

NEW PROTEIN FEEDS AND STRATEGIES FOR FUTURE ANIMAL PRODUCTION

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It has been suggested that the energy crisis of the seventies will be succeeded by a protein crisis during the eighties (Humphrey, 1973). Recent reports indicate that the global outlook for protein is beset by a tightening supply – demand situation (Howard, 1980). Based on growth trends during the previous decade and incorporating population and gross domestic product growth rates to 2 000 A.D., Hoshiai (1981) assessed global protein supply and demand for humans as follows (Table 1).

On the global front the protein situation obviously presents a serious situation and of significance in Hoshiai's comprehensive assessment is the suggestion that contrary to expectations, human requirements for animal protein until the turn of the century will increase more rapidly (3,4% p.a.) than for plant proteins (2,0% p.a.). Verification for more intensive animal production practices in future thus seems obvious. However, the major protein source for livestock feeding viz. oilcakes would appear to be deficient by 22 million tons protein for 2000 A.D.

The Republic of South Africa occupies a unique position on the African continent in that it produces one-

quarter of total feed proteins (Cloete, 1975). Notwithstanding its prominent standing as a protein producer on this continent, concern has been expressed (Cloete, 1979) as to South Africa's own protein solidarity for animal feeding (Table 2).

Table 1

*World protein supply and demand for humans
1975 – 2000 A.D. (million tons protein)*

	Protein supply (1)	Protein demand	Global status
1975	101	100	+ 1
1985	126	128	- 2
2000	164	178	- 14

(1) Recalculated from Hoshiai (1981)

Table 2

Anticipated protein deficit for animal feeding during 2000 A.D. based on growth trends during the previous decade (Cloete, 1980 – unpublished)

Annual protein production 1970 – 1979 (tons)	Expected protein production (at existing growth rate – 0,52% p.a.) during 2000 A. D. (tons)	Protein requirements 2000 A. D. at a population growth rate of 2,7% p.a. (tons)	Protein deficit 2000 A. D. (tons)
(1)			
505 000	557 000	783 000	226 000

(1) Only protein sources containing 12 per cent or more protein considered.

On an oil cake equivalent basis the deficit during 2000 A. D. is likely to amount to \pm 565 000 tons oilcakes (present production 250 000 tons). This projection is however, dwarfed by the estimate of Griesel (1979) which points to a requirement of about 1 000 000 tons animal feed proteins. Consequently, it appears as if South Africa is heading for a substantial deficiency in protein feeds when judged by precious growth trends.

Comparison of the geometric growth and per capita consumption tendency (Griesel, 1979) points to the following increased requirements for the various animal products during 2000 A. D.: poultry meat 194 per cent (570 000 tons), eggs 102 per cent (235 000 doz), pork 95 per cent (86 000 tons), milk 62 per cent (1420 million l), mutton 84 000 tons (49 per cent) and beef 217 000 tons (26 per cent). Consequently, the most significant increases are expected in the more intensive animal production sectors which should be accorded access to protein sources of superior protein value (fish meal, soya and oilcakes). Furthermore, 49 per cent of all cattle marketed as well as 6,8 million sheep will have to be intensively raised (presently \pm 20 per cent for cattle). The necessity for greater intensification is again clearly apparent. This will necessarily place a heavy burden on our already stretched protein supply. A realistic new protein strategy appears to be urgently required. The ensuing discussion attempts to evaluate options to be considered in constructing such a strategy.

New protein sources for animal production

Future by-product proteins

Increasingly stringent environmental pollution legislation (Oberholster, 1978) and growing industrial and agricultural waste production (Knoesen & Joubert, 1978) coupled with an inherent profit motive (Van Niekerk, 1979), serve as incentives to the recycling of protein by-products from the animal, plant and industrial sectors. Some of these protein products not commonly used in the recycling source, namely animal feeds, and their potential contribution to protein supply during 2000 A. D. are presented in Table 3.

Calculations indicate that exploitation of the aforementioned by-products may greatly assist in bridging the anticipated protein deficit twenty years hence. Apart from poultry droppings (80 000 tons p.a. - Hyman, 1978), however, none of these sources have been exploited to any significant extent. Other sources which may also be developed include dehydrated ammoniated citrus pulp (16,5 per cent protein), condensed fish solubles (57 per cent protein), animal hair meal (95 per cent protein), dried spent sulphite liquor from the paper pulp industry (25 per cent protein) and hydrolysed

leather meal. Before animal waste proteins will be used extensively as livestock feeds, the following hazards will have to be overcome: (1) the effects of drugs and heavy metal residues contained therein on animals (Calvert, 1971), (2) the transmission of disease from feeding manure (Hyman, 1978), (3) the effect of molds or fungi common in litter on animals (Smith, 1971), (4) possible imbalances created by the high mineral content on manure (Frobish, 1971), (5) high costs incurred in collecting and processing excretory products (Knoesen & Joubert, 1978) and (6) aesthetic considerations (Rudd, 1978).

Leaf protein concentrates (L. P. C.)

A research goal in many laboratories has been to fractionate forage into (a) high protein products for monogastrics and humans and (b) a residue to be used for ruminants (Kohler, Chrisman & Bickoff, 1973). Although about 30 plant species have already been considered for this purpose (Pirie, 1971), the majority of research inputs have been directed at lucerne (Cheeke, 1976) and grass (Cadenhead, 1972).

Mechanical extraction of green crops creates the possibility of extracting protein hitherto not utilised extensively in agricultural systems (Houseman & Connell, 1976) and this has now become commercially feasible in many overseas countries (Braude, 1976). Green crop juice can be used now by non-ruminants in the liquid form (37 per cent protein), either freshly extracted or preserved with chemicals (HCl and metabisulphite) (Braude, 1976) or further processed into a protein-rich coagulum (59 per cent leaf protein concentrate) (Cheesman, 1974).

Screw-press processing results in a pulp residue containing 1 to 5 per cent less crude protein than in the original crop (Houseman & Connell, 1976). This pulp residue can be directed to ruminants in the fresh, dried or ensiled form (Meyer, Cheeke, & Kennick, 1975). The amino acid composition of L.P.C. is comparable to that of conventional protein sources (Byers, 1971) although methionine may appear to be the first limiting amino acid (Gerloff, Lima & Stahmann, 1965). Biological value of L.P.C. may exceed 70 per cent (Henry & Ford, 1965).

In the Balanced Feed Industry the demand for pelleted dehydrated alfalfa should serve as a rider to extended operations in this field. Furthermore, continually rising prices of conventional protein sources will strengthen the bargaining power of L.P.C. and curtail the present exportation of valuable protein in this form owing to monetary considerations.

Table 3

Animal and plant protein by-products for potential utilisation in animal feeds

By-product	Present production (DM tons)	Protein (%)	Protein production (tons)	Potential protein production 2000 A. D. (tons) (5)
Poultry industry				
Layer litter	160 000	22	35 600	104 000
Broiler litter	155 000	24	37 200	109 000
By-products meal ⁽¹⁾	—	55	—	27 000
Feather meal ⁽²⁾	—	80	—	14 000
Cattle industry				
Rumen contents (dry) ⁽³⁾	38 000	17	4 500	6 000
Cattle manure (feedlots)	263 000	13	34 000	48 000
Pig industry				
Pig manure	88 000	20	17 500	34 000
Dairy industry				
Whey powder	14 400	13	1 900	3 000
Brewing industry				
Brewers grains	15 000	22	3 300	5 000
Sorghum grains	20 000	25	5 000	7 000
Maize industry				
Maize gluten	7 500	60	4 500	7 000
Distillers grains solubles ⁽⁴⁾	166 000	27	45 000	89 000
TOTAL	927 000	—	188 500	453 000

(1) Assuming 24,4g by-products meal per broiler (Griesel, 1981 – pers. comm.).

(2) Assuming 45,7g feather and blood meal per broiler (Griesel, 1981 – pers. comm.).

(3) Only animals slaughtered in control areas.

(4) Assuming 500 000 tons maize to be processed presently and 1 million tons during 2000 A.D.

(5) Data of Smith (1971), Griesel (1979) and Van Niekerk (1979) used in calculations.

Single cell proteins (S. C. P.)

Various scientific symposia on single cell proteins serve as a barometer of thinking to develop novel protein sources in a future protein hungry world. The rationale behind this interest is clearly apparent when it is considered that while calves take about 2 months to double their initial mass, S. C. P. may achieve the same in $\frac{1}{2}$ – 1 h (Bomar, 1981), S. C. P. may be produced by non-photosynthetic (yeasts, bacteria and fungi) and photosynthetic (algae) organisms. Progress in this field may be summarised as follows:

Yeast as S. C. P.

The most familiar strains of yeast employed for protein production comprise *Torula*, *Candida* and *Saccharomyces* (Naess & Slagswold, 1973) grown on substrates such as cereals, sugars, molasses, waste sulphite liquor, cheese whey, alcohol, sewage and petroleum products. In South Africa, molasses has also been used as substrate (De Bruyn & Lategan, 1968). The nutritive value of particularly hydrocarbon based yeasts (Toprina) has been well established for pigs (Barber, Braude, Mitchell & Myers, 1971; Oslage & Peterson, 1973) and poultry (Van Weerden, Schacklady & Van der Wal, 1970). Oil price increases have, however, severely curtailed the production of hydrocarbon yeasts.

Bacteria

Petrochemicals produced from hydrocarbons e.g. acetic acid, ethanol, methanol have been used as bacterial substrates. The most widely used fermentation product has been Pruteen produced from methanol using *Pseudomonas*. Whilst containing 83 per cent crude protein, Braude (1976) pointed out that due to its high nucleic and acid content its use may be restricted for some monogastrics which do not possess the urate oxidase enzyme. It has, however, subsequently been confirmed that pigs and calves could use this bacterial protein (Braude & Rhodes, 1977) to good advantage. Cellulosic waste has subsequently been used as substrate (Bomar, 1981).

Fungi

The Finnish process which utilises the fungus strain *Paecilomyces* on sulphite spent liquor from paper pulp to produce Pekiloprotein is the most wellknown in this field although barley has also been considered as a substrate for *Aspergillus* and *Rhizopus* (Braude, 1976). Studies with pigs indicated that Pekiloprotein could replace fish meal in diets (Barber, Braude & Mitchell, 1977).

Algae

Algae proliferate spontaneously, in the presence of sunlight, CO₂, inorganic culture media to produce substantial quantities of protein and is relatively easy to grow. The strains *Spirulina*, *Chlorella* and *Scenedesmus* have already been exploited for commercial purposes and the proteins used in pig nutrition (Braude, 1976).

At present considerable interest is focussed on algae production in South Africa and substrates used on an experimental scale include sewage effluent (Viviers, Briers & Van Vuuren, 1980), industrial effluent (Basson, 1980 – pers. comm.), effluent from intensive animal production units (Pieterse, 1980) and mineralised water (Chutter, 1980).

The chemical composition of S. C. P. reflects, to a certain extent, potential nutritive value and the proximate chemical composition is indicated in Table 4.

Despite their rapid multiplication rate, the following problems should be considered prior to their application in animal feeding:

Harvesting – A major difficulty in the use of single cell proteins is the harvesting of material. Currently dehydration, filtration, centrifugation and flocculation are used (Johnson, 1967; Oswald, 1969). Algae are generally more easily separable than yeasts and yeasts more than bacteria (Asplund & Pfander, 1973).

Palatability – Unprocessed microbial cells are normally not very palatable since yeast has a characteristic bitter flavour, while algae and bacteria have less acceptable flavours than conventional proteins (Waslein, Calloway, & Margen, 1969). In order to overcome this problem S.C.P. should, therefore, be used as supplements.

Digestibility – Unless S.C.P. is treated (cooked) to kill the cells, digestibility is poor especially in the case of yeasts and algae (Miller, 1968). Reduced digestibility of bacteria is associated with substantial quantities of diaminopimelic acid or muramic acids as cell wall constituents which are not absorbed (Mason & Milne, 1971).

Nucleic acid content – The high levels of nucleic acids in S.C.P. are clearly apparent from Table 4. When the purines of the nucleic acids are metabolised, uric acid is formed. In man, uric acid is relatively insoluble. Elevated blood urate levels were noted after the consumption of yeasts or algae by humans (Waslein, Calloway, Margen & Costa, 1970). In ruminants the enzyme uricase metabolises uric acid to the much more soluble allantoin which is excreted. Whilst not expected to produce phy-

Table 4

Proximate chemical composition of single cell proteins

Constituent	Yeast (1) (BP)	Bacteria (1) (Pruteen)	Fungi (1) (Pekilo protein)	Algae (2)
Dry matter	94,2	95,0	93,4	91,1
Crude protein	62,0	77,5	47,5	54
Nucleic acid	10,0	14,7	10,0	3,7
Crude fiber	—	0,03	6,1	3,3
Ash	5,7	10,1	5,3	14,5
Calcium	0,07	0,04	0,07	0,24
Phosphorus	1,5	2,6	0,2	0,9
Lysine (g/kg protein)	7,3	6,5	5,6	3,2
S Amino acids (g/kg protein)	0,27	0,33	0,26	9,80

(1) Braude (1976).

(2) Basson (1981 – pers. comm.).

biological problems in livestock feeding, the consuming public will, however, have to be appeased and informed that animal products resulting from S.C.P. consumption will not be harmful. However, the reduction of nucleic acids in S.C.P. for human feeding is possible by means of anaerobic after-fermentation techniques (Bomar, 1981).

Toxicity — Two sources of harmful compounds in S.C.P. exist viz. selective absorption by organisms of potentially toxic substances in the industrial growth substrate (eg pesticides and trace elements), and toxins specifically produced in microbial cells as regular or secondary metabolites (Asplund & Pfander, 1973). Since 1970, Japan has developed assessment methods for the safe use of S.C.P. for animal feeding including pathogenicity, mutagenicity, toxicity (mycotoxins and heavy metals) and carcinogenicity (Fudjimaki, 1981). Results were generally negative when tested on livestock (Yu, Da Chen & Kang-Lin, 1981).

Protein quality — A relative deficiency in S— amino acids in S.C.P. is apparent from Table 4, while lysine and isoleucine may be marginal (Waldroup, 1972). The amino acid profile of S.C.P. is usually superior to that of cereals but inferior to that of commonly used protein supplements (Miller, 1968). This inferiority may, however, be largely overcome by methionine supplementa-

tion (Asplund & Pfander, 1973). The biological value of yeast proteins is generally around 60 per cent without methionine supplementation while with D. L. methionine supplementation it may be increased to that of dried skim milk protein (Shacklady, 1972).

Economic aspects — Without becoming embroiled in a lengthy involvement in economics, engineering and related fields, it appears feasible that a multidisciplinary approach to future S.C.P. production should be sought. As long as conventional protein sources eg. oilcakes are freely available at reasonable prices, S.C.P. appears to be a relatively obscure alternative. However, in view of their ability to conserve energy (14,56 MJ ME/kg), to combat increasing pollution and, most importantly, to potentially supplement an increasing protein deficit for animal feeding, the increased production of S.C.P. should be supported.

Notwithstanding the availability of a wide variety of substrates, the choice of substrate and the economics of energy inputs will be deciding factors. Despite escalating substrate prices, S.C.P. production is going ahead in many parts of the world. eg. Japan, India, U.S.S.R., China, W. Germany etc. and the verdict appears to be that even under these conditions prices for S.C.P. products still appear to be marginal for petroleum substrates.

Table 5

Changes in the production of animal protein feeds during the past decade in South Africa ('000 tons) (Cloete, 1980 – unpublished)

Protein source	Protein production		Annual change in protein production	
	1970 – 74	1975 – 79	(tons)	(%)
Oilcakes	47	66	+ 3 800	+ 8,8
Lucerne hay	188	192	+ 800	+ 0,4
Fish meal	144	119	– 5 000	– 3,5
Carcass and blood meal	7,2	8,7	+ 300	+ 4,2
Urea	68	71	+ 600	+ 0,9
Wheaten bran	41	43	+ 400	+ 1,0
Soybean	3	11	+ 1 600	+ 53,0
TOTAL	498	511	+ 2 600	+ 0,52

In view of local constraints in respect of increasing arable land for protein production, a fresh and unified look at research in this field appears opportune in order to exploit a vast potential.

New protein strategies for intensive animal production

An anticipated global decrease in fish meal protein from 2,72 million tons in 1975 to 1,59 million tons in 2000, and a deficit of 22 million tons of oilcakes (Hoshiai, 1981) coupled with our own projected deficit in protein for animal feeding (Table 2), require objective appraisal of a viable future protein strategy. Perspective of some of the options to be considered may be deduced from Table 5.

Dwindling fish meal supplies (Table 5), prompted the Protein Advisory Committee to advise the Minister for Agriculture that, as an interim measure, oilseed production, and particularly sunflower and soya should be advocated. A few realities attached to sunflower and soya as oilseeds should, however, be considered. Since oilseeds and edible plant oils are produced concurrently, it is feared that oilcakes (as one of the most important animal feed proteins) may be in short supply in future due to a world trend of an oversupply of vegetable oils. Furthermore, plant oil expressing facilities in the country offer a potential oilcake production about 650 000 tons (present production 250 000 tons) whilst about 1,1 million tons oilcake will be required in 2000 A.D. (Griesel, 1979), which implies, furthermore, that oil expressing facilities will have to be extended. Evidently problems

will be encountered to produce the required 425 000 tons soy cake during 2000 A.D. since potential production appears to be only about 250 000 tons (Snyman 1980 – pers. comm.).

The complexity of constructing any worthwhile protein feeding strategy is also confounded by a present growth rate of only 0,52 per cent p.a. (2 600 tons protein) as against an anticipated 6,4 per cent p.a. (18 400 tons protein) requirement in 2000 A.D. In addition to the use of protein by-products, single cell protein and leaf protein concentrates, a number of additional prospects may be explored.

Technical aspects of a future protein strategy

Improved protein requirement models

For many years the digestible crude protein system has been used in South Africa to express the protein requirements of farm livestock. In order to save protein, various models have been developed since 1975 to express the protein requirements of ruminants eg. the British (Roy, Balch, Miller, Orskov & Smith, 1977), French (Journet & Verity, 1977), West German (Kaufmann, 1977) and U.S.A. (Satter & Roffler, 1975; Burroughs, Nelson & Mertens, 1975; Fox, Crickenberger, Bergen & Black, 1977) models. Essentially, all these models are based on the concept of amino acid absorption from the small intestine of ruminants with the objective of quantifying the exact requirement for protein in more precise terms and also incorporating the imperative energy concept.

Criticism which may be advanced at present against the construction of these models may be directed at the various constants employed viz.

- (a) the validity of using a constant of 0,65 for indicating the proportion of apparently digested organic matter apparently digested in the rumen (in the British model), in view of the difficulty of estimating the contribution of microbial organic matter (Smith, 1975). Values may in fact vary from 0,42 to 0,83, with relatively large differences existing between sheep and cattle (Waldo, 1973).
- (b) the acceptability of using a constant of 30g microbial N/kg organic matter apparently digested in the rumen while values may vary from 6,2 to 42 (Stern & Hoover, 1979; Armstrong, 1980 pers. comm.). The most acceptable markers for this purpose still appear to be ^{35}S and ^{15}N (Beever, 1980 – pers. comm.).
- (c) the apparent confusion precipitated by the various methods adopted to estimate rumen degradable N eg. by means of diluted NaOH (Lyman, Chang & Couch, 1953), artificial saliva (Tagari, Ascarelli & Bondi, 1962), autoclaved rumen fluid (Wohlt, Sniffen & Hoover, 1973), diluted pepsin – HCL (Beever, Thomson, Cammell & Harrison, 1977), water (Mertens, 1977), suspended dacron bags (Mehrez & Orskov, 1977) etc. Confusion exists in interpreting values obtained either by degradability or solubility (Satter, Whitlow & Beardsley, 1977).
- (d) These limitations also cast doubt on the values used for undegraded (bypass) N which are normally determined by difference. A considerable quantity of N entering the small intestine may be of endogenous origin (Cloete, 1964a), thus questioning the validity of the constant used for dietary amino acid absorption from the small intestine. Incidentally, the assumption that metabolic faecal nitrogen consists primarily of microbial protein (ARC., 1980) may be erroneous when related to the passage of nitrogen-free diets through the ileo-caecal junction (Cloete, 1964b).

Notwithstanding these difficulties new concepts of protein utilisation emerged in relation to the relative value of different protein sources as eg. based on their degradability in relation to the quantities of by-pass protein reaching the small intestine. The ranking order appears to be brewers grains, fish meal, bloodmeal, meat and bone meal, heated soya meal, sunflower meal, groundnut meal and casein varying in degradability from 0,15 to 0,90 (Miller, 1978).

The construction of protein models for ruminant and non-ruminant production in South Africa thus warrants elucidation. Wide variation in available feedstuffs and processing techniques, will, however, present formidable challenges. For ruminants, models based on the aforementioned concepts will have to be contemplated, whilst for non-ruminants (pigs and poultry), models based on dietary energy supply and available amino acids will have to be considered. In the latter case deviations from the currently used ARC (1967) requirements for pigs and NRC (1977) requirements for poultry will have to be investigated.

Methods to enhance protein utilisation in ruminants

While efforts in the non-ruminant field to enhance protein utilisation have been restricted mainly to improving energy – amino acid relationships, various alternatives have been investigated in the ruminant field of which the following may be fruitfully considered:

Feed processing. Some factors involved in the processing of roughage (Beever, Thomson & Cammell, 1976), grains (Hale, 1973) and other protein feeds (Bjarnason & Carpenter, 1970), decrease the solubility of dietary protein and increase the passage of by-pass protein to the small intestine (Armstrong & Hutton, 1972). Such changes could be effected through heating, drying, ensiling, grinding or pelleting (Miller, 1978). The general criterion to enhance protein utilisation is to restrict heating to a point prior to the onset of the maillard reaction (Goering, Van Soest & Hemken, 1973). Efficient feed processing appears to be one of the most important factors to preserve and enhance protein quality under local conditions. The protein quality of fish meal and oilcakes may, however, be damaged to the extent of about 30 and 25 per cent respectively (Smith, 1980) under normal processing conditions in South Africa.

Chemical methods. Some chemical reagents induce reverse cross linkages with amino and amide groups. These cross linkages are subsequently dissolved under lower pH conditions in the small intestine. Methods include formaldehyde (Ferguson, 1971), tannins (Mc Donald, 1968), phosphonitryl halide (Miller, 1972), acrolyn acetal (Miller, 1973), acetyl esters (Wildi & Miller, 1973) and other halides and triazines, all of which have been patented. Of these, formaldehyde has been most widely used in treating casein (Ferguson, 1975), oilseed meals (Schoeman, De Wet & Burger, 1972; Broderick, 1975) and grass silages (Beever, *et al.*, 1977). The greatest response was obtained in the case of wool production (Barry, 1976). Responses in meat production were generally much smaller (Chalupa, 1975), whilst only Verity & Jourmet (1977) obtained a significant response in milk production with formaldehyde-treated soya meal.

Advantages of using formaldehyde in increasing amino acid flow to the small intestine, have, however, lately been clouded by the possibility that it could produce the carcinogen, bis - chloromethyl ether (Williams, 1980 - pers. comm.). Other substances eg. glutaraldehyde etc. will thus have to be considered as alternatives. Attempts to protect highly degradable protein should obviously guard against over-protection. Suggested optimal levels for formaldehyde application (or that of a suitable alternative) appear to be 0,8 to 1,2 per cent per protein source (w/w) for casein, 2 per cent for oilcakes and 3 per cent for silages (Broderick, 1975).

Encapsulating of amino acids. The possibility of coating amino acids using enteric coating reagents (polymers) was proposed by McDonald (1968) in order to facilitate their release under acidic conditions. Consideration of exploiting this possibility should obviously be linked to limiting amino acids for the various productive functions. Whilst the abomasal and duodenal infusion of S-amino acids or casein proved to increase woolgrowth (Reis & Schinkel, 1963, Smith, 1979), the limiting amino acids for meat and milk production have yet to be determined. Methionine, lysine, phenylalanine, tyrosine, and threonine have already been considered (Chandler & Polan, 1972).

However, Teichman, Caruola & Mochrie (1969) who infused methionine directly into the blood of dairy cows and Broderick, Kowalczyk & Satter (1970) who fed encapsulated methionine could detect no advantages. Since, under most feeding conditions the protein supply in the small intestine appears to be sufficient for about 25 kg milk (Tamminga & Van Hellemond, 1977), limiting amino acids for milk production and possibilities of their encapsulation should obviously be assessed at levels beyond 25 kg (Tamminga, 1979).

Closure of the oesophageal groove. Reflex closure of the oesophageal groove is stimulated by liquids in the back of the mouth (Comline & Titchen, 1951). Using sodium salts or copper sulphate to stimulate groove closure produced variable results (Rieke, 1955). However, Orskov (1972) managed to exploit reflex closure in lambs up to a year-old. It would appear as if greatest possibilities to avoid rumen fermentation by this means probably exist in exploiting liquid feeding systems in ruminants (Cunha, 1972). It should be conceded, however, that notwithstanding possibilities, practical methods for stimulating the reflex have not been adequately established.

Treatment with antibiotics. While it is known that antibiotics inhibit proteolytic and deaminative activities of rumen microbes (Turner & Hodges, 1952), the use of neomycin, oxytetracycline or streptomycin as suppressing agents were not very promising (Hogan & Weston,

1969). Some positive results were obtained with dimethyl diphenyl iodonium chloride (Chalupa & Scott, 1976) and monensin (Van Nevel & De Meyer, 1977). The possibility exists, however, that antibiotics may not only inhibit deaminative ability, but may also decrease microbial protein synthesis particularly from N.P.N. (Tamminga, 1979).

Defaunation. Notwithstanding previous indications that protozoal N may account for 20 per cent of microbial N leaving the rumen (Pilgrim, Gray, Weller & Belling, 1970), Weller & Pilgrim (1974) destroyed the argument when they indicated that in fact only 2 per cent of the flow of protein from the rumen were protozoal.

Since protozoal protein is derived largely from bacterial protein (90 per cent - Kennedy & Milligan, 1978), they, therefore, compete with the host animal for both energy and protein (Moir, 1979). Bird, Baigent, Dixon & Leng (1978) substantiated this finding when they reported defaunated sheep to have a mass advantage of 2 kg at 6 weeks on low protein diets. Moir (1979) suggested further studies on the limitations imposed on the host by protozoa and their possible elimination by means of detergents eg. alcohol ethoxylates.

Use of fats or oils. In order to supplement energy to the high yielding dairy cow, recent studies indicated that large amounts of fats can be included in the diet (Palmquist & Conrad, 1978). An increase in N digestibility but not N retention was noted. Corroborating earlier findings of a reduction in organic matter digestibility associated with high fat diets, Ikwuegbu, Sutton & Mc Allan (1979) recorded a 50 per cent increase in the efficiency of microbial protein synthesis and reduced ruminal NH₃ levels in dairy cows receiving linseed oil as 10 per cent of the concentrates. Although variable, results indicate further investigation on using fats or oils to increase amino acid flow to the small intestine.

Amino acid analogues. Structural manipulation of amino acids to create resistance to ruminal degradation offers a potential for the rumen by-pass of amino acids. Generally methionine hydroxy analogues, while possessing methionine activity in ruminants, (Belasco, 1972) hitherto, produced inconclusive results (Swan, 1971) due to their instability in the rumen (Amos, Little, Digenis, Schelling, Tucker & Mitchell, 1974). Progress in this field is, nonetheless reflected in attempts to change amino acids to imides which survived rumen condition *in vitro* (Ku & Simon, 1973).

Treating N.P.N. compounds. Urea hydrolysis normally exceeds the utilisation of ammonia by microbes. A variety of agents inhibit ruminal urease activity (Chalupa, 1972). Streeter, Oltjen, Slyter & Fishbein (1969) re-

ported lower ammonia concentrations with acetohydroxamic acid supplementation which resulted in higher N retention.

Positive results were also obtained by using lactocyl urea (Merry, Smith & Mc Allan, 1979) and dymethylol urea. Further work is, however, required to assess the potential of urease inhibitors.

Strategic protein feeding. New concepts introduced in the protein nutrition of ruminants i.e. rumen degradable (microbial) and rumen undegraded (by-pass) protein call for judicious application in practical feeding systems. Microbial protein alone seems to be adequate for the maintenance protein requirements of steers and for the production of about 7.5 kg of milk in dairy cows (Miller, 1978), but additional by-pass protein (fish meal, chemically treated oilcakes, dried brewers grains, linseed meals, blood meal etc.) is required for higher production levels and in the case of rapidly growing young steers and lambs. At moderate production levels, the normal mixture of microbial and by-pass protein will suffice (Preston, 1973). Responses to abomasally infused proteins and amino acids suggest that the genetic potential of high producing dairy cows, rapidly growing sheep and cattle and woolled sheep is limited by inadequate amounts of absorbable amino acids (Johnson, 1972, Chalupa, 1974). The efficient use of N.P.N. is thus also placed in true perspective (Satter, 1975) under conditions when the requirement for rumen degradable N supervenes (Orskov, Fraser, Mc Donald & Smart, 1974).

Since the majority of methods dealt with, to enhance protein utilisation in ruminants, precipitate alteration of the site of digestion in the gut, it is feasible that the endocrine status of the animal may also be influenced (Clark, 1975). Growth hormone and insulin concentrations were increased in cattle, sheep and goats when amino acids were infused intravenously (McAttee & Trenkel, 1971), whilst close relationships between plasma insulin and protein utilisation post-ruminally have been reported (Bassett, Weston & Hogan, 1971).

Exploitation of these methods present a worthwhile challenge to the animal nutritionist and obviously calls for elevated research inputs. It would appear as if the maximisation of rumen by-pass protein and their augmentation of non-degradable amino acids are feasible approaches as long as other aspects of ruminal metabolism and post-ruminal digestion and absorption are not interfered with.

General aspects of a future protein strategy

Apart from exploiting protein by-product feeds (Table 3), leaf protein concentrates, S.C.P. and technical as-

pects of enhancing protein utilisation, it appears feasible that the following general aspects of a future protein strategy should also be considered as indicated by the Protein Advisory Committee and accepted in principle by the Minister for Agriculture.

Efforts to increase the production of protein-rich plant protein sources eg. sunflower, groundnut, cottonseed and soya should be extended notwithstanding world plant oil problems since these sources currently offer the greatest possibilities as replacements for declining fish meal supplies. Means should be investigated to diversify the use of plant oils possibly in the direction of fossil fuel replacements. In obviating the over-supply of plant oils it is imperative that the Balanced Feed Industry should be geared to increasingly use soya in the full-fat form.

The introduction of legumes in the high-potential areas (presently 250 000 ha) should be extended. About 9.2 million ha in these areas (White-owned) are potentially available for this purpose.

Lucerne production as the major source of protein for animal production (Table 5) should be extended and possibilities investigated for its additional use as leaf protein concentrates and dehydrated pellets thus effecting greater incorporation in the Balanced Feed Industry.

The production of high lysine cereal varieties eg. high lysine maize should be encouraged in view of their protein-sparing effect on conventional protein sources.

In view of the shortage of fish meal, its use in ruminant diets should be strongly discouraged and the limited quantities directed to non-ruminant production in which case it will be used with a greater efficiency of protein conversion. However, plant protein sources supplemented with synthetic amino acids will gradually replace fish meal in non-ruminant diets, thus enforcing the concept of optimal instead of maximal production practices. Ruminant production in future will rely heavily on by-product proteins. N.P.N. and oilcakes of lower protein value eg. ground nut.

Application of more efficient feed processing techniques eg. heat and chemical treatment, pelleting, flaking, micronisation, popping, extrusion etc. will preserve protein quality, induce a greater amino acid flow to the small intestine, and consequently save considerable protein. An experimental feed mill where these aspects could be intensively studied, should be erected by the Department of Agriculture and Fisheries.

Protein sources used in the non-ruminant sector will eventually have to be sold on a protein quality basis, prices of which will be linked to intrinsic protein value

(available amino acid content). In the ruminant sector prices are likely to be linked to protein degradability parameters. These will form the basis of more exact protein quality standards in the Farm Feeds Act (No. 36/1947).

Unpredictability of climatic influences and boycott threats tend to favour the idea of constructing efficient storage facilities for protein materials in order to promote a more stable supply during times of scarcity.

Competition between the human and animal sectors for available protein sources (soya, fish meal, oilcakes) will increase in future. The demand for protein by-product feeds, plant leaf protein concentrates and pulp residues, single cell proteins, methods to enhance protein utilisation and strategic protein feeding will gain in significance in order to promote intensive animal production practices.

In view of the anticipated shortage of feed proteins in the world in general and South Africa in particular, the establishment of a suitably staffed permanent Protein Administration appears more than justified.

Activities will entail:

- (a) constant monitoring of global and local protein supply and demand for animal feeding.
- (b) regular evaluation of the competition between the human and animal production sectors for available protein sources.
- (c) Evaluation of changes in the human consumption of animal and plant proteins in view of changes in the buying power of the different population groups.

- (d) An annual assessment of research progress in respect of enhancing protein utilisation in livestock.

The monitoring of these aspects will assist the Protein Advisory Committee to recommend sound short, medium and long-term planning policies to the Minister for Agriculture. The Animal Production Advisory Council should also be regularly alerted about recommendations of the Protein Advisory Committee and closer liaison should be established between these two bodies.

It is obvious, therefore, that a future viable protein strategy should accommodate a wide spectrum of considerations. Since the strategic importance of protein for animal production, and, hence human consumption is indisputable, the Government of South Africa should initiate and co-ordinate efforts to increase its production and efficient utilisation by livestock.

Conclusions

On the global front protein supply for human consumption is heading for a substantial deficit during 2 000 A.D. Judged by protein growth rates for animal feeding during the previous decade, a substantial deficiency of between 225 000 – 500 000 tons protein appears likely at the turn of the century in South Africa. The contribution of plant, animal and industrial by-product proteins, leaf protein extracts, single cell proteins, more exact protein requirement models, methods to enhance protein utilisation and other general aspects have been considered as options in constructing a future protein strategy for animal production. In view of the strategic importance of protein, it is proposed that the Government should initiate and coordinate efforts to increase protein production and utilisation for animal production in order to meet future human requirements.

References

- AMOS, H.E., LITTLE, C.O., DIGENIS, G.A., SCHELLING, G.T., TUCKER, R.E. & MITCHELL, G.E., 1969. Methionine, DL – homocysteine thiolactone and N- acetyl – DL – methionine for ruminants. *J. Anim. Sci.* 39, 612.
- AGRICULTURAL RESEARCH COUNCIL, 1967. Nutrient requirements of farm livestock. No. 3 Pigs. *London, Agric. Res. Counc.*
- AGRICULTURAL RESEARCH COUNCIL, 1980. The nutrient requirements of ruminant livestock. *Surrey, Gresham Press.*
- ARMSTRONG, D.G. & HUTTON, K., 1972. Digestion of protein and other energy-yielding substrates in the ruminant animal. *IInd World Congr. on Anim. Feeding, Madrid, Sept. 1972.*
- ASPLUND, J.M. & PFANDER, W.H., 1973. Production of single cell protein from solid waste. In *Alternative sources of protein for animal production*. Washington, National Academy of Sciences.
- BARBER, R.S., BRAUDE, R. & MITCHELL, K.G., 1977. The value of Pekilo protein for pigs. *Anim. Feed Sci. Tech.* 2, 161.

- BARBER, R.S., BRAUDE, R., MITCHELL, K.G. & MYRES, 1971. The value of hydrocarbon-grown yeast as a source of protein for growing pigs. *Brit. J. Nutr.* 25, 285.
- BARRY, T.N., 1976. Evaluation of formaldehyde-treated lucerne hay for protecting protein from ruminal degradation for increasing nitrogen retention, wool growth, live weight gain and voluntary intake when fed to young sheep. *J. agric. Sci. (Camb.)* 86, 379.
- BASSETT, J.M., WESTON, R.H. & HOGAN, J.P., 1971. Dietary regulation of plasma insulin and growth hormone concentration in sheep. *Aust. J. Biol. Sci.* 24, 321.
- BEEVER, D.E., THOMSON, D.J. & CAMMELL, S.B., 1976. The digestion of frozen and dried grass by sheep. *J. agric. Sci.* 86, 443.
- BEEVER, D.E., THOMSON, D.J. CAMMELL, S.B. & HARRISON, D.G., 1977. The digestion by sheep of silages made with and without the addition of formaldehyde. *J. agric. Sci. (Camb.)* 88, 61.
- BELASCO, I.J., 1972. Stability of methionine hydroxy analog in rumen fluid and its conversion *in vitro* to methionine by calf liver and kidney. *J. Dairy Sci.* 55, 353.
- BIRD, S., BAIGENT, D.R., DIXON, R. & LENG, R.A., 1978. Ruminal protozoa and growth in lambs. *Proc. Aust. Soc. Anim. Prod.* 12, 137.
- BJARNASON, J. & CARPENTER, K.J., 1970. Mechanisms of heat damage in proteins. 2. Chemical changes in pure proteins. *Brit. J. Nutr.* 24, 313.
- BOMAR, M.T., 1981. Bacterial proteins from cellulose. A.P.R.I.A. Int. Symp. on single cell proteins. Paris, Jan 1981 (In press).
- BRAUDE, R., 1976. New sources of protein for pigs. *Proc. Nutr. Soc.* 35, 93.
- BRAUDE, R. & RHODES, D.N., 1976. Pruteen, a new source of protein for growing pigs. *Proc. Nutr. Soc.* 34, 51A.
- BRODERICK, G.A., 1975. Factors affecting ruminant responses to protected amino acids and proteins. In: *Protein nutritional quality of foods and feeds*. Vol 1, 211. New York, Marcel Dekker.
- BRODERICK, G.A., KOWALCZYK, T. & SATTER, L.D., 1970. Milk production response to supplementation with encapsulated methionine *per os* or casein *per abomasum*. *J. Dairy Sci.* 53, 1714.
- BURROUGHS, W., NELSON, D.K. & MERTENS, D.R., 1975. Protein physiology and its application in the lactating cow. The metabolisable protein feeding standard. *J. Anim. Sci.* 44, 933.
- BYERS, M., 1971. Leaf protein, its agronomy, preparation, quality and use p. 95. Oxford, Blackwell Sci. Publ.
- CADENHEAD, A., 1972. Grass juice for pigs. *Pig farming*, Aug. 1972.
- CALVERT, C.C., 1971. Animal waste reuse – Nutritive value and potential problems from feed additives p. 14. *Agric. Res. Serv., U.S.D.A.* 1971.
- CHEEKE, P.R., 1976. Alfalfa as a protein source for non-ruminant animals. Rep. of 25th alfalfa improvement. *Conf. Cornell Univ.* p. 25. July 13 – 15, 1976.
- CHEESEMAN, G.C., 1974. Conf. on Extraction and use of juice from lucerne and grass. Reading. Nov. 1974.
- CHALUPA, W., 1972. Metabolic aspects of non-protein-nitrogen utilisation in ruminant animals. *Fed. Proc.* 31, 1152.
- CHALUPA, W., 1974. Amino acid degradation by rumen microbes. *Fed. Proc.* 33, 708.
- CHALUPA, W., 1975. Rumen by-pass and protection of proteins and amino acids. *J. Dairy Sci.* 58, 1198.
- CHALUPA, W. & SCOTT, G.C., 1976. Protein nutrition of growing cattle. In *Tracer studies on non-protein-nitrogen for ruminants*. III. IAEA, Vienna. p. 13.
- CHANDLER, P.T. & POLAN, C.E., 1972. Considerations in interpretation of serum amino acids in lactating cows. *J. Dairy Sci.* 503, 709 (Abstr).
- CHUTTER, F.M., 1980. Aquaculture can provide water and protein. Symp. on *Aquaculture*, C.S.I.R. Dec. 1980 (In press).
- CLARK, J.H., 1975. Lactational responses to post-ruminal administration of proteins and amino acids. *J. Dairy Sci.* 58, 1178.
- CLOETE, J.G., 1964a. Studies on metabolic faecal nitrogen excretion in sheep. D.Sc. (Agric) Thesis. Univ. of Stellenbosch.
- CLOETE, J.G., 1964b. The passage of endogenous nitrogen through various sections of the digestive tract of the intact sheep. *Proc. S. Afr. Soc. Anim. Prod.* 3, 189 – 192.
- CLOETE, J.G. The protein supply position in Southern Africa. *Mimeo. rep. S.A.R.C.C.U.S. Stand. Com. Anim. Prod. Pretoria*. September 1975.
- CLOETE, J.G., 1979. Protein requirements of the South African livestock industry during 1980. *Dept. Agric. T.S. Tech. Bul.* No. 153 pp. 1 – 8.
- COMLINE, R.S. & TITCHEN, D.A., 1951. Reflex contraction of the oesophageal groove in young ruminants. *J. Physiol.* 115, 210.
- CUNHA, T.J., 1972. The effect of wet feeding on livestock performance. IInd World Congress on animal feeding. Madrid IV 619.

- DE BRUYN, S.J. & LATEGAN, P.M., 1968. Factors influencing yeast protein synthesis in molasses media. *Symp. on Proteins and Food Supply. Bloemfontein*. April 8 – 11, 1968.
- FERGUSON, K.A., 1971. Method and food composition for feeding ruminants. U.S. Patent 31, 696.
- FERGUSON, K.A., 1975. The protection of dietary proteins and amino acids against microbial fermentation in the rumen. In *Digestion and metabolism in the ruminant*. Armidale, Univ. of New England.
- FOX, D.G., CRICKENBERGER, R.W., BERGEN, W.G. & BLACK, J.R., 1977. A net protein system for predicting protein requirements and feed protein values for growing and finishing beef cattle. *Mich. Sta. Univ. Agric. Expt. Sta.* No. 328.
- FROBISH, L.T., 1971. Animal waste reuse – Nutritive value and potential problems from feed additives. Agricultural Research Service. U.S.D.A.
- FUDJIMAKI, M., 1981. Research on the development of assessment methods for safety of SCP for animal feeding in Japan. APRIA Symp. on Single Cell Protein Paris, Jan. 1981 (In Press).
- GRIESEL, M., 1979. A protein utilisation strategy for Southern Africa. *S. Afr. J. Sci.* 9(2), 119.
- GERLOFF, E.D., LIMA, I.H. & STAHMANN, M.A., 1965. Amino acid composition of leaf protein concentrates. *J. Agric. Fd. Chem.* 13, 139.
- GOERING, H.K., VAN SOEST, P.J. & HEMKEN, R.W., 1973. Relative susceptibility of forages to heat damage as affected by moisture, temperature and pH. *J. Dairy Sci.* 56, 137.
- HALE, W.H., 1973. Influence of processing on the utilisation of grains (starch) by ruminants. *J. Anim. Sci.* 37, 1075.
- HENRY, K.M. & FORD, J.E., 1965. The nutritive value of leaf protein concentrates determined in biological tests with rats and by microbiological methods. *J. Sci. Fd Agric.* 16, 425.
- HOGAN, J.P. & WESTON, R.H., 1969. The effects of antibiotics on ammonia accumulation and protein digestion in the rumen. *Aust. J. agric. Res.* 20, 339.
- HOSHIAI, K., 1981. Present and future protein demand for animal feeding. APRIA Symp. on single cell protein. Paris, Jan. 1981 (In press).
- HOWARD, J.O., 1980. World food, feed and fiber prospects. AGROCON Conference, Pretoria, Nov. 1980 (In press).
- HOUSEMAN, R.A. & CONNELL, J., 1976. The utilisation of the products of green-crop fractionation by pigs and ruminants. *Proc. Nutr. Soc.* 35, 213.
- HUMPHREY, H.H., 1973. Proposal for a world protein research network. World Soy Protein Conf. Munich, Nov. 1973.
- HYMAN, W.B., 1978. Animal Health in relation to manure management. Symp. Agricultural Waste Management (Alfa Laval), Irene, Sept. 25, 1978.
- IKWUEGBU, O.A., SUTTON, J.D. & McALLAN, A.B., 1979. Effect of oil supplements on rumen metabolism. *Ann. Rep. Nat. Inst. Res. in Dairying*, 1979, p. 52.
- JOHNSON, M.J., 1967. Growth of microbial cells on hydrocarbons. *Science* 155, 1515.
- JOURNET, M. & VERITY, R., 1977. Levels of energy and nitrogen intake in relation to animal protein production during lactation. *Proc. IInd Intern. Symp. Protein Metabolism, Wageningen 1977*, Pudoc.
- JOHNSON, D.E., 1972. Heat increment of acetate and corn and effects of casein infusion with growing lambs. *J. Nutr.* 102, 1093.
- KAUFFMAN, W., 1977. Calculation of the protein requirements for dairy cows according to measurements of N metabolism. *Proc IInd Intern. Symp. Prot. Metabolism, Wageningen 1977*, Pudoc.
- KENNEDY, P.M. & MILLIGAN, L.P., 1978. Quantitative aspects of the transformations of sulphur in sheep. *Brit. J. Nutr.* 39, 63.
- KNOESEN, J.G. & JOUBERT, A.B.D., (1978). Practical aspects of animal waste handling and utilisation as experienced by the South African farmer. Symp. on waste management, Irene, Sept. 25, 1978.
- KOHLER, G.O., CHRISMAN, J. & BICKOFF, E.M., 1973. Separation of protein from fiber in forage crops. In *Alternative sources of protein for animal production*. National Academy of Sciences. Washington, Nat. Acad. Sci.
- KU, Y. & SIMON, P.W., 1973. Ruminant feeding supplement. *U.S. Patent* 3, 751, 262.
- LYMAN, C.M., CHANG, W.Y. & COUCH, J.R., 1953. Evaluation of protein quality in cottonseed meals by chick growth and by the chemical index method. *J. Nutr.* 49, 679.
- MASON, C.V. & MILNE, G., 1971. The digestion of bacterial mucopeptide constituents in sheep. 2. The digestion of muramic acid. *J. agric. Sci.* 77, 99.
- McATTEE, J.W. & TRENKLE, A., 1971. Metabolic regulation of plasma insulin levels in cattle. *J. Anim. Sci.* 33, 438.
- MEHREZ, A.Z. & ORSKOV, E.R., 1977. A study of the artificial fiber bag technique for determining the digestibility of feeds in the rumen. *J. agric. Sci. (Camb.)* 88, 645.
- McDONALD, I.W., 1968. Nutritional aspects of protein metabolism in ruminants. *Aust. Vet. J.* 44, 145.
- MERRY, R.J., SMITH, R.H. & McALLAN, A.B., 1979. Lactocyl urea in ruminant feeding. *Ann. Rep. Nat. Inst. Res. in Dairying, Reading*, 1979.

- MERTENS, D.R., 1977. Importance and measurements of protein insolubility in ruminant diets. Congr. Feed Ind. Georgia.
- MEYER, R.O., CHEEKE, P.R. & KENNICK, W.H., 1975. Utilisation of alfalfa protein concentrate by swine. *J. Anim. Sci.* 40 (5) 885.
- MILLER, S.A., 1968. Nutritional factors in single cell protein. In *Single cell protein, Mateles & Tannenbaum*. Cambridge, Mass, M.I.T. Press.
- MILLER, R.E., 1972. Protein cross linked with phospho-nitrilic halide, *U.S.A. Patent* 3, 674, 509.
- MILLER, R.E., 1973. Protein-acrolein acetal complex ruminant feed complex. *U.S.A. Patent* 3, 711, 290.
- MILLER, E.L., 1978. Evaluating the protein contribution of feedstuffs for ruminants. *Int. Assoc. Fish Meal Manuf.* Aug. 1978.
- MOIR, R.J., 1979. Protein in the post ruminal intestinal tract. Proc. Florida Nutr. Conf. St Petersburg Beach. Jan. 1979.
- NAESS, B. & SLAGSVOLD, P., 1973. The nutritive value for growing pigs of single cell proteins (*saccharomyces cerevisiae*) produced from sulphite spent liquor. *Acta vet Scand.* 14, 160.
- NATIONAL RESEARCH COUNCIL, 1977. Nutrient requirements of poultry. 7th Ed. National Academy of Sciences. Washington, National Academy of Sciences.
- OBERHOLSTER, G., 1978. The pending legislation and regulations pertaining to intensive livestock production. *Symp. Agric. Waste Management. Irene*, Sept. 1978.
- ORSKOV, E.R., 1972. Technology so that the rumen is bypassed following artificial rearing. II *World Congress on animal feeding. Madrid*, Oct. 1972. IV, 627.
- ORSKOV, E.R., FRASER, C., McDONALD, I. & SMART, R.I., 1974. Digestion of concentrates in sheep. *Brit. J. Nutr.* 31, 89.
- OSLAGE, H.J. & PETERSEN, U., 1973. Symposium on new developments in the provision of amino acids in diets of pigs and poultry (2), 333, New York, F.A.O. .
- OSWALD, W.J., 1969. Current status of micro-algae from wastes. *Chem. Eng. Prog. Symp. Ser.* 65 (93) 87 – 92.
- PALMQUIST, D.L. & CONRAD, H.R., 1978. High fat diets for dairy cows. Effects on feed intake, milk and fat production and plasma metabolites. *J. Dairy Sci.* 61, 890.
- PILGRIM, A.F., GRAY, F.V., WELLER, R.A. & BELLING, G.B., 1970. Synthesis of microbial protein from ammonia in the sheep's rumen and the proportion of dietary nitrogen converted into microbial nitrogen. *Brit. J. Nutr.* 24, 589.
- PIRIE, N.T., 1971. Leaf protein; its agronomy, preparation, quality and use. Oxford, Blakewell Sci. Publ.
- PIETERSE, A.J.H., 1980. Feedlot wastes can be utilised. *Symp. on Aquaculture. Pretoria*, Nov. 1980.
- PRESTON, R.L., 1973. Supplemental protein needs of growing – finishing cattle. *Proc. Nutr. Council. Amer. Feed Manuf. Assoc.* 33, 36.
- REIS, P.J. & SCHINCKELL, P.G., 1963. Some effects of sulphur-containing amino acids on the growth and composition of wool. *Aust. J. Biol. Sci.* 16, 218.
- RIEKE, R.F., 1955. The influence of sodium salts on the closure of the oesophageal groove in calves. *Aust. Vet. J.* 30, 29.
- ROY, J.H.B., BALCH, C.C., MILLER, E.L., ORSKOV, E.R. & SMITH, R.H., 1977. Calculation of the N requirement for ruminants from nitrogen metabolism studies. *Proc IInd Intern Symp. on Prot. & Nutr. Wageningen*, Pudoc.
- RUDD, R.T., 1978. Pollution hazards from intensive livestock production units. *Symp. Agric. Waste Management. Irene*, Sept. 1978.
- SATTER, L.D. & ROFFLER, R.E., 1975. Nitrogen requirement and utilisation in dairy cattle. *J. Dairy Sci.* 58, 1219.
- SATTER, L.D., WHITLOW, L.D. & BEARDSLEY, C.L., 1977. Resistance of protein to rumen degradation and its significance to the dairy cow. *Proc 32nd Distillers feed Res. Conn. Conf.* p. 63.
- SCHACKLADY, C.A. & GATUMEL, E., 1972. Safety in use and nutritional value of yeasts grown on alkanes. *IInd World Congr. on Anim. Feeding. Madrid*, Oct. 23 – 28, 1972, p. 417.
- SCHOEMAN, E.A., DE WET, P.J. & BURGER, W.J., 1972. The evaluation of the digestibility of treated proteins. *Agroanimalia* 4, 35.
- SMITH, L.W., 1971. Feeding value of animal wastes. In *Animal waste reuse – nutritive value and potential problems from feed additives. Agric. Res. Serv. U.S.D.A.* p. 5.
- SMITH, R.H., 1975. In *Digestion and metabolism in the ruminant. IVth Intern. Symp. Ruminant Physiol, Sydney*, 1974. p. 399.
- SMITH, R.H., 1979. Synthesis of microbial nitrogen compounds in the rumen and their subsequent digestion. *J. Anim. Sci.* 49, 1604.

- SMITH, G.A., 1981. Kwantifisering van die samestelling en proteienkwaliteit van vismeel en sonneblomkoekmeel met verwysing na spesifieke chemiese en biologiese kwaliteitsparameters. Ph. D. (Agric) Thesis, Univ. of Stell.
- STREETER, C.L., OLTJEN, R.R., SLYTER, L.L. & FISHBEIN, W.N., 1969. Urea utilisation in wethers receiving the urease inhibitor, acetohydroxamic acid. *J. Anim. Sci.* 29, 88.
- STERN, M.D. & HOVER, W.H., 1979. Methods for determining and factors affecting rumen microbial protein synthesis. A review. *J. Anim. Sci.* 49 (6), 1590.
- SWAN, H., 1971. Protein, amino acids and urea in ruminant diets. Univ. Nottingham *Nutr. Conf. Feed Manuf.* p. 126. London, Livingston.
- TAGARI, H., ASCARELLI, I. & BONDI, A., 1962. The influence of heating on the nutritive value of soyabean meal for ruminants. *Brit. J. Nutr.* 16, 237.
- TAMMINGA, S., 1979. Protein degradation in the forestomachs of ruminants. *J. Anim. Sci.* 49, 1615.
- TAMMINGA, S. & VAN HELLEMOND, K.K., 1977. The protein requirements of dairy cattle and developments in the use of protein, essential amino acids and non-protein nitrogen in the feeding of dairy cattle. In *Protein and non-protein nitrogen for ruminants*. Oxford, Pergamon Press.
- TEICHMAN, R., CARUOLA, E.V. & MOCHRIE, R.D., 1969. Milk production and composition responses to intravenous infusion of L-methionine. *J. Dairy Sci.* 52, 942. (Abstr.).
- TURNER, A.W. & HODGES, V.E., 1952. Depression of ruminal digestion in Adult sheep by aureomycin. *Aust. J. Agric. Res.* 3, 453.
- VAN NEVEL, C.J. & DE MEIJER, D.I., 1977. Determination of rumen microbial growth *in vitro* from ³²P-labelled phosphate incorporation. *Brit. J. Nutr.* 38, 101.
- VAN NIEKERK, B.D.H., 1979. Agricultural and industrial by-products in beef production *World Aberdeen Angus Congr., Johannesburg*, Apr. 1979.
- VAN WEERDEN, E.J., SCHACKLADY, C.A. & VAN DER WAL, P., 1970. Hydrocarbon grown yeast in rations for chicks. *Brit. Poultry Sci.* 11, 189.
- VERITY, R. & JOURNET, M., 1977. Utilisation des tourreaux traités au formol par les vaches laitières. II Effects sur la production laitière du traitements des tourreaux et du niveau d'apport azoté au début de la lactation. *Ann. Zootechn.* 26, 185.
- VIVIERS, J.M.P., BRIERS, J.H. & VAN VUUREN, L.R.J., 1980. Harvesting of algae grown on raw sewage. *C.S.I.R. Repr.* No. 792.
- WALDO, D.R., 1973. Extent and partition of cereal grain starch digestion in ruminants. *J. Anim. Sci.* 37, 1075.
- WALDROUP, P.W., 1972. The future of petroleum derived protein sources for livestock. *Proc. Distill, Feed Res. Conf.* p. 27.
- WASLEIN, C.I., CALLOWAY, D.H. & MARGEN, S., 1968. Uric acid production of men fed graded amounts of egg protein and yeast nucleic acid. *Amer. J. Clin. Nutr.* 21, 892.
- WASLEIN, C.I., CALLOWAY, D.H., MARGEN, S. & COSTA, F., 1970. Uric acid levels in men fed algae and yeast as protein sources. *J. Food Sci.* 35, 294.
- WELLER, R.A. & PILGRIM, A.F., 1974. Passage of protozoa and volatile fatty acids from the rumen of the sheep and from a continuous *in vitro* fermentation system. *Brit. J. Nutr.* 32, 341.
- WILDI, B.S. & MILLER, R.E., 1973. A protein acetylenic ester complex to retard digestion in the rumen. *U.S.A. Patent* 3, 718, 478.
- WOHLT, J.E., SNIFFEN, C.J. & HOOVER, W.H., 1973. Measurement of protein solubility in common feedstuffs. *J. Dairy Sci.* 56, 1052.
- YU, W., DACHEN, W. & KANG-LIN, L., 1981. Further studies on n - paraffin yeast as fodder in China. APRIA Intern. Symp. on Single cell proteins. Paris Jan. 1981.