IMPROVING THE NUTRITIVE VALUE OF LOW QUALITY FORAGES

R.C. KELLAWAY*

Summary

The availability of, and nutrient deficiencies in, low quality forages in Australia are discussed. Effects of NaOH, KOH, $Ca(OH)_2$, Na_2CO_3 and NH_4OH on the digestibility and edibility of forages are reviewed, together with the techniques used in application of alkalis. It is concluded that substantial increases in the nutritive value of low quality forages can be effected by spraying solutions of alkali and supplementary nutrients onto forages, using batch or continuous-flow processes suitable for use on farms.

I. INTRODUCTION

Low quality forages are characterised primarily by their low edibility and low content of available energy. These deficiencies frequently are compounded by low contents of nitrogen and certain minerals. The edibility and available energy content of forages can be increased by chemical, physical and enzymic processes. Commercial adoption of such processes is being determined by the cost of measured improvements in nutritive value in relation to the cost of alternative feedstuffs.

II. AVAILABLE FORAGES

Cereal straws represent the most readily accessible source of low quality forages. Approximately 12 million hectares of cereals grown in Australia produce about 30 million tonnes straw annually. Much of this is burnt, a practice which is becoming increasingly unacceptable because of air pollution, and much of it is grazed by sheep and cattle. Grazing may assist straw dispersal, but the animals are unable to maintain body-weight on cereal straw residues which are free of weeds (Mulholland et al. 1976).

The composition of cereal straws varies considerably as shown in Table 1. Comparisons of mean values for components of straws with dietary concentrations recommended for the maintenance of 200 kg steers, indicates that these cereal straws are deficient in available energy as measured by digestible organic matter in the dry matter (DOMD), as well as nitrogen and phosphorus. Certain straws would also be deficient in calcium, sodium and potassium. In order to maintain a nitrogen (N) to sulphur (S) ratio of 10 : 1 in the diet a sulphur concentration of 1.36 g S/kg DM would be required. Sulphur levels of 0.8-2.1 g S/kg DM have been recorded in wheat straw in South Australia (Schultz and French 1976).

DOMD values in Table 1 rank the cereals in the order barley > oats > wheat, with considerable overlap between species. DM digestibility was found to be negatively related to the length of the growing season within the range 22-36 % DMD and 8.0-3.5 months growing season (Dr. D.B. Purser - personal communication).

---

* Department of Animal Husbandry, University of Sydney, Camden, N.S.W. 2570.

TABLE 1 Chemical composition and digestible organic matter in the dry matter (DOMD) of cereal straws collected from seven locations in Victoria(1) and dietary concentrations recommended for the maintenance of 200 kg steers(2)

	Recommended dietary concentration	Wheat (16)†		Oat (3)		Barley (5)	
		Mean	Range	Mean	Range	Mean	Range
Nitrogen (g/kg DM)	13.6	4.2	2.4-7.8	6.2	1.4- 7.5	4.7	4.0-6.4
Calcium "	1.8	1.8	1.0-3.1	1.1	0.7- 1.5	1.9	1.3-2.4
Phosphorus "	1.8	0.8	0.3-1.2	0.8	0.4- 1.4	0.6	0.4-0.9
Magnesium "	0.4-1.0	0.6	0.4-0.8	0.6	0.6- 0.7	0.9	0.6-1.1
Sodium "	0.6	0.4	0.1-0.8	5.2	1.2- 8.1	1.4	1.0-2.2
Potassium "	6.8	6.3	3.5-8.8	7.9	5.7-10.7	4.3	3.7-5.0
DOMD (%)	55*	34	28-42	38	32-43	42	37-45

† Number of samples in parentheses
* MJ ME/kg ÷ 0.15
(1) Pearce, Beard and Hilliard (1979)
(2) National Research Council (1976)

Mature pasture grasses, native and improved, constitute an even greater reservoir than cereal straws of low quality forages which are potentially useful to ruminants. Difficulties in harvesting native pastures from uncultivated land may be well worth overcoming, if promising improvements in nutritive value effected by alkali treatments (Siebert 1974) are confirmed by further study.

III. ALKALIS USED TO INCREASE FORAGE DIGESTIBILITY AND EDIBILITY

The alkalis NaOH, KOH, $Ca(OH)_2$, Na_2CO_3 and NH&OH have all been shown to improve the nutritive value of low quality forages. The mode, of action is to disrupt cell walls by dissolving hemicellulose, lignin and silica, by hydrolysing uronic and acetic acid esters and by causing cellulose fibres to swell (Jackson 1977).

(a) NaOH

NaOH has been used to upgrade low quality forages for over 80 years, much longer than other chemicals. For this reason a considerable amount of information has accumulated concerning its use (see review by Jackson 1977). Recently, information was recorded on the kinetics of digestion of untreated and NaOH-treated forages (Table 2). These observations showed that NaOH treatment increased the proportion of potentially digestible cell walls and increased clearancerates of cell walls from the rumen, both by digestion and onward passage of undigested materials. The distribution of particle sizes in the rumen indicates that the clearance of particles small enough to pass through the reticulo-omasal orifice (< 1 mm) was more rapid'with NaOH-treated than with untreated forages.. A consequence of this was that the ratio of cell walls digested in the rumen : cell walls digested in the caecum was reduced by NaOH treatment (Redman, R.G. and Kellaway, R.C., unpublished data). This resulted in a small loss of microbial protein synthesised in the caecum, but was more than compensated for by greater quantities of microbial protein synthesised in the rumen (<u>loc. cit.</u>). Intakes of dry matter (DM) and digestible DM were increased greatly by NaOH treatment

(Table 2).

TABLE 2 Effects of NaOH treatment (40 g NaOH/kg forage) on chemical composition, digestion kinetics in and intake by steers eating two forages

NaOH treatment	Wheat straw –	Wheat straw +	Paspalum hay –	Paspalum hay +
Chemical composition (g/kg DM)				
Cellulose	446	444	390	372
Hemicellulose	313	266	288	259
Lignin	70	74	62	64
Silica	19	9	31	23
Digestion kinetics of cell walls				
Potential digestibility	0.52	0.72	0.51	0.70
Fractional digestion rate h^{-1}	0.010	0.026	0.011	0.018
Fractional passage rate h^{-1}	0.011	0.013	0.023	0.033
Rumen pool size ($g/kg^{0.75}/day$)	98	99	109	99
Ratio particle sizes in rumen > 1 mm : < 1 mm	0.19	1.26	0.40	0.88
Dry matter intake ($g/kg^{0.75}/day$)	43	88	80	129
Digestible dry matter intake ($g/kg^{0.75}/day$)	20	50	37	71

(Thiago, Kellaway and Leibholz 1979)

NaOH effects linear increases in DM digestibility of straw in <u>vitro</u> corresponding to about 4.5 digestibility units for each 10 g increment in NaOH over the range 0-100 g NaOH/kg forage dry matter (Chandra and Jackson 1971; Robb 1976). Above 80 g NaOH/kg forage, DOMD <u>in vitro</u> was found to fall, due to the diminishing response in digestibility and the increasing dilution effect of forage dry matter with NaOH (Robb 1976).

When NaOH-treated forages are fed to ruminants, organic matter (OM) digestibility increases by about 3.6 units per 10 g increment in NaOH over the range 0-45 g NaOH/kg forage dry matter (Rexen and Thomsen 1976). Above 45-50 g NaOH/kg forage OM digestibility does not increase when the forage contributes over 70% of the diet (Rexen and Thomsen 1976; Singh and Jackson 1971). This suggests that high pH or higher intakes of Na could be interfering with rumen function. However, this is not supported by observations that digestibilities of wheat straw treated with 30 and 60 g NaOH/kg DM were similar when the wheat straw contributed only about 30% of DM intake (Holzer, Levy and Folman 1978). Also, neutralization of excess NaOH does not appear to change the NaOH level (45-50 g NaOH/kg forage), above which digestibility <u>in vivo</u> is not increased (Jayasuriya and Owen 1975; Holzer, Levy and Folman 1978). A possible reason for this is that with high levels of NaOH treatment, incremental increases in passage rates of fibre from the rumen are greater than incremental increases in digestion rates of fibre.

NaOH treatment of low quality forages generally increases their edibility by up to 100 % (Table 2) but as with digestibility, responses only occur up to about 45-50 g NaOH/kg forage (Singh and Jackson 1971; Holzer, Levy and Folman 1978).

(b) KOH

Ruminants are well adapted to high intakes of potassium. It is of interest that steers given a free choice of NaOH or KOH-treated forages showed a strong preference for the latter (Siebert 1974). Without free choice, the edibility of KOH-treated forage was shown to be higher than that of NaOH-treated forage (Petchey and Mbatya 1977). KOH increases digestibility to about the same extent as NaOH (Rounds et al. 1976; Wilkinson and Santillana 1978), but its use is likely to be restricted because it costs about three times more than equi-molar amounts of NaOH.

(c) $Ca(OH)_2$

In contrast to KOH, $Ca(OH)_2$ is about a quarter of the cost of NaOH on an equi-molar basis. However, it is much less. soluble'than NaOH and as a consequence it reacts more slowly. When forage is kept moist for long periods, as with ensilage, $Ca(OH)_2$ has proved to be almost as effective as NaOH (Wilkinson and Santillana 1978). Combinations of NaOH and $Ca(OH)_2$ may prove to be more effective than either alkali alone (Waller and Klopfenstein 1975).

(d) Na_2CO_3

Na_2CO_3, like $Ca(OH)_2$, is a much safer chemical to use than NaOH. Evidence on its efficacy is conflicting; Chandra and Jackson (1971) found it to be much less effective than NaOH, whereas Coombe and Dove (1978) found that DM digestibility of oat straw in vitro was increased from 47 to 84 % in 1-3 days by NaOH and from 47 to 71 % in 7 days by Na_2CO_3.

(e) NH_4OH

Recently, considerable interest has been shown in the use of anhydrous ammonia, NH_3, and aqueous ammonia, NH_4OH, for treating low quality forages. Anhydrous NH_3 is cheaper than aqueous ammonia but it can only act as an alkali when it dissolves in water to form NH_4OH. Comparisons between NaOH and NH_4OH are given in Table 3.

Anhydrous NH_3 is more costly than NaOH, but because the optimum level of application is lower (Jackson 1977; Sundstøl, Said and Arnason 1979) the cost of the chemicals per tonne forage treated is similar. About 26 % of the nitrogen in NH_4OH is retained in the forage after treatment (Table 3) so that less urea is required to overcome deficiencies'of nitrogen in NH_4OH-treated forages.

Comparisons of NaOH and NH_4OH-treated forages indicate that increases in digestibility in vitro. effected by NH_4OH are about 64 % (Hartley and Jones 1978) to 79 % (Bales, Kellogg and Miller 1979) of those effected by NaOH. In vivo, 3 % NH_3 was found to increase DM digestibility of cereal straw from 42 to 57 % and DM intake by sheep from 257 to 457 g/day (Lawlor and O'Shea 1979). More comparative information on the efficacy of NaOH and NH_4OH is required.

The reaction times for low quality forages treated with 35 g NH_4OH/kg forage are 4-8 weeks at 5-15°C, 1-4 weeks at 15-30°C and less than 1 week above 30°C (Sundstøl, Coxworth and Mowat 1978). In contrast, NaOH reactions with forage fibre appear to be complete in about 2 days at 20°C (Kellaway et al. 1978) and 20 seconds under conditions of high pressure

TABLE 3 Comparisons between NaOH and NH_4OH as alternative alkalis for upgrading the nutritive vaiue of forages

	NaOH	NH_4OH
Cost of alkali ($/t)	314	383(NH_3)
Optimum rate of application (kg/t)	45	35
Cost of alkali application ($/t forage)	14.1	13.4
Nitrogen added to forage by alkali (g/kg forage)(1)	0	7.5
Urea required to add 11.5 g N/kg forage (kg/t forage)	25.0	8.7
Cost of urea @ $268/t ($/t forage)	6.7	2.3
Total cost of alkali + urea ($/t forage)	20.8	15.7
Reaction time at 20°C (days)	2	7
Reaction conditions:-		
Minimum moisture (g/kg forage)	150-250	150-250
Gas tight seal	No	Yes
Cost of polythene cover ($/t forage)(2)	0	20.2
Total cost of chemicals & polythene cover ($/t forage)	20.8	35.9
Additional water intake by animals (l/kg forage)	1.3	0
Additional Na excretion by animals (kg/t forage)	26	0

(1) Mean value of 26 % NH_3-N retained in forage (Horton and Steacy 1979; Kernan et al. 1979; Lawlor and O'Shea 1979; Oji, Mowat and Buchanan-Smith 1979)

(2) 45.3 m^2/t forage @ 37.3¢/m^2, plus $3.33/t forage for sandbags and laths (Sundstøl, Coxworth and Mowat 1978)

and temperature (Rexen and Thomsen 1976). During the reaction period the forage has to be kept at about 150-250 g H_2O/kg forage. In Europe, the moisture content of straw at harvest is normally about 150 g/kg forage, whereas in Australia, moisture levels of 70-80 g/kg are common. Thus, straw in Europe can be treated with anhydrous NH_3 without addition of water (Sunstøl, Coxworth and Mowat 1978), a distinct advantage over NaOH treatment, which requires the use of sufficient water to distribute the alkali evenly over the forage. It is possible that this advantage of NH_3 treatment may be lost in Australia if it proves necessary to apply additional water to the forage.

When the initial moisture content of NaOH-treated forage is 200-250 g/kg, compression of the forage, in bales, pits or stacks is normally sufficient to maintain adequate moisture levels for the duration of the reaction. In contrast, NH_4OH-treated forage has to be kept under gas-tight conditions. The most inexpensive method of retaining NH_3 is probably a polythene cover, the cost of which is $20.2/t forage. Thus, the cost of chemicals plus a polythene cover for NH_4OH treatment is $35.9/t forage compared with $20.8/t forage for the chemicals used in NaOH treatment.

Forage treated with 45 g NaOH/kg contains 26 g Na/kg forage which is greatly in excess of dietary requirements (Table 1). Excess Na is excreted in the urine, which is facilitated by anincrease in water consumption of about 50 ml/g Na (Pirie and Greenhalgh 1978) or 1.3 l/kg treated forage. These increases in water consumption and urine output can cause difficulties in animal management. Also, Na in the urine may adversely affect soil structure and the quality of stream water.

IV. TECHNIQUES FOR APPLYING ALKALIS TO FORAGES

A technique for applying anhydrous NH_3 to forage is described in detail by Sundstøl, Coxworth and Mowat (1978).

Techniques for applying NaOH to forages may be classified as soaking or spraying. Soaking methods entail immersing forage in NaOH solution for 18-20 hours, washing it free of excess NaOH, and drying it (Beckmann 1921 cited by Jackson 1977). Spraying techniques entail applying a spray of concentrated solution of NaOH with no subsequent washing or drying (Wilson and Pigden 1964). Spraying techniques require much less water, produce a lighter product and do not wash out soluble nutrients.

(a) Industrial spraying techniques .

Spraying techniques developed for industrial use in Europe, involve grinding the forage, spraying it with NaOH solution and pelleting under conditions of high temperature and pressure (Rexen and Thomsen 1976; Wilson and Brigstocke 1977). The product is incorporated into commercial concentrate mixtures at 5-20 % of the mixtures, although there does not appear to be any information on the nutritive value of treated straw utilised in this way (Jackson 1977). It is known that untreated cereal straws which are ground and pelleted with concentrates can supply up to 20% of the mixture without affecting growth or feed conversion ratios (Lamming, Swan and Clarke 1966). It is unlikely that similar commercial methods will be developed in Australia because the cost of the product is likely to be too high in relation to that of cereal grain, which has a much superior nutritive value.

(b) Farm spraying techniques --

When alkali-treated forages can be consumed on the farms where the forages are grown, there is considerable merit in carrying out the treatment process on the farm. At the present time there are two alternative methods:-

(i) Mixer trailer (Greenhalgh 1976)

The forage is passed through a hammer-mill (4 cm screen) into a mixer trailer. NaOH solution is sprayed onto the forage whilst mixing and the treated forage is transferred into sacks. Urea and mineral solutions also can be sprayed onto the forage in the trailer. The results of a feeding trial with cattle (Table 4) can be used to calculate the value of untreated and NaOH-treated barley straw. If the cost of rolled barley and soya-bean meal are assumed to be $154 and $400/t respectively, the calculated values of untreated and NaOH-treated straws in this experiment were - $31 and + $21/t respectively. On this basis, both types of straw would be uneconomic alternatives to barley grain. However, if the inclusion level of soya-bean meal had been 29 kg/t in all three diets and the nitrogen deficits in diets. AS_{40} and WS_{40} had been supplied by urea, it may be calculated that the value of untreated and NaOH-treated straws would have been $7 and $61/t respectively (assuming that feed conversion ratios had stayed the same). There is evidence that cattle eating alkali-treated straw utilise urea very efficiently and may not need a protein supplement. Coombe et al. (1979) fed steers untreated and NaOH-treated wheat straw together with nitrogen supplements containing urea (U) and soya-bean meal (SBM) supplying nitrogen in the ratios

TABLE 4 Comparisons between a concentrate diet (C) and diets in which 40 % of the diet was replaced with NaOH-treated (AS_{40}) or water-treated (WS_{40}) barley straw which was coarsely milled (4 mm screen) and sprayed in a mixer trailer.
Diets fed to cattle (10 per treatment)

	C	Diets AS_{40}	WS_{40}	SE Mean
Diet composition (kg/t)				
Barley straw	-	380	390	
Rolled barley	947	495	508	
Soya-bean meal	29	76	78	
Minerals and vitamins	24	24	24	
NaOH	-	25	-	
Days on experiment	132	174	195	
DM intake (kg/day)	7.88	9.67	8.60	0.394
Empty body-weight gain (kg/day)	1.16	1.03	0.78	0.076
Final empty-body weight (kg)	414	437	415	6.7

(Pirie and Greenhalgh 1978)

TABLE 5 Comparisons between wheat straw which was coarsely milled (1.9 cm screen) (C) or finely milled (0.6 cm screen) and pelleted (P), each with and without NaOH treatment in a mixer trailer (A + or -). Diets were fed to cattle (4 per treatment) with supplements supplying urea (U) or urea + soya-bean meal (US)

Diets	Dry matter intake (kg/day)	Liveweight gain (kg/day)	Feed conversion ratio
C - U	4.28	-0.09	127.4
C - US	4.76	0.11	21.8
P - U	6.58	0.50	14.0
P - US	5.70	0.22	37.6
AC - U	6.15	0.48	13.3
AC - US	5.57	0.33	19.5
AP - U	7.79	0.61	12.7
AP - US	8.19	0.62	14.0

(Coombe et al. 1979)

100 u : 0 SBM and 90 U : 10 SBM (Table 5). This experiment showed that replacement of urea with soya-bean meal did not increase feed intake or liveweight gain. It also showed that fine grinding and pelleting greatly increased feed intake and growth rate with untreated straw, and had smaller effects with NaOH-treated straw. In a survey on the effects of grinding and pelleting roughages, Greenhalgh and Wainman (1972) concluded that pelleting and grinding generally increase intake by up to 30 %, with smaller responses from more-digestible material.

In the mixer trailer technique discussed the amounts of water applied were 360 (Greenhalgh 1976) and 400 (Coombe et al. 1979) kg/t air dry straw. An application rate of 200 kg/t is almost as effective (Kellaway et al. 1978) and has the advantages of requiring less water and producing a stable product which can be stored indefinitely without mould development.

In conclusion, the mixer trailer technique of alkali treatment is suitable for batch treatment of forage which has been baled, Machines capable of holding 500 kg forage cost about $8,000.

(iii) 'Alkalage'* technique

This technique has been developed in the Department of Animal Husbandry at the University of Sydney during the past three years. It is a continuous-flow process in which forages are treated before being packaged for transport or storage. This eliminates the double handling of forage, required in all other systems and this results in a considerable reduction in costs. Forages are collected by a forage harvester fitted with spray jets in the chute, through which chemicals are applied to the continuous stream of forage. Turbulent air movement in the chute provides very effective conditions for achieving uniform coverage of forage with the chemical solutions. Two separate spray systems are used, one for NaOH solution (21.6 % w/w), applied at the rate of 190 l/t forage, and the other for an acid solution containing urea, sulphuric acid and phosphoric acid, which supplies 11.5 g N, 1.2 g S and 1.6 g P/kg forage. The acids neutralize 16.5 % of the NaOH, leaving 40 g NaOH/t forage.

Treated forage should be kept moist for about 2 days (Kellaway et al. 1978). This is done by compressing the forage in bales, stacks or bulk storage containers. Conventional bales are made by directing the forage harvester chute into a baler fitted with a hopper above the pickup drum. For bulk storage, the forage harvester chute is directed into a tipping trailer in which the forage is transported to a pit or tower silo. Both these systems require two men and two tractors during the harvesting operation. A simpler system which uses one man and one tractor has been developed for use with the 'Stak Hand' harvesting machine. This machine consists of a forage harvester joined to a forage compression box. A spray trailer has been designed for towing behind a forage harvester or alongside a 'Stak Hand' machine. The capacity of the spray trailer currently used is 3400 1, which is sufficient to treat 13 t forage.

When wheat Straw was treated by the 'Alkalage' technique, DOMD increased from 38 to 51 % and the growth rates of heifers fed the forages were -312 and +23 g/day on the respective treatments (Kellaway et al. 1978). When oat straw was treated by the same technique DOMD increased from 47 to 58 % and the growth rates of heifers fed the forages were 143 and 564 g/day on the respective treatments (op. cit.). In both these experiments the straw was baled. In a subsequent experiment (Table 6) the straw was stored in pits and in 'Stak Hand' stacks. DOMD and nitrogen values on treated straws indicate that the straw in pits was more effectively treated than that in stacks. Approximately 30 % of urea nitrogen was lost. It is believed that much of this loss occurred before spraying because in this experiment the urea solution was mixed in the same tank as the NaOH solution and evolution of NH_3 was apparent. Urea and alkali solutions are now kept in separate tanks. Despite these technical difficulties, animal responses were very large, indicating that the technique upgraded the nutritive value of the straw sufficiently to convert it from a sub-maintenance diet into a diet on which modest growth was made. Rumen VFA concentrations were higher and ammonia concentrations lower in

* Registered as a trade name by the University of Sydney

TABLE 6 Comparisons between wheat straw sprayed by the 'Alkalage' technique with urea + minerals (U) and NaOH + urea + minerals (A), stored in pits (P) and in 'Stak Hand' stacks (S), fed to Hereford steers (15 per treatment)

Storage system	P		S	
Chemical treatment	U	A	U	A
DOMD *in vitro* (%)	49	62	47	54
Nitrogen (g/kg)	11	14	12	11
Initial live weight (kg)	236	238	239	237
Liveweight change over 49 days (g/day)	-56	+337	-239	+68
Rumen VFA (mM/l)	35	53	35	32
Rumen NH_3 (mg/l)	74	37	94	40

(Dunlop, A., Ryan, D., Sriskandarajah, N. and Kellaway, R.C. unpublished data)

cattle eating NaOH-treated straw than in cattle eating untreated straw which indicates that microbial fermentation was more active in animals eating the NaOH-treated straw.

In studies on the flow of microbial protein to the intestines in cattle fed NaOH-treated wheat straw, we have determined that the optimum level of urea is about 25 g/kg forage (Leibholz, J.M.L. and Kellaway, R.C.; unpublished data). In relation to 'Alkalage' utilisation we are currently investigating responses to protein supplements and efficiencies of mineral absorption.

Costs of producing 'Alkalage' are $36-$50/t forage, comprising $27 for chemicals and $9-$23/t for labour and equipment depreciation, based on the production of 600 - 200 t 'Alkalage' per annum respectively. The low cost and efficiency of this continuous-flow process suggest that the technique should have widespread application. When NaOH-treated forage is required for sale off the farm, it could be pelleted through a mobile pelleting machine operating alongside the stacks. The cost of this operation would be partly offset by a further increase in forage nutritive value (Table 5).

V. REFERENCES

BALES, G.L., KELLOGG, W. and MILLER, D.D. (1979). J. anim. Sci. 49: 1324.
CHANDRA, S. and JACKSON, M.G. (1971). J. agric. Sci., Camb. 77:11.
COOMBE, J.B. and DOVE, H. (1978). Rep. Div. Pl. Ind. C.S.I.R.O. Aust. p. 103.
COOMBE, J.B., DINIUS, D.A., GOERING, H.K. and OLTJEN, R.R. (1979). J. anim. Sci. 48:1223.
GREENHALGH, J.F.D. (1976). ARC Res. Rev. 2:67.
GREENHALGH, J.F.D. and WAINMAN, F.W. (1972). Proc. Br. Soc. anim. Prod. p. 61.
HARTLEY, R.D. and JONES, E.C. (1978). J. Sci. Fd Agric. 29:92.
HOLZER, Z., LEVY, D. and FOLMAN, Y. (1978). Anim. Prod. 27:147.
HORTON, G.M.J. and STEACY, G.M. (1979). J. anim. Sci. 5:1239.
JACKSON, M.G. (1977). Anim. feed Sci. Technol. 2:105.
JAYASURIYA, M.C.N. and OWEN, E. (1975). Anim. Prod. 21:313.

KELLAWAY, R.C., CROFTS, F.C., THIAGO, L.R.L., REDMAN, R.G., LEIBHOLZ, J.M.L. and GRAHAM, C.A. (1978). Anim. feed Sci. Technol. 3:201.

KERNAN, J.A., CROWLE, W.L., SPURR, D.T. and COXWORTH, E.C. (1979). Can. J. anim. Sci. 59:511.

LAMMING, G.E., SWAN, H. and CLARKE, R.T. (1966). Anim. Prod. 8:303.

LAWLOR, M.J. and O'SHEA, J. (1979). Anim. feed Sci. Technol. 4:169.

MULHOLLAND, J.G., COOMBE, J.B., FREER, M. and McMANUS, W.R. (1976). Aust. J. agric. Res. 27:881

NATIONAL RESEARCH COUNCIL (1976). "Nutrient Requirements of Beef Cattle" 5th Ed. (National Academy of Sciences: Washington, D.C.).

OJI, U.I., MOWAT, D.N. and BUCHANAN-SMITH, J.G. (1979). Anim, feed Sci. Technol. 4:187.

PEARCE, G.R., BEARD, J. and HILLIARD, E.P. (1979). Aust. J. exp. Agric. Anim. Husb. 19:350.

PETCHEY, A.M. and MBATYA, P.B.A. (1977). Anim. feed Sci. Technol. 2:315.

PIRIE, R. and GREENHALGH, J.F.D. (1978). Anim. feed Sci. Technol. 3:143.

REXEN, F. and THOMSEN, K.V. (1976). Anim. feed Sci. Technol. 1:73.

ROBB, J. (1976). In "Feed Energy Sources for Livestock", H. Swan and D. Lewis Ed. (Butterworths: London).

ROUNDS, W., KLOPFENSTEIN, T., WALLER, J. and MESSERSMITH, T. (1976). J anim. Sci. 43:478.

SCHULTZ, J.E. and FRENCH, R.J. (1976). Aust. J. exp. Agric. Anim. Husb. 16:887.

SIEBERT, B.D. (1974). Proc. Aust. Soc. anim. Prod. 10:86.

SINGH, M. and JACKSON, M.G. (1971). J. agric. Sci., Camb. 77:5.

SUNDSTØL, F., COXWORTH, E. and MOWAT, D.N. (1978). Wld Anim. Rev. 26 13.

SUNDSTØL, F., SAID, A.N. and ARNASON, J. (1979). Acta Agric. Scand. 29:179.

THIAGO, L.R.L., KELLAWAY, R.C. and LEIBHOLZ', J.M.L. (1979). Ann. Rech. Vet. 10:329.

WALLER, J.C. and KLOPFENSTEIN, T. (1975). J. anim. Sci. 41:424.

WILKINSON, J.M. and SANTILLANA, R.G. (1978). Anim. feed Sci. Technol. 3:117.

WILSON, P.N. and BRIGSTOCKE, T. (1977). Process Biochem.' 12:17.

WILSON, R.K. and PIGDEN, W.J. (1964). Can. J. anim. Sci. 44:122.