the straw (400 g LS/day poured onto the straw when in the racks with a small watering can. About half being applied at 8.00 h and the rest at 16.00 h).

(C) 1·5 kg barley plus LS in the drinking water, available all day (400 g LS in 60 litres water).

(D) 1·4 kg barley plus 1·2 kg LL/group of cattle in a ball-licker (2 balls) given as the cattle finished consuming the barley concentrates at 08.00 h.

The barley was ground and cubed and included 10 g chromic oxide each day. The concentrate ration was given individually to all the cattle in locking feeders at 07.30 h.

Diets B,C and D gave the cattle a possible daily allocation of 100 g LS/head. The animals on diet D were given 0·1 kg less barley cubes to compensate for the energy obtained from the molasses in the LL.

Oat straw was given ad libitum on a group basis, being replenished in the racks twice daily (08.00 and 16.00 h).

In the preliminary period it was found that a group of four cattle consistently consumed about 60 litres water/day. On this basis LS was offered at 400 g LS in 60 litres to the group/day. If at any time the trough was emptied, fresh water was made available for the rest of the day. This ensured that their water intake (and in turn their voluntary straw intake) was not restricted. On one day in each week the cattle were given only 40 litres of water to ensure that all the LS water mixture was consumed. This ensured that a residual amount of LS did not build up in the trough. On these days, after the LS/water mixture had been entirely consumed, fresh water was made available.

The four feeding periods were each of 21 days and straw intake was recorded separately for days 8-14 and days 15-21. Blood samples were taken at 12.00 h from the jugular vein on day 21 of each period and analysed for urea.

Rectal grab samples of faeces were taken once daily over days 15-21 of each period for chromium determination.

The animals were weighed and their body condition was assessed at the start, and end of the experiment.

Samples of oat straw and barley cubes were taken daily over days 8-21 and analysed for DM, crude protein, crude fibre, ether extract, ash, calcium, phosphorus and chromium. Samples of LS and molasses were analysed for crude protein, calcium, phosphorus, and pH (Table 32).

Table 32. Expt 2.8. The mean compositions of oat straw, barley cubes (g/kg DM), LS and molasses (g/kg FM).

	Oat straw	Barley cubes	LS	Molasses
Dry matter	821	844	-	-
Crude protein	19	104	1088	33
Crude fibre	504	53	-	-
Ether extract	8	7	-	-
N-free extract	427	803	-	-
Ash	42	33	-	-
Ca	2·1	1·0	24·8	5·5
P	0·7	1·8	17·9	0·7
pH	-	-	1·5	5·0

Results.

Over the total 84 days of the experiment the mean live weight of the cattle changed from 243 kg to 247 kg, and the mean body condition score from 2.1 to 1.8.

The barley cubes were readily and completely consumed.

The data for voluntary straw intake has been analysed in three ways; between days 8-14, 15-21 and 8-21 of each period (Table 33). The mean voluntary intake of straw was very similar for days 8-14, 15-21, 8-21 and between treatments.

Blood urea concentrations (Table 33) were all higher on treatments with LS added. Giving LS in the drinking water or as LL significantly

increased blood urea concentrations (3·89 and 3·33 mmol/litre respectively) compared with the unsupplemented treatment (1·10 mmol/litre). Application of LS to the straw gave an intermediate blood urea concentration (2·71 mmol/litre).

Faecal chromium concentrations were similar for each treatment (Table 33). A reduction in the faecal content of chromium might imply that an individual animal in a group was eating more straw. This in turn may be correlated to its blood urea concentration, indicating a less than normal consumption of LS. The faecal chromium concentration was slightly lower when LL was given due to the lower chromic oxide intake, as the animals given this diet were given 0·1 kg less barley chromic oxide cubes to compensate for the energy obtained from the molasses. However, the faecal chromium concentration for the LL is in proportion to the other treatments being 61% of the total chromium given while the mean of the other treatments was 62%.

Table 33. Expt 2.8. Voluntary straw intake (kg DM/day), mean blood urea (mmol/litre) and faecal chromium concentrations (g/kg DM).

Treatment	A Nil	B LS on straw	C LS in water	D LL	SEM	Significance
Straw intake						
Days 8-14	2·10	2·18	2·19	2·18	0·195	NS
Days 15-21	2·35	2·37	2·22	2·38	0·345	NS
Days 8-21	2·23	2·28	2·16	2·28	0·139	NS
Blood urea	1·10	2.71	3·89	3·33	0·472	C>A**;D>A*
Faecal chromium	3·75	3·84	3·94	3·44^{+}		
CV%	13·6	12·8	18·6	16·8		

$^{+}$The faecal chromium concentration was slightly lower when LL was given due to the lower chromic oxide intake, as when the animals were on this

diet they were given 0·1 kg less barley chromic oxide cubes to compensate for the energy obtained from the molasses.

Discussion.

The apparently similar coefficients of variation around the mean chromium concentrations further imply that the straw intakes for all animals on whichever treatment were similar. The blood urea concentrations on treatments with LS added were all higher, but not significantly so for LS given on the straw. It must be noted that the blood samples were taken at 12.00 h and that the cattle would have consumed the whole daily supply of LS given in the molasses, but not all that given/day in the water or on the straw. The apparently similar mean coefficients of variation for the blood urea concentrations would seem to indicate that none of the three methods of giving LS resulted in a greater variation in individual intake.

None of the methods of supplying LS to these animals affected the voluntary intake of straw. The crude protein content of the oat straw was 19 g/kg DM (as in Expt 2.6 where increases in voluntary intakes were recorded). The overall crude protein content of the diet without LS supplementation would be about 43 g/kg DM and thus there might have been an expected increase in straw consumption.

Both the cattle in Expt 2.6 and this experiment were the same age (9 months) and had comparable weights (mean 260 kg for Expt 2.6 and a mean 240 kg for this experiment). However the mean voluntary intake of straw by the calves in this experiment was 2·33 kg/day (recorded between days 15-21) which was lower than the nil treatment intake for Expt 2.6 (2·9 kg/day recorded between days 15-21). The overall mean intake of straw on this experiment was 27% lower than that for Expt 2.6 (3·19 kg/day) when considering days 15-21. It could therefore be assumed that the maximum appetite of the cattle was already fulfilled and no amount of NPN supplementation would be able to increase intake, or that some other factor was restricting straw consumption.

Experiment 2.9. An assessment of the effect of method of provision of LS on the voluntary intake and digestibility of oat straw by suckler cows in pregnancy.

Introduction.

The results obtained in Expts 2.6 and 2.8 were inconsistent. It was therefore decided to investigate individually fed animals as opposed to a group-fed situation. The objective of this present experiment was to examine the effect of giving LS (i) in the drinking water (ii) on the straw (iii) as LL in comparison with soya bean meal on the voluntary intake and digestibility of oat straw by suckler cows in late pregnancy. LS was given at the rate of 250 g/head/day.

Materials and methods.

Ten pregnant beef cows, principally Hereford cross of mean live weight 500 kg and mean body condition score 2·7 (Lowman, et al., 1973) were individually housed in a byre. The cows were on average 18 weeks from calving at the onset of the experiment. Following an initial acclimatization period of 2 weeks when the cows were given oat straw ad libitum and 2 kg barley cubes, the cows were arranged into two groups each of five animals according to live weight, body condition score and expected calving date. Each group formed a separate 5 x 5 Latin square, each treatment being given in appropriate sequence for 21-day periods (105 days in total).

Four of the five dietary treatments contained nitrogen supplements such that each provided about equivalent amounts of crude protein and ME.

Each treatment received ad libitum oat straw which was replenished three times a day 8.00, 12.00 and 15.00 h, and one of the five dietary treatments.

Dietary treatments.

A. 2·0 kg barley cubes.

B. 2·0 kg barley cubes + 250 g LS sprinkled on the straw.

C. 2·0 kg barley cubes + 250 g LS in the drinking water.

D. 1·7 barley cubes + 750 g LL. (the molasses/water lick was calculated to supply the same energy as 0·3 kg barley cubes).

E. 1·2 kg barley cubes and 0·8 kg soya bean meal (supplying the same energy as 2·0 barley cubes).

The concentrates were given at 07.30 h.

For diet B half the LS was applied to the straw at the time of feeding (The straw allocation was placed in a dustbin and the LS was poured over it from a small watering can. It was then allowed to stand for 5 min to allow the LS to percolate through the straw) at 08.00 h and the other half at 12.00 h. This ensured that straw residues (which were largely derived from the further untreated straw given at the 16.00 h feed) did not contain LS.

For diet C, the water bowl of each appropriate animal was turned off and LS in the water was offered in buckets (wedged into the feeding trough to prevent spillage). Prior to this present experiment it was found that a cow in late pregnancy would drink at least 25 litres of water per day when given similar high straw diets. In this experimental situation it was imperative that all the LS in the water was consumed. Therefore the LS supplement was offered in the first 20 litres of water provided to the cow. This gave a LS concentration of 1·25% and in accordance with Expts 2.4 and 2.5 this concentration should have been palatable. The water in the buckets was replenished (as required) four times a day and when all the LS water had been consumed, the cows were allowed ad libitum water.

For diet D the LL was given at the same time as the concentrate in the trough, i.e. it was poured over the concentrates (It would have been

consumed rapidly in any event). Different amounts of barley were fed in diets D and E in order that all the dietary treatments had the same ME as 2 kg of barley plus 250 g LS. The ME of barley and soya were assumed to be the same.

Chromic oxide (15 g) was included in the cubed barley concentrates throughout the whole 105 days of the experiment.

Straw intake was measured in the last 7 days of each 21-day period. Straw residues were collected once daily. This procedure allows for a low error when using this experimental design. For example Fishwick et al. (1974) measured straw consumption on the last 7 days of each 21 day period and achieved a satisfactory low error (SE of mean 0·115) for a similar type of experiment, but using two 4 x 4 Latin squares.

During the last 6 days of each period when straw consumption was being measured, rectal grab samples of faeces were obtained from each cow at three times during the day (07.30, 11.30 and 16.00 h). These samples of faeces were bulked during the collection week for dry matter, nitrogen, crude fibre, ether extract, ash and chromium analyses. The results of the analyses were used to calculate the digestibility of the diets.

A water meter was fitted below the header tank in the byre to record the water intake of the eight (of the total of ten cows) drinking fresh water. The water consumed when the cows were given diet C (LS in water, provided in buckets) was also recorded.

On day 21 of each period blood samples were taken at 10.00 h from the jugular vein, and analysed for Ca, P and urea.

The cows were weighed and body condition scored at the start and the end of the experiment.

Samples of oat straw, soya bean meal and barley cubes were taken daily over each collection period, bulked and analysed for DM, crude protein, crude fibre, ether extract, ash, calcium and phosphorus. In addition, the barley cube was analysed for chromium content. Samples of

LS and molasses were analysed for crude protein, calcium, phosphorus and pH. The results of analyses are presented in Table 34.

Table 34. Expt 2.9. The mean compositions of oat straw, soya bean meal, barley cubes (g/kg DM), LS and molasses (g/kg FM).

	Oat straw	Soya bean meal	Barley cubes	LS	Molasses
Dry matter	831	840	836	-	-
Crude protein	36	503	108	1057	30
Crude fibre	469	75	48	-	-
Ether extract	6	14	7	-	-
N-free extract	451	338	805	-	-
Ash	38	70	32	-	-
Ca	2·7	3·7	1·1	28·3	6·4
P	0·7	7·3	2·8	17·3	0·4
pH	-	-	-	1·7	5·3

Results.

Over the 15 weeks of the experiment the mean live weight of the cows decreased from 500 to 491 kg and the mean body condition score from 2·7 to 1·5. The concentrates and the straw were readily consumed by all the cows. At each change of diet the cows given the LS in the water took 3-4 days to become accustomed to the LS-containing water. One cow of the 10 took 4 days before it would consume all the soya bean meal in the soya bean meal/barley mixture.

The voluntary intake of straw, digestibility coefficients and blood parameters are presented in Table 35.

Table 35. Expt 2.9. The mean voluntary straw intake (kg DM/day), blood parameters (mmol/litre) and digestibility coefficients of the cows.

Treatment						
A Nil	B LS on straw	C LS in water	D LL	E Soya bean meal	SE of mean	Significance
Straw intake						
4·66	5·09	4·42	5·21	5·77	0·189	D>A*;E>A*;B>C*; D>C**;E>C***
Digestibility coefficients						
Total diet DM						
0·598	0·599	0·608	0·588	0·586	0·0136	NS
Total diet OM						
0·617	0·610	0·616	0·598	0·607	0·0245	NS
Straw alone OM						
0·531	0·512	0·517	0·510	0·535	0·0250	NS
Total diet N						
0·812	0·837	0·853	0·815	0·831	0·0150	NS
Total diet CF						
0·814	0·817	0·824	0·814	0·820	0·0164	NS
Blood urea						
2·87	5·35	7·26	5·83	5·06	0·445	B,C,D>A***;E>A**; C>D*;C>B,E**
Blood phosphorus						
2·04	2.09	1·92	1·89	2·00	0.070	NS
Blood calcium						
2·58	2·47	2·52	2·50	2·52	0·033	A>B*

Supplementation with soya bean meal had the largest and most significant effect on increasing voluntary straw consumption (+ 1·11 kg DM/day). LL also had a large and significant effect, intake being 0·55 kg DM/day higher than that of the nil treatment. However, although LS given on the straw increased the voluntary straw intake by 0·43 kg DM/day, this was not significant. The inclusion of LS in the drinking water marginally depressed straw intake (- 0·24 kg DM/day). The straw intake when the cows were given LS in the water was significantly lower than for all the other supplemented diets.

None of the treatments affected any of the digestibility parameters.

All the sources of supplementary nitrogen gave significantly higher concentrations of urea in the blood than were recorded when the unsupplemented diet was given. Both the calcium and phosphorus concentrations in the blood were satisfactory throughout the period of the experiment. The blood calcium concentration when the cows were given LS on the straw was significantly lower than ($P < 0·05$) for the nil treatment. There was no obvious explanation for this result and it may be entirely fortuitous.

Discussion.

Supplementation with soya and LL significantly increased the voluntary intake of straw (by 23·8 and 11·8%) while LS on the straw (increase of 9·2%) just failed to significantly increase (LSD = 0·55 at $P < 0·05$) intake. However, LS given in the drinking water did not increase straw intake. One suggestion might be that the water intake was restricted when LS was included, as the LS/water was given to the cows in buckets for that feeding treatment only. From the data obtained from the water meter, it was found that each cow when given LS in the water consistently drank above the mean water intake of the rest of the eight cows (28·0 compared with 24·4 litres/cow/day for the first 3 feeding

periods (After this the meter was broken by frost)). Accordingly limitation of water intake would not seem to be the explanation. The protein content of the oat straw (36 g/kg) was considerably higher than that which had been used in a whole series of previous experiments (c. 22 g/kg) (Hemingway, personal communication). The percentage increases in straw intake above the nil treatment were in the same order as has previously been recorded for the same cows given similar diets. Generally increases in the order of 10-15% have been found (Hemingway, Fishwick and Parkins, personal communication) with these same animals in previous NPN supplementation experiments. The increase of 23·8% with the soya treatment is larger than has been normally found. It was therefore decided to measure the rumen degradability of the protein in the soya bean meal.

One factor determining protein utilization in the rumen is the extent of rumen degradation. In the past, work has suggested that protein supplements are almost completely degraded in the rumen (e.g. Hogan and Weston, 1967). However, it has now become accepted that protein supplements are only partly degraded in the rumen (Miller, 1973). Amino acids are absorbed from the small intestine. They originate from two sources, microbial protein and undegraded dietary protein. It is important to determine both the requirement of the ruminant animal for protein and the requirement of the rumen microbial population for nitrogen (Roy, Balch, Miller, Ørskov and Smith, 1977).

In the past the use of digestible crude protein for formulating rations for ruminants has been the normal. It is now being superceeded due to the above limitations. In the last few years different schemes have been proposed for estimating the amount of degradable protein in ruminant diets (Burroughs, Trenkle and Vetter, 1972; Burroughs, Nelson and Mertens, 1975a,b; Satter and Roffler, 1975; Roy et al., 1977).

Several factors influence the extent to which dietary protein is degraded in the rumen. These include protein solubility, and rations containing a high proportion of soluble protein tend to be readily degraded. Protein solubility is governed by the particle size and density of the feed, the structure of the plant cell wall and whether the feed has been treated with heat or chemical substances. It will be affected by residence time in the reticulorumen, which in turn is influenced by feed intake and the physical features of the ingested food. It is for these reasons that in vivo protein degradability can be very variable. This can be further complicated as the yield of rumen microbial protein/unit of fermented organic matter can itself be variable (Kennedy, Christopherson and Milligan, 1976). Rumen retention time is probably the most important single factor in influencing the extent of rumen degradation. Ørskov and Fraser (1973) showed that with a low level of feeding (below maintenance energy level) protein from soya bean meal appeared to be completely degraded, while with a high level of feeding (more than twice the maintenance energy level) the degradation appeared to be only in the region of 40%.

The methods available for estimating microbial degradation of protein have been discussed by Satter (1978).

The method used in this experiment for estimating the protein degradability of the soya bean meal was the nylon bag technique. (Mehrez and Ørskov, 1977). Four cows fitted with rumen fistula were given a basal diet of 2 kg barley plus oat straw ad libitum. The mean rumen degradability of the protein in the soya bean meal measured over a period of 24 h was 0·75. This figure was in agreement with various workers although slightly lower e.g. Mathers, Horton and Miller (1976) estimated the rumen degradability of the protein in soya bean meal to be 0.95, measured over a period of 24 h using ruminally cannulated sheep given 840 g/day grass nuts. As already discussed Ørskov and Fraser (1973) found

that with low protein diets that soya bean meal appeared to be completely degraded.

LS supplementation appeared to result in higher concentrations of blood urea than did the soya addition. Blood samples were taken at 10.00 h following the giving of concentrates at 07.30 h. The cows given the LL treatment would have consumed all the LS supplement by 10.00 h. However, when given LS in the water or on straw the cows would only have been able to consume up to one-half the full daily LS allocation. Even so the cows when given LS in the water treatment had significantly higher blood urea concentrations, than when given all the other treatments. The blood urea concentrations when the cows were given the soya treatment may be expected to rise throughout the day.

Experiment 2.10. An assessment of the effect of method of presentation of LS on the voluntary intake and digestibility of oat straw by non-productive Ayrshire cows fitted with a rumen fistula.

Introduction.

In the previous experiment (Expt 2.9) it was found that the voluntary straw intake for suckler cows in pregnancy when supplemented with LS in the water was significantly lower than for other methods of supplementation. This had not been the case for Expts 2.6, 2.7 and 2.8 which used 250 kg cattle and lactating beef cows. Having established that the water intake of the cows was not restricted by the water containing LS presented in a bucket regime, it was decided to examine the effect of presenting LS to cows fitted with a rumen fistula either in their drinking water or directly through the fistula and to examine the effects on voluntary straw intake, digestibility and rumen parameters. LS supplementation given directly into the rumen was investigated because LS in the water may have stimulated oesphageal groove closure and therefore the LS/water may have by-passed the rumen.

Materials and methods.

Four non-productive rumen fistulated Ayrshire cows of mean live weight 587 kg were individually stalled in a byre. The cows formed a 4 x 4 Latin square with each treatment being given in appropriate sequence in 21-day feeding periods (84 days in total). There were four dietary treatments given in addition to ad libitum oat straw and 2 kg cubed barley:

Dietary treatments

A. No supplement.

B. 250 g LS in the drinking water.

C. 250 g LS through the rumen fistula.

D. 250 g LS on the straw.

The straw was replenished in the racks at 08.00, 12.00 and 16.00 h.

The barley cube included chromic oxide (2 kg barley cubes supplied 15 g chromic oxide) and was given at 07.30 h.

When diet B was given the water bowl of the animal was turned off and LS was offered in buckets (as previously described in Expt 2.9). The water in the buckets was replenished 4 times/day and when all the LS-containing water had been consumed the cows were allowed ad libitum fresh water. The LS was given in the first 2 buckets of water offered (~ 10/ litre/bucket) to ensure that the daily allocation of LS was consumed.

For diet C, one half of the daily allocation of LS was poured directly into the rumen through the fistula, at 08.00 h and the other half at 12.00 h.

For diet D, half the LS was poured onto the straw at each feeding time (08.00 and 12.00 h). This ensured that straw residues (which were largely derived from the 16.00 h feed) did not contain residues of LS.

Faecal grab samples were obtained 3 times/day during the last 6 days of each period and bulked for chromium analysis and hence indirect assessment of digestibility. Food samples were taken throughout each collection period and analysed for DM, crude protein, crude fibre, ether extract, ash, calcium and phosphorus (Table 36). In addition the barley cubes were analysed for chromium. Blood and rumen liquor samples were taken on the last day of each period at 07.30, 10.00, 12.00, 14.00, 16.00 and 18.00 h for determination of blood urea and ammonia and rumen ammonia, total nitrogen and pH. The straw intake was recorded for days 14-20 of each period and blood and rumen samples were taken on day 21.

Results.

Over the 12 weeks of the experiment the mean live weight of the cows increased from 587 to 601 kg. The barley and the straw were readily consumed by all the cows.

Table 36. Expt 2.10. The mean compositions of oat straw, barley cubes (g/kg DM) and LS (g/kg FM).

	Oat straw	Barley cubes	LS
Dry matter	799	815	-
Crude protein	25	98	1068
Crude fibre	499	55	-
Ether extract	6	6	-
N-free extract	412	809	-
Ash	58	32	-
Ca	2·2	1·1	31·8
P	0·7	2·9	14·5
pH	-	-	1·6

Supplementation with LS either in the water or directly into the rumen, increased voluntary straw intake significantly compared with the non-supplemented treatment by 22·5 and 19·1% respectively (Table 37). Addition of LS to the straw just failed to increase the intake significantly. The increase was 13·1% but due to one cow having an exceptionally low intake when that treatment was given it reached significance at only $P<0·1$. None of the treatments affected digestibility parameters (Table 37).

The data obtained for the digestibility of the straw OM for each treatment has been used to calculate the apparent ME of the straw DM (ME = 0·15 x DOMD% M.A.F.F. et al., 1975) and from this the amount of ME provided by the actual amounts of straw DM consumed (Table 37). The ME intake from the straw consumed although markedly higher for treatments B and C (43·0 and 40·6) failed to be significantly greater than for the diet without LS supplementation (34·8).

LS supplementation resulted in significantly higher concentrations of urea in the blood (Table 38) compared with the unsupplemented diet

at all times except 07.30 h (where the LS in the water treatment just failed to reach significance).

Rumen ammonia concentrations (Table 39) were higher when the cows were given the supplemented diets at all times of the day, but because of the large variation between animals the concentrations were not always significant. At 16.00 h the rumen ammonia concentration of the animals when given LS via the fistula were significantly higher than for the other treatments.

Rumen pH (Table 39) results did not differ markedly, but giving LS via the fistula had the most effect on increasing rumen pH.

Table 37. Expt 2.10. The mean voluntary straw intake (kg DM/day), digestibility coefficients and ME intake from straw consumed (MJ) of the cows.

Treatment	A Nil	B LS in water	C LS in fistula	D LS on straw	SEM	Significance
Straw intake	4·44	5·34	5·29	5·02	0·198	B,C> A*
Digestibility coefficients						
Total diet DM	0·553	0·594	0·580	0·585	0·0235	NS
Total diet OM	0·579	0·609	0·574	0·601	0·0274	NS
Straw alone OM	0·481	0·527	0·515	0·518	0·0358	NS
ME intake from straw consumed	34·8	43·0	40·6	38·5	4·07	NS

Table 38. Expt 2.10. The mean concentrations of urea (mmol/litre) and ammonia ug/dl in the blood of the cows.

Treatment	A Nil	B LS in water	C LS in fistula	D LS on straw	SEM	Significance
Blood urea						
07.30 h	1·49	2·40	2·53	2·48	0·270	C,D > A*
10.00	1·46	2·71	2·80	2·55	0·159	B,D > A**; C > A***
12.00	1·29	2·79	2·94	2·30	0·201	D > A*; B,C > A**
14.00	1·28	2·80	3·26	2·34	0·258	D > A*; B,C > A**
16.00	1·18	3·01	2·96	2·53	0·367	B,C,D > A*
18.00	1·29	2·91	3·93	2·56	0·272	D > A*, B > A** C > A***, C > B,D*
Blood ammonia						
07.30 h	46	53	54	58	8·6	NS
10.00	53	56	72	61	9·8	NS
12.00	57	67	41	49	8·6	NS
14.00	32	56	73	63	15·9	NS
16.00	43	71	61	71	6·3	B,D > A*
18.00	28	62	73	70	18·9	NS

Table 39. Expt 2.10. The mean concentration of ammonia (mg/dl), total nitrogen (g/litre) and pH in the rumen of the cows.

Treatment	A Nil	B LS in water	C LS in fistula	D LS on straw	SEM	Significance
Rumen ammonia						
07.30 h	2·03	7·26	5·61	5·61	0·262	B,C,D> A***;B> CD**
10.00	3·08	10·92	11·67	7·84	2·734	NS
12.00	2·52	8·68	7·00	4·06	1·425	B> A*
14.00	3·64	8·96	12·88	6·44	2·632	C> A*
16.00	2·25	7·00	10·36	5·88	0·941	B,D> A*;C> A***; C> BD*
18.00	2·24	6·44	5·94	4·79	1·401	NS
Rumen total nitrogen						
07.30 h	0·188	0·240	0·221	0·211	0·0137	B> A*
10.00	0·168	0·299	0·346	0·218	0·0487	C> A*
12.00	0·153	0·258	0·268	0·205	0·0162	B,C> A**;C> D*
14.00	0·175	0·241	0·335	0·245	0·0165	B,D> A*;C> A***; C> B,D***
16.00	0·158	0·239	0·291	0·234	0·0243	C> A**
18.00	0·240	0·273	0·259	0·245	0·0230	NS
Rumen pH						
07.30 h	6·99	7·03	7·07	7·01	0·018	C> A*
10.00	6·91	6·89	7·12	6·91	0·053	C> A,B,D*
12.00	6·79	6·72	6·87	6·75	0·115	NS
14.00	6·85	6·66	6·89	6·76	0·085	NS
16.00	6·86	6·80	6·93	6·71	0·043	A,C> D*
18.00	6·84	6·89	6·90	6·70	0·065	NS

The total nitrogen concentration in the rumen liquor (Table 39) of the cows receiving no LS supplementation was consistently lower than for those cows receiving LS supplementation by each of the three methods. However, there were no real changes in total nitrogen concentration in the rumen with time during the day for any of the treatments.

The blood ammonia concentration (Table 38) for the LS supplemented diets did not change with time over the day. However, the ammonia concentration on the unsupplemented diet began to fall from 12.00 h until 18.00 h. Results indicated that the nil treatment did have the lowest value, but this was not significant. All the values recorded lie within the normal range for bovines (Parkins, 1972). None of the various methods of LS supplementation resulted in the production of excessive ammonia, which was indicated by the low concentrations of blood ammonia recorded. Accordingly there was no risk of toxicity.

Discussion.

This experiment was designed to confirm if LS presented in the drinking water did not improve straw intake (as was recorded in Expt 2.9) and to attempt to elucidate the reasons for this occurrence. One possibility was that LS in the water may have stimulated oesphageal groove closure and therefore the LS/water may have by-passed the rumen. For this reason rumen parameters were studied, and treatment C (LS via the fistula) allowed the parameters to be measured knowing that the full allocation of LS had been put directly into the rumen. However, the results of this experiment contradict those reported in Expt 2.9 as LS given in the water has significantly increased straw intake. Oesphageal groove closure did not occur as rumen total nitrogen concentrations for the LS/water treatment are higher than for the nil treatment and comparable with those for LS put directly into the rumen through the fistula.

In the previous experiment (Expt 2.9) all the cows given LS in the

water took 3-4 days to become accustomed to full consumption of the supplemented water. This acclimatization period did not occur during this experiment.

LS supplementation did not result in the production of ammonia above that produced from the basal diet. The sensitivity of the analytical technique is low at such low concentrations of blood ammonia (10-70 μg/dl) (Parkins, 1972), which resulted in large variations between periods and a relatively high standard error of the mean.

General discussion.

The majority of work comparing urea with other NPN sources has been concerned with predominantly cereal based diets. It is possible that any differences in the efficiency of utilization of NPN sources may be more apparent when animals are given NPN in association with predominantly straw-based diets. Oat straw was used throughout the work in this thesis because of its lower and more regular protein content which make it a more suitable experimental material.

The response to feeding urea by cattle given high roughage rations has not always been consistent and depends essentially on the protein content of the ration. Chicco et al. (1972) supplemented a mature grass (60 g CP/kg) with urea/molasses and improved daily gain (275 vs - 15 g/day) in cattle. Bond and Rumsey (1973) found no response in dry cows, yearlings or calves allowed access to a low nitrogen (90 g CP/kg) urea/molasses mixture.

The amino acid complement of the diet may be limiting for growth on certain diets. Methionine and threonine appeared to be limiting for growth of calves given urea or soya bean meal as a supplement (Liebholz, 1976) and the sulphur-containing amino acids were the most limiting for sheep given urea containing diets (Owens, Knight and Nimrick, 1973). With high straw diets performance tends to be less with urea than soya bean meal (Bhattacharya and Khan, 1973). Various workers have studied ruminant growth on diets where virtually all of the dietary nitrogen was supplied by NPN (Oltjen, 1969). If vegetable protein supplementation is completely replaced by NPN the rate of growth and feed efficiency are generally lower than when soya bean protein is used (Oltjen, Sirny and Tillman, 1962; Goodrich and Tillman, 1968).

Table 40 summarizes the response of the yearling cattle, the beef cows and the fistulated cows to the different methods of LS

supplementation.

Table 40. The responses to different methods of supplementation of LS (% increase/decrease in straw DM intake).

Experiment		Method of supplementation					
		LS in barley	LS in water	LL	LS on straw	LS via fistula	SBM+
Expt 2.6	Yearling cattle	+13	+18	+9	-	-	-
Expt 2.7	Yearling cattle	-	equal	equal	-	-	-
2.7	Lactating beef cows	-	equal	equal	-	-	-
Expt 2.8	Yearling cattle	-	No response			-	-
Expt 2.9	Pregnant beef cows	-	-5	+12	+9	-	+24
Expt 2.10	Fistulated cows	-	+23	-	+13	+19	-

+ Soya bean meal.

When LS was given in a barley cube (Expt 2.6) although this method of supplementation increased the voluntary intake, it probably fell short of the maximum possible effect due to palatability problems. The ration was predominantly straw-based with the minimum amount of concentrate, which resulted in the concentration of LS in the barley cube being high (6·6%). Fishwick and Parkins (1979) have given pregnant beef cows a diet of oat straw and cubed barley containing 4% LS. At this concentration of LS the barley cube was readily accepted by all the cows. LS mixed in with a concentrate feed up to 4% addition would seem a satisfactory method of including LS into the diet.

Supplying LS to animals in a home-made free access liquid was experimentally satisfactory. In Expt 2.6 the cattle were in a confined

space (compared with grazing animals) and 4 animals had access to 2 balls to lick. The results of the time lapse photography showed that each animal took some LL each day. In Expt 2.9 the cows were individually fed and therefore had their assigned allocation of LL. As already discussed in the introduction to this section, in a field situation the individual intake of any liquid supplement from ball lickers is very variable.

In both experiments Expt 2.9 and 2.10 the increase in straw intake achieved by the addition of LS to the straw just failed to be significantly greater than no supplemented intake (9 and 13% respectively). However, these were positive increases.

The results obtained from supplementing LS via the water supply are contradictory. In Expt 2.6 the LS was supplied to the cattle at a concentration of 0·67%; in Expt 2.7 to the cattle at 0·67% and the cows 0·60%, in Expt 2.9 to the cows at 1·25% and in Expt 2.10 to the fistulated cows at 1·25%. No palatability problems occurred with any of the animals except in Expt 2.9 where on changing to LS in the water the cows took about 3 days to become accustomed to its taste. In Expt 2.9 the straw intake for the LS in the water treatment was significantly lower than that of all the other supplemented diets, and marginally lower than the non-supplemented diet. However, although Expt 2.10 was designed to confirm the findings of Expt 2.9 it in fact, demonstrated to be the opposite. The supposition that at a concentration of 1·25% LS oesophageal groove closure may have been stimulated was disproved, as rumen total nitrogen concentrations for the LS/water treatment were comparable with those for LS put directly into the rumen through the fistula and higher than for the nil treatment. At the moment no explanation can be offered for the failure of LS in the water to increase voluntary straw intake of the cows in Expt 2.9.

It is concluded that in terms of animal acceptance/response and practical application that the most acceptable methods of LS application

are either LS on the straw or in the barley (or other concentrate feed). The practical uses of these methods have already been discussed in the general introduction to this thesis. LS in a molasses lick would be acceptable in situations where the animals are not given other supplementary feeds (e.g. straw or concentrates), but it would have to be accepted that up to about 40% of the animals may receive little or none of the liquid supplement. Before it could be recommended that LS be provided via the water supply more work would be required to investigate animal responses to the supplement. The other difficulties with this method have been discussed in the introduction to this section and would also have to be considered on an individual farm scale. These include the type of water supply on the farm (piped or natural) and the classes and physiological states of the animals to be supplemented.

SECTION 3

THE EFFECT OF LS SUPPLEMENTATION ON THE PERFORMANCE OF RUMINANTS

Introduction.

This section of the thesis deals with LS supplementation to ruminants and its effect on given production parameters.

The rate of use of any feed supplement containing principally non-protein nitrogen and additionally various minerals and vitamins will be primarily governed by the amount of supplementary nitrogen required in a given particular circumstance. Therefore the contained amounts of minerals provided by the feed plus supplement may not always be adequate to meet current (A.R.C., 1965) recommendations for minimal intakes.

A number of feeds do not provide adequate mineral intakes for animals of differing physiological states. For example a high proportion of straws and hays provide much less phosphorus than recommended for maintenance of adult cattle (Hemingway et al. 1968; Hemingway, 1971). Diets composed principally of cereals may be low or marginal in the amount of calcium required by growing lambs and especially beef cattle unless a supplemented calcium source is added to the ration.

The dietary standards for ruminant feeding published by the A.R.C. (1965) and the N.R.C. (1976) are widely used and accepted by those concerned with ruminant nutrition. However, various workers have shown that the standards applying to dietary phosphorus (e.g. Little, 1980) and calcium (e.g. Hodge, 1973) requirements are too high. At the moment the A.R.C. are currently revising the A.R.C. (1965) recommendations and it is believed that the recommended mineral intakes will be reduced.

This section of the thesis monitors the effect of giving less calcium and/or phosphorus than the A.R.C. (1965) recommendations in differing production trials :- growing lambs and cattle, lactating ewes

and their lambs and pregnant and lactating beef cows.

LS contains 152 mg copper/kg. Adult cattle appear to be able to tolerate the continuous intake of relatively large amounts of copper without ill effects. Sheep are much more susceptible to copper poisoning than adult cattle, and doses of 20- 110 mg of copper/kg body weight produce copper poisoning. The normal range of copper in the blood of sheep lies between 0·7 to 1·2 mg/kg (MacPherson, Brown and Hemingway, 1964). Although copper is essential to maintain life an excess can be fatally toxic. Sheep are peculiar in the way in which copper is handled metabolically. Increased absorption is not easily achieved, but abnormally high excretion is more difficult still so that there is the general tendency for copper to accumulate in the body of sheep (Neethling, Brown and De Wet 1968). Excess copper is stored in the liver. When it reaches a critical concentration copper is released into the blood producing haemolysis (24 h before symptoms appear blood copper concentration can rise to 250 mg/kg).

If copper-supplemented diets are to be given great care should be taken to ensure that the recommended level is not exceeded, that mixing is adequate and that none of the supplemented diet is fed to sheep (Todd, 1962). Over a period of time copper accumulates and results in poisoning. Animals will show normal health until the haemolytic crisis occurs. Chronic copper poisoning is characterized by hepatic and renal cell degeneration, haemoglobinuria, acute anaemia and jaundice. Serum enzyme activity increases just before the haemolytic crisis. In sheep serum glutamic-oxalacetic transaminase (GOT) increase with a rise up to 880 S.F. (Sigma Frankel) units/ml up to 6 weeks before obvious clinical signs appear (MacPherson and Hemingway, 1969).

It is for the above reasons that supplementary copper is not recommended for use in diets for sheep. (The Fertilisers and Feed Stuffs Regulations, 1973) and therefore LS cannot be recommended. In

three of the experiments in this section LS was given to sheep and/or lambs. In these cases either blood GOT or copper concentrations were monitored.

Experiment 3.1. Soya bean meal, crystalline urea and LS as nitrogen sources for lactating ewes given whole oats.

Introduction.

The objective of this experiment was to compare LS with crystalline urea and soya bean meal as protein supplements for lactating ewes, and as a secondary object to monitor the effects of supplying less calcium and phosphorus than the A.R.C. (1965) recommendations.

Materials and methods.

Experiments were conducted in each of the years 1978 and 1979 involving similar numbers of ewes, dietary treatments and housing conditions. As the results of each year were essentially similar, the data are presented as a combined work.

The experiment involved a total of 138 adult female sheep (ewes) of mixed ages of which 94 were Greyface (Border Leicester male x Scottish Blackface female) ewes which had been mated to Suffolk males and 44 were Finnish Landrace x Dorset Horn ewes mated with Texel males. A larger number of ewes than this had been mated at grass and this number was selected from those lambing within a four-week period. About three weeks before lambing, which occurred from February to March, the ewes were housed in open-fronted buildings and given, on a group-basis, 1 kg hay and 1 kg of equal parts of a mixture of the four diets offered in lactation to enable them to become accustomed to consuming such mixtures. At lambing, the ewes were individually penned with their lambs for two days and appropriate husbandry measures were employed to ensure intake of colostrum and the development of the ewe/lamb relationships. Thereafter the ewes were allocated to one of the four dietary treatments on a basis of ewe breed, live weight and body condition score and the number of lambs suckled. There were a total of 51 ewes with single and 87 ewes with twin lambs. Thereafter the ewes received the experimental diets on a group-feeding basis. The ewes were grouped according to dietary

treatment in pens containing 10 - 12 ewes which had lambed within a one-week period. Each pen contained ewes with single and twin lambs in appropriate proportions. Ewes were given concentrates in troughs at 08.00 h and hay in racks at 16.00 h each day. No other feeds were given separately to the lambs.

All the sheep were given 1·0 kg hay (FM)/day. Three of the four concentrate diets used were each formulated to have the same amount of crude protein (FM basis) and the fourth contained no additional protein. The compositions of the hay, oats, soya bean meal and LS used are given in Table 41. The amounts of feeds given/day are detailed in Table 42. Diet A consisted of whole oats to which was added 40 g LS/kg followed by uniform mixing. Batches of 40 kg were made by hand mixing in polypropylene containers. Absorption of LS by the oats was rapid. A sufficient quantity was made at one time to last the ewes for one week and there was no sign of run-off at the base of the containers. Diet B consisted of whole oats to which crystalline urea was added, followed by hand mixing as above. Diet C was composed of whole oats and soya bean meal. Diet D was whole oats with no protein addition. Dicalcium phosphate, calcium carbonate and sodium chloride were added to diets B, C and D to provide the same amounts of calcium, phosphorus and salt as were added to diet A by LS. A trace element/vitamin supplement identical to that used in LS (supplied by the manufacturer) was also added appropriately to diets B, C and D.

The total nutrient intakes of the ewes are given in Table 42. The overall mean amounts were calculated (M.A.F.F., et al., 1975) to be about 16·7 MJ ME, about 100 g digestible crude protein (DCP) (unsupplemented) and about 145 g DCP (as supplemented with the various additions) and (by analysis) about 4·1 g Ca and 4·7 g P.

Table 41. Expt 3.1. The mean compositions of hay, oats, soya (g/kg DM) and LS (g/kg FM).

	Hay		Oats		Soya		LS	
	1978	1979	1978	1979	1978	1979	1978	1979
Dry matter	796	786	823	773	858	840	-	-
Crude protein	75	73	107	134	513	512	1090	1087
Crude fibre	342	352	121	128	63	97	-	-
Ether extract	9	8	53	49	10	12	-	-
N-free extract	523	512	694	663	348	344	-	-
Ash	51	55	25	26	66	71	-	-
Ca	3·9	2·3	0·9	0·6	3·2	3·3	25·3	26·8
P	1·5	1·8	3·4	3·4	6·5	7·0	13·8	14·5
pH	-	-	-	-	-	-	1·6	1·6

Table 42. Expt 3.1. The amount of each feed given/day (fresh matter basis) and the calculated daily intakes of metabolizable energy (ME), digestible crude protein (DCP), calcium and phosphorus.

	1978				1979			
	A	B	C	D	A	B	C	D
Protein source	LS	Urea	Soya	Nil	LS	Urea	Soya	Nil
Hay (kg)	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
Oats (kg)	1·0	1·0	0·88	1·0	1·0	1·0	0·87	1·0
Soya (kg)	-	-	0·12	-	-	-	0·13	-
Urea (g)	-	16	-	-	-	16	-	-
LS (g)	40	-	-	-	40	-	-	-
Minerals and Vitamins*	-	+	+	+	-	+	+	+
Total intakes								
ME (MJ)	17·35	17·35	17·25	17·35	16·07	16·07	16·03	16.07
DCP (g)	139	141	135	95	150	152	146	106
Ca (g)	4·9	4·9	5·1	4·9	3·2	3·2	3·5	3·2
P (g)	4·6	4·6	4·9	4·6	4·6	4·6	5·2	4·6

*3·4 g dicalcium phosphate, 1·1 g calcium carbonate, 2·0 g sodium chloride plus trace elements and vitamins to provide equivalent supplementation to the amounts present in 40 g LS.

The ewes and lambs were weighed at birth and 3 and 6 weeks after lambing. At the same three times blood samples were also obtained from the ewes for the determination of urea, calcium, phosphorus and copper.

The data for the parameters measured for all the sheep combined for both years were analysed by separate t-test comparisons for the four treatments. Only the differences between treatments within single and twin lambs have been considered and indicated in the tabulated results.

Results.

All the four concentrate mixtures were palatable and were readily and completely consumed by the ewes. As the lambs reached 3-4 weeks of age they showed interest in the concentrate mixtures, but the rate of consumption by the ewes was such that the lambs were able to eat little if any. The hay was eaten by the ewes within 2 h of feeding.

The principal results regarding mean ewe and lamb live weights are given in Table 43. The Finnish Landrace/Dorset Horn ewes weighed on average 4 kg less than the Greyface ewes throughout the six week period (not significant). The overall mean live-weight gain of the single lambs to 6 weeks was about 11 kg. There were no significant differences between treatments. However, for the twin lambs, those reared by ewes given diet C (oats/soya) and diet A (oats/LS) grew significantly faster than those given diet D (unsupplemented oats) as determined at both 3 and 6 weeks of age (Table 43). Lambs reared by ewes given diet B (oats/crystalline urea) had an intermediate growth rate which was significantly greater at 3 weeks, but not at 6 weeks, than for those lambs reared by ewes given unsupplemented oats.

There were consistent and progressive reductions in the live weight of the ewes. The overall mean losses to 6 weeks were 6·0 and 8·9 kg respectively for those suckling single and twin lambs. Live-weight losses were least for those ewes given diet C (oats/soya) and greatest for those ewes given diet A (oats/LS) for both those with single and twin lambs.

Table 43. Expt 3.1. Mean live weight and live-weight changes of ewes and lambs.

	Ewes with singles					Ewes with twins				
	A	B	C	D	Mean	A	B	C	D	Mean
Nitrogen source	LS	Urea	Soya	Nil	SE	LS	Urea	Soya	Nil	SE
Number of ewes	12	12	13	14	-	22	21	23	21	-
Ewe live-weight after lambing	70·4	66·5	65·9	68·1	2·87	64·9	67·1	66·8	65·4	1·85
Ewe live-weight loss to										
3 weeks	4·25	3·08	1·39	3·21	1·227	$8·43^{h}$	6·43	4·91	$4·67^{h}$	1·124
6 weeks	$8·33^{c}$	4·58	$3·81^{c}$	7·39	1·488	$10·50^{d}$	$10·26^{e}$	$6·61^{de}$	8·33	1·115
Lamb birth weight	4·5	5·1	4·5	5·4	0·33	4·2	4·3	4·2	4·5	0·12
Lamb live-weight gain to										
3 weeks	6·77	5.96	6·42	7·01	0·484	$4·52^{b}$	$4·40^{a}$	$4·78^{i}$	$3·84^{abi}$	0·186
6 weeks	11·30	10·27	10·66	11·57	0·803	$7·50^{g}$	7·10	$7·77^{f}$	$6·41^{fg}$	0·311

Means followed by the same letter are significantly different: a,b,c,d,e ($P<0·05$); f,g,h ($P<0·01$); i ($P<0·001$).

Table 44. Expt 3.1. Mean concentrations of urea, calcium and phosphorus (mmol/litre) in the blood of the ewes.

	Ewes with singles					Ewes with twins				
	A	B	C	D	Mean	A	B	C	D	Mean
Nitrogen source	LS	Urea	Soya	Nil	SE	LS	Urea	Soya	Nil	SE
Weeks post partum										
Urea										
0+	4·4	5·5	4·3	5·1	0·65	4·9	5·4	5·0	4·7	0·65
3	$3·4^{a}$	3·3	$3·5^{e}$	$2·2^{ae}$	0·41	$4·5^{f}$	$3·6^{b}$	$3·6^{g}$	$2·1^{bfg}$	0·34
6	4·3	$4·9^{cd}$	$3·6^{d}$	$2·6^{c}$	0·38	$5·0^{jk}$	$4·8^{hi}$	$3·3^{ik}$	$2·2^{hj}$	0·36
Calcium										
0+	2·6	2·2	2·3	2·3	0·15	2·3	2·2	2·2	2·4	0·12
3	2·5	2·4	2·5	2·6	0·06	2·4	2·4	2·5	2·5	0·04
6	2·5	2·3	2·3	2·5	0·06	2·4	2·3	2·5	2·4	0·05
Phosphorus										
0+	1·0	1·1	1·2	1·2	0·10	1·1	1·2	1·4	1·0	0·14
3	1·4	1·6	1·6	1·5	0·09	$1·2^{lmn}$	$1·6^{n}$	$1·6^{m}$	$1·6^{l}$	0·07
6	1·5	1·6	1·6	1·6	0·09	1·5	1·5	1·6	1·6	0·07

+Values for 1979 only. Means followed by the same letter are significantly different: a,b,c,d ($P < 0·05$); e ($P < 0·01$); f,g,h,i,j,k,l,m,n ($P < 0·001$).

Ewes given diet D (unsupplemented oats) had significantly lower concentrations of urea in the blood than for any of the supplemented diets (Table 44). The blood of the ewes given either crystalline urea or LS generally had higher concentrations at 6 weeks, but not at 3 weeks after lambing than those given soya. None of the supplementary nitrogen treatments influenced the concentrations of calcium and phosphorus in the blood of the ewes which would be considered normal throughout (Table 44). Ewes with both single and twin lambs given LS appeared to have lower concentrations of phosphorus in their blood 3 weeks after lambing relative to the other treatments. There is no obvious explanation for this and by 6 weeks after lambing the difference had largely disappeared. The overall mean concentrations of copper in the blood of the ewes (1979 group only) were normal 0·97 (at parturition), 1·00 (3 weeks) and 0·96 (6 weeks) mg/kg and there were no differences between treatments.

Discussion.

The ewes were given diets supplying about 17 MJ ME and 140 g digestible crude protein/day. The amount of ME provided was lower than the mean feed allowances of 20·8 and 26·6 MJ ME currently recommended (M.A.F.F. et al., 1975) over the first two months of lactation for 67 kg ewes. The amount of DCP provided was also lower than the 215 and 282 g DCP respectively suggested for 67 kg ewes with single and twin lambs in early lactation (ADAS, 1976). Gonzalez, Robinson and McHattie (1979a) have demonstrated that when ewes in lactation are given less than their full feed allowance for energy, milk production differences associated with alternative dietary protein sources can be observed. The amounts of both ME and DCP provided were in the same order as have previously been given to housed ewes which demonstrated differences in growth of lambs suckling ewes offered feeds with a mixture of ground nut/cotton seed

meals or urea as protein sources. (Ducker, Fraser and Hemingway, 1976).

The overall mean live-weight gain of the single lambs to 6 weeks of age was 11·0 kg. This was considered to be satisfactory and compares with a mean gain of about 12·0 kg recorded for similar ewes and lambs in a previous comparable experiment by Ducker et al. (1976). There were no differences between treatments nor any indication of response to any form of nitrogen supplementation. However, the ewes with single lambs given LS or urea lost more live weight (mean 6·5 kg) than those given soya (3·8 kg). Ducker et al. (1976) similarly recorded a greater live-weight loss for ewes with single lambs when given barley with urea (11·0 kg) than when given barley with ground nut and cotton seed meals (6·1 kg).

The twin lambs reared by the ewes given LS or soya gained comparable and significantly more live weight to 6 weeks than those given no nitrogen supplement. Those reared by ewes given crystalline urea had intermediate growth rates. The mean live-weight gain of those lambs given either LS or urea (7·3 kg) was about 0·5 kg less than those given oats/soya. Previously, Ducker et al. (1976) have recorded live-weight gains of twin lambs to 6 weeks of about 8·1 kg (barley with urea) compared with about 9·6 kg (barley with ground nut and cotton seed meals).

Parkins (1974) has demonstrated that the addition of urea to low-protein diets given to ewes in late pregnancy significantly increased nitrogen retention, but there are very few references to the comparative effects of urea and various protein sources on milk yields in ewes. Jordan (1952) and Pope, Gallup and Read (1952) have indicated that urea was comparable to soya bean meal and cotton seed cake as a source of nitrogen for ewes in late pregnancy and early lactation. Similarly, Parkins, Fraser, Ritchie and Hemingway (1974) found that the addition of urea to molassed sugar beet pulp was as effective as the addition of decorticated ground nut cake, but Ducker et al. (1976) considered that urea was significantly less efficiently utilized than a mixture of

decorticated ground nut and cotton seed meals by lactating ewes. In a series of papers McHattie, Fraser, Thompson and Robinson (1978), and Gonzalez, Robinson, McHattie and Mehrez (1979b) have concluded that the milk yield of ewes suckling twin lambs is related to the proportion of the supplementary source of protein which is degraded in the rumen. They concluded (Gonzalez et al., 1979b) that in relation to urea, ground nut and soya bean meals both with rumen degradabilities of 0·47 increased milk yields by 7 and 19% respectively. In contrast, meat and bone, fish and blood meals with reduced rumen degradabilities (0·37 - 0·1) increased milk yields by 15 and 35%.

In the present experiment the mean rumen degradability (the fraction of the total nitrogen lost) of the protein in the soya bean meal (1979 only) measured over a period of 24 h by a Nylon bag technique in the rumen of four cows was 0·75. The growth of twin lambs to 6 weeks of age of ewes given soya was 9% greater than that of ewes given crystalline urea. This increase seems to be in the same order as those recorded by Gonzalez et al. (1979b). Ducker et al. (1976) also found performance of twin lambs to be 17% better when given a mixture of ground nut and cotton seed meals compared with urea.

Both Greyface and Finnish Landrace x Dorset Horn ewes were used in this experiment, which were respectively mated to Suffolk and Texel males. For this reason the live-weight gain to 6 weeks for both crosses of lambs has been calculated and is summarized in Table 45. The mean live-weight gains of the 2 breeds of lambs to 6 weeks for both singles and twins irrespective of treatment were similar (not significantly different).

Table 45. Expt 3.1. Mean live-weight gains to 6 weeks of the Greyface and Finnish Landrace x Dorset Horn cross lambs irrespective of treatment.

	Number	Mean	SE	Significance
Singles				
Finnish Landrace x Dorset Horn	12	11·4	0·75	NS
Greyface	39	11·9	0·81	NS
Twins				
Finnish Landrace x Dorset Horn	64	7·2	0·28	NS
Greyface	110	7·2	0·33	NS

For each particular dietary treatment ewes rearing twin lambs lost considerably more live weight over the first six weeks of lactation than those rearing single lambs. For ewes rearing twin lambs the live-weight losses of those given LS or crystalline urea were significantly greater than for those given soya (although the live-weight gains of their twin lambs were comparable). Ewes with twin lambs given no nitrogen supplement lost an intermediate amount of weight, but their lambs grew significantly more slowly (Table 43).

The loss in live weight of the ewe contributes to the effective ME available for milk production. Gardner and Hogue (1964) have indicated that the energy value of 1 kg live-weight loss of the lactating ewe is 25·5 MJ. If it is assumed by analogy with the lactating cow that the efficiency of conversion of live-weight loss to energy for milk production is 0·82 and the efficiency of utilization of ME for milk production is 0·62 it may be calculated (M.A.F.F. et al., 1975) that

each kilogram live-weight loss in the ewe is equivalent to 33·7 MJ dietary ME. It may then be speculated (Table 46) that the total ME available for milk production (i.e. the mean overall feed intake given of 16·7 MJ plus that calculated from the mean live-weight loss to six weeks after lambing for each group of ewes) can be related to the total live-weight gain of the lambs/day to six weeks. From these have been derived the ratio of the live-weight gain : unit of ME available for milk production.

Table 46. Expt 3.1. The total live-weight gain (LWG) of the single or twin lambs (g/day) and the effective amounts of metabolizable energy (MJ ME/day) available for milk production.

Diet	A	B	C	D
Additional nitrogen source	LS	Urea	Soya	Nil
Ewes with single lambs				
LWG	269	245	256	276
ME available[+]	23·3	20·4	19·6	22·7
LWG : ME ratio	11·5	12·0	13·1	12·1
Ewes with twin lambs				
LWG	357	338	369	305
ME available[++]	25·0	24·9	21·9	23·3
LWG : ME ratio	14·3	13·6	16·8	13·1

Suggested ME requirements for 67 kg ewes for the first 2 months of lactation. [+]Single lambs 19·8; [++]Twin lambs, 25·3 (M.A.F.F., et al. (1975) less the 5% safety margin).

The overall mean effective daily ME thus calculated to be available for milk production for ewes with single lambs was 21·5 MJ ME compared to the 19·8 ME/day given as the suggested mean feed allowance for 67 kg ewes over the first two months of lactation (M.A.F.F. et al. (1975) less the 5% safety margin). In this situation where the nitrogen supply did not influence lamb live-weight gain and thus, by implication, the amount and quality of the milk available, the ratio lamb live-weight gain : unit ME was constant at about 12·2.

In contrast, none of the groups of ewes with twins were calculated to have attained the effective total ME available for milk production of the suggested (M.A.F.F. et al. (1975) less the 5% safety margin) intake of 25·3 MJ for 67 kg ewes. The mean live-weight gain of twin lambs given soya bean meal to 6 weeks was 369 g/day achieved with an effective ME available of 21·9 MJ i.e. 16·8 g live-weight gain/unit ME. The corresponsing effective ME available to ewes given LS or urea were about 25 MJ and the ratios of lamb live-weight gain/unit ME were about 14·0. This reduction in the efficiency of the use of the effective ME available to the ewe of some 20% suggests that LS and urea supplied nitrogen of either inadequate quantity or quality relative to soya. This is supported by the still further reduced efficiency of 13·1 g live-weight gain/unit ME for the ewes with twin lambs given no supplementary nitrogen even although their effective ME intake was comparable to the other groups.

During lactation the concentration of urea in the blood of the ewes given no nitrogen supplement was lower (for both single and twin-suckling ewes) than for other groups. For those ewes with twin lambs the mean value of about 2·2 mmol/litre approached the concentration (1·7 mmol/litre) below which Parkins et al. (1974) considered a reduction in ewe performance became apparent. However, the absence of any difference between the overall mean concentrations for the three

methods of supplementation for either single or twin lambs tends to suggest that supplementation of the diet to give a total of about 14·5 g DCP/day was not markedly inadequate.

During the last three weeks of pregnancy and the first six weeks of lactation, the ewes received totals of about 4·1 g Ca and 4·7 g P/day of which about 1 g Ca and 0·6 g P were provided by LS or the mineral supplements. These intakes were very low in relation to the A.R.C. (1965) recommended minimal intakes for 67 kg ewes with twin lambs of about 12 g Ca and about 8 g P in late pregnancy and about 18 g Ca and about 12 g P in early lactation. There was no indication from the blood samples obtained from the ewes that the concentrations of calcium or phosphorus were abnormally low or that there was any progressive reduction during the course of lactation. Further evidence to suggest that these intakes were adequate during the period of the experiment, is that the overall mean concentrations of calcium and phosphorus six weeks after lambing were identical for ewes suckling either single or twin lambs.

The overall mean copper intake of the ewes from the hay and oats was about 11 mg/day and this was increased by a further 6 mg to about 17 mg by the copper present in the LS or the trace element additions present in the other diets. Again over the nine week period there were no suggestions of abnormality or a progressive increase in the concentration of copper in the blood.

It is concluded that under the circumstances of this experiment LS was a convenient and adequate method of supplementing whole oats given to lactating ewes with twin lambs. The growth rate of twin lambs was equivalent to that recorded when soya bean meal was the protein source, but there was an accompanying larger reduction in ewe live weight during early lactation.

Experiment 3.2. Soya bean meal and LS (± limestone) as protein and mineral sources for growing lambs given whole barley.

Introduction.

The purpose of this experiment was to assess the adequacy of LS supplementation to growing lambs with particular reference to the calcium content of the diet. Whole cereals are frequently given to ewes. However, there has been increasing interest in giving lambs whole cereals (e.g. Ørskov and Grubb, 1977). Giving whole cereals would provide a feed with no physical processing costs. Ørskov, Fraser and McHattie (1974) have shown that the digestibility of whole cereals given to lambs was rather higher than when they were ground and pelleted before feeding. The mixing of crystalline or prilled urea with whole cereals is, however, potentially hazardous because of possible segregation. Ørskov, Smart and Mehrez (1974) have shown the benefits of adding urea in solution to whole cereals given to lambs in terms of greater feed intake and a reduced tendency to increase the concentration of ammonia in the rumen liquor. Ørskov and Grubb (1977) suggested that for most sheep production systems in which concentrates are used, the use of whole cereals supplemented with the necessary nutrients is all that is required to achieve optimum results.

Materials and methods.

The lambs were weaned at 6 weeks and housed in open fronted buildings and given an ad libitum mixture of whole barley supplemented with LS and soya bean meal (SBM) and mixed (50 : 50) with lamb creep (BOCM Silcock, Lambwena), the proportion of creep decreasing with time. This preliminary feeding regime allowed the lambs to become accustomed to consuming the experimental diets. During this preliminary (3 week) period an outbreak of coccidiosis occurred which was suitably treated with sulphamezathine. Although no deaths occurred the coccidiosis

outbreak increased the lambs post-weaning growth check.

A total of 84 lambs (Greyface x Suffolk) were grouped on the basis of live weight and sex (~ 50 : 50 male : female) into 21 groups of 4 lambs. The groups were individually housed in open fronted buildings and dietary treatments allocated to them. The dietary treatments and number of lambs on each treatment are presented in Table 47. The diets were given ad libitum in feed hoppers which were replenished when necessary. Dicalcium phosphate, calcium carbonate and sodium chloride where added to the diets not given LS to provide the same amounts of calcium, phosphorus and salt as was added in the LS supplemented diets. A trace element/vitamin supplement identical to that used in LS (supplied by the manufacturer) was also added appropriately to the diets not given LS. In addition all the lambs were given 100 g hay (FM)/day (on a group basis). Four of the diets were formulated to have the same amount of crude protein (FM basis) (Table 48) and the other two contained no additional protein. Dietary mixes were made in batches of 40 kg by hand in polypropylene containers. The compositions of hay, barley soya bean meal and LS used are given in Table 49. The lambs were weighed at 3, 6 and 9 weeks. At the same three times feed intakes were recorded and blood samples were also obtained (10.00 h) from the lambs for the determination of urea, calcium, phosphorus, copper and glutamic-oxalacetic transaminase (GOT).

However, during this experiment a number of serious illnesses occurred. Table 47 details the numbers of lambs that were removed and that died whilst on the experiment. Although the lambs were housed in open fronted, well ventilated buildings and bedded frequently on dry wheat straw this did not prevent the occurrence of pneumonia. Six lambs died of pneumonia and a total of 17 were removed throughout the experiment. Of these 2 had cerebro cortical necrosis and 4 had rectal prolapses. The lambs were removed when they were seen to be ill, or

when they were not gaining weight. The veterinary surgeon on duty had strong views about the use of whole barley and believed the rectal prolapses to be caused by the diet.

Table 47. Expt 3.2. The original number of animals/treatment, number of animals that were removed and that died and the total remaining animals.

Treatment	No. at start of experiment	No. dead	No. removed	No. used on experiment
Nil	16	2	2	12
LS (at 4%)	16	1	3	12
SBM	16	-	4	12
Nil + 1% limestone	12	-	4	8
LS (at 4%) + 1% limestone	12	2	3	7
SBM + 1% limestone	12	1	1	10

Table 48. Expt 3.2. The proportions of LS, Soya, minerals/vitamins and whole barley in the dietary treatments.

	No limestone			With 1% limestone		
	Nil	LS	SBM	Nil	LS	SBM
Oats (kg)	1·0	1·0	0·87	1·0	1·0	0·87
Soya bean meal (kg)	-	-	0·13	-	-	0·13
LS (g)	-	40	-	-	40	-
Limestone (g)	-	-	-	10	10	10
Minerals/vitamins	+	-	+	+	-	-

+3·4 g dicalcium phosphate, 1·1 g calcium carbonate, 2·0 g sodium chloride, trace elements and vitamins to provide equivalent supplementation to the amounts present in 40 g LS.

Table 49. Expt 3.2. The mean compositions of hay, barley, soya (g/kg DM) and LS (g/kg FM).

	Hay	Barley	Soya	LS
Dry matter	849	841	864	-
Crude protein	74	102	482	1040
Crude fibre	279	33	59	-
Ether extract	10	14	13	-
N-free extract	587	830	385	-
Ash	50	21	61	-
Ca	4·4	0·6	3·4	26·7
P	1·7	3·6	6·2	16·8
pH	-	-	-	1·6

The remaining 61 lambs (mean initial live weight 14·4 kg) continued on the experiment. When a lamb died or was removed the other lambs were weighed and the feed intake recorded for that group. The amount of food that the removed lamb consumed was calculated on the assumption that each lamb, whether ill or not, consumed an equal proportion of food as the others in the group. It was on this assumption that the feed intakes were calculated. Although the above is not necessarily correct, this method was used to standardize the situation as no alternative was available. It would have been equally practicable to assume that the removed lamb only ate half the amount of the others in the group.

Results and discussion.

The six concentrate mixtures were equally palatable. However, preferential selection of the SBM occurred on both the SBM-supplemented diets. The hay was consumed rapidly within 30 min of being offered. The total DM intakes, live-weight gains and food conversion ratios are presented in Table 50. The results were not analysed statistically due

to the nature of the experiment and the problems encountered.

Table 50. Expt 3.2. Total DM intake (g/day), mean live-weight gains (g/day) and food conversion ratios (kg/kg LWG).

	No limestone			With 1% limestone		
	Nil	LS	SBM	Nil	LS	SBM
Total DM intake	590	570	825	615	679	735
LWG	90	124	197	190	222	200
FCR	6·56	4·60	4·19	3·24	3·06	3·68

There were clear responses in live-weight gain to additional protein (either vegetable protein or NPN) and improvements in food conversion ratios. Giving extra calcium (in the form of limestone) increased live-weight gains (two fold) and improved the food conversion ratios for both the nil and LS treatments. Additional calcium did not increase live-weight gains, but improved the food conversion ratio for the SBM treatment.

The total nutrient intakes of the lambs are detailed in Table 51. The ME and DCP of the dietary constituents were taken from M.A.F.F. et al. (1975). The lambs in the present experiment were given diets supplying a mean of 8·5 MJ ME which was adequate, the feed allowances of 6·8 and 10·4 MJ ME are currently recommended for 20 kg lambs growing at 100 and 200 g/day respectively (M.A.F.F. et al., 1975). The currently recommended intakes for DCP for 20 kg lambs growing at 100 and 200 g/day are 57 and 81 g/day (A.D.A.S., 1976). The amounts of DCP from the nil and nil plus limestone treatments were lower than the recommended intakes for the lambs at their given daily gain. It is therefore interesting to note that the addition of 1% limestone doubled live-weight gains while the DCP intake remained constant. LS supplementation produced live-weight

gains, intakes and food conversion ratios intermediate to the SBM and non supplemented diets.

Blood copper and GOT concentrations were normal throughout the experiment (Table 52).

Table 51. Expt 3.2. The calculated daily intakes of metabolizable energy, digestible crude protein, calcium and phosphorus.

	No limestone			With 1% limestone		
	Nil	LS	SBM	Nil	LS	SBM
ME (MJ)	7·5	7·2	10·6	7·8	8·5	9·3
DCP (g)	41	63	95	43	75	82
Ca (g)	1·3	1·3	1·9	3·8	3·9	4·2
P (g)	2·2	2·2	3·4	2·3	2·6	3·0

The recommended daily intakes of calcium and phosphorus for 20 kg lambs gaining 100 and 200 g/day are 2·4 and 3·6 g Ca and 1·5 and 1·8 g P respectively (A.R.C., 1965). The intakes of calcium on diets without additional calcium were very low (about 1·5 g Ca/day) in relation to the recommended mineral intakes for growing lambs. The phosphorus intakes were more than adequate, all diets supplying 2·2 g P and above per day. There was no indication from the blood samples obtained from the lambs (Table 52) that the concentrations of calcium or phosphorus were abnormally low or that there was any progressive reduction during the growth period. Additional calcium to the SBM treatment did not increase live-weight gains although the daily calcium intake was below the A.R.C. (1965) recommendation. It did, however, improve the food conversion ratio. This may suggest that the additional calcium was not exerting its effect by merely supplying extra calcium to the ration, but by acting as a rumen buffer against a lowered pH in the digestive tract. This is a major problem associated with feeding high concentrate diets to ruminants.

Table 52. Expt 3.2 Mean concentrations of urea, calcium, phosphorus (mmol/litre) copper (mg/kg) and GOT (u/litre in the blood of the lambs.

Weeks	No limestone			With 1% limestone		
	Nil	LS	SBM	Nil	LS	SBM
Urea						
3	1·5	3·7	2·4	1·5	3·6	2·7
6	1·9	3·3	2·7	1·1	2·8	3·3
9	2·6	4·7	3·7	2·0	4·2	4·3
Calcium						
3	2·6	2·4	2·4	2·6	2·6	2·3
6	2·5	2·4	1·9	2·8	2·7	2·6
9	2·4	2·3	1·7	2·7	2·7	2·5
Phosphorus						
3	2·1	2·3	2·4	2·4	2·3	2·3
6	2·2	2·1	2·7	2·5	2·5	2·5
9	2·2	2·1	2·4	2·7	2·6	2·5
Copper						
3	1·2	1·1	1·1	1·0	1·0	1·2
6	1·2	1·2	1·1	1·1	1·2	1·0
9	1·2	1·2	1·0	1·0	1·0	1·0
GOT						
3	63·8	71·8	51·7	55·8	96·9	60·2
6	56·7	53·1	64·1	37·6	37·8	65·7
9	82·6	61·1	60·2	39·0	40·9	42·2

Digestive disorders are often associated with cereal grain feeding of sheep and cattle. These disorders are related to an increased acid concentration in the rumen resulting from the rapid breakdown of the soluble carbohydrate in the grain. Attempts to overcome these acid conditions have included the use of feed additives. Most commonly these have been mineral buffers. Their use has resulted in varied responses in animal productivity, but recent experimental feeding of supplements composed of mixed buffers have shown significant improvements in wheat intakes and live-weight gains of lambs (McManus, Bingham and Edwards, 9172).

The addition of starch or some other form of readily available carbohydrate to a ruminant diet usually decreases the digestibility of the fibrous portion of the ration (e.g. Summers, Baker and Grainger, 1957). White, Grainger, Baker and Stroud (1958) showed that the addition of calcium to lamb diets alleviated the depressing effect of corn oil on digestibility. Davison and Woods (1961) reported that addition of $CaCO_3$ to sheep rations counteracted the depressing effect of starch upon cellulose and organic matter digestibility. These observations infer that calcium levels are important in diets when conditions are favourable for depressed cellulose digestion.

Buffering agents have been used to modify rumen pH for a number of years. Results, however, are contradictory. Bhattacharya and Warner (1968) have discussed the literature on the use of buffers in ruminant diets. Shelton, Huston and Calhouri (1969) have showed improvements in the feedlot performance of lambs given high concentrate diets when a 1 : 1 combination of sodium and potassium carbonates were given as 2% of the diet. Saville, Davis, Willats and McInnes (1973) have also shown the use of buffers to be beneficial when included in high concentrate diets. Herod, Bechtle and Bartley (1977) tested the buffering ability of 23 combinations of compounds <u>in vitro</u> and reported the carbonates and bicarbonates in proper combination were the most promising of the

buffers investigated. Varner and Woods (1972a) used 40 steers and measured the effect of added $CaCO_3$, starch and $CaCO_3$ plus starch upon the digestibility and rumen fermentation when a 30% roughage diet was given. The effect of adding $CaCO_3$ was to increase cellulose digestibility in the basal ration. They suggested that although the function of calcium is not understood it appears to be altering microbial metabolites as judged by the alteration in the proportion of VFA. The addition of $CaCO_3$ decreased protozoa concentrations, increased molar concentrations of rumen acetate and decreased molar concentration of propionate. Wheeler, Noller and Lowrey (1976) reported that steers given all-concentrate rations had large quantities of starch in the faeces with intestinal pH values below neutrality. In contrast Kern, Slyter, Leffel, Weaver and Oltjen (1974) found that steers given an all timothy hay diet had intestinal pH values between 7·0 and 7·3. These observations suggested to Wheeler and Noller (1976) that decreased starch digestion at high intakes may be related in part to a reduced activity of pancreatic alpha amylase in the small intestine due to pH values below the optimal 6·9. Therefore if the intestinal pH of cattle given high energy diets is below 6·9 the addition of buffers capable of increasing intestinal pH should reduce the loss of starch in the faeces and improve feed efficiency. Wheeler and Noller (1976) added limestone buffers to high energy diets for dairy cattle, and found that giving limestone increased faecal pH and feed efficiency and decreased starch losses in the faeces.

In conclusion, it is suggested that the calcium intake from the three treatment diets was probably adequate (in terms of growth requirements), but due to a probable lower pH in the digestive tract, the early age of weaning and the use of whole barley in this experiment that the addition of 1% limestone assisted by its buffering action in increasing live-weight gains and improving food conversion ratios.

Experiment 3.3. Effect of additional limestone on the live-weight gains and food conversion ratios of growing lambs given bruised barley supplemented with LS.

Introduction.

At the end of Expt 3.2 a group of 10 lambs were changed from whole barley diets and were given a mixture of the six dietary treatments but based on bruised barley. The general acceptance of the bruised barley was much better than the whole barley. The purpose of this present experiment was to assess the adequacy of LS supplementation of bruised barley and the effect of additional calcium in the form of limestone on the growth rate of lambs.

Materials and methods.

The lambs were weaned at 6 weeks and housed in open fronted buildings and given ad libitum lamb creep (BOCM Silcock, Lambwena) and hay for 3 weeks. They were then introduced to the experimental diet over a further period of 2 weeks where the lamb creep was gradually replaced by bruised barley supplemented with LS (4%).

A total of 42 lambs were selected (Greyface x Suffolk) and grouped on the basis of live weight (mean initial live weight 18 kg) and sex into 2 groups of 21 lambs (12 females and 9 males/group). The groups were housed in open fronted buildings. One treatment consisted of bruised barley plus 4% LS. The other treatment was bruised barley plus 4% LS plus 1% limestone. Both diets were given ad libitum in feed hoppers which were replenished when necessary. In addition, all the lambs were given 140 g hay (FM)/day (on a group basis). The dietary mixes were made in batches of 40 kg by hand in polypropylene containers. The compositions of hay, barley and LS used are given in Table 53.

The lambs were weighed at 3 and 6 weeks. Feed intake was recorded at 3 and 6 weeks. Blood calcium was monitored at the time of weighing.

Table 53. Expt 3.3. The mean compositions of hay, barley (g/kg DM) and LS (g/kg FM).

	Hay	Barley	LS
Dry matter	823	821	-
Crude protein	86	96	1065
Crude fibre	325	61	-
Ether extract	11	12	-
N-free extract	527	810	-
Ash	51	21	-
Ca	3·2	0·7	30·6
P	1·9	3·1	14·7
pH	-	-	1·8

Blood samples were taken from a representative number of lambs from each group (at the start of the experiment 10 lambs/group were picked at random and their blood calcium monitored at 3 weekly intervals).

During the experiment two lambs contracted pneumonia (both on the LS treatment), these were removed from the experiment. The same procedure for estimating food intake was followed as in Expt 3.2.

Results.

The two dietary treatments were equally palatable and readily consumed. The hay was consumed rapidly within 30 min of being offered. The total DM intakes, live-weight gains and food conversion ratios are presented in Table 54. There were no differences in live-weight gains or food conversion ratios. The total nutrient intakes of the lambs are detailed in Table 55. The ME and DCP of the dietary constituents were taken from M.A.F.F. et al., (1975).

Table 54. Expt 3.3. Total DM intake (g/day), mean live-weight gains (g/day), food conversion ratios (kg/kg LWG) and mean blood calcium concentration (mmol/litre).

	A LS	B LS + limestone	Pooled SEM	Significance
Total DM intake	978	925	n.a.†	
LWG	164	151	11·1	NS
FCR	5·96	6·12	n.a.	-
Blood calcium				
3 weeks	2·3	2·4	0·12	NS
6 weeks	2·3	2·7	0·06	B>A***

†n.a. Not applicable as group-fed.

Table 55. Expt 3.3. The calculated daily intakes of metabolizable energy, digestible crude protein, calcium and phosphorus.

	LS	LS + limestone
ME (MJ)	12·4	11·4
DCP (g)	105	97
Ca (g)	2·2	6·0
P (g)	3·4	3·2

The lambs in the present experiment were given diets which supplied a mean of 11·9 MJ ME which was above the currently recommended allowance of 8·6 MJ ME for 20 kg lambs growing at 150 g/day. The currently recommended intake for DCP for 20 kg lambs growing at 200 g/day is 81 g DCP/day (ADAS, 1976). Both the dietary treatments provided more than adequate intakes of DCP. The recommended daily intakes of calcium and phosphorus for 20 kg lambs gaining 100 and 200 g/day are 2·4 and 3·6 g Ca and 1·5 and 1·8 g P respectively (A.R.C., 1965). Both groups of lambs

were growing at about 150 g/day and therefore requirements would be intermediate. The phosphorus intakes were more than adequate both diets supplying a mean of 3·3 g P/day. The calcium intake on the LS plus limestone treatment was 6·0 g/day, and 2·2 g/day on the LS treatment. This smaller amount was adequate as there were no responses either in live-weight gain or food conversion to the additional calcium supplied by the limestone.

There was no indication from the blood samples obtained (Table 54) that the concentrations of calcium were abnormally low. However, by 6 weeks the blood calcium concentrations of the lambs given the LS plus limestone treatment were significantly higher than the group without limestone.

Discussion.

In this experiment there was no response to additional calcium in either increased feed intake or increased food conversion ratios, both were similar. The A.R.C. (1965) recommendations are 2·4 and 3·6 g Ca/day for 20 kg lambs gaining 100 and 200 g/day. The lambs on this experiment received 2·2 and 6·0 g Ca/day for the LS and LS plus 1% limestone treatments respectively and gained about 150 g/day. Calcium intakes were, therefore, adequate on the LS supplemented diet which partly explains the reason for no response to extra calcium in the form of limestone.

Recent work with lambs from 5 - 70 days of age has defined the calcium requirements in these animals. Hodge (1973) found that an intake of 250 mg Ca/kg body weight/day was adequate for young lambs slaughtered at an early age. The estimated requirements for calcium (Hodge, 1973) for young lambs gaining at a rate of 100, 200, 300 and 400 g/day were 1·0, 1·9, 2·9 and 3·9 g/day for 10 kg lambs and 1·2, 2·4, 3·6 and 4·8 g/day for 18 kg lambs. These are lower than the A.R.C.

(1965) recommendations, and within the range of intake received by the lambs in this experiment.

In Expt 3.2, it was discussed how the limestone may have acted as a buffer resulting in increased live-weight gains and improved food conversion ratios. When high grain diets are given an increased acid concentration occurs in the rumen resulting from the rapid breakdown of soluble carbohydrate in the grain. It would be expected that the soluble carbohydrate in bruised grain would be broken down more rapidly than when whole grain was given and, therefore calcium buffers would have a greater effect when given to animals receiving bruised grains as opposed to whole grains. However, in this present experiment and Expt 3.2 the opposite happened. Calcium requirements are related to a number of factors which include phosphorus and vitamin D status, density of the ration (if Ca requirement is expressed in terms of % of dietary intake), level of performance (rate of gain, or amount of milk produced), age of animal, amount of fat in the diet, species of animal and the solubility and digestibility of the Ca source (milk vs. mineral supplementation vs. plant sources). It is the latter fact which is believed to be important in explaining why additional limestone gave a response in Expt 3.2 and not in Expt 3.3. In Expt 3.3 the total DM intakes for LS and LS plus limestone respectively were 978 and 925 g/day while for Expt 3.2 570 g/day and 679 g/day. The mean initial live weights for Expt 3.3 were 18 kg and for Expt 3.2 14·4 kg, both being weaned at 6 weeks. This difference in initial live weight could not have been the sole reason for the difference in the total DM intakes of the lambs on both the experiments.

In Expt 3.2 due to the lower intake of barley less Ca was present however, it can be postulated that the lower intake was due to the nature of the barley. The general acceptance of the bruised barley was much

better than the whole barley. Although no whole barley grains were evident in the faeces of lambs in Expt 3.2, the whole barley would be less digestible to the animals at such an early stage in ruminant life and the calcium therein less available. This is probably why a response in increase live-weight gains and food conversion ratios occurred in Expt 3.2 and not Expt 3.3. This would exclude the possibility that the limestone was acting as a buffer in either this experiment or Expt 3.2. However, these assumptions are speculative due to the nature of Expt 3.2 and the disease problems encountered.

Experiment 3.4. The effect of limestone addition upon the growth rate and voluntary intake of LS supplemented barley by Hereford cross cattle.

Introduction.

Cereal diets are low in the amount of calcium they provide. To maintain an adequate intake of calcium growing beef cattle require a supplementary calcium source if the diet contains a high proportion of cereal.

The purpose of this experiment was to assess the adequacy of LS supplementation to growing steers with particular reference to the calcium content of the diet.

Materials and methods.

Twenty Hereford cross steers were brought in from grass and weaned in late October (mean age 9 months). The animals were eventually to be given ad libitum one of two differently supplemented bruised barley diets. Due to the digestive disorders associated with an abrupt change to a cereal diet the animals on housing were given ad libitum hay and individually given progressively increased amounts of concentrates, the hay being gradually decreased over a period. This dietary change over is summarized in Table 56.

Once the animals had become accustomed to the experimental diet, they were paired into two balanced groups each of ten animals (mean live weight, 280 kg).

Each group of 10 steers was given 0·75 kg hay (FM)/day on a group basis together with one of the two differently supplemented bruised barley (treated with propionic acid) diets. One group received bruised barley plus 4% LS, while the other received bruised barley plus 4% LS and 1% limestone. The composition of the oat straw, barley and LS are detailed in Table 57. The diets were hand mixed and made up in batches of 80 kg and stored in bins holding up to 400 kg at one time. The

animals were bedded on poor quality wheat straw. The concentrate mixtures were given in ad libitum hoppers which were replenished 2 to 3 times/day so that at least 20% more than the anticipated ad libitum consumption was available.

Table 56. Expt 3.4. The feeding regime for the gradual change over to a cereal diet from a high roughage diet.

Day	Intake: Hay (kg/head/day) group fed	Intake: Concentrates (kg/head/day) given individually+
1-5	ad libitum	nil
5-9	2·0	0·5 - 1·0
9-14	2·0	1·0 - 2·0
14-19	1·0	2·0 - 3·0
19-23	1·0	3·0 - 4·5
23-26	1·0	4·5 - 5·0
27	1·0	Changed to full ad libitum feeding
29	1·0	ad libitum
35	0·75	"

+split into 2 to 3 feeds/day.

Between days 1-35 the concentrate mixture began at 60% barley, 20% SBP and 20% siftings + 1% LS and was gradually changed to 100% barley + 4% LS.

Feed intake was recorded at 3 weekly intervals, at the same time the animals were weighed and blood samples were taken for analysis for calcium, phosphorus and urea.

Table 57. Expt 3.4. The mean compositions of hay, barley (g/kg DM) and LS (g/kg FM).

	Hay	Barley	LS
Dry matter	775	732	-
Crude protein	88	103	1073
Crude fibre	423	75	-
Ether extract	6	9	-
N-free extract	385	788	-
Ash	98	.25	-
Ca	2·9	0·7	29·7
P	2·8	3·6	14·6
pH	-	-	1·6

Results.

The two experimental diets were well consumed. There were clear and significant responses in live-weight gains to the addition of limestone and improvements in food conversion ratios (Table 58), over a 15 week period. Fig.12 details the growth rate of the animals to 15 weeks. After 15 weeks 7 steers were removed from the experiment and sold as finished cattle. At 21 weeks the experiment was terminated and the remaining 13 steers were sold, a further 8 as finished cattle and 5 as store cattle. Table 59 details the mean live weight and number of animals sold as finished or as stores for each dietary treatment.

At the end of 21 weeks a total of 9 steers (mean live weight 440 kg) and 6 steers (mean live weight 427 kg) which had received the LS + limestone and LS treatments respectively had been sold as finished cattle.

Table 58. Expt 3.4. The mean initial live weight (kg), live-weight gains (kg/day) and food conversion ratios (kg/kg LWG) (on a total DM basis).

	A LS	B LS+limestone	SED	Significance
Initial live weight	280	280		
Live-weight gain/day	0·87	1·18	0·088	B>A**
Food conversion ratio	6·76	5·85	n.a.+	

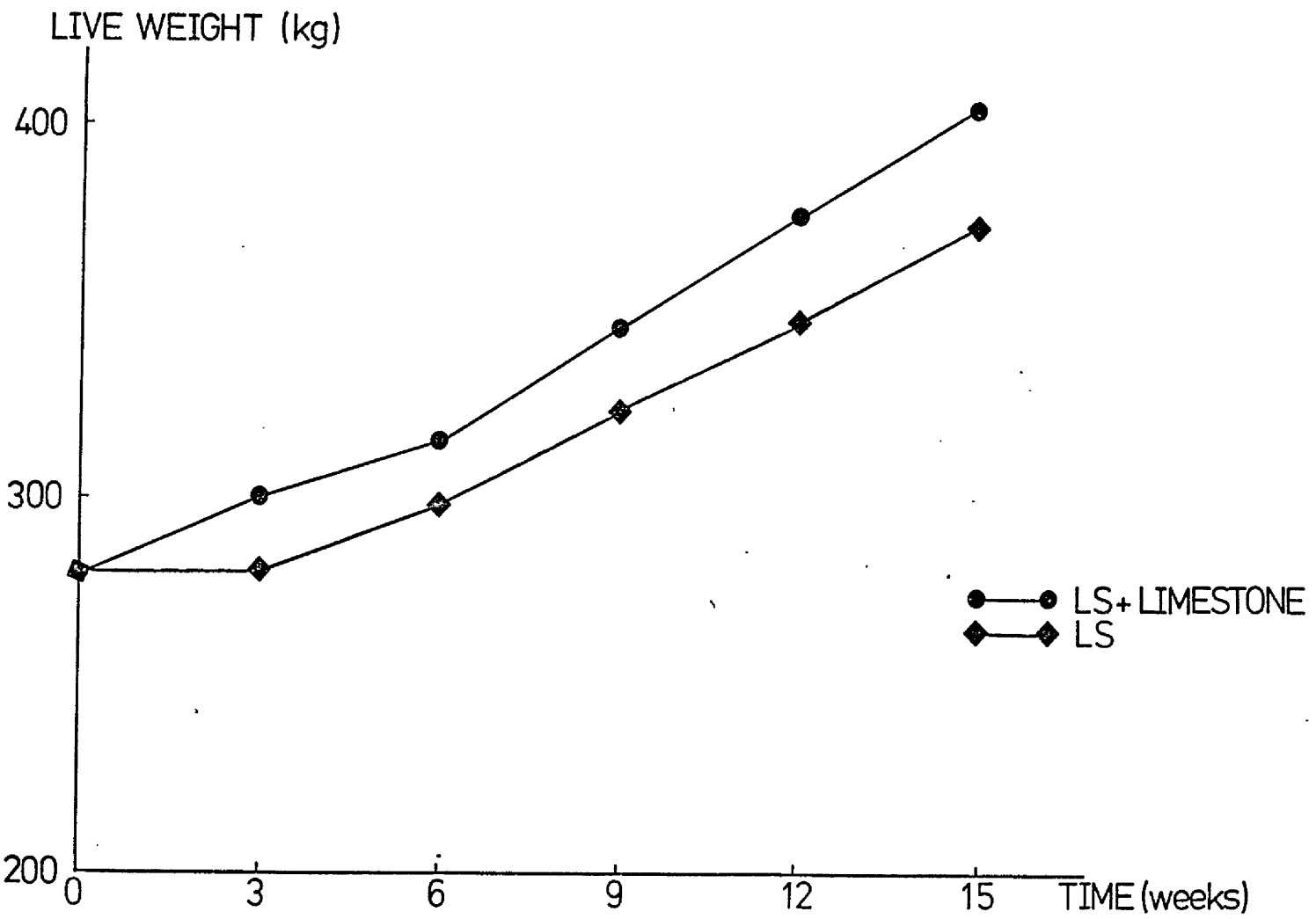
+n.a. Not applicable as group-fed.

Table 59. Expt 3.4. The mean live weight (kg) and number of steers sold as finished or store animals.

	A LS			B LS + limestone		
	no.	live weight	class	no.	live weight	class
15 weeks	2	426	finished	5	437	finished
21 weeks	4	427	finished	4	443	finished
	4	379	store	1	380	store
Overall	6	427	finished	9	440	finished
	4	379	store	1	380	store

The mean concentrations of calcium, phosphorus and urea in the blood of the steers are presented in Table 60. Additional limestone did not influence the concentrations of calcium or phosphorus in the blood of the steers which would be considered normal throughout. There was a progressive increase in blood urea concentrations during the experiment. This was reflected in the increase in barley consumption as the

Fig.12. Expt 3.4. Live-weight gains during the first 15 weeks of the experiment (mean of 10 animals).


LIVE WEIGHT (kg)
400
300
200
0
3
6
9
12
15
TIME (weeks)
LS+ LIMESTONE
LS

experiment progressed. At 9 and 12 weeks the blood urea concentrations of the animals given the LS + limestone diet were significantly higher than for the animals given the LS treatment.

Table 60. Expt 3.4. The mean concentrations of calcium, phosphorus and urea (mmol/l) in the blood of the steers.

		Weeks					
Blood	Supplement	0	3	6	9	12	15
Calcium	LS	2·6	2·5	2·5	2·6	2·5	2·7
	LS+limestone	2·6	2·5	2·6	2·7	2·5	2·6
	SED	0·06	0·05	0·04	0·05	0·04	0·05
Phosphorus	LS	1·7	2·4	2·6	2·7	2·9	2·7
	LS+limestone	2·0	2·4	2·5	2·6	2·8	2·5
	SED	0·13	0·16	0·12	0·10	0·16	0·13
Urea	LS	3·0	4·3	5·0	$5·5^{b}$	$5·9^{a}$	6·2
	LS+limestone	2·8	4·0	5·2	$7·2^{b}$	$6·9^{a}$	5·7
	SED	0·36	0·36	0·42	0·27	0·39	0·86

Means followed by the same letter are significantly different: a ($P<0·05$); b ($P<0·001$).

Table 61 details the calculated daily intakes of digestible crude protein, calcium and phosphorus and the current recommended requirements. The requirements for digestible crude protein and phosphorus are adequately met by the given intakes. However only the calcium intake from the LS + limestone treatment met the currently recommended intake. The LS treatment supplied 14·6 g/day, while the recommended intake for the given live-weight gain (A.R.C., 1965) is 31 g Ca/day. The ME intakes were 75 and 87 MJ/day (calculated using

M.A.F.F. et al., 1975) for the LS and LS + limestone treatments respectively. Using the equation Total ME allowance = Mm + Mg (where Mm = ME maintenance allowance and Mg = ME for body gain) (M.A.F.F. et al., 1975), the calculated ME allowances for the fattening cattle were 60 and 74 MJ/day for the LS and LS + limestone treatments respectively. These requirements were calculated using the actual daily live-weight gain and energy concentration of the ration for each treatment. Applying these ME requirements it can be concluded that the daily live-weight gains were adequate for the ME intakes.

Table 61. Expt 3.4. The calculated daily intakes of digestible crude protein, calcium and phosphorus (g) and the current recommended requirements for 300 kg growing cattle for the attained live-weight gains.

	LS		LS + limestone	
	Intake	Requirement+ at 0·87 kg LWG	Intake	Requirement at 1·18 kg LWG
DCP	753	512	885	570
Ca	14·6	31	52·2	35
P	25·6	19	28·8	21

+DCP requirements Roy (1958); Ca and P requirements A.R.C. (1965).

Discussion.

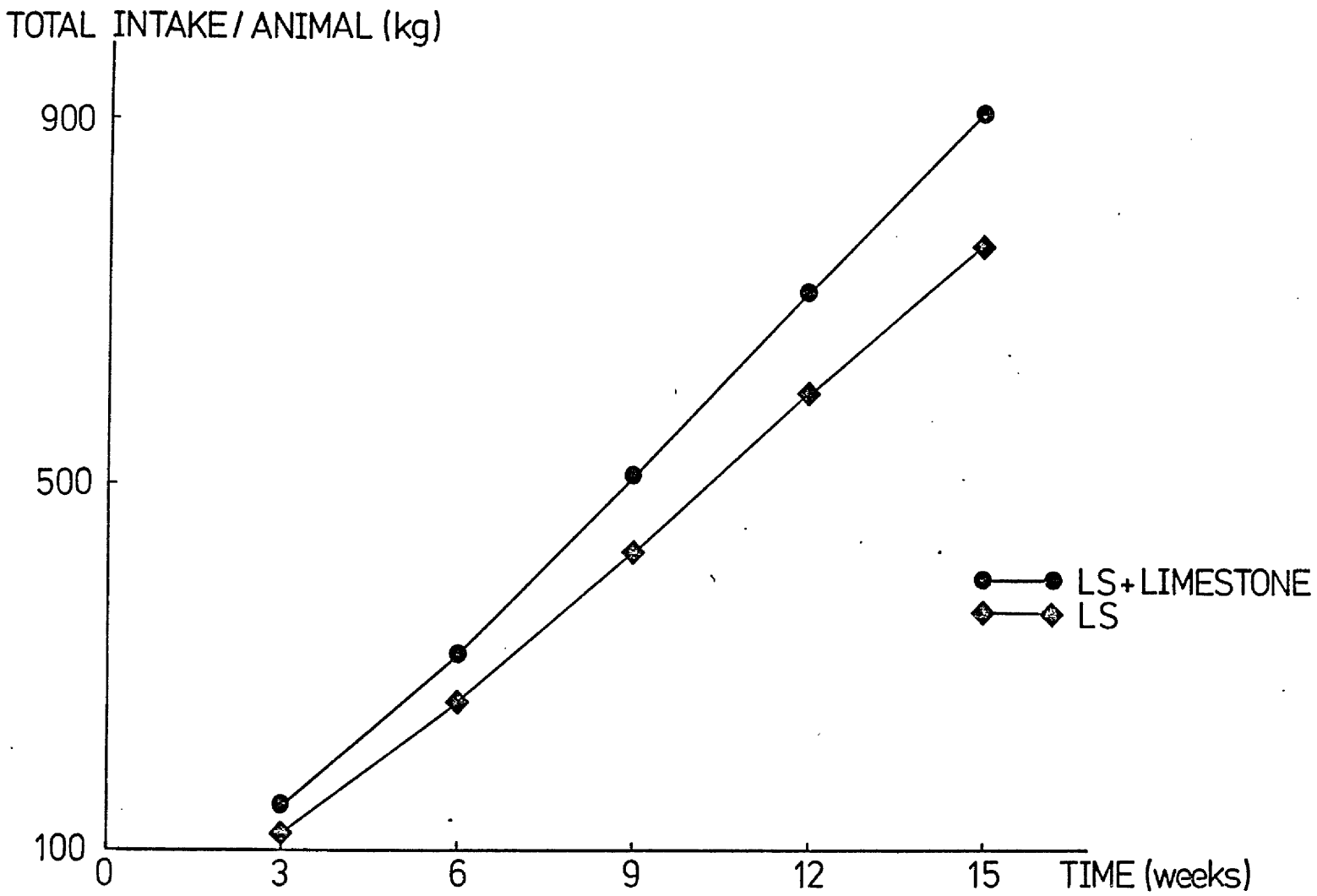
There were significant responses in live-weight gains to the addition of limestone and improvements in feed conversion ratios. At the end of 21 weeks 90% and 60% of the steers had been sold as finished from the LS + limestone and LS treatments respectively.

Fig.12 details the growth rate of the steers to 15 weeks. During weeks 0 to 3 the mean live weight of the steers given the LS only treatment remained relatively constant, a growth rate of 0·05 kg/day

compared with 0·97 kg/day for the LS + limestone group. Fig.13 details the total barley plus supplements (FM) consumed/animal during the first 15 weeks of the experiment. Throughout the experiment the LS group consumed less barley than the group given the LS + limestone supplement. If the growth rates of the steers are calculated between weeks 3 to 15, the growth rates are 1·10 and 1·23 kg/day compared with 0·87 and 1·18 kg/day for the LS and LS + limestone treatments respectively. The growth rates between weeks 3 to 15 are not significantly different. The question arises as to why the LS supplemented animals failed to grow in the first 3 weeks of the experiment. Barley (plus supplements) intakes for the first 3 weeks for both treatments were similar 119 and 148 kg FM/head for the LS and LS + limestone treatments respectively. After 3 weeks the LS + limestone consistently consumed more barley and the difference in intake increased throughout the experiment (Fig.13). The method of dietary change-over at the beginning of the experiment was such that the steers were gradually introduced to LS. It would therefore be assumed that if any dietary up set was to occur it would have been the LS + limestone group, as they were abruptly changed to limestone at the beginning of the experiment. However, there were significant responses in live-weight gains to the addition of limestone and improvements in feed conversion ratios, and 90% of the steers were sold as finished from the LS + limestone compared with only 60% for the LS treatment. Whether these responses would have been as large if the initial "lag" period had not occurred for the LS group, is a matter of speculation, which could only be answered by repeating the experiment.

Table 61 details the intakes and current recommended requirements of digestible crude protein, calcium and phosphorus. The requirements for digestible crude protein and phosphorus were adequately met by the given intakes. The proportion of the intake of digestible crude protein, calcium and phosphorus supplied by LS and the proportion supplied by the

Fig.13. Expt 3.4. Total intake (Barley plus supplements kg FM)/animal during the first 15 weeks of the experiment (mean of 10 animals).


TOTAL INTAKE / ANIMAL (kg)
900
500
100
0
3
6
9
12
15
TIME (weeks)
LS + LIMESTONE
LS

rest of the diet are presented in Table 62. The rest of the diet (i.e. barley, hay, ± limestone) provided adequate phosphorus intakes for both groups of animals. The rest of the diet only provided adequate calcium for the animals given the LS + limestone treatment. Both the treatment diets provided about 70 g DCP less than the current recommended requirements for the given live-weight gains. Supplying LS at 4% to both treatment diets supplied about 50 % more DCP than the current recommended requirements. Therefore the addition of 4% LS was wasteful in respect of the digestible crude protein and phosphorus additions, and the calcium content only increased the total daily intake to 50% of the current required intake. Further work is required to ascertain whether the addition of LS is necessary in respect of supplying additional protein and at what concentration the addition would be optimal. It is apparent that the LS addition is inadequate in supplying calcium in this kind of production diet. The addition of limestone (1%) supplies adequate calcium which is necessary for optimum growth as demonstrated by the response in growth rate.

Table 62. Expt 3.4. The proportion of the intake of digestible crude protein, calcium and phosphorus (g) supplied by LS and the proportion supplied by the remainder of the diet.

	Diet	LS	LS+limestone
DCP	LS	312	370
	Remainder	441	515
Ca	LS	8·6	10·3
	Remainder	6·0	41·9
P	LS	4·3	5·1
	Remainder	21·3	23·7

The N.R.C. (1976) reported that finishing steers require from 0·18 - 1·04% calcium in the dry matter of their diet depending on the energy concentration of the feed given. Varner and Woods (1972b) reported that steers given a high concentrate diet containing 0·31% Ca had higher mean daily live-weight gains and food conversion efficiencies than steers given a basal diet containing 0·20% Ca. Increasing the calcium levels to 0·41% resulted in further increases in animal performance. In this present experiment the steers received 0·25 and 0·76% Ca in the total dry matters of the LS and LS + limestone treatments respectively. Bushman, Embry, Luther and Emerick (1967) reported no significant differences in mean daily gains when cattle were given all-concentrate diets containing 0·15, 0·30 or 0·60% calcium.

The use of buffers in high concentrate diets have already been discussed and the report of Wheeler et al. (1976) which discussed how steers given all concentrate rations had considerable quantities of starch in the faeces with intestinal pH values below neutrality. Wheeler and Noller (1976) found that the addition of magnesium limestone decreased the starch in the faeces from 5·60 to 1·14% when given to dairy heifers. However, at 15 weeks in the present experiment random samples of faeces were taken from each group and bulked for starch analysis. The concentration of starch present in the faeces was 0·37 and 0·53% for the LS and LS + limestone treatments respectively. This extremely low concentration of starch in the sample from both treatments would indicate that the 1% limestone addition was improving feed conversion efficiency and daily gain by supplying extra calcium and not by acting as a buffer. A future experiment would be to have four treatments, in addition to the present 2 treatments one group with no addition of LS and one group given sodium bicarbonate $\pm$ LS.

Experiment 3.5. The effects of dietary phosphorus inadequacy during pregnancy and lactation on the voluntary intake and digestibility of oat straw by beef cows and the performance of their calves I.

Introduction.

The purpose of this experiment was to examine the adequacy of the phosphorus content of LS in supplementing a diet which was low in phosphorus when given to pregnant and lactating beef cows and its effect on the voluntary intake and digestibility of oat straw and the performance of their calves. Molassed sugar beet pulp (SBP) is an ideal concentrate to provide a low phosphorus diet. SBP is a carbohydrate-rich by product of the sugar industry, it is high in fibre for a concentrate and deficient in fat, phosphorus, carotene and certain B-vitamins (Morrison, 1959).

The first evidence of phosphorus inadequacy is a reduction in plasma phosphorus below the normal values of about 1·9 to 2·6 mmol/litre for young cattle and about 1·2 to 1·9 mmol/litre for adult cattle. Later the mineral content of the bones may be reduced. The joints become stiff and lameness may develop. However, reduced appetite may often be the first clinical symptom of phosphorus deficiency. Reduced roughage intake due to phosphorus deficiency has been demonstrated, for example, by Playne (1969) with sheep given low-phosphorus lucerne, Little (1968) with cattle and Fishwick et al. (1977) with beef cows given straw.

The phosphorus requirement of any animal would depend upon the phosphorus status of that animal (Cohen (1980) a review). Phosphorus turnover is an important factor in calculating the phosphorus requirement of an animal. Phosphorus turnover is governed by 4 mechanisms. I Salivary phosphorus:- The daily turnover of phosphorus in ruminant saliva is similar to or greater than daily phosphorus intake. II Phosphorus absorption:- The main site for absorption being

the small intestine and transport is both active and passive diffusion. III Phosphorus excretion:- In the non-lactating ruminant, the faeces are the major vehicle for the excretion of phosphorus (Barrow and Lambourne, 1962). However, in the lactating ruminant the major source of loss of endogenous phosphorus is in the milk, because the phosphorus content of milk is independent of phosphorus intake, phosphorus concentration in the milk remains constant. IV Accretion and resorption of phosphorus in bone:- The rate of bone deposition is adjusted in response to changes in nutrition and in response to the onset of lactation (Ramberg, Kronfeld, Phang and Berman, 1970). In normal circumstances, the accretion and resorption of phosphorus in a well nourished animal is in dynamic equilibrium. In phosphorus deficiency the mature animal appears to lose its ability to adjust its rate of bone accretion (Braithwaite, 1975). Thus there is a higher rate of phosphorus turnover in the mature animal when given a low phosphorus diet. In cases of severe phosphorus depletion about 40% of the bone mineral of ewes can be mobilised in pregnancy and lactation to meet the animals phosphorus requirements (Benzie, Boyne, Delgarno, Duckworth and Hill, 1959).

Materials and Methods.

Ten beef cows, principally Hereford cross of mean live weight 477 kg and mean body condition score 2·5 (Lowman et al., 1973) were individually housed in a byre. The cows were on average 15 weeks from calving at the onset of the experiment. Following an initial acclimatization period of 2 weeks when the cows were given oat straw ad libitum and 2 kg FM SBP, the cows were arranged into two groups each of five animals according to live weight, body condition score and expected calving date.

Each group of five cows were given oat straw ad libitum together with one of two differently supplemented SBP concentrates. Dietary treatment A consisted of 2 kg FM SBP supplemented with an equivalent amount of minerals/vitamins/trace elements and urea to that present in 250 g LS, but excluding phosphorus. Dietary treatment B consisted of 2 kg FM SBP supplemented with 250 g of LS (poured onto the SBP at the time of feeding). The amounts of SBP which the cows received were increased during the experiment from 2 kg FM/day (during pregnancy) to 3 kg FM/day (during lactation).

In each case the minerals in diet A were supplied as calcium carbonate and sodium chloride plus urea and a trace element/vitamin supplement identical to that used in LS (supplied by the manufacturer). The SBP concentrates were given in one feed/day (07.30 h) and the oat straw three times/day (08.00, 12.00 and 16.00 h) or as required. Voluntary straw consumption was recorded on three occasions during pregnancy (between weeks 12 - 11, 6 - 5 and 3 - 2 before calving) and twice during lactation (between weeks 2 - 3 and 5 - 6 after calving), straw residues being collected daily. At the same time estimates of digestibility were made using chromic oxide. Chromic oxide (10 g) was added to the SBP for 7 consecutive days prior to and on each of the subsequent 7 days when straw intake was recorded.

Samples of oat straw, SBP and LS were taken weekly. In addition samples of oat straw and SBP were taken daily over each collection period. The results of analyses are presented in Table 63. During the last 6 days of each recording period rectal grab samples of faeces were obtained from each animal at 07.30, 11.30 and 16.00 h. The faeces were bulked during the collection period, the results of the analyses were used to calculate the digestibilities of the diets.

Table 63. Expt 3.5 The mean compositions of oat straw, sugar beet pulp (g/kg DM) and LS (g/kg FM).

	Oat straw	SBP	LS
Dry matter	830	846	-
Crude protein	34	106	1080
Crude fibre	443	136	-
Ether extract	6	4	-
N-free extract	465	676	-
Ash	52	78	-
Ca	2·7	4·3	30·5
P	0·7	0·7	15·3
pH	-	-	1·6

The cows were weighed and an assessment made of their body condition score at the start of the experiment and at 3 weekly intervals, when blood samples from the jugular vein were also obtained (for analysis for calcium, phosphorus and urea). Additionally, the cows were weighed 2-3 days before and 2-3 days after calving.

Before calving the cows were removed from the byre and placed in individual loose boxes, where they calved. The cows remained in the loose boxes for 2-3 days and appropriate husbandry measures were employed to ensure intake of colostrum and the development of the cow/calf relationship. The cows and calves were then returned to the byre. The calves were tied individually behind the cows, on raised slats (Plate 2). The calves were released to suckle to satiation three times/day, in addition to this a minimum amount of hay was provided to help stimulate rumen function. The live weights of the calves were recorded at birth, 3 and 6 weeks, when blood samples from the jugular vein were also obtained. The cows continued to receive their appropriate diets

Plate 2a. Expt 3.5. The calves tied individually behind the cows on raised slats .

Plate 2b. Expt 3.5. The cows in their individual standings, (08.00 h) the straw residues have been removed, the SBP given and the calves released to suckle.


8

until transfer to grass in late May. This occurred at a mean of 63 days after calving. On transfer to grazing a Hereford bull fitted with a chin-ball marking device (Universal livestock Services, Banbury, Oxfordshire) was introduced and service dates were recorded. Blood samples were taken twice weekly for the first fortnight at grass, then once a week for a further 2 weeks.

Results.

During pregnancy, at -12 to -11 and -3 to -2 weeks before calving there were no significant differences between treatments in either the voluntary intake or the digestibility of the oat straw (Table 64). However during weeks -6 to -5 the intake of oat straw by the animals given the LS supplement was 5·82 kg which was significantly ($P < 0.01$) greater than the animals given no supplementary phosphorus (5·00 kg). During lactation there were no significant differences between treatments in either the digestibility or voluntary intake of oat straw. However, there was a consistent trend in that the straw intake of the animals given the LS supplement was greater than that of the no-P-supplemented animals. The difference was non significant because of large individual differences in intake. In late pregnancy the digestibility of the diet tended to decrease. After calving this effect was reversed for both treatments.

Supplementation with extra phosphorus (in the form of LS) had no effect on the voluntary intake or digestibilities of the diet. The amounts of crude protein, phosphorus and calcium provided are detailed in Table 65.

It was apparent after 3-4 days after the commencement of the experiment that one animal on the no-P-supplemented diet would not consume the alloted amount of SBP. For this reason the animal was removed leaving 4 animals receiving the low phosphorus diet.

Table 64. Expt 3.5. Mean voluntary intakes of oat straw (kg DM/day) and the digestibility coefficients of the DM and OM.

	Weeks before (-) or after (+) calving				
	-12 to -11	-6 to -5	-3 to -2	+2 to +3	+5 to +6
Straw DM intake					
No-P-supplement	4·48	5·00[a]	5·19	5·33	5·27
LS supplement	4·87	5·82[a]	4·89	6·53	6·86
SED	0·461	0·224	0·420	0·548	0·943
	Digestibility of DM				
Complete diet					
No-P-supplement	0·48	0·44	0·39	0·46	0·47
LS supplement	0·47	0·53	0·39	0·47	0·47
SED	0·051	0·067	0·044	0·050	0·081
	Digestibility of OM				
Complete diet					
No-P-supplement	0·49	0·46	0·41	0·48	0·48
LS supplement	0·48	0·55	0·41	0·49	0·48
SED	0·167	0·068	0·046	0·050	0·086
Straw alone†					
No-P-sipplement	0·36	0·34	0·27	0·33	0·42
LS supplement	0·43	0·47	0·27	0·35	0·35
SED	0·658	0·087	0·056	0·070	0·078

Means followed by the same letter are significantly different

a ($P < 0·01$)

†Digestibility of the OM of SBP taken as 84%.

Table 65. Expt 3.5. The amounts of crude protein, phosphorus and calcium supplied by the SBP, oat straw supplements and recommended requirements (g/day).

	Weeks before (-) or after (+) calving			
	-12 to -11		+5 to +6	
	A	B	A	B
	No-P-supplement	LS supplement	No-P-supplement	LS supplement
Crude protein	607	617	724	773
Phosphorus	4·3	8·4	5·5	10·4
Calcium	26·8	28·0	32·6	37·0

Requirements

	Month of pregnancy		Lactation
	6	9	(7·5 kg milk/day)
Phosphorus[+]	26·4	33·5	35·0
Calcium[+]	20·2	33·3	39·0
DCP[++]	430		827

[+]A.R.C. (1965); [++]A.D.A.S. (1976).

The mean live-weight gain of the cows during the 15 weeks before calving was 14 kg (no-P-supplement) and 12 kg (LS supplemented) and this difference between treatments was not significant (Table 66). Table 66 also details the calf live weight data. There was no significant difference between treatments in mean calf birth weights which at about 34 kg were greater than the live-weight gain of the cows during pregnancy. This infers that the live-weight gain of the cows during pregnancy was inadequate. This is further supported by the decline of about 0·9 - 1·2 in body condition score which was similar for both groups. However, during the first 6 weeks of lactation the cows given

LS lost a total of 25 kg live weight compared with a loss of 36 kg live weight where no-P-supplementation was provided. The marked reduction in live weight (non significant) during lactation of the cows given the diet with no-P-supplementation was associated with a continuing (but non-significant) reduction in body condition score. In contrast the animals given LS started to increase in condition after calving.

Table 66. Expt 3.5. Changes in live weight (kg) and body condition score of the cows and birth weight and live weight gain (kg) of their calves to 6 weeks.

Weeks before(-) or after(+) calving	Cow live weight			Cow body condition score		
	No-P-supplement	LS supplement		No-P-supplement	LS supplement	
-15	472	482		2·5	2·5	
-12	476	495		-	-	
- 6	474	489		-	-	
- 3	477	488		-	-	
At calving	485	494		-	-	
After calving	431	447		1·6	1·3	
+ 3	412	428		-	-	
+ 6	395	422		1·4	1·5	
	Change in live weight and body score					
			SED			SED
-15 to calving	+14	+12	6·3	-0·9	-1·2	0·7
Calving to +6	-36	-25	14·0	-0·2	+0·2	0·9
Calf live weight						
Birth	33·8	33·7				
+ 3	48·5	51·7				
+ 6	65·5	67·7				
Live-weight gain	31·8	34·0	38·9			

Table 67. Expt 3.5. The mean concentration of phosphorus, calcium and urea (mmol/litre) in the blood of the cows during pregnancy and lactation and in the blood of the calves.

	Weeks before (-) or after (+) calving							
Cows	-15	-12	-6	-3	0	+3	+6	+9
Phosphorus								
No-P-supplement	1·73	1·31[e]	1·53	1·13[a]	0·98	1·12	1·01	0·74[b]
LS supplement	1·55	1·91[e]	1·81	1·73[a]	1·31	1·48	1·8	1·23[b]
SED	0·277	0·132	0·174	0·207	0·259	0·269	1·484	0·183
Calcium								
No-P-supplement	2·60	2·62	2·54	2·59[f]	2·49	2·66[c]	2·64	3·15
LS supplement	2·55	2·57	2·47	2·45[f]	2·46	2·51[c]	2·29	2·80
SED	0·051	0·085	0·050	0·042	0·140	0·058	0·170	0·176
Urea								
No-P-supplement	4·35	6·45	5·68	6·41	7·34	4·12	5·58	5·40
LS supplement	4·76	5·82	6·26	6·54	5·60	4·48	5·30	4·14
SED	0·554	0·733	0·876	0·941	0·907	0·603	0·795	0·517
Calves								
Phosphorus					2·86	3·01	2·56	2·80
No-P-supplement					2·38	2·68	2·82	2·82
LS supplement					0·309	0·180	0·177	0·102
SED								
Calcium								
No-P-supplement					3·11	3·08	2·95	3·45
LS supplement					2·82	2·92	2·61	3·40
SED					0·163	0·127	0·230	0·205
Urea								
No-P-supplement					5·31	2·63	2·56	1·75
LS supplement					4·67	3·81	3·10	2·23
SED					0·761	0·863	0·410	0·284

Means followed by the same letter are significantly different

a,b,c ($P<0·05$); e,f ($P<0·01$).

The mean daily live-weight gain to 6 weeks of the calves in the no-P-supplemented group was 0·76 kg/day and in the LS supplemented group was 0·81 kg/day (not significantly different).

The mean blood concentrations of phosphorus, calcium and urea for the cows in pregnancy and lactation and for the calves are given in Table 67. Normal blood phosphorus concentrations were maintained throughout both pregnancy and lactation when additional P was given. Blood phosphorus concentrations on the no-P-supplemented diet were normal, but lower than the other animals until 6 weeks after calving. At 9 weeks after calving blood phosphorus concentrations were beginning to fall. However at 9 weeks the animals were turned out to graze to allow re-mating with the bull. Blood phosphorus concentrations were significantly lower, but normal at -12, -3 and +9 weeks than for the LS-supplemented animals. At grass the blood phosphorus concentrations of all the cows increased steadily. After 4 weeks at grass the blood phosphorus concentrations were 2·12 and 1·93 mmol/litre for the cows that had previously received the no-P-supplemented and the LS supplemented diets.

Blood calcium concentrations remained normal throughout the experiment. However at -3 and +3 weeks the blood calcium concentrations of the no-P-supplemented cows were significantly higher. This normally reflects the change in blood phosphorus concentrations in that when blood phosphorus concentrations are reduced because of dietary P inadequacy there is an associated increase in calcium concentrations. However, in this situation although the blood phosphorus concentrations were lower on the no-P-supplemented diet they were still normal.

Blood urea concentrations were similar for both treatments.

Blood calcium, phosphorus and urea concentrations were normal and similar for both groups of calves.

None of the cows were ovulating prior to transfer to grass. After a mean period of 20 days (LS supplemented) and 22 days (no-P-supplement) following introduction of the bull, all the cows had been served. All four cows which had previously been given the no-P-supplement conceived to one service compared with four cows given the LS supplement. One cow in the LS-supplemented returned to the bull, but was successfully mated. One cow given the low phosphorus diet apparently conceived to one service, was diagnosed pregnant, but later lost the foetus.

Discussion.

The mean amounts of oat straw and SBP eaten/day by the cows over the 24 week experimental period were such that their total phosphorus intakes were about 4·6 g P/day (no-P-supplement) and 8·6 g P/day (LS supplement) during pregnancy and 5·5 g P/day (no-P-supplement) and 10·3 g P/day (LS supplement) during lactation. In comparison, the recommended (A.R.C., 1965) intake of phosphorus for a 480 kg cow in the 6th - 9th months of pregnancy is 26·4 increasing to 33·5 g P/day with 35 g P/day during lactation (assuming a daily milk yield of 7·5 kg). In spite of the greatly reduced phosphorus intake of the cows given both the diets, digestibility or voluntary intake of oat straw were not adversely affected during the last 15 weeks of pregnancy and the first 9 weeks of lactation. This is in direct conflict with the findings of Fishwick et al. (1977). This group of workers gave two groups of nine pregnant beef cows similar diets composed of ad libitum oat straw together with one of two differently supplemented SBP concentrates during the last 16 weeks of pregnancy and the first 6 weeks of lactation. The mean amounts of oat straw and SBP eaten/day by the cows over the 22 week experimental period were such that their total phosphorus intakes were about 27 g P/day and 12·5 g P/day during pregnancy and 29 g P/day and 12 g P/day during lactation for a phosphorus supplemented and non-

supplemented diet respectively. They found that during pregnancy that both diets, even the one with the severely reduced phosphorus intake did not reduce either calf birth weight or the digestibility and voluntary intake of the straw. However, the low phosphorus diet (~12 g P/day) resulted in a significant decline in voluntary straw consumption and digestibility during lactation. This was accompanied by an increased weight loss in the cows and a depression in their milk yield such as to significantly reduce calf live-weight gain. The low phosphorus diet also resulted in a significant reduction in the concentration of phosphorus in the blood.

The low phosphorus diet of Fishwick et al. (1977) supplied the cows on average 12 g P/day, while the present LS supplemented diet only supplied a maximum of 10·3 g P/day during lactation. The cows on both the diets in this present experiment did not show any signs of phosphorus inadequacy even though they were given the diets over an extended period of 24 weeks.

Straw intake was not significantly depressed by the low phosphorus diet. However, by 6 weeks after calving the LS supplement had increased intake by 30% compared with the un-supplemented diet.

The intake of about 5 g P/day (no-P-supplement) and 9 g P/day (LS supplement) over the whole experiment was only about one-seventh and one-quarter of the current requirements suggested by the A.R.C. (1965). In spite of the extended period of severe phosphorus inadequacy there was no significant effect on digestibility, voluntary intake of oat straw, cow live-weight changes, calf growth rates, blood parameters and subsequent reproductive performance. However, it can be noted that by 9 weeks after calving the blood phosphorus concentrations on the no-P-supplemented treatment had decreased, but whether blood concentrations would have decreased further and digestibility and intake decreased, if the cows had been given the diets for a more extended period is a matter for speculation.

Call, Butcher, Blake, Smart and Shupe (1978) used Hereford heifers which had been individually fed for 2 years on a basal ration containing 0·14% phosphorus on an 'as fed basis' which approximated to 66% NRC recommendations. Fourty-eight animals were limited to this low phosphorus diet. Another 48 received sufficient monosodium phosphate added to the basal ration to elevate phosphorus intake to 0·36% on an 'as fed' basis (174% NRC recommendations). The average daily live-weight gain for both groups was 0·45 kg and feed efficiency was similar. There was no evidence of lack of appetite or depraved appetite in either group. There was no difference in age of puberty, and the low phosphorus cattle had a 96% pregnancy rate with 91% live calves compared to 100% and 93% respectively for the high phosphorus cattle. Many scientists have associated reduced reproductive performance with a phosphorus deficient diet. Ovarian dysfunction and reduced fertility in cattle were reported by Hignett and Hignett, (1951); Short and Bellows, (1971); Theiler (1928). Reduced weight gains were reported by Winks and Laing (1972).

Other scientists have reported that phosphorus supplementation had little effect on reproductive efficiency (Eckles et al., 1935; Palmer et al., 1941). In this present experiment there was no evidence to suggest that the long-continued low phosphorus diet had impaired reproductive efficiency, but it is appreciated that the cows were changed to a grass diet when the bull was introduced.

Experiment 3.6. The effects of dietary phosphorus inadequacy during pregnancy and lactation on the voluntary intake and digestibility of oat straw by beef cows and the performance of their calves II.

Introduction.

The purpose of this experiment was to repeat Expt 3.5 in an attempt to achieve a significant depression in the voluntary intake of oat straw on a diet low in phosphorus and to examine the adequacy of the phosphorus content of LS supplementing the diet.

Materials and methods.

Sixteen beef cows, principally Hereford cross of mean live weight 504 kg and mean body condition score 2·5 (Lowman et al., 1973) were individually housed in a byre. The cows were on average 19 weeks from calving. The housing, dietary treatments and feeding regimes were exactly the same as described in Expt 3.5. The composition of the oat straw, SBP and LS are detailed in Table 68.

Table 68. Expt 3.6. The mean compositions of oat straw, sugar beet pulp (g/kg DM) and LS (g/kg FM).

	Oat straw	SBP	LS
Dry matter	797	853	-
Crude protein	25	105	1067
Crude fibre	495	161	-
Ether extract	7	4	-
N-free extract	416	652	-
Ash	57	78	-
Ca	2·6	4·6	29·9
P	0·8	0·8	14·5
pH	-	-	1·6

The method of grouping the animals into two paired sets differed in this experiment. After the initial acclimatization period, all sixteen animals were given the LS-supplemented diet for 3 weeks and the straw intake recorded. The cows were then arranged into two groups each of eight animals according to voluntary straw intake, live weight, body condition score and expected calving date. Thereafter each group received one of the two dietary treatments described in Expt 3.5. Voluntary straw consumption was recorded on two occasions during pregnancy (between weeks 15 to 14 and 4 to 3 before calving) and twice during lactation (between weeks 2 - 3 and 5 - 6 after calving). The sampling techniques and husbandry of the cows and calves were identical to Expt 3.5. Additionally milk samples were taken at 3 and 6 weeks after calving and analysed for phosphorus and calcium.

The cows continued to receive their appropriate diets until transfer to grass in late May. This occurred at a mean of 60 days after calving.

Five days before transfer to grass the tail bone of each cow (mid region of the coccygeal vertabrae) was X-rayed, this occurred at a mean of 55 days after calving. Assessments of radiographic density were made by means of comparison with a standardized aluminium step-wedge.

On transfer to grazing a Hereford bull fitted with a chin-ball marking device (Universal Livestock Services, Banbury, Oxfordshire) was introduced and service dates were recorded. Blood samples were taken once each week for 5 weeks while the cows were at grass and analysed for phosphorus.

Results.

Although each treatment originally had 8 animals one cow died in calving, one cow aborted (perhaps due to an inexperienced rectal examination) and one cow did not hold to her expected calving date and therefore was removed from experiment. Unfortunately all 3 animals belonged to the no-P-supplemented group. Therefore all the results after calving presented in the Tables refer to 8 animals for the LS supplemented

group and 5 for the no-P-supplemented group.

During pregnancy there were no significant differences between treatments in either the voluntary intake or digestibility of the oat straw (Table 69).

During lactation there were marked treatment differences in respect of voluntary straw intake and apparent digestibility. Supplementation with LS significantly ($P < 0.01$) increased the intake of straw DM during weeks 2 to 3 and 5 to 6 after calving (Table 69). The amounts of crude protein, phosphorus and calcium provided by the diets are detailed in Table 70. During weeks 2 to 3 the straw DM intakes were 4·41 and 6·73 kg and between weeks 5 to 6, 5·20 and 6·90 kg for the no-P and LS-supplemented diets respectively. However, these results give an incorrect impression, from the data it could be inferred that the straw intake had actually increased by 6 weeks after calving for the no-P-supplemented treatment. Twenty four days after calving the voluntary straw intake of one cow had been depressed to such an extent, that it was decided to remove her from the experiment. Hence this cows extremely low straw intake is included in the mean intake and digestibility data for weeks 2 to 3, but not 5 to 6 after calving, therefore altering the mean results for this period.

After calving this cow gradually became weak and had difficulty in getting up from a lying position. The straw intake dropped to 2·59 kg DM/day (2 - 3 weeks after calving) from 6·64 kg DM (-4 to -3 weeks before calving). The gait of the animal was slow and lethargic. Twenty one days after calving the animal was examined by a veterinary surgeon. She was found to be bright and both respiratory and cardiac rates were normal. However, the animal was showing signs of anaemia, the mucus membranes being palid. The blood was thin having a packed cell volume (PCV) of 15% (normal range 24 - 46%). The blood phosphorus concentration was 0·38 mmol/litre having decreased from 1·44 mmol/litre at the start

of the experiment. No detrimental effect was observed in the growth or health of the calf. It was found that the animal had been suffering from post-parturient haemoglobinuria, a metabolic disease often associated with diets low in phosphorus (especially in the early lactation of high yielding dairy cows (Blood, Henderson and Radostits, 1979)). No signs of pica were observed. The hip bones had running sores.

The cow was removed from the experiment, and for observation her diet was changed to the LS-supplemented treatment. Thereafter PCV values were obtained weekly from all the cows, so as to monitor whether haemoglobinuria was imminent in any of these animals.

During lactation there were marked treatment differences in respect of apparent digestibility of the DM, OM and the OM of straw alone (calculated by difference assuming the OM of SBP to be 84% digestible). Supplementation with LS significantly prevented the depression of digestibility of DM, OM and OM of straw alone which occurred on the no-P-supplemented diet (Table 69) at 2 to 3 weeks.

At 5 to 6 weeks after calving the differences in the digestibility of the DM and OM of the two treatment diets just failed to reach significance even though the digestibilities of the DM and OM for the LS supplemented treatment were greater than 50% than the values for the no-P-supplemented treatment. For the straw alone there were marked significant reductions in the calculated OM digestibility for both weeks 3 to 4 and 5 to 6 (from about 0·44 to 0·16).

During pregnancy the estimated ME intakes from straw of the cows (calculated from the % digestible OM in the DM of the straw x 0·15 M.A.F.F. et al., 1975) were similar for both diets. In lactation the ME intake from straw of the cows given the LS supplemented diet was significantly higher than the no-P-supplemented diet (by about 27%).

Table 69. Expt 3.6. Mean voluntary intakes of oat straw (kg DM/day) the digestibility coefficients of the DM and OM and the amounts of ME consumed as straw.

	Weeks before (-) or after (+) calving			
	-15 to -14[+]	-4 to -3	+2 to +3	+5 to +6
Straw DM intake				
No-P-supplement	5·64	5·86	4·41[f]	5·20[g++]
LS supplement	5·97	5·90	6·73[f]	6·90[g]
SED	0·325	0·376	0·725	0·467
	Digestibility of DM			
Complete diet				
No-P-supplement	0·45	0·47	0·23[a]	0·24
LS supplement	0·44	0·48	0·54[a]	0·52
SED	0·146	0·043	0·124	0·139
	Dugestibility of OM			
Complete diet				
No-P-supplement	0·47	0·50	0·23[b]	0·19
LS supplement	0·47	0·50	0·56[b]	0·54
SED	0·032	0·047	0·118	0·215
Straw alone[+++]				
No-P-supplement	0·35	0·39	0·15[c]	0·16[d]
LS supplement	0·36	0·38	0·45[c]	0·42[d]
SED	0·048	0·060	0·109	0·107
Calculated ME of straw DM (MJ/kg)				
No-P-supplement	5·3	5·9	2·3[i]	2·4[e]
LS supplement	5·3	5·7	6·7[i]	6·4[e]
SED	0·73	0·90	0·89	1·61
ME intake from straw (MJ/day)				
No-P-supplement	30·6	34·9	12·1[h]	13·1[j]
LS supplement	31·8	34·2	46·7[h]	45·0[j]
SED	4·92	6·46	10·45	10·16

Means followed by the same letter are significantly different a,b,c,d,e ($P<0·05$); f,g,h, ($P<0·01$); i,j ($P<0·001$).

[+]Both groups given LS supplement, [++]5·2 reduced to 4·68 if intake of cow with haemoglobinuria included, [+++]digestibility of the OM of SBP taken as 84%.

Table 70. Expt 3.6. The amounts of crude protein, phosphorus and calcium supplied by the SBP, oat straw, supplements and recommended requirements (g/day).

	Weeks before (-) or after (+) calving			
	-4 to -3		+5 to +6	
	A	B	A	B
	No-P-supplement	LS supplement	No-P-supplement	LS supplement
Crude protein	593	594	666	708
Phosphorus	6·1	9·8	6·3	11·3
Calcium	30·4	30·5	32·6	36·9

Requirements

	Month of pregnancy		Lactation
	6	9	(7·5 kg milk/day)
Phosphorus[+]	26·4	33·5	38·4
Calcium[+]	20·2	33·3	39·0
DCP[++]	430		827

[+]A.R.C. (1965); [++]A.D.A.S. (1976).

One cow given the low phosphorus diet consistently refused about 0·4 kg of its daily allocation of concentrates during lactation.

The mean live-weight change of the cows during the 15 weeks before calving was -21 kg (no-P-supplemented) and +15 kg (LS supplemented) this difference being significant ($P < 0·05$). Table 71 details the changes in live weight and body condition score of the cows and birth weight and live-weight gain of their calves. There was no significant difference between mean calf birth weights which at about 34 kg were greater than the live-weight gain of the cows during pregnancy. This infers that the live-weight gain of the cows during pregnancy was inadequate, this is further supported by the decline in body condition score by 0·6 for both groups. However, during lactation the cows given LS lost a total of 31 kg live weight compared with a loss of 14 kg when given the no-P-supplemented treatment.

The mean daily live-weight gain to 6 weeks of the calves in the no-P-supplemented group was 0·82 kg/day and in the LS supplemented group was 0·83 kg/day (not significantly different).

The mean blood concentrations of phosphorus, calcium and urea for the cows in pregnancy and lactation and for the calves are detailed in Table 72. Normal blood phosphorus concentrations were maintained throughout both pregnancy and lactation when additional phosphorus was supplied in the form of LS. Blood phosphorus concentrations were significantly lower on the no-P-supplemented diet than the LS supplemented diet throughout the experiment.

Blood phosphorus concentrations on the no-P-supplemented diet remained stable during pregnancy at about 1·2 mmol/litre, but dropped to a mean of 0·71 mmol/litre after calving.

Blood calcium concentrations remained normal for both dietary treatments throughout the experiment. However, at calving the blood calcium concentration of the LS-supplemented cows was significantly higher.

Table 71. Expt 3.6. Changes in live weight (kg) and body condition score of the cows and birth weight and live-weight gain (kg) of their calves to 6 weeks.

Weeks before(-)or after(+) calving	Cow live weight		Cow body condition score	
	No-P-supplement	LS supplement	No-P-supplement	LS supplement
-15[+]	506	502	2·6	2·4
-12	497	500	-	-
- 9	494	502	-	-
- 6	492	499	-	-
- 3	504	523	-	-
At calving	493	517	-	-
After calving	456	474	2·0	1·8
+ 3	455	451	-	-
+ 6	441	442	1·8	1·8

Change in live weight and body score

			SED			SED
-15 to calving	-21[a]	+15[a]	13·9	-0·6	-0·6	0·15
Calving to +6	-14	-31	14·6	-0·2	0·0	0·16

Calf live weight			
Birth	32·9	34·8	
+3	51·9	54·3	
+6	67·4	69·6	
Live-weight gain	34·5	34·8	2·65

Means followed by the same letter are significantly different, a($P < 0.05$).

[+]Both groups given LS supplement.

Table 72. Expt 3.6. The mean concentrations of phosphorus, calcium and urea (mmol/litre) in the blood of the cows during pregnancy and lactation and in the blood of the calves.

	Weeks before (-) or after (+) calving							
Cows	-15[+]	-12	-9	-6	-3	0	+3	+6
Phosphorus								
No-P-supplement	1·48	1·07[e]	1·14[i]	1·12[j]	1·18[k]	0·65[f]	0·69[g]	0·78[a]
LS supplement	1·39	1·60[e]	1·72[i]	1·71[j]	1·70[k]	1·20[f]	1·16[g]	1·20[a]
SED	0·156	0·132	0·118	0·093	0·116	0·134	0·149	0·143
Calcium								
No-P-supplement	2·41	2·44	2·49	2·59	2·46	2·29[b]	2·34	2·42
LS supplement	2·47	2·42	2·42	2·53	2·45	2·46[b]	2·45	2·59
SED	0·032	0·029	0·047	0·052	0·039	0·065	0·094	0·227
Urea								
No-P-supplement	3·74	4·14[h]	4·01	5·03[c]	5·05	6·46	3·39	2·59
LS supplement	3·61	3·24[h]	3·41	4·49[c]	4·76	5·95	3·55	3·13
SED	0·265	0·281	0·336	0·244	0·355	1·075	0·313	0·502
Calves								
Phosphorus								
No-P-supplement						2·82	2·96	2·80
LS supplement						3·26	3·23	2·93
SED						0·310	0·156	0·178
Calcium								
No-P-supplement						2·86	2·75	2·62
LS supplement						2·83	2·83	2·83
SED						0·105	0·053	0·209
Urea								
No-P-supplement						4·72[d]	3·35	2·52
LS supplement						3·36[d]	3·56	3·38
SED						0·305	0·247	0·354

[+]Both groups given LS supplement.

Means followed by the same letter are significantly different·
a,b,c,d ($P<0·05$); e,f,g,h ($P<0·01$); i,j,k ($P<0·001$).

Blood urea concentrations were significantly higher for the no-P-supplemented diet than the LS supplemented diet at 12 and 6 weeks before calving, for which there is no obvious explanation. However, after calving the blood urea concentrations for both groups were lower than during pregnancy.

Blood calcium, phosphorus and urea concentrations were normal and similar for both groups of calves. However, blood urea concentrations at birth were significantly higher ($P < 0.05$) for the calves on the no-P-supplemented diet.

Table 73. Expt 3.6. Radiographic data of the tail bones and concentrations of phosphorus and calcium (mg/dl) in the fat free milk of the cows.

	Weeks after calving	No-P-supplement	LS supplement	SED
Tail bone density (equivalent thickness of aluminium)	8	3·7	4·9	1·32
Milk phosphorus	3	55·8	66·1	6·63
	6	45·1[a]	63·7[a]	6·40
Milk calcium	3	116·5	130·2	8·89
	6	90·0	123·8	15·39

Means followed by the same letter are significantly different a ($P < 0.05$).

Table 73 details the radiographic data of the tail bones and concentrations of phosphorus and calcium in the milk of the cows. There were no significant differences in the mean concentration of calcium in the milk of the cows. However, by 6 weeks after calving the milk calcium concentration of the cows given the no-P-supplement was considerably lower (90·0 mg/dl) as compared with the LS-supplemented

animals (123·8 mg/dl). Milk phosphorus concentrations were lower for the no-P-supplemented treatment at both 3 and 6 weeks after calving (being significant ($P<0·05$) at 6 weeks).

The assessment of the radiographic density of the tail bones of the cows indicated the density was less in the absence of phosphorus supplementation (not significant).

None of the cows were ovulating prior to transfer to grass. After a mean period of 21 days (LS supplement) and 23 days (no-P-supplement) following introduction of the bull all the cows had been served. There were three exceptions, one cow from the LS group became lame and was not put to the bull, while another had a cystic ovary.

It was also decided that the cow that had haemoglobinuria would not be served again, but was kept to rear her calf and would be later culled. However, both this latter animal and the lame animal were cycling normally.

It is not possible to present any further pregnancy data, because at the time of this thesis being written it was too early to obtain positive pregnancy diagnoses.

Discussion.

The mean amounts of oat straw and SBP eaten/day by the cows over the 26 week experimental period were such that their total phosphorus intakes were about 6·0 g P/day (no-P-supplement) and 9·8 g P/day (LS supplement) during pregnancy and 6·0 g P/day (no-P-supplement) and 11·2 g P/day (LS supplement) during lactation. In comparison, the recommended (A.R.C., 1965) intake of phosphorus for a 500 kg cow in the 6th - 9th months of pregnancy is 26·4 increasing to 33·5 g P/day with 38·4 g P/day during lactation (assuming and daily milk yield of 7·5 kg). In spite of the much reduced phosphorus intakes of the cows given both the diets, this did not appear to adversely effect either

The digestibility or voluntary consumption of oat straw during the last 18 weeks of pregnancy.

During lactation phosphorus inadequacy markedly reduced both the digestibility of the diet and the voluntary straw consumption.

The apparent lack of effect of a reduction in phosphorus intake during pregnancy on voluntary straw consumption is reflected in the similarity of the estimated ME intakes of the cows (calculated from the % digestible OM in the DM of the complete diets x 0·15 M.A.F.F. et al., 1975) which were 52 and 57 MJ/day (no-P-supplement) and 54 and 57 MJ/day (LS supplement) for weeks 15 to 14 and 4 to 3 before calving respectively. The suggested ME allowance including a 5% safety margin (M.A.F.F. et al., 1975) for 500 kg cows in the 6th - 9th months of pregnancy is 61 increasing to 74 MJ/day. However, although both groups had similar losses in body condition only the no-P-supplemented cows had a reduction in live weight (21 kg) during pregnancy (i.e. from 15 weeks before calving to just before parturition).

During lactation the ME intakes of the cows were 24 and 22 MJ/day (no-P-supplement) and 78 and 77 MJ/day (LS supplement) for weeks 2 to 3 and 5 to 6 after calving respectively. The suggested ME allowance including a 5% safety margin (M.A.F.F. et al., 1975) for lactating 500 kg cows (assuming a milk yield of 7·5 kg/day of average composition and with no live-weight change) is 93 MJ/day. The calculated ME intakes during lactation for the cows given no supplementary phosphorus were severely reduced compared with the ME intakes for the LS supplemented animals. At such low ME intakes it would have been expected that cow live-weight losses would have been marked and that their calf live-weight gains would have been severely reduced due to lower milk yields. However, the cows given the LS supplement lost more weight, 0·7 kg/day compared with 0·3 kg/day for the no-P-supplemented animals during the first 6 weeks of lactation, and both groups of calves had similar live-

weight gains. The results of the analyses were repeated to confirm the severe reduction in digestibilities for the low phosphorus group in an attempt to explain the discrepancy of the low ME intakes that were not accompanied by reduced performance. The original results were confirmed by the repeat analyses.

The results obtained in this present experiment where severe reductions in ME intakes were recorded over a 6 week period on a low phosphorus diet are questionable as the performance of the cows and their calves was not impaired.

The cows given supplementary phosphorus in the form of LS maintained normal concentrations of blood phosphorus throughout the experiment although their total phosphorus intakes were generally about 27 g P/day below the recommended (A.R.C., 1965) level of minimum intake. Blood phosphorus concentrations of the cows given no-P-supplement were significantly lower than the LS-supplemented animals throughout pregnancy, although within the normal range. It was not until after calving that the blood phosphorus concentrations of the cows given the no-P-supplement were severely reduced. Their intake at 6·0 g P/day was only about one-sixth of the minimum requirement suggested by the A.R.C. (1965). The blood phosphorus concentrations were comparable with those found by Fishwick et al. (1977), using animals on similar diets (as already discussed). They found that in lactation blood phosphorus concentrations were 1·68 and 0·52 mmol/litre at 3 weeks after calving and 1·65 and 0·42 mmol/litre at 6 weeks after calving for diets that contained 29 and 12 g P/day respectively. However, their low blood phosphorus concentrations were obtained from a diet that provided 12 g P/day while in this present experiment the phosphorus (LS) supplemented diet only provided 11·2 g P/day and severely reduced concentrations were not obtained until the diet contained about 6·0 g P/day. In Expt 3.5 blood phosphorus concentrations remained normal although slightly lower

on the no-P-supplemented diet, throughout pregnancy and lactation, even though the experimental diets only provided 5·5 g P/day (no-P-supplement) and 10·3 g P/day (LS supplement) during lactation.

It is interesting to note, that after the animal, which had been suffering from haemoglobinuria had been changed over to the LS-supplemented diet marked improvements occurred. Within four days the blood phosphorus concentration had risen from 0·38 to 0·64 mmol/litre and within 3 weeks to 0·90 mmol/litre. After 3 weeks of LS supplementation the voluntary straw intake increased from 2·59 to 5·59 kg DM/day and the packed cell volumed of the blood rose to 25%. At the level of straw intake of 2·59 kg DM/day the animal would have been receiving about 4 g P/day, the addition of LS provided a further 3·6 gP and with the increase in straw consumption phosphorus intake was about 10 g/day after 3 weeks of LS supplementation. The PCV values obtained from all the other animals remained within the normal range of 24 - 46%. The question arises as to why this one animal suffered from haemoglobinuria and not any of the other animals on the low phosphorus diet. However, although the mean body condition score of the cows of the no-P-supplemented group was 2·6 at the start of the experiment, this one individual animal had a body condition score below the mean (1·5) and was in poorer condition than any of the other animals.

There were differences in the mean concentrations of calcium and phosphorus in the milk, concentrations being lower for the no-P-supplemented treatment. It would be expected that, the growth rate of the calves would have been impaired, but this was not so. The growth rates of the calves were almost identical (0·82 and 0·83 kg/day for the no-P-supplement and LS supplement groups respectively). It can therefore be assumed that the milk yield of the cows given both diets was similar. The reduced intake of calcium and phosphorus in the milk might have resulted in lower calcium and phosphorus concentrations in the blood of

the calves. However, it must be noted that the calves had access to a minimum amount of hay (to help stimulate rumen function, and to avoid scour by encouraging them not to consume their bedding).

The assessment of radiographic density is a general method of assessing bone mineral mobilisation. Fishwick et al. (1977) found a decrease in the radiographic density of the tail bones by cows on a low phosphorus diet (12 g P compared with 29 g P/day) during lactation but not in late pregnancy. Although in this present experiment the density of the tail bones of the cows given the low phosphorus diet was lower than that of the LS supplemented cows. It cannot correctly be inferred that this reduction was due to the absence of phosphorus supplementation as unfortunately no X-rays were taken at the start of the experiment.

After 5 weeks at pasture the mean blood phosphorus concentration of both groups was 1·4 mmol P/litre which would be considered normal. The ability of beef cows to recover from the effects of dietary phosphorus inadequacy during late pregnancy and early lactation is evidenced by the results of this present experiment.

In Expt 3.5 the animals received 5·5 g P/day (no-P-supplement) and 10·3 g P/day (LS supplement) during lactation and these severe phosphorus inadequacies did not significantly effect straw intake or digestibility. In this present experiment they received 6·0 g P/day (no-P-supplement) and 11·2 g P/day (LS supplement) and straw intake and digestibilities were significantly affected by the low phosphorus diet. This effect was similar to Fishwick et al. (1977), these workers found that an inadequate phosphorus intake during lactation (29 compared with 12 g P/day) resulted in a significant decline in voluntary straw consumptions and digestibility.

These workers showed that the digestibility coefficients of OM of straw alone were 0·50 (29 g P/day) and 0·34 (12 g P/day) at 5 to 6

weeks after calving. In the present study comparable digestibility coefficients were 0·42 (11·2 g P/day) and 0·16 (6·0 g P/day).

It is also interesting to note that the calf live-weight gains recorded by Fishwick et al. (1977) were 0·70 and 0·44 kg/day for the diets supplying 29 and 12 g P/day in lactation respectively. In this present experiment the calves grew at 0·82 and 0·83 kg/day when the diets supplied 6·0 and 11·2 g P/day in lactation respectively.

It is evident from the results of this present experiment that the A.R.C. (1965) recommendations for the phosphorus requirements are over estimated. This is further substantiated by the response of the cow which had haemoblobinuria. The addition of only 3·6 g P to a basal intake of 4 g P increased straw intake from 2·59 to 5·95 kg DM/day in just 3 weeks.

Other workers have suspected that the standards applying to dietary phosphorus requirements were too high. For example, Little (1980) suggests that the recommendations of the A.R.C. (1965) and N.R.C. (1976) for the intake of phosphorus by young growing cattle over estimate requirements by approximately 35%.

In this present study and Expt 3.5 the low phosphorus intakes did not appear to adversely affect either the digestibility or voluntary consumption of oat straw during the last 16 weeks of pregnancy. It would be interesting to determine, if a reduction of voluntary straw intake could be achieved in lactation if both groups were kept on a phosphorus supplemented diet until calving. This would depend upon the phosphorus status of the cows; This aspect has been discussed in a review by Cohen (1980).

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APPENDIX I

EXPERIMENTAL TECHNIQUES

I Analytical methods.

All the analytical methods used were established procedures.

(i) Dry matter.

The dry matter (DM) in the food and faecal samples was determined by heating 0·2 to 1·0 kg quantities in a hot air oven at 90°C for 36 to 48 h until a constant weight was attained.

(ii) Total nitrogen.

The total nitrogen in food and faecal samples was measured by an Automated Kjeldahl technique (Kjel-Foss Automatic 16210). Before analysis faecal samples were macerated with distilled water and a small amount of toluene, (Grassland Research Institute (C.A.B., 1961)).

(iii) Ether extract, crude fibre and ash.

The ether extract (EE), crude fibre (CF) and ash contents of the food and faecal samples were determined by the standard methods (The Fertiliser and Feeding Stuffs Regulations, 1976).

(iv) Chromium.

The chromium content of food and faecal samples was determined by atomic absorption spectrophotometry according to the method of Williams, David and Iismaa (1962). The samples were initially dry ashed.

(v) Calcium and magnesium.

The calcium and magnesium contents of blood, food and faecal samples were determined by Atomic absorption spectrophotometry (Perkin-Elmer, 1976). Prior to analysis, samples of faeces and food were

prepared by dry combustion and the soluble mineral constituents in the ash were dissolved in dilute hydrochloric acid. Calcium in the fat free milk was estimated by atomic absorption spectrophotometry after precipitation of the milk protein by trichloracetic acid.

(vi) Phosphorus

Phosphorus in food and faecal samples was determined by a modification of the colormetric method of Cavell (1955). Phosphorus in the blood was determined by the colormetric method of Fiske and Subbarow (1925). Phosphorus in fat-free milk was analysed by a modification of the above method.

(vii) Sodium.

The sodium content of food samples was determined by flame photometry. Prior to analysis samples were prepared by dry combustion and the soluble mineral constituents in the ash were dissolved in dilute hydrochloric acid.

(viii) Blood urea.

The urea content of blood samples was determined by a urease-Nesslerization method (modified Twort and Archer, 1923).

(ix) Copper.

The copper content of food and blood samples was determined colorimetrically following acid digestion by means of zinc dibenzyldithiocarbomate (Brown and Hemingway, 1962).

(x) Glutamic-oxalacetic transaminase.

The glutamic-oxalacetic transaminase (GOT) (Aspartate Aminotransferase EC 2.6.1.1.) content of blood was determined using a Boehringer Mannheim GOT optimised UV-system (Wallnöfer, Schmidt and Schmidt, 1974).

(xi) Volatile fatty acids.

Quantitative analyses for volatile fatty acids (VFA) concentration in rumen liquor samples were determined by gas/liquid chromatography following treatment with 20% w/v metaphosphoric acid by a modification of the method of Mahadevan and Stenross (1967) using 150-200 mesh untreated Porapak Q.

(xii) Total rumen nitrogen.

Rumen liquor samples were filtered through muslin and centrifuged to remove particulate matter. Total nitrogen was determined in the supernatant liquid using an Automated Kjeldahl technique.

(xiii) Rumen liquor ammonia.

Rumen liquor samples were filtered through muslin and ammonia was determined following deproteinization with acidified sodium tungstate using a modification of the method of Waite and Wilson (1968).

(xiv) Blood ammonia.

Ammonia-N in whole blood was determined using the cation exchange method of Hutchinson and Labby (1962) in which the ammonium is exchanged for sodium and potassium ions. The exchanged ammonia was subsequently determined directly by colorimetry after reaction with Nessler's reagent (Parkins, 1972).

(xv) pH.

The pH of food, rumen and LS samples was determined using a Pye Unicam Ltd. pH meter with a combined glass and reference electrode. Determinations of pH on samples of LS and liquor from the rumen were made directly by immersing the electrode into the fluid. A given weight of each food sample (25 g) was left to soak in 300 ml of distilled water for 30 min. The mixture was then agitated and the

electrode placed in the mixture and the pH value obtained.

(xvi) Starch.

The determination of starch in the faeces; starch in 50 g samples was determined using a modification of the method of Hassid and Neufeld (1964) using phenol sulphuric acid in the place of anthrone.

APPENDIX II

TIME LAPSE PHOTOGRAPHY STUDIES

The camera fitted with a time lapse mechanism and a flash unit was mounted on a moveable platform about 5 m above the ground. The camera was equipped with a wide angled lens so that the water trough/ball-licker and the surrounding area could be photographed. The camera and attachments were totally encased to protect them from the weather. However, during a trial run the mean ambient temperature dropped below freezing and the camera ceased to function. This was rectified by fitting a heater into the camera box. Each film lasted 2·75 days and a frame was taken every 65 sec. For each period the camera was positioned to run for 2 days above the water trough and for 4 h above the ball-licker. This was ample time as from previous observations all the allocated LL was consumed within approximately 2 hours.

For the purpose of animal identification on the film, each animal wore a different coloured collar. In the event of one of the collars coming off a record was kept of the animals colour markings.

APPENDIX III

A NYLON-BAG TECHNIQUE FOR ESTIMATION OF PROTEIN DEGRADATION IN THE RUMEN

The nylon-bag technique is an alternative method for estimating protein degradation in the rumen. It is a short cut method which only provides relative estimate of protein degradation.

The test material is suspended in a permeable bag in the rumen and the disappearance of the test material from the bag contents is measured over a period of time. This technique is only useful as a guide for measuring the disappearance of nutrients from the rumen as a number of variables affect the results. Mehrez and Ørskov (1977) found that the most important factor determining variability in the disappearance from bags incubated together was the sample size in relation to the bag size. They also concluded that there was a large variation between animals and for the same animal on different days. The length of time that a bag is left suspended in the rumen is important and will influence the degradability value observed (Neathery, 1969). The length of time in the rumen may not accurately reflect the length of time the test material would have been in the rumen if it had been ingested. Van Keuren and Heinemann (1962) reported that as the amount of test material increased, dry matter disappearance values decreased. The position of the bags in the rumen is important. Balch and Johnson (1950) showed that the test material dry matter loss was almost twice as much in the ventral as in the dorsal sac of the rumen. Van Keuren and Heinemann (1962) emphasized the importance of the pore size of the bag in regulating the passage of solid particles. The movement of ingestia particles in and out of the bag is an important factor in estimating the disappearance of the test material. The basal diet of the animal used for estimating the test material disappearance can have significant effects on the results (Neathery, 1969).

The method of processing the bag and contents after removal from the rumen can greatly effect the reliability of the values obtained. McManus, Manta and McFarlane (1972) studied the effect of time of rinsing of the bag on the values obtained. As the washing time increased, dry matter disappearance increased.

The above discussion emphasises the importance of standardizing the procedure of the nylon bag technique.

The technique employed throughout this thesis was as follows. Each bag was 14 x 12 cm square of nylon cloth having a pore size of 24 μ or 43 μ. A nylon cord 80 cm long was sewn to one side of the bag. After the test material was placed in the bag the open end was folded over twice and stapled closed. The free end of the cord was tied around a short length of rubber tubing (to which a number of bags could be attached). Each cord was tied so that each bag would be suspended in the rumen to a depth of 60 cm.

After removal of the bags from the rumen at the allotted time, the bags were immediately washed. Each bag was individually washed in 10 litres of water being constantly agitated for 30 sec. The bags were then dried to a constant weight when samples were weighed and protein determinations were carried out. Degradabilities were assessed over a period of 4, 8, 12, 24 and 48 h (although results for 24 h have only been quoted in the experimental text). The degradability values for the dry matter and protein of the material tested were found to be equal whether a 23 or 43 μ bag was used.

APPENDIX IV

THE DAILY ROUTINES FOR BALANCE TRIALS FOR SHEEP HOUSED IN METABOLISM CAGES.

Weighing of foods.

The food required by the sheep for the whole trial was weighed into paper bags at the beginning of the experiment.

Feeding and watering.

The food was given 3 x/day to minimise spillage. Water was provided in containers which were replenished twice per day.

Faecal collection.

The ewes (clipped free of wool around the hind quarters) were fitted with a standard type of harness which included a chest strap. An open mesh canvas bag (to allow urine to pass) was attached to the leather harness by four quick-release, spring loaded scissor-grip hooks, for collection of faeces. The bags were removed daily, emptied into numbered bags behind each cage and refitted to the animal. The faeces for the separate 7 days of collection were bulked, thoroughly intermixed and an appropriate sub-sample was dried and ground for analysis.