Effect of level and degradation of dietary protein on performance of feedlot steers

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Optimal levels of crude (CP) and undegraded (UDP) dietary protein were studied in feeding systems based on whole maize fed free-choice and on complete mixed diets composed from by-products of the milling industry. On the whole maize free-choice system, animal performance was improved when more CP and UDP were fed. With by-product feeds, the higher CP treatment did not improve animal performance, which suggests that the lower CP treatment was adequate in meeting requirements. Better results were obtained with treatments that contained 35% and 40% UDP in the CP than 45% UDP. Cost benefits were realized when CP level was decreased steadily in agreement with requirements. We recommend that the CP of feedlot diets should contain 35 to 40% UDP and that the CP level during the fattening period should be reduced from 14% to 10% in the dry matter by adopting the principle of three diets ('starter', 'grower' and 'finisher').

Optimum peile van ruproteïen (RP) en nie-degradeerbareproteïen (NDP) is bestudeer in voedingstelsels gebaseer op heel mielies wat vrye keuse gevoer is en in volledigvermengde neweprodukte van die maalbedryf. Groeiresultate op die heelmielie-vryekeusestelsel was beter op die hoër RP- en hoër UDP-behandelings as op die ooreenstemmende laer behandelings. Met die neweprodukstelsel het die hoër RP-behandeling nie tot beter groeiresultate gelei nie, wat daarop dui dat die laer RP-behandeling reeds in die behoeftes voldoen het. Resultate was beter met behandelings wat 35 en 40% NDP in die RP voorsien het as met behandelings wat 45% NDP voorsien het. Behandelings waarin die RP-inhoud geleidelik verlaag is in ooreenstemming met behoeftes het 'n kostevoordeel gehad bo behandelings waarin die RP-inhoud konstant gehou is. Ons beveel aan dat die RP-inhoud in voerkraaldiëte 35 tot 40% NDP moet bevat en dat die RP-vlak gedurende afronding verlaag moet word vanaf 14% tot 10% van droë materiaal deur die beginsel van drie diëte ('aanvangs-', 'groei-' en 'afrondingsdieet') te aanvaar.

Keywords: Degradation, feedlot diets, protein level, steers.

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From an economic and availability viewpoint, care should be used in formulating protein supplements (Cloete, 1982). Current feedlot feeding systems often supplement unnecessarily high amounts of protein. In general, feedlots in South Africa formulate diets to contain 12% or more crude protein (CP) on a DM basis. Yet, requirements decline towards the end of the fattening phase. Based on calculations from the NRC (1984), this surplus could amount to 5—10 kg supplementary protein per animal. This represents a substantial cost on a national basis.

Maize (usually processed) was the favoured energy source in feedlot diets in the past, but today many by-products of the milling industry have become popular. Such products often contain more CP than maize and may differ considerably in extent of ruminal degradation (Erasmus *et al.*, 1988; 1990; Meissner *et al.*, 1992). Such products may reduce the need for supplementary protein by decreasing the ratio of rumen degraded protein (RDP) to undegraded protein (UDP). The present study examined these issues.

Compared to processed maize, whole maize has a cost advantage but results may be variable. The free-choice system (Van Niekerk & Tarr, 1982), wherein the roughage and protein supplements in pellet form are fed separately, has given promising results. However, as with by-products, little is known about the optimum level of supplementary protein and ratio between RDP and UDP. These two feeding systems, furthermore, offer an opportunity to compare results. Our hypothesis was that if in two systems so vastly different, optimal protein levels and degradations were similar, they also should be similar in most other systems.

The concern for studying RDP–UDP ratios stems from the haphazard method of supplementing protein discussed above. Degradation ratios may be critical in high energy diets. This is because the ratio between protein and energy is important for microbial protein production (Owens & Bergen, 1983) in the small intestine and at the tissue level to facilitate utilization of substrates in the correct proportions (Kempton *et al.*, 1978; Storm *et al.*, 1983; MacRae & Lobley, 1986). Protein status, however, is not easy to control because ruminal output of protein and energy differ with feeding system and roughage source and level. Furthermore, the efficiency of microbial protein production usually decreases as concentrate level in the diet increases (Van Soest *et al.*, 1982), partially because ruminal turnover and dilution rate decrease (Stern & Hoover, 1979; Owens *et al.*, 1984). These reports imply that amino acid supply to the host animal sometimes may be inadequate. If so, a growth response to UDP should be seen. The question of optimal UDP levels was addressed in a growth study.

Our final objective was to determine if the protein–energy ratio should be altered during the course of fattening. Protein requirements decline proportionally as the feedlot steer gets larger while energy requirements increase (NRC, 1984). Feedlots in the USA attempt to match the changing requirements by employing at least three diets, often called 'starter', 'grower' and 'finisher'. Feedlots in South Africa often employ only one diet after the adaptation phase. Whether the altering of the protein content according to requirements is beneficial, has not been tested adequately.

Procedures

Experiment 1

Objective

The effect of protein supplementation at two levels of crude protein and degradation was investigated using medium frame steers fed whole maize free-choice.

Animals

Seventy Bonsmara-type steers with an initial mass of 188 ± 20.5 kg were allocated at random to one of four treatments of 15 each; 10 served to determine initial carcasses. The treatment steers were implanted with an anabolic growth promoter (zeranol) and fed until they had reached a condition of Super A before being slaughtered to obtain carcass yield. Initial carcass yield was calculated from data of the initial slaughter group with cold carcass mass being regressed on live mass. The resulting equation showed a satisfactory fit:

$$\text{Cold carcass (kg)} = 0.73 \text{ live mass (kg)} - 43.1; \; r^2 = 0.81$$

Diets

Whole maize and pelleted supplements were available free-choice. We assumed that supplement intake would comprise about 10% of total intake (Van Niekerk & Tarr, 1982). Accordingly, supplements were compiled to contain enough protein so that total diets had 13.5 and 11.5% CP on a DM basis. We anticipated that live mass-gain should be about 1.4 kg/d, which would require 12.5% CP in the DM of diets fed to medium frame steers (NRC, 1984). By altering the amounts of urea and fish-meal in the supplement, we formulated supplements containing two protein levels (25 and 47% CP) and two levels of UDP (2.5 and 8.5% of diet). The four supplements were formulated to be equal in crude fibre, calcium and phosphorus content, but they differed slightly in ME content (Table 1).

Table 1 Composition of pelleted supplements used in combination with whole maize and fed free-choice

Ingredient	Supplement composition (%) 1	2	3	4
Cottonseed hulls[1]	32	32	32	32
Fish-meal	–	18	–	17.5
Limestone ($CaCO_3$)	14	12	13.5	12.5
Lucerne, pelleted	–	5	–	13.5
Maize bran, high fibre	9.9	4.4	10	4.4
Maize germ, defatted	19.5	9.5	28.4	9.5
Molasses	5	5	5	5
Monocalcium phosphate	4	2.5	3.5	2
Salt	0.5	–	0.5	–
Urea	15	11.5	7	3.5
Vitamins and minerals[2]	0.1	0.1	0.1	0.1
Analysis (% of DM)[3]				
Crude protein (CP)	47	47	25	25
Undegraded protein (UDP)	2.5	8.5	2.5	8.5
Crude fibre	20	20	21	21
ME content (MJ/kg)	6	6	7	7
Calcium	5.5	5.5	5.5	5.5
Phosphorus	0.95	0.95	0.95	0.95

[1] Including some hulls and husks of other oilseeds.
[2] Including an ionophore and antibiotic.
[3] Calculated form Meissner *et al.* (1992).

Statistical analysis

Differences in live mass, carcass, slaughter percentage and gains were tested by two-way analysis of variance and Tukey's test (SAS, 1985). Variables were CP and UDP. Differences between treatments in feed intake and in feed conversion ratio could not be determined because steers were fed in groups and pens were not replicated.

Experiment 2

Approach

Growth was evaluated in large frame steers between 170 and 410 kg live mass on diets based on by-products. Crude protein levels were chosen to supplement protein at a level equal to 5% below and 5% above NRC recommendations, taking into consideration the proportional decline in requirements as the steers gain mass (NRC, 1984). At 40 kg mass intervals, the high protein level was fed to detect compensatory growth responses as might be expected if requirements exceeded the low protein level. Our second hypothesis was that the requirement would be influenced by the ratio between RDP and UDP. Accordingly, this ratio was varied (55:45, 60:40 and 65:35). The effects of protein level and degradation ratios were tested at two dietary energy levels.

Treatments

Forty-eight Holstein steers (170 ± 16.5 kg) were implanted with zeranol and allocated at random to one of eight groups. Four groups received a diet of 12 MJME/kg DM and four received a diet of 10.5 MJME/kg DM. Within each dietary energy level, the protein level was allocated as shown in Table 2. Two treatments consisted of a RDP–UDP ratio of 60:40 (designated 40 UDP), with one treatment fed at a crude protein level 5% above the NRC recommendation and the other treatment fed at a crude protein level 5% below that recommendation. The other two treatments consisted of a RDP–UDP ratio of respectively 65:35 (35 UDP) and 55:45 (45 UDP). The crude protein level in these two treatments was sequentially increased to 5% above or decreased to 5% below NRC recommendations. These changes were made after steers had gained 40 kg in live mass.

Table 2 Protein allocation (%) to large frame steers in diets based on by-products and fed at two energy levels

Mass interval (kg)	High protein 40 UDP[1]	Low protein 40 UDP	Changing protein 35 UDP	Changing protein 45 UDP
A. Energy concentration: 12 MJME/kg DM				
170—210	17.3	15.7	15.7	15.7
210—250	15.4	13.9	15.4	15.4
250—290	14.0	12.7	12.7	12.7
290—330	12.9	11.7	12.9	12.9
330—370	12.0	10.9	10.9	10.9
370—410	11.3	10.2	11.3	11.3
B. Energy concentration: 10.5 MJME/kg DM				
170—210	14.8	13.4	13.4	13.4
210—250	13.4	12.1	13.4	13.4
250—290	12.3	11.1	11.1	11.1
290—330	11.5	10.4	11.5	11.5
330—370	10.8	9.76	9.76	9.76
370—410	10.2	9.27	10.2	10.2

[1] Undegraded protein.

Table 3 Composition of diets based on by-products and fed to steers in the mass interval 170—210 kg

	Composition (%)			
Ingredient	High CP 40 UDP	Low CP 40 UDP	Changing CP 35 UDP	Changing CP 45 UDP
A. Energy concentration: 12 MJME/kg DM				
Cottonseed hulls	3	3	3	3
Dicalcium phosphate	0.96	1.05	1.12	0.95
Limestone ($CaCO_3$)	1.12	0.87	0.69	1.12
Lucerne, pelleted	2	2	2	2
Maize bran, low fibre	48.9	36.1	26.8	47.1
Maize germ	15	15	15	16
Maize germ, defatted	16.3	31.5	41.7	16.8
Maize gluten, 60% CP	7.1	4.8	2.4	7.5
Maize meal	–	–	1.5	–
Molasses meal[1]	3	3	3	3
Salt	2.5	2.5	2.5	2.5
Urea	0.07	0.05	0.09	–
Vitamins and minerals[2]	0.1	0.1	0.1	0.1
Analysis (% of DM)[3]				
Crude protein (CP)	17.3	15.7	15.7	15.7
Undegraded protein (UDP)	6.9	6.3	5.5	7.1
Crude fibre	10.8	11.0	11.0	10.8
Calcium	0.82	0.82	0.82	0.82
Phosphorus	0.47	0.47	0.47	0.47
B. Energy concentration: 10.5 MJME/kg DM				
Cottonseed hulls	4	4	4	4
Dicalcium phosphate	0.58	0.42	0.32	–
Hominy chop	–	–	5.4	–
Limestone ($CaCO_3$)	1.22	1.31	1.36	1.08
Lucerne, pelleted	8	8	8	8
Maize bran, high fibre	10	7.2	5	34.4
Maize bran, low fibre	14.5	11.5	7.9	1
Maize gluten, 20% CP	–	2	–	–
Maize gluten, 60% CP	4.6	3	1.26	5.4
Maize meal	32.5	34.4	35	35
Molasses meal[1]	6	6	6	6.7
Monocalcium phosphate	–	–	–	1.3
Salt	2.7	2.7	2.7	2.7
Urea	0.04	–	0.03	–
Vitamins and minerals[2]	0.1	0.1	0.1	0.1
Wheat bran	15.8	19.4	22.9	0.4
Analysis (% of DM)[3]				
Crude protein (CP)	14.8	13.4	13.4	13.4
Undegraded protein (UDP)	5.9	5.3	4.7	6.0
Crude fibre	12.0	12.0	12.0	12.2
Calcium	0.8	0.8	0.8	0.8
Phosphorus	0.45	0.45	0.45	0.45

[1] Calorie 3 000.

[2] Including an ionophore and antibiotic.

[3] Calculated from Meissner *et al.* (1992).

Steers were given *ad libitum* access to feed and were fed individually. They were slaughtered when reaching 410 kg live mass. An additional eight Holstein steers were slaughtered at the start of the trial to estimate initial carcass yield. The prediction equation was:

Cold carcass (kg) = 0.47 live mass (kg) + 3.96; $r^2 = 0.67$

Diets

Diets were changed every 40 kg mass-interval. The dietary compositions for the interval 170—210 kg are shown as an example in Table 3.

Statistical analysis

Data were analysed by the General Linear Model's procedure (Prog GLM) of SAS (1985) with variables growth interval, crude protein plus protein degradation level, and dietary energy concentration.

Experiment 3

Objective

This study was conducted to determine whether the protein–energy ratio should be altered during the course of fattening.

Animals and design

In replication 1, 24 Bonsmara steers (215 ± 26.4 kg) were allocated at random to one of four treatments. In replication 2, 44 Holstein steers (230 ± 28.5 kg) were used. Both steer groups were implanted with zeranol. The treatments were designed to supply ME and protein at either a fixed level or a changing level, *i.e.* an increasing ME and a decreasing protein level:

	% CP in DM	MJME/kg DM
Treatment 1	12	12
Treatment 2	14—10	12
Treatment 3	12	11—13
Treatment 4	14—10	11—13

The change was according to the following design:

Days	% CP in DM	MJME/kg DM
0	14	11
8	13	11.5
32	12	12
60	11	12.5
88 to end of trial	10	13

Table 4 Intake and growth performance of steers fed whole maize and pellets free-choice as affected by level of crude protein (CP) and undegraded protein (UDP) in the diet

		Treatment (supplement)				
		1 47 CP 2.5 UDP	2 47 CP 8.5 UDP	3 25 CP 2.5 UDP	4 25 CP 8.5 UDP	MSE[2]
Initial mass	(kg)	184	186	196	188	5.48
Slaughter mass	(kg)	374	381	374	385	4.64
Carcass mass	(kg)	213	213	213	214	5.32
Slaughter percentage		57.0	55.9	57.0	55.6	1.54
DM intake	(kg/d)	6.50	7.02	6.68	7.16	–
ME intake	(MJ/d)	81.5	87.9	83.5	89.6	–
CP intake	(kg/d)	0.93	1.05	0.80	0.87	–
UDP intake[1]	(kg/d)	0.33	0.41	0.33	0.42	–
Live mass-gain	(kg/d)	1.44[ab]	1.51[b]	1.32[a]	1.48[ab]	0.20
Carcass gain	(kg/d)	0.92[b]	0.93[b]	0.84[a]	0.90[ab]	0.13
kg DM/kg live mass-gain		4.51	4.65	5.06	4.84	–
kg DM/kg carcass gain		7.07	7.55	7.95	7.96	–
		47 CP	25 CP	2.5 UDP	8.5 UDP	
Slaughter percentage		56.5	56.3	57.0[y]	55.8[x]	
DM intake	(kg/d)	6.76	6.92	6.59	7.09	
ME intake	(kg/d)	84.7	86.6	82.5	88.8	
CP intake	(kg/d)	0.99	0.84	0.87	0.96	
UDP intake	(kg/d)	0.37	0.38	0.33	0.42	
Live mass-gain	(kg/d)	1.48	1.40	1.38[x]	1.50[y]	
Carcass gain	(kg/d)	0.93[j]	0.87[i]	0.88	0.92	
kg DM/kg live mass-gain		4.57	4.94	4.78	4.73	
kg DM/kg carcass gain		7.27	7.95	7.49	7.71	

[1] The UDP of whole maize was assumed to be 45% (Meissner *et al.*, 1992) and the UDP values of the supplements are shown in Table 1.

[2] MSE = mean standard error.

[a,b; i,j; x,y] Values in the same line with different superscripts differ significantly ($P \leq 0.05$).

Bonsmara as well as Holstein steers were slaughtered when they weighed about 400 kg. In contrast to the previous experiments there were no initial slaughter groups.

Diets

Diets were compiled from by-products similar to the diets used in Experiment 2. The ratio between RDP and UDP was 60:40 in all diets. Steers were given *ad libitum* access to feed and were fed individually.

Statistical analysis

Results were analysed by Prog GLM of SAS (1985) as discussed under Experiment 2. Variables were fixed vs. changing crude protein, fixed vs. changing energy level, and Bonsmaras vs. Holsteins.

Results and Discussion

Whole maize free-choice system

Growth results are shown in Table 4 and the pattern of intake of maize and pellets for the four groups combined is displayed in Figure 1.

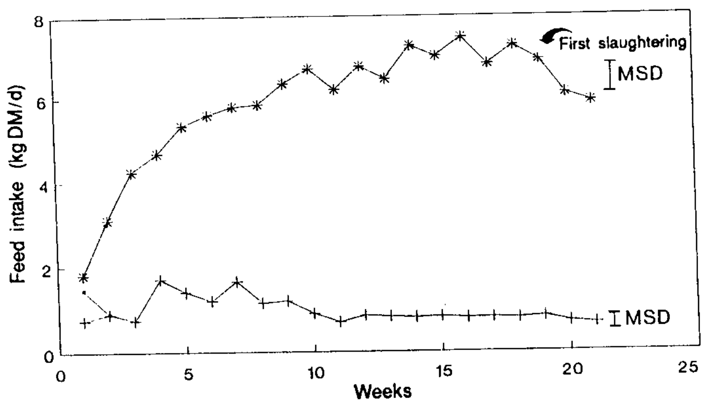

Figure 1 Pattern of feed intake in the whole maize free-choice system. • Hay (given for the first two weeks only); + protein roughage pellets; ✳ maize.

The pattern of intake of pelleted supplement and whole maize was as described by Van Niekerk & Tarr (1982). Supplement intake increased during the first few weeks and then declined to a relatively constant level. In contrast, intake of whole maize increased steadily to a plateau (Figure 1). As a percentage of total intake, supplement intake was 14% in comparison to the anticipated 10% (Van Niekerk & Tarr, 1982). Consequently, daily CP intake was 40—80 g (5—8%) per animal more than planned.

Steers fed Treatment 3 (25 CP; 2.5 UDP) gained slower ($P \leq 0.05$) than those fed Treatment 2 (47 CP; 8.5 UDP) in both live mass and carcass (Table 4). Overall, the effect of CP level was significant for carcass gain and approached significance ($P \leq 0.05$) for live mass-gain. Live mass-gain, but not carcass gain, was increased ($P \leq 0.05$) by a higher UDP intake. Carcass gain was not increased significantly because slaughter percentage was reduced ($P \leq 0.05$) by the higher UDP intake. Our interpretation is that on the higher UDP intake, where the supplements also contain fish-meal, more amino acids with better composition were absorbed from the small intestine. These amino acids should promote protein synthesis and decrease fat synthesis (Lindsay & Davies, 1981) and thereby decrease slaughter percentage. Also, the higher UDP intake tended to increase feed intake (Table 4), contributing to an increase in live mass-gain. The interaction between CP and UDP levels was significant ($P \leq 0.05$), which suggests that intake of both CP and UDP on Treatment 3 (25 CP; 2.5 UDP) was responsible for the lower live mass and carcass gains.

If Treatment 3 is ignored, the average rate of live mass-gain was about 1.48 kg/d (Table 4). This was attained with CP and UDP intakes of respectively 0.95 and 0.39 kg/d. Estimates from requirements for microbial protein and 'escape' protein (NRC, 1985) to realize a rate of live mass-gain of 1.50 kg/d for medium frame steers, correspond closely (0.98 kg CP and 0.40 kg UDP/d). NRC (1984) requirements are lower than this and ARC (1984) indicates no requirement for UDP. The response in live mass and carcass gain obtained with Treatments 2 and 4 in comparison to Treatments 1 and 3, indicates that UDP was required. The average ratio between RDP and UDP in the CP of the diet for the growth interval studied is about 60:40 (NRC, 1985).

Variable protein level and degradation

Although live mass-gain in growth intervals differed ($P \leq 0.05$), differences were not related to the change to a higher protein level. We hypothesized that compensatory growth should result when steers were changed from the low CP to the high CP diet if requirements were not met by the lower CP diet. Results in Table 5 suggest that, in general, requirements probably were met by the lower CP level, because gains in live mass and carcass and feed conversion efficiency did not differ between the high CP and low CP treatments. However, the interaction between CP and the energy concentration of the diet was significant ($P \leq 0.05$). Steers fed the low CP diet with an energy content of 10.5 MJME/kg DM gained slower than steers fed the high CP diet with this energy concentration. The corresponding response to added CP with the 12 MJME/kg DM diet was not significant. Regression analysis showed that variation among animals in gain was more closely associated with energy intake than either CP or UDP of the 10.5 MJME diet. In contrast, for the 12 MJME diet, energy intake was not closely related to gain. Thus, interpretation of the effects of CP and UDP on results obtained on treatments where the energy content is 10.5 MJME/kg DM, is tentative.

Dry matter and energy intake were greater for the high CP than the low CP diets ($P \leq 0.05$), but this did not increase gains in live mass and carcass or improve feed conversion efficiency (Table 5). Between UDP treatments, 35% UDP compared favourably with 40% UDP in gains and feed conversion efficiency, but feed conversion efficiency was poorer for 45% UDP. These results indicate that added CP and UDP were not beneficial with the 12 MJME diet. The interpretation for the diet with an energy content of 10.5 MJME/kg DM is less conclusive because of the effect of energy intake on gain as discussed above.

The average live mass-gain on diets with an energy content of 12 MJME/kg DM was 1.51 kg/d. If it is accepted that the high CP and high UDP intakes were not warranted, CP and UDP intakes of respectively about 1.03 and 0.40 kg/d were apparently sufficient to attain a live mass-gain of 1.5 kg/d (Table 5). These estimates are somewhat higher than those calculated from the whole maize free-choice experiment. The difference probably can be attrituted to many factors, amongst

Table 5 Intake and growth performance of steers fed diets based on by-products as affected by growth interval, level of crude (CP) and undegraded (UDP) protein, and energy level (ME) of the diet

		Treatment								
		High CP; 40 UDP		Low CP; 40 UDP		Changing CP; 35 UDP		Changing CP; 45 UDP		
		12 ME	10.5 ME	12 ME	10.5 ME	12 ME	10.5 ME	12 ME	10.5 ME	MSE
Initial mass	(kg)	167	173	165	173	167	172	170	171	6.75
Slaughter mass	(kg)	418	413	412	411	416	416	411	412	9.42
Carcass mass	(kg)	229	222	229	220	228	224	225	222	5.15
Slaughter percentage		54.8^{bc}	53.8^{ab}	55.6^{c}	53.5^{a}	54.8^{bc}	53.8^{ab}	54.7^{bc}	53.9^{ab}	0.85
DM intake	(kg/d)	8.8^{ab}	8.30^{b}	7.91^{ab}	7.54^{a}	8.06^{ab}	8.39^{b}	7.98^{ab}	8.13^{ab}	0.18
ME intake	(MJ/d)	98.1^{c}	87.2^{b}	94.9^{c}	79.2^{a}	96.7^{c}	88.1^{b}	95.8^{c}	85.4^{ab}	2.03
CP intake	(kg/d)	1.13^{d}	1.01^{bc}	0.99^{b}	0.83^{a}	1.06^{c}	0.97^{b}	1.05^{c}	0.94^{b}	0.06
UDP intake	(kg/d)	0.45^{c}	0.40^{b}	0.39^{b}	0.33^{a}	0.37^{ab}	0.34^{a}	0.46^{c}	0.42^{bc}	0.04
Live mass-gain	(kg/d)	1.47^{bc}	1.44^{b}	1.57^{c}	1.30^{a}	1.54^{c}	1.44^{b}	1.44^{b}	1.36^{ab}	0.06
Carcass gain	(kg/d)	0.86^{c}	0.82^{bc}	0.94^{d}	0.74^{a}	0.90^{cd}	0.82^{bc}	0.84^{bc}	0.78^{ab}	0.04
kg DM/kg live mass-gain		5.56^{b}	5.76^{bc}	5.04^{a}	5.80^{bc}	5.23^{ab}	5.83^{c}	5.54^{b}	5.98^{d}	0.18
kg DM/kg carcass gain		9.51^{b}	10.1^{c}	8.41^{a}	10.2^{c}	8.96^{ab}	10.2^{c}	9.50^{b}	10.4^{c}	0.31

		Growth interval					
		170—210 kg	210—250 kg	250—290 kg	290—330 kg	330—370 kg	370—410 kg
DM intake	(kg/d)	5.99^{a}	7.28^{b}	7.55^{b}	8.60^{c}	9.30^{d}	9.64^{d}
ME intake	(MJ/d)	67.4^{a}	81.9^{b}	84.9^{b}	96.8^{c}	105^{d}	108^{d}
CP intake	(kg/d)	0.92^{a}	1.04^{b}	0.94^{ab}	1.04^{b}	1.00^{ab}	1.03^{ab}
UDP intake	(kg/d)	0.37^{a}	0.42^{b}	0.38^{ab}	0.42^{b}	0.40^{ab}	0.41^{ab}
Live mass-gain	(kg/d)	1.20^{a}	1.67^{b}	1.62^{b}	1.39^{ab}	1.42^{ab}	1.37^{ab}
kg DM/kg live mass-gain		4.99^{b}	4.36^{a}	4.66^{ab}	6.19^{c}	6.55^{cd}	7.04^{d}

		Level of CP and UDP			
		High CP; 40 UDP	Low CP; 40 UDP	Changing CP; 35 UDP	Changing CP; 45 UDP
Slaughter percentage		54.3	54.6	54.3	54.4
DM intake	(kg/d)	8.24^{b}	7.73^{a}	8.23^{ab}	8.06^{ab}
ME intake	(MJ/d)	92.7^{b}	87.1^{a}	92.4^{ab}	90.6^{ab}
CP intake	(kg/d)	1.06^{c}	0.92^{a}	1.01^{bc}	0.99^{b}
UDP intake	(kg/d)	0.42^{b}	0.37^{a}	0.35^{a}	0.45^{b}
Live mass-gain	(kg/d)	1.46	1.44	1.49	1.40
Carcass gain	(kg/d)	0.85	0.84	0.86	0.81
kg DM/kg live mass-gain		5.64^{ab}	5.36^{a}	5.52^{ab}	5.76^{b}
kg DM/kg carcass gain		9.69^{ab}	9.20^{a}	9.57^{ab}	9.95^{b}

		Energy level	
		12 MJME	10.5 MJME
Slaughter percentage		55.0^{b}	53.8^{a}
DM intake	(kg/d)	8.03	8.09
ME intake	(MJ/d)	96.4^{b}	85.0^{a}
CP intake	(kg/d)	1.06^{b}	0.94^{a}
UDP intake	(kg/d)	0.42^{b}	0.37^{a}
Live mass-gain	(kg/d)	1.51^{b}	1.39^{a}
Carcass gain	(kg/d)	0.89^{b}	0.79^{a}
kg DM/kg live mass-gain		5.32^{a}	5.82^{b}
kg DM/kg carcass gain		9.02^{a}	10.2^{b}

$^{a-d}$ Values in the same line with different superscripts differ significantly ($P \leq 0.05$).

others, differences in feeding system, in energy intake and in frame size (ARC, 1984; NRC, 1984; 1985; Meissner, 1986; Shirley, 1986). Again, these estimates correspond with NRC (1985) recommendations and the RDP–UDP ratio of about 60:40 as an average for the feedlot feeding period.

Fixed or changing protein and energy level

The results of replications 1 and 2 were pooled as treatment–replication interaction was not significant. The combined results are shown in Table 6, together with comparisons between fixed and changing protein levels, between fixed and changing energy levels, and between Bonsmaras and Holsteins.

Intake of DM, ME and CP differed ($P \leq 0.05$) between the fixed and changing protein levels and between Bonsmaras and Holsteins, but not between the fixed and changing energy levels. Intake was higher on the fixed protein levels than on the changing protein levels and higher for Bonsmaras than for Holsteins. The higher intake for Bonsmaras partly explains the higher slaughter percentage ($P \leq 0.05$) of this breed in comparison to Holsteins. Another explanation for the higher slaughter percentage is that the two breeds were slaughtered at equivalent live masses, which means that the larger frame Holsteins were less mature than the medium frame Bonsmaras.

The higher intakes did not result in higher live mass-gains or better feed conversion efficiencies (Table 6). In fact, feed conversion efficiency on the changing protein levels tended to be better than on the fixed protein levels. Feed conversion efficiency on treatment 14—10% CP, 12 MJME of replication 1 (Bonsmaras) was better ($P \leq 0.05$) than feed conversion efficiency on treatment 12% CP, 12 MJME, but the difference in replication 2 (Holsteins) was not significant. From the viewpoint of cost, the higher DM and CP intakes on the fixed protein treatments were a disadvantage. The average CP percentage in the decline from 14—10% was 11.6% instead of 12% in the fixed protein treatments which yielded a saving of 10.1 kg CP per animal for the fattening period.

The average live mass-gain obtained in Experiment 3 was 1.52 kg/d (Table 6). The average CP intake was 0.87 kg/d and, since a RDP–UDP ratio of 60:40 was used, UDP intake was 0.35 kg/d. This is less than the averages in Experiment 2 where the same feeding system and feedstuffs were used, and where ME intakes corresponded. It is also less than NRC (1985) recommendations (0.98 kg CP; 0.40 kg UDP/d), but more in line with NRC (1984) calculations (0.84 kg CP/d).

Estimates of CP and UDP as shown above and as indicated by the difference between NRC (1984) and NRC (1985) calculations are too variable for exact predictions, even if major variables such as feeding system, energy content of diet, energy intake and type of cattle are controlled. Nevertheless, a guideline to the feedlot industry that uses similar diets to ours is warranted. Estimates were obtained from the relationship lines of maximum likelihood fit (Harvard Graphics, 1987) shown in Figure 2. Predicted daily amounts of CP and UDP to attain specific live mass-gains as an average for a feeding period are shown in Table 7.

These relationships predict a decline in live mass-gain when both CP and UDP intake exceed a particular maximum (Figure 2). Any explanation, apart from suggesting that energy intake was not a significant variable, would be speculative because the present experiments were not designed to further investigate this observation. At a live mass-gain of 1.5 kg/d, to comply with previous comparisons, predicted requirements for CP and UDP are 0.88 kg and 0.35 kg/d (Table 7). This implies a RDP–UDP ratio of 60:40. The average DM intake of all experiments (dietary energy content of about 12 MJME/kg DM) that yielded 1.5 kg live mass per day was about 7.5 kg/d. This implies a mean CP percentage in the DM of 11.7 for the total feeding period.

Table 6 Intake and growth performance of steers fed diets based on by-products as affected by a fixed or changing crude protein and energy level of the diet, and by cattle breed

		Treatment				
		12% CP		14—10% CP		
		12 MJME	11—13 MJME	12 MJME	11—13 MJME	MSE
Initial mass	(kg)	231	231	233	233	9.38
Slaughter mass	(kg)	397	408	408	405	8.90
Carcass mass	(kg)	219	225	226	224	5.13
Slaughter percentage		55.2	55.1	55.4	55.3	1.67
DM intake	(kg/d)	7.64[c]	7.60[bc]	7.09[ab]	7.05[a]	0.23
ME intake	(MJ/d)	91.7[b]	92.7[b]	85.1[a]	86.0[ab]	2.78
CP intake	(kg/d)	0.92[b]	0.91[b]	0.82[a]	0.82[a]	0.03
Live mass-gain	(kg/d)	1.53	1.56	1.50	1.49	0.07
kg DM/kg live mass-gain		4.99	4.87	4.73	4.73	0.20

		12% CP	14—10% CP	12 MJME	11—13 MJME	Bonsmaras	Holsteins
Slaughter percentage		55.2	55.4	55.3	55.2	57.2[y]	54.3[x]
DM intake	(kg/d)	7.62[j]	7.07[i]	7.37	7.32	7.66[y]	7.18[x]
ME intake	(MJ/d)	92.1[j]	85.4[i]	88.5	89.1	92.7[y]	86.9[x]
CP intake	(kg/d)	0.91[j]	0.82[i]	0.87	0.87	0.90[y]	0.85[x]
Live mass-gain	(kg/d)	1.55	1.50	1.52	1.53	1.57	1.50
kg DM/kg live mass-gain		4.93	4.73	4.86	4.80	4.90	4.79

a,b,c; i,j; x,y Values in the same line between treatments and breeds with different superscripts differ significantly ($P \leq 0.05$).

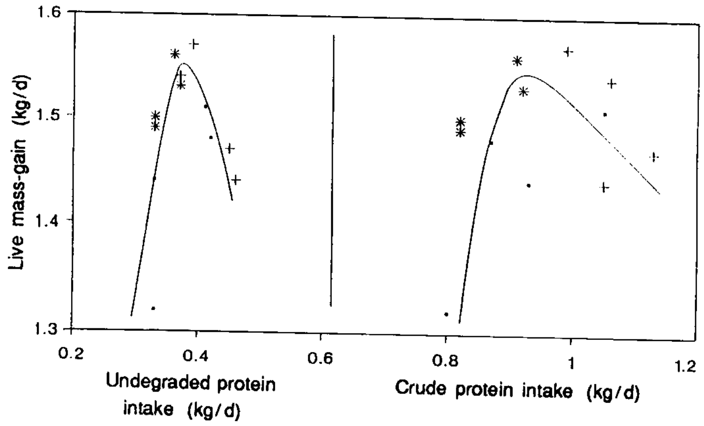

Figure 2 Relationship between ADG and respectively undegraded and crude protein intake as affected by diet and feeding system. ▪ Whole maize fed free-choice (Experiment 1); + variable protein level and degradation (Experiment 2); ⁎ fixed and changing protein level (Experiment 3).

Table 7 Estimates[1] of crude protein (CP) and undegraded protein (UDP) intakes at different live mass-gains, and the degradation associated with it

Daily gain (kg)	CP intake (kg/d)	UDP intake (kg/d)	UDP intake (% of CP intake)
1.30	0.80	0.30	37.5
1.35	0.81	0.31	38.3
1.40	0.83	0.32	38.6
1.45	0.84	0.33	39.3
1.50	0.88	0.35	39.8
1.55	0.93	0.37	39.8

[1] Estimates apply for feedlot diets with an energy content of about 12 MJME/kg DM and compiled from feedstuffs used in the present investigation.

Conclusions and Recommendations

One of the intentions of the present study was to quantify optimal crude protein levels for current feeding systems. The approach was to obtain results from vastly different feeding systems and, if they match satisfactorily, one can accept that the recommendations probably would hold in most other feeding systems used by feedlots in South Africa. The agreement between results of the whole maize free-choice system and feeding systems based on by-products was satisfactory and the predicted crude protein levels (Table 7) should apply under most circumstances.

Our second aim was to quantify the optimal RDP–UDP ratios in the crude protein when formulating diets. This proved more difficult because of interacting factors and unexpected tendencies (Figure 2). Nevertheless, RDP–UDP ratios of 60:40 to 65:35 were more consistent in realizing good live mass-gains and feed conversion efficiencies than other ratios. This agrees with results of NRC (1985) if the total feeding period is taken into account. Because Meissner & Du Plessis (1992) reported promising digestibility results at a similar ratio, we recommend that 60:40 to 65:35 be used in formulation. In compliance with NRC (1985) though, it would be preferable if starter diets contain somewhat more UDP and finisher diets somewhat less. This, however, will depend upon the particular feedstuffs that are used.

Our final objective was to determine whether protein and energy levels should be adjusted according to changing requirements as fattening progresses. One concern is that adjustments may cause digestive disturbances and palatability changes that may negate possible advantages. In the present experiments, neither impaired intake nor variable growth was detected, either in Experiment 2 where protein levels were adjusted every 40 kg mass-interval, or in Experiment 3 where protein levels were lowered from 14 to 10% quite rapidly. Even in the whole maize free-choice system, where the pattern of pelleted supplement intake led to a steady decline in protein intake, no negative effects on intake or performance were detected. In fact, a steady reduction in protein level may be advantageous to performance. It certainly can reduce cost of supplementation. The calculated reduction in this investigation (Experiment 3) was 10 kg CP per animal because the average CP level for the total feeding period was about 11.6% of DM instead of 12%. We recommend that South African feedlots reduce protein levels from 14% to 10% in the DM as fattening progresses by adopting a similar approach to the American 'starter', 'grower' and 'finisher' dietary system.

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