Netherlands Journal of Agricultural Science 43 (1995) 297-311

Protein evaluation of cattle compound feeds: comparison of in sacco measurements and tabular values[1]

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Recieved 22 February 1995; accepted 1 May 1995

Abstract

The supply of true protein to the small intestine (DVE) and the degraded protein balance (OEB) of 29 experimental compound feeds were estimated by *in sacco* ruminal and intestinal incubations with dairy cows (reference). DVE and OEB were also calculated from the values of the ingredients, given in the Dutch CVB-tables, assuming additivity. Reference DVE was on average 11 g/kg DM lower and OEB 6 g/kg DM higher than the tabular values, resulting from a lower rumen resistance of protein (–5.5%-units) and intestinal digestibility of rumen-resistant protein (–2.0%-units) and a higher rumen resistance of starch (+5.8%units) and DOM-content (+27 g/kg DM). The possible causes of these significant differences are discussed. After elimination of the systematic differences, residual errors between reference and tabular values amounted to 5.9% for DVE and 14.9% for OEB. It is concluded that a reasonable relationship exists between the DVE- and OEB-content of compound feeds based on tabular values for the ingredients and those calculated from *in sacco* measurements.

Keywords: compound feeds, cattle, protein, *in sacco*, feed tables

Introduction

Tables are practical tools for feed manufacturers in least cost formulation of compound feeds to a preconceived feeding value. By that, additivity of the tabular feeding values of the composing raw materials is assumed. For the energy evaluation of ruminant compound feeds, the Dutch tables of the Centraal Veevoederbureau (CVB) proved to be reliable, particularly if the chemical composition of the ingredients is known. In a study of 28 mixed feeds, the net energy content, calculated from determined chemical composition and tabular digestion coefficients, deviated on average 4.4% from the *in vivo* value. This error was only slightly higher than by using regression equations based on rumen fluid (4.2%) or enzymatic (3.6%) digestibility (De Boever *et al.*, 1994).

With the recent introduction of the DVE/OEB-system (Tamminga *et al.*, 1994), it

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[1] Communication n° 922 of the institute.

is interesting to know how reliable CVB-tables are for the protein evaluation of compound feeds. The supply of true protein to the small intestine (DVE) and the degraded protein balance (OEB) are difficult to determine *in vivo*. Therefore, the accepted reference method is to calculate DVE and OEB based on nylon bag incubations in the rumen and the intestines of fistulated dairy cows.

The aim of this study is to compare the DVE- and OEB-value of compound feeds derived from nylon bag incubations with those calculated from the values of the ingredients, given in the CVB-tables (Anonymous, 1991).

Material and methods

Feeds

In 1992 and 1993 the DVE and OEB-value of respectively 16 and 13 compound feeds were estimated. The formulation number and ingredient composition of the 29 compound feeds are given in Table 1. In this and the following tables, feeds examined in 1992 are above the blank line and those from 1993 under it. The feeds were composed for experiments with dairy (n=12) and fattening (n=17) cattle. F88-19, F88-21 and F91-21 to F91-26 were formulated to study the nature of the carbohydrates on rumen fermentation in dairy cows. F85-08 and F92-05 are two balanced concentrates and F88-24 and F92-27 two protein-rich concentrates for dairy cattle. F90-21 to F90-24 and F92-46 to F92-51 were composed to study the optimal protein level for double-muscled bulls fed maize silage at respectively 50 and 35% of the ration DM. F91-27 to F91-29 were compared to find the optimal protein level for bulls of normal conformation fed maize silage at 67% of the ration DM. F92-52 to F92-55 were involved in a study of the optimal OEB-value at similar DVE-value for normal bulls fed 65% maize silage DM. With exception of F88-24, all feeds were pelletized. Further, two soya bean meals (one in 1992 and one in 1993) and one formaldehyde treated soya bean meal (in 1993), used in the compound feeds, were examined.

Animals and feeding

In 1992 two (n°s 140 and 157) and in 1993 four (n°s 140, 288, 317 and 395) Holstein-Friesian cows were used for nylon bag incubations. They were in the second to fourth month of lactation at the start of the experiments. Mean milk production during the period of rumen incubations amounted in 1992 to 33.9 and 27.1 kg for cows 140 and 157, respectively and in 1993 to 30.6, 37.0, 26.8 and 22.2 kg for cows 140, 288, 317 and 395, respectively. The animals were fed according to their requirements with maize silage and concentrates in a ratio of about 70/30 in 1992 and 65/35 in 1993 (DM-basis). Equal amounts of the unmixed ration were given at 8.0 a.m. and 8 p.m. The main chemical characteristics of the maize silages in 1992 and 1993 were DM: 306 and 334 g/kg, crude fibre: 218 and 211 g/kg DM and starch: 291 and 280 g/kg DM, respectively. F88-24 and F92-27 were given as protein sup-

Table 1. Ingredient composition of the 29 compound feeds (g/kg).

Feed	wheat	maize	sorghum	barley	tapioca	soya beans extracted	maizeglutenfeed	rape seed extracted	form. soya beans ext.	coconut expeller	cottonseed extracted	sugarbeet pulp	wheat middlings	malt sprouts	citruspulp	alfafameal	grassmeal	soya bean hulls	beet molasses	beet vinasses	animal fat	MgO	feed phosphate	chalk	salt	trace elements	vitamin A+D3	vitamin E	Lignosulphonate
F88-19						205	140					357						120	70		30	4	24	5	4	18	2	1	20
F88-21	170			200	140	207	120												70		15	4	22	7	4	18	2	1	20
F88-24						600	50	166											70		30	5	9	22	20	20	2	6	
F90-21	150					92		100		100		304		100						50	23		19	10	3	20	4	5	20
F90-22	150					210	80			190		237							50				18	13	3	20	4	5	20
F90-23						350				220		294							50		5		18	11	3	20	4	5	20
F90-24						210	170			200		238							50		50		17	13	3	20	4	5	20
F91-21	220				220	335	90												70			2	8	11	3	18	2	1	20
F91-22		204	230			330	100												70			2	6	13	4	18	2	1	20
F91-23						310	78					269			200				70		15	2	12		3	18	2	1	20
F91-24						360	95									150	240		70		30	2	5	4	3	18	2	1	20
F91-25						258	133				200							250	70		31	2		11	4	18	2	1	20
F91-26	130				130	250	78				135							125	70		20	2	5	10	4	18	2	1	20
F91-27	150				56	50	107					355		100						60	23		33	13	4	20	4	5	20
F91-28	150					50	200	66				272		82						60	23		25	19	4	20	4	5	20
F91-29	150				51	150	176	43				150		100						60	22		24	21	4	20	4	5	20
F85-08	180					140	100					300		100					70		24	5	26	7	5	20	2	1	20
F92-05	50					210	200	100				167		100					70		30	5	9	9	5	20	2	3	20
F92-27						650				158									70		20	7	12	20	15	20	2	6	20
F92-46	110			150			117	9		34		200	114	150						80				13	3	15	2	7	
F92-47				150				142	57	149		220	34	132						80				10	3	15	2	7	
F92-48				150				143	162	76		240	12	102						80				9	3	15	2	7	
F92-49	439			145			249							27						80	15		1	17	3	15	2	7	
F92-50	200					24	103	54		250		236								80	15			11	3	15	2	7	
F92-51	93					66	113		76	250		271								80	15			10	3	15	2	7	
F92-52	151					286	250	66				16		54					60		20		17	27	5	20	4	5	20
F92-53	100					246	211	66		46		155							60		20		21	22	4	20	4	5	20
F92-54	75					248	64	40		77		320							60		20		29	14	4	20	4	5	20
F92-55	47					52	250		88	72		315							60		20		25	18	4	20	4	5	20

plement in 1992 and 1993, respectively. The balanced concentrate was always F92-05 except for testing F91-21 to F91-26, when F85-08 was used.

Rumen nylon bag method

Not dried samples, ground to pass a 5-mm sieve, equivalent to about 5.0 g DM (the double amount for the 336 h incubation) were weighed in sealed nylon bags of 10 × 8 cm (Nybolt, Switzerland: polyamide, porosity 26%, mesh size 40 μm). The bags were incubated during 0, 3, 6, 12, 18, 24 and 336 hours in the rumen of two (1992) or four (1993) fistulated cows (respectively 1, 2, 3, 4, 5, 6 and 6 bags per time, per feed and per cow). All incubations started after the morning feeding with exception of the 18h-bags, which were inserted after the evening feeding. In 1992 all incubation intervals up to 24 hours were done for two feeds on the same day (30 bags per cow at the morning feeding), whereas in 1993 25 feeds were simultaneously incubated following a random distribution of intervals over days. The incubation for 336 hours occurred afterwards. After incubation, bags were automatically washed with cold water during 50 min. (no spinning). Residues were dried in a ventilated oven at 60-70 °C and weighed. They were pooled per time and per cow, ground through a 1 mm-sieve and analyzed for DM, ash and nitrogen. For starch analysis, residues were composed per time over the 4 cows. The potentially degradable CP fraction was calculated from 100 – U – W, with U: the undegradable fraction after 336 h of incubation, and W: the washable fraction. The degradation rate was estimated by iteration from the first order model of Orskov & McDonald (1979). The %BRE was calculated assuming a passage rate of 6%/h (Tamminga *et al.*, 1994). The %USTA was obtained in a similar way, but considering U = 0 and 10% of W escaping rumen degradation (Tamminga *et al.*, 1994).

Mobile nylon bag method

Feed residues after 12 h rumen incubation were washed, freeze dried and ground to pass a 3-mm sieve. About 0.5 g was weighed in nylon bags (same material as rumen bags) of 3 × 7 cm (6 bags per feed and per cow). After incubation in a solution of pepsin (Riedel-de Haën, min. 700 FIP-U/g) in HCl (0.1 M) at 37 °C for 1 h, bags were inserted via a T-cannula in the duodenum behind the pancreas at a rate of 4 bags per 20 min. In 1992, %DVBE was measured with only one cow (n° 140), while with four cows in 1993. Intestinal digestibility of F91-21 to F91-26 was not determined, but estimated from the equation: $\%DVBE = 101.3 - 0.24 \times W - 1.65 \times U$ ($R^2 = 84\%$), based on the other 11 feeds, measured in 1992. After recovering from the faeces, bags were cleaned with water and stored at −18 °C. When the collection from the faeces was stopped, bags were thawed and intensively washed during 110 min. first with cold, subsequently with warm (40 °C) water and finally spin-dried. Residues were dried at ± 70 °C, weighed, pooled per feed and per cow, ground over a 1-mm sieve and analyzed for DM, ash and nitrogen. %DVBE was calculated using the residue after 12 hours rumen incubation as input.

Analyses

Dry matter content (DM) was determined by drying at 103 °C for 3 h. Crude ash content was obtained after ignition in a furnace at 550 °C. Crude protein (CP: N × 6.25) was analyzed with a Kjeltec-apparatus. Crude fat (Cfat) was extracted with petroleum ether during 6 h. Neutral detergent fibre (NDF) was determined following a pretreatment with α-amylase (Wainman *et al.*, 1981). Starch (STA) was determined after hydrolysis with amylogluosidase (Van Gelder *et al.*, 1992). Organic matter digestibility (OMD) of feeds F9-21 to F90-24 and F92-46 to F92-51 was determined with 6 sheep, fed concentrates and hay in a 80/20 ratio at maintenance level (about 23 g digestible OM per kg metabolic weight). For the other feeds, OMD was obtained with an enzymatic method and corrected to *in vivo* digestibility level (De Boever *et al.*, 1994).

Calculations

The DVE and OEB-content and their factorial components were calculated according to Tamminga *et al.* (1994), on the one hand by using the data of the wet chemical analyses and the nylon bag incubations, at the other by adding the data of the ingredients from the CVB-tables (Anonymous, 1991) in agreement with the formulation.

The supply of true protein to the small intestine (DVE) originates from feed protein escaping rumen degradation (DVBE) and from microbial protein synthesized in the rumen (DVME), corrected for endogenous losses due to digestion (DVMFE):

$$\mathrm{DVE} = \mathrm{DVBE} + \mathrm{DVME} - \mathrm{DVMFE} \tag{1}$$

$$\mathrm{DVBE} = \mathrm{CP} \times (1.11 \times \%\mathrm{BRE}/100) \times (\%\mathrm{DVBE}/100)$$

$$\mathrm{DVME} = \mathrm{FOM} \times 0.150 \times 0.75 \times 0.85$$

$$\mathrm{FOM} = \mathrm{DOM} - \mathrm{Cfat} - \mathrm{CP} \times (\%\mathrm{BRE}/100) - \mathrm{STA} \times (\%\mathrm{USTA}/100)$$

$$\mathrm{DVMFE} = 0.075 \times (1000 - \mathrm{DOM} - \mathrm{VRAS})$$

with

%BRE:	fraction of undegraded feed CP in total feed CP
%DVBE:	digestion in small intestine of the undegraded feed protein
FOM:	fermentable organic matter
DOM:	digested organic matter
%USTA:	fraction of undegraded starch
VRAS:	digestible fraction of crude ash (assumed digestion coefficient of 0.50)

The degraded protein balance (OEB) shows the (im)balance between microbial protein synthesis potentially possible from available rumen degradable crude protein (MREN) and that from the energy extracted during anaerobic fermentation in the rumen (MREE):

$$\mathrm{OEB} = \mathrm{MREN} - \mathrm{MREE} \tag{2}$$

$$\mathrm{MREN} = \mathrm{CP} \times (1 - 1.11 \times \%\mathrm{BRE}/100)$$

$$\mathrm{MREE} = \mathrm{FOM} \times 0.15$$

Tabular values for %BRE and %DVBE were mainly derived from compiled

Dutch and international data (Van Straalen & Tamminga, 1990). For feeds of which no data were available, values were estimated from information of comparable feeds. Products of which information was completely lacking, were given a value of 35% for %BRE and of 75% for %DVBE. The USTA values originate from Tamminga *et al.* (1990) and Nocek & Tamminga (1991). If relevant, they were corrected with a factor 0.75 to account for the observed negative effects of pelletizing. For the formaldehyde treated soya bean meal measured data were used. DVE of the minerals MgO, feed phosphate and chalk was calculated from ash content and assuming a digestion coefficient of 50%; salt was considered 100% soluble. For the trace elements and vitamins, added on a carrier of sorghum, the tabular data of the latter were taken. DVE and OEB-value of lignosulphonate were estimated as –51 and –11 g/kg DM, respectively based on the following chemical analysis: CP: 6, starch: 53, sugars: 63, ash: 116 g/kg DM and assuming the protein and starch not rumen resistant.

Statistics

Differences between measured (or reference) and tabular values were tested by a paired *t*-test.

Results

The chemical composition, OMD and rumen degradation characteristics of protein and starch for the 29 compounds and the 3 raw materials are given in Table 2. The compound feeds showed a wide variation in chemical composition. CP-content ranged from 156 (F91-27) to 357 g/kg DM (F88-24), Cfat from 11 (F91-21) to 87 g/kg DM (F90-24), ash from 68 (F91-22) to 117 g/kg DM (F92-27), NDF from 120 (F91-22) to 310 g/kg DM (F88-19) and starch from 33 (F90-23) to 407 g/kg DM (F92-49). The two soya bean meals were of comparable chemical composition, whereas the treated soya bean meal contained 4%-units more protein and 5%-units less cell-walls. Apparent OMD of the compounds varied from 80.8 (F91-24) to 89.8% (F91-21). The three soya bean meals had a similar OMD of about 89%.

The washable CP-fraction of the compound feeds varied considerably from 23.2 (F88-24) to 63.6% (F92-49). Only about 10% of the CP of the soya bean meals disappeared during the washing procedure. For all feeds, including the soya bean meals, there appeared a highly significant ($P < 0.001$) negative relationship between W (%) and CP-content (g/kg DM): $W = 69.2 - 0.122 \times CP$ ($n = 32$; $r = 0.86$). The undegradable CP-fraction of the mixed feeds and the soya bean meals was almost negligible, being lower than 3%, with exception of the feeds F92-46 and F92-47. For the latter, the U-fraction of more than 4% seems related to the incorporation of wheat middlings and malt sprouts. The degradation rate of CP ranged from 2.3 (F92-48 and F92-55) to 9.0%/h (F88-24) for the compound feeds. The big difference in c between treated and untreated soya bean meals (0.8 vs. 6.1%/h) clearly showed the efficiency of formaldehyde in protecting against rumen degradation.

Table 2. Chemical composition, OMD and rumen degradation characteristics of protein and starch for 29 compound feeds and 3 raw materials.

Feed	DM	CP	Cfat	Ash	NDF	STA	OMD[1]	CP			Starch	
	g/kg	g/kg DM					%	W[2]	U[3]	c[4]	W	c
								%	%	%/h	%	%/h
F88-19	882	189	45	92	310	72	88.1	37.9	1.2	6.6	53.7	10.0
F88-21	878	193	31	82	152	361	87.1	44.7	0.9	7.1	69.0	26.6
F88-24	870	357	53	115	156	62	86.5	23.2	1.3	9.0	50.4	10.9
F90-21	873	200	53	87	304	128	84.5	37.7	2.4	6.8	71.0	8.1
F90-22	887	213	35	85	269	135	86.1	39.6	1.0	5.3	67.0	6.2
F90-23	889	252	40	93	275	33	87.2	24.1	1.3	6.7	47.8	4.3
F90-24	897	211	87	89	291	81	86.7	36.4	1.6	5.6	50.5	8.4
F91-21	876	239	11	74	121	340	89.8	31.2	0.5	6.1	86.7	9.8
F91-22	871	241	21	68	120	353	89.2	29.5	0.0	4.6	27.8	4.6
F91-23	878	225	30	80	221	43	89.3	35.4	0.3	4.2	45.3	7.9
F91-24	894	278	51	93	276	37	80.8	31.3	1.5	5.2	31.5	9.2
F91-25	871	276	54	79	291	64	83.0	36.3	1.2	5.7	60.7	11.1
F91-26	871	245	36	73	207	226	85.0	35.9	1.0	5.7	82.1	12.4
F91-27	888	156	40	97	258	218	87.4	53.3	2.6	5.4	73.4	11.9
F91-28	885	179	43	96	263	193	86.6	52.7	2.3	6.4	67.1	11.8
F91-29	877	210	43	98	224	213	85.6	43.6	1.9	7.2	70.2	11.9
Sbm92[5]	866	480	14	76	135	27	88.8	10.7	0.0	8.0	42.2	11.3
F85-08	884	187	38	94	241	145	86.5	50.5	2.0	4.5	88.3	4.9
F92-05	879	235	53	91	245	92	83.5	45.5	2.6	5.2	83.3	4.2
F92-27	870	348	48	117	173	50	88.5	28.7	0.5	6.3	79.7	4.2
F92-46	869	163	22	81	282	233	85.3	60.7	4.8	5.2	90.4	6.2
F92-47	868	205	34	90	297	138	85.0	44.7	4.1	3.8	92.6	3.4
F92-48	863	232	24	90	256	123	86.4	40.8	1.5	2.3	91.8	3.0
F92-49	863	163	35	71	155	407	89.4	63.6	2.4	7.3	82.0	19.1
F92-50	874	188	61	76	297	150	87.4	49.0	2.4	4.7	77.8	10.7
F92-51	876	224	60	81	301	94	88.3	44.2	2.1	3.2	73.8	8.6
F92-52	888	263	42	101	175	141	85.4	49.1	2.0	5.0	80.4	6.7
F92-53	891	241	45	102	197	111	86.0	45.3	2.0	4.8	74.5	7.4
F92-54	897	221	44	101	203	71	87.4	35.3	2.0	5.2	78.3	5.0
F92-55	897	197	45	100	246	85	85.8	50.8	2.2	2.3	64.5	7.0
Sbm93	860	483	17	72	131	13	89.4	11.4	1.0	6.1	48.4	8.3
Sbmp93[6]	866	521	14	75	83	8	89.9	11.7	1.0	0.8	29.8	3.8

[1] Organic matter digestibility determined *in vivo* for feeds F90-21 to F90-24 and F92-46 to F92-51, whereas *in vitro* for the other feeds.

[2] washable fraction ; [3] undegradable fraction ; [4] degradation rate.

[5] Soya bean meal ; [6] Soya bean meal protected.

The washable starch-fraction was also highly variable with a minimum of 27.8% for F91-22 and a maximum of 92.6% for F92-47. The W-fraction was lowest for the starchy concentrate containing maize and sorghum, whereas for the other feeds it tended to increase with higher starch content. The variation in starch degradation rate was even higher, going from 3.0 (F92-48) to 26.6%/h (F88-21). Leaving F91-22 with a very high content of rumen-resistant starch aside, there appeared a significant

($P < 0.001$) positive correlation between starch content (g/kg DM) and c (%/h): c = 4.10 + 0.0335 x starch (r = 0.67).

In Table 3, the parameters, necessary to calculate the DVE and OEB-value, are given for the 29 compound feeds. The values as determined or calculated from chemical composition and *in sacco* incubations are put against the differences with the tabular values. All parameters showed a highly significant ($P < 0.001$) difference

Table 3. Rumen resistance of CP (%BRE) and starch (%USTA), intestinal digestibility of undegraded feed protein (%DVBE), fermentable organic matter (FOM) and digestible crude ash (VRAS) for the 29 compound feeds : reference (R) and difference reference – tables (D).

Feed	BRE %		DVBE[1] %		USTA %		FOM g/kg DM		VRAS g/kg DM	
	R	D	R	D	R	D	R	D	R	D
F88-19	30.3	–7.6	89.7	–2.6	22.7	11.3	681	55	46	–9
F88-21	25.9	–8.8	90.4	–5.0	12.6	1.2	674	37	41	–9
F88-24	31.5	–5.8	93.7	–1.8	22.7	11.1	587	29	57	–25
F90-21	30.5	–4.7	90.7	0.8	19.4	6.4	632	17	44	–10
F90-22	32.5	–8.6	91.9	–2.7	18.0	4.7	660	31	42	–12
F90-23	36.7	–5.9	91.6	–4.2	35.1	17.4	647	37	46	–12
F90-24	33.6	–7.9	90.9	–3.3	25.6	12.7	611	38	45	–10
F91-21	34.3	–1.6	92.9	–4.0	13.7	2.5	691	35	37	–10
F91-22	40.0	–0.7	94.2	–2.3	43.5	15.3	561	–6	34	–12
F91-23	38.0	0.2	92.3	–3.1	28.1	13.0	694	34	40	–5
F91-24	37.6	–1.0	91.3	2.8	30.3	11.8	567	29	47	–9
F91-25	33.2	–5.7	90.6	0.5	19.9	7.3	606	47	40	–6
F91-26	33.4	–4.4	91.0	–1.2	14.0	2.9	639	39	36	–10
F91-27	25.8	–5.2	84.0	–6.5	16.3	5.6	674	42	48	–14
F91-28	24.1	–7.0	80.7	–8.2	17.8	6.5	663	50	48	–14
F91-29	26.8	–5.0	86.6	–5.4	17.0	5.2	638	33	49	–15
F85-08	29.1	–4.3	91.4	–1.6	15.3	1.5	669	30	47	–9
F92-05	30.4	–3.5	91.0	–0.6	18.2	2.3	618	17	46	–7
F92-27	35.0	–5.1	97.0	–0.9	19.9	8.4	602	43	58	–22
F92-46	23.1	–5.5	85.5	–1.4	13.8	2.4	693	36	41	–5
F92-47	35.6	–3.8	88.3	–0.6	14.0	2.9	648	33	45	–4
F92-48	43.1	–4.2	92.0	0.0	14.6	2.1	644	42	45	–4
F92-49	17.8	–9.3	87.3	–3.5	12.5	0.0	716	42	35	–7
F92-50	29.5	–9.0	88.7	–1.9	15.8	1.6	668	33	38	–9
F92-51	37.3	–9.5	93.7	–0.3	18.1	2.6	651	37	40	–10
F92-52	28.7	–5.7	93.0	–0.9	17.3	1.0	626	35	50	–13
F92-53	31.2	–5.6	93.6	0.0	18.9	2.5	631	34	51	–11
F92-54	35.7	–3.5	93.7	–0.6	19.7	2.2	649	37	51	–10
F92-55	36.2	–11.0	94.5	0.7	22.8	3.9	637	44	50	–10
Mean	32.0	–5.5*	90.8	–2.0*	19.9	5.8*	644	35*	45	–10*
SD	5.5	2.8	3.4	2.4	7.0	4.8	37	11	6	5
Min.	17.8	–11.0	80.7	–8.2	12.5	0.0	561	–6	34	–25
Max.	43.1	0.2	97.0	2.8	43.5	17.4	716	55	58	–4

[1] %DVBE estimated from W and U for feeds F91-21 to F91-26.

* Significantly different from 0 ($P < 0.001$).

between reference and tabular values. Reference rumen resistance of CP, varying from 17.8 (F92-49) to 43.1% (F92-48: highest percentage of protected soya bean meal), was on average 5.5%-units lower than the tabular value. Mean intestinal digestibility of rumen-resistant protein was high (90.8%), ranging from 80.7 (F91-28) to 97.0% (F92-27: highest percentage of soya bean meal). %DVBE was on average 2.0%-units lower than the tabular value. It could be remarked that the differences in %DVBE were generally greater for the feeds, examined in 1992 than for those from 1993. Former data could be considered less reliable as 10 of them were determined with only one cow and the other 6 were estimated. Compared with protein, starch was less rumen-resistant (19.9 vs. 32.0%) and varied from 12.5 (F92-49: highest percentage of wheat) to 43.5% (F91-22: containing maize and sorghum). In contrast with protein, reference %USTA was 5.8%-units higher than the tabular values. The difference was most pronounced for compound feeds with a low starch content, but also for the starchy feed F91-22, containing maize and sorghum. Reference fermentable organic matter content, varying from 561 (F91-22) to 716 g/kg DM (F92-49), amounted to 35 g/kg DM more than the tabular value. This was the result of DOM and rumen resistant starch being respectively 27 and 7 g/kg DM higher and rumen-resistant protein and crude fat being respectively 14 and 2 g/kg DM lower. VRAS content varied from 34 (F91-22) to 58 g/kg DM (F92-27), with a mean of 45 g/kg DM.

In Table 4, the DVE- and OEB-value and their factorial components, calculated from measurements as well as the difference with tabular values, are given for the 29 compound feeds. All reference parameters differed significantly ($P < 0.001$) from tabular values. Mean DVE, being 123 g/kg DM, was high and varied from 86 (F92-49: lowest protein level tested for double-muscled bulls) to 177 g/kg DM for the protein-concentrate F92-27. As a result of the lower %BRE and %DVBE, but also of the lower CP-content (mean: 225 vs. 230 g/kg DM) reference DVBE was on average 15 g/kg DM lower than the tabular value. On the other hand, reference DVME was 3 g/kg DM higher and the negative component DVMFE was 1 g/kg DM lower. Consequently, the difference in DVE-value, being 11 g/kg DM, was the result of some compensation. Despite this significant difference, there was a close relationship ($r = 0.95$) between reference and tabular DVE-values as shown in Figure 1. In comparison, the relationship between reference DVE and CP, both in g/kg DM, was:

$$DVE = 30.84 + 0.411 \times CP \ (r = 0.87;\ rsd = 11.4 \text{ g/kg DM}) \qquad (3)$$

OEB was always positive with a mean of 47 g/kg DM and a range from 11 (F91-27: high amount of sugarbeet pulp) to 145 g/kg DM for the protein-concentrate F88-24. Compared with the tables, reference MREN, MREE and OEB were respectively 11, 5 and 6 g/kg DM higher. The correlation ($r = 0.97$) between measured and tabular OEB was very high as shown in Figure 2. OEB was also highly correlated to CP following the equation:

$$OEB = -89.20 + 0.607 \times CP \ (r = 0.94;\ rsd = 11.1 \text{ g/kg DM}) \qquad (4)$$

Table 4. DVE- and OEB-values and their factorial components (g/kg DM) for the 29 compound feeds : reference (R) and difference: reference – tables (D).

Feed	DVBE		DVME		DVMFE		DVE		MREN		MREE		OEB	
	R	D	R	D	R	D	R	D	R	D	R	D	R	D
F88-19	57	–18	65	5	12	–2	111	–10	125	14	102	8	24	6
F88-21	50	–20	64	3	12	–1	103	–15	138	20	101	6	36	14
F88-24	117	–33	56	3	13	1	160	–31	232	10	88	4	145	6
F90-21	61	–10	60	1	14	–1	108	–7	132	10	95	3	38	8
F90-22	71	–23	63	3	13	–1	121	–19	136	18	99	5	37	13
F90-23	94	–22	62	4	12	–1	144	–17	149	14	97	6	52	8
F90-24	72	–22	58	3	12	–1	118	–17	132	15	92	6	40	9
F91-21	84	–6	66	3	10	–2	141	1	148	9	104	5	44	3
F91-22	101	–4	54	0	10	–2	144	–3	134	1	84	–1	50	2
F91-23	88	0	66	3	10	–2	144	6	130	3	104	5	26	–2
F91-24	106	0	54	3	16	–1	144	4	162	2	85	4	77	–1
F91-25	92	–15	58	5	15	–2	135	–9	174	18	91	7	83	10
F91-26	83	–10	61	4	13	–2	131	–4	154	15	96	6	58	9
F91-27	38	–10	64	4	12	–2	90	–3	111	11	101	6	11	5
F91-28	39	–18	63	4	13	–2	89	–12	131	9	99	8	32	2
F91-29	54	–15	61	3	13	–1	102	–10	148	9	96	5	52	4
F85-08	55	–8	64	3	13	–1	107	–4	127	11	100	5	26	6
F92-05	72	–14	59	2	15	0	117	–12	156	1	93	3	63	–2
F92-27	131	–27	58	5	12	0	177	–22	213	12	90	6	123	6
F92-46	36	–13	66	3	13	–1	89	–9	121	–1	104	5	17	–7
F92-47	71	–17	62	3	14	–2	120	–12	124	–4	97	5	27	–9
F92-48	102	–21	62	4	13	–2	151	–15	121	0	97	6	24	–7
F92-49	28	–19	68	4	10	–1	86	–14	131	11	107	6	24	6
F92-50	55	–19	64	3	12	–1	107	–15	127	17	100	5	26	12
F92-51	87	–20	62	3	11	–1	138	–15	131	25	98	6	34	20
F92-52	78	–19	60	4	14	0	124	–15	179	13	94	5	85	7
F92-53	78	–15	60	3	13	–1	125	–11	158	13	95	5	63	8
F92-54	82	–8	62	3	12	–2	132	–3	134	9	97	5	36	4
F92-55	75	–20	61	4	13	–1	122	–15	118	26	96	7	22	19
Mean	74	–15[*]	61	3[*]	13	–1[*]	123	–11[*]	144	11[*]	97	5[*]	47	6[*]
SD	25	8	3	1	1	1	23	8	27	7	6	2	31	7
Min.	28	–33	54	0	10	–2	86	–31	111	–4	84	–1	11	–9
Max.	131	0	66	5	16	1	177	6	232	26	107	8	145	20

[*] Significantly different from 0 ($P < 0.001$)

Discussion

With the present study we intended to evaluate the calculation of the DVE and OEB-value of compound feeds based on tabular values for the ingredients assuming additivity. The 29 feeds studied, showing a generally high DVE- and a positive OEB-level, are characteristic for maize silage based rations. Although these experimental feeds do not give a representative picture of the compounds on the market, their chemical and ingredient composition may be considered as variable enough to show some tendencies.

From Table 4, it could be calculated that DVE and OEB, based on the tabular values of the ingredients, deviated respectively 11.1 and 19.2% from the values calculated from direct measurements on the compound feeds. These at first sight appreciable errors are in fact for a great part systematic, the reference DVE and OEB being respectively 11 g/kg DM lower and 6 g/kg DM higher than the tabular values. These systematic deviations can only for a small part be explained by the 5 g/kg DM lower CP-content as compared with the tables, but are to be sought in the factorial components of DVE and OEB. So, measured rumen resistance of CP was on average 5.5%-units lower than the tabular value. On the other hand, measured %BRE for the two soya bean meals Sbm92 and Sbm93 (38.2 and 45.0% respectively) was comparable or even higher than the tabular value of 39%. As soya bean meal was the most important protein ingredient used, the systematic deviation found for compounds was obviously not the result of differences in the rumen bag technique. Van Straalen *et al.* (pers. comm.), observing a similar difference for one compound feed, suggested as possible causes: the technological treatment of the feeds during the compounding process or an interaction between ingredients during rumen incubation. In our case, raw materials were hammer-milled to pass a 6-mm screen, subsequently mixed and finally pelletized without steam using a die of 6 mm. When preparing the compound feed samples for rumen incubations, the incorporated raw materials were in fact ground for the second time. Hence, it is quite evident that the particle size of the raw materials is smaller after pelletizing than when taken directly and ground once. This assumption is strengthened by the fact that the washable fraction of the protein-concentrate F92-27, being 28.7%, is far higher than could be calculated from its main protein ingredients: soya bean meal with a measured W of 11.7%, coconut expeller and sugarbeet pulp with assumed W's of 13.9% and 23.8%, respectively according to Van Straalen & Tamminga (1990). For four compound feeds, it was shown that the W-fraction was on average 7.2%-units higher after pelletizing than after simply mixing the ingredients (41.9 vs. 34.7%), whereas no effect of the compounding process was observed on the soluble fraction (27.1 vs. 27.9%), measured after 1h soaking and filtering (De Boever *et al.*, pers. comm.). The influence of particle size on the washable fraction, which is assumed as soluble, is a weak point in the determination of rumen degradability. An alternative is to measure the really soluble fraction and to correct degradation characteristics according to Lopez *et al.* (1994). By this correction the potentially degradable and undegradable fraction are adjusted for loss of particulate matter, whereas degradation rate is considered unchanged. To have an idea of the possible implications of that approach, we redetermined in 1994 rumen degradation of feeds F92-46 to F92-55 (same formulation but other batches of ingredients) and also measured the soluble fraction. Mean washable and soluble protein fraction of the 10 feeds amounted to 43.7 and 28.0%, respectively. Correcting degradation parameters of both protein and starch for loss of particulate matter, increased %BRE from 33.6 to 42.9%, DVBE from 72 to 91 g/kg DM, DVE from 119 to 135 g/kg DM and decreased OEB from 32 to 16 g/kg DM. Because of these appreciable effects, the current corrections in the DVE/OEB-system of multiplying %BRE by 1.11 to obtain DVBE and of assuming 10% of the washable starch fraction as potentially degradable need reconsideration. The aspect of interaction, by which mixtures of feeds favor microbial activity within the bags through a better balance of substrates, also deserves attention. Considering the experiments of Vik-Mo & Lindberg (1985), higher N disappearance by combining feeds of widely varying composition seems acceptable. Following Chapoutot *et al.* (1990), the impact on effective rumen degradability is more pronounced when less soluble and slowly degrading feeds interact. In our study however, the difference between reference and tabular values significantly ($P < 0.05$) increased with decreasing %BRE of the compound.

Measured %DVBE of the compounds was on average 2%-units lower than calculated from the tables. The lower intestinal digestibility could partly be explained by a certain compensation for the higher rumen degradability. There was further a clear year-effect as the difference amounted to $-2.9\pm2.8\%$ in 1992 and $-0.9\pm1.1\%$ in 1993. The first year %DVBE of 10 feeds was determined with only one cow. Generally, this animal, also involved in the experiments of 1993, showed the lowest %BRE and %DVBE when compared with the other 3 cows. For the other 6 feeds of 1992 %DVBE was estimated from a regression equation based on W and U.

In contrast with %BRE, measured rumen resistance of starch was on average 5.8-units higher than according the tables. This is surprising as an overestimation of W after pelleting could also be expected for starch. Indeed, for the same aforementioned 4 compound feeds the W-fraction was on average 32.4%-units higher for the pellets than for the ingredient mixtures (60.2 vs. 27.8%). This important difference is however not only due to supplemental particulate loss after pelleting, but also to a certain degree of starch gelatinization by the rise of the temperature during processing. To account for this negative effect of pelletizing, tabular %USTA-values are decreased by 25%. Recent studies (Tamminga & Goelema, 1994, pers. comm.) have shown that this correction is too high and should be halved. But even then, the difference would remain 3.5%-units. On the other hand, the effect on rumen-resistant starch and FOM content was relatively small as the difference decreased with higher starch content. The only exception on that tendency was the starchy compound, containing maize and sorghum, suggesting that their tabular value for %USTA of 30% is probably too low. Other factors that could play a role are the nature of the ration and the intake level of the experimental animals. Tamminga *et al.* (1989) observed lower %USTA-values with rations containing fast degradable starch (tapioca and flaked maize). The ration fed in our study, containing a moderate starch content (about 210 g/kg DM) mainly from maize silage (slow degradable), was probably not suited for a high amylolytic activity. Rate of starch degradation tends to increase with higher intake level (Tamminga *et al.*, 1989). However, this effect can be considered less important here, as the intake level in our and the Dutch experiments was comparable.

The systematic higher DOM-content of 27 g/kg DM as compared with the tables probably results from some difference in (*in vivo*) digestibility level between institutes. The maintenance level of feeding at our institute, defined as 23 g DOM per kg metabolic weight (MW), is lower than at the Dutch Institute in Lelystad, where the aim for a more or less constant intake level means that about 30 g DOM per kg MW are fed with concentrates (Steg, pers. comm.). From the lower VRAS-content of the compound feeds as compared with the tables can be concluded that a digestion coefficient of 65% for ash would be better than the currently assumed 50%.

Regressing measured and tabular values, by which systematic error is eliminated, reduced the errors to 5.9% for DVE and 14.9% for OEB. This residual variation can mainly be ascribed to the use of mean tabular data, by wich no account is taken of the variation within raw materials. Due to the complex nature of the compounds, it is very difficult to ascribe differences to specific ingredients. Differences with the DVE regression line (Figure 1) of more than 10 g/kg DM were observed at the upper side for F91-21, F91-23 and F91-24, probably the result of less accurate *in sacco* data, and at the under side for F88-24, mainly as a consequence of a too high tabular CP-content. Concerning the OEB-regression line, positive as well as negative deviations were most pronounced for compounds containing formaldehyde treated soya bean meal. The linear equations for DVE and OEB showed high determination coefficients of respectively 89 and 95%. The somewhat lower but still very significant

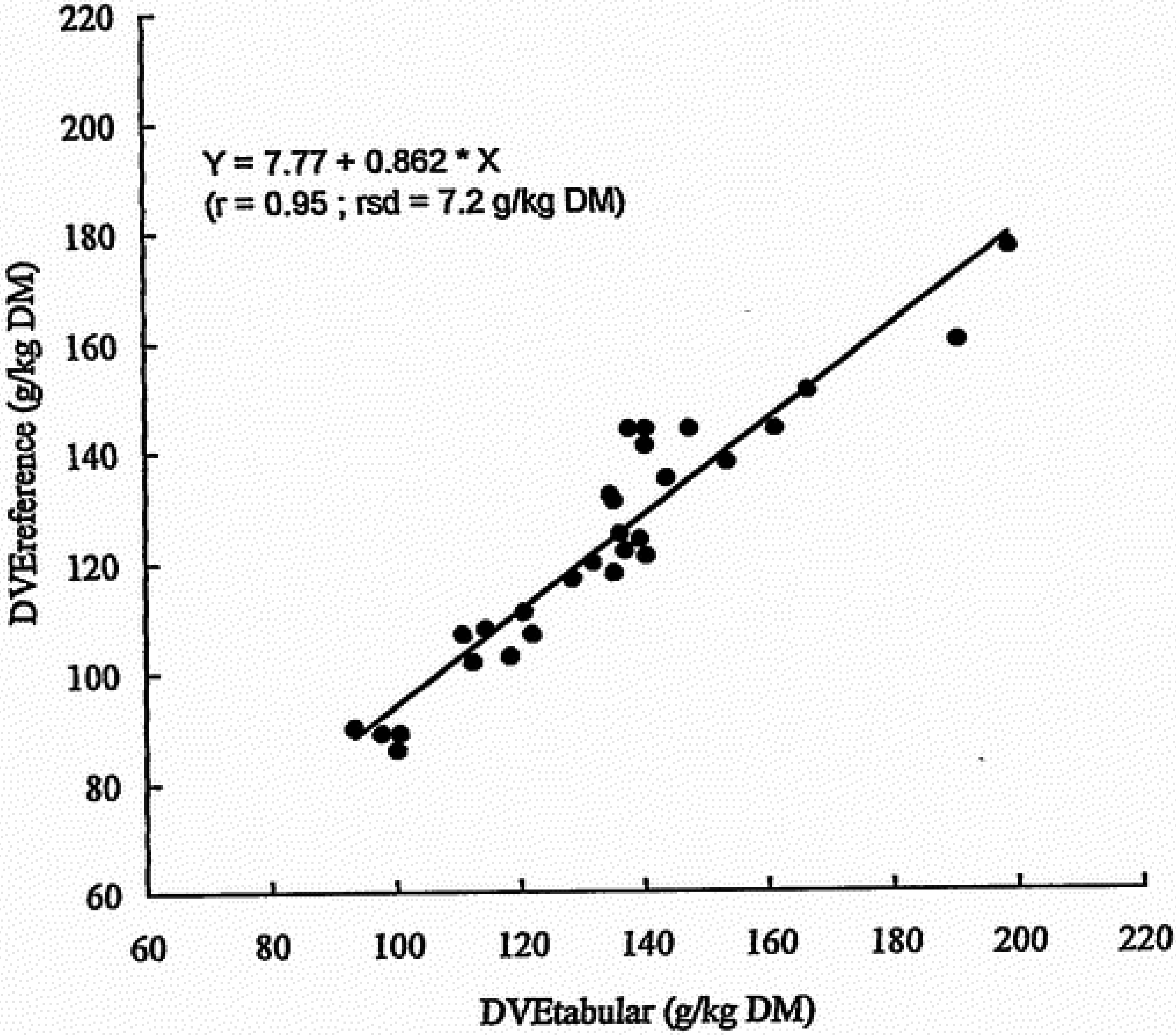

Figure 1. Relationship between reference and tabular DVE for 29 compound feeds.

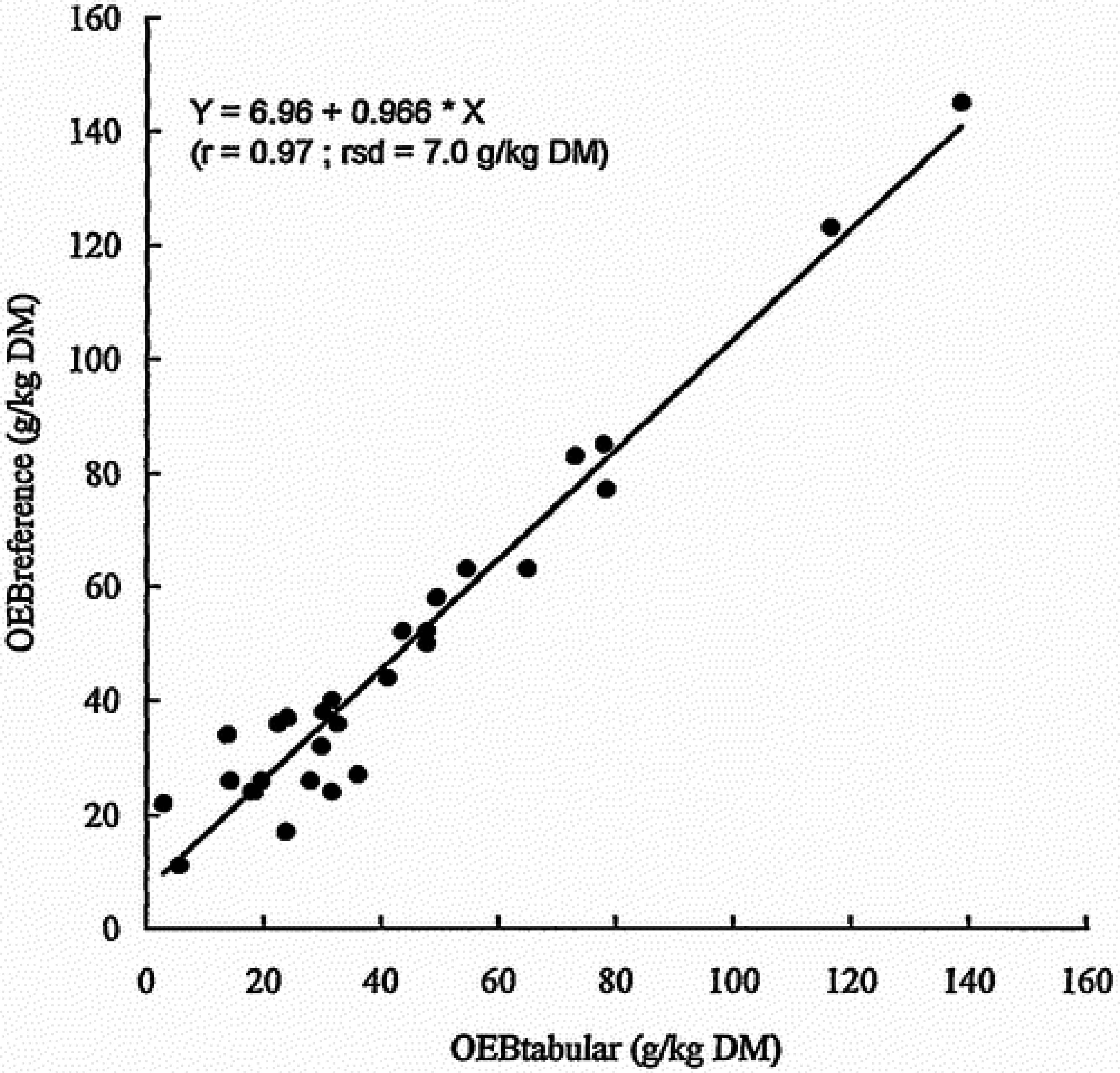

Figure 2. Relationship between reference and tabular OEB for 29 compound feeds.

correlation between CP-content and DVE or OEB could be expected with such a broad range. However, CP is less suited as predictor, particularly when raw materials protected against rumen degradation are used.

From this study can be concluded that there is a reasonable relationship between the DVE- and OEB-content of compound feeds based on tabular data of the ingredients and those calculated from *in sacco* measurements. The particulate loss by washing bags after rumen incubation deserves further attention because of its important and not systematic influence on the final protein value.

Acknowledgements

The authors are grateful to the personnel of the laboratory for the careful assessment of the many samples.

References

Anonymous, 1991. Veevoedertabel. Chemical composition, digestibility and feeding value of feedstuffs (In Dutch). Centraal Veevoederbureau, Lelystad, 250 pp.

Chapoutot, P., S. Giger, D. Sauvant & S. Jeantet, 1990. Etude de l'additivité de la dégradation in sacco de la matière sèche des mélanges simples d'aliments concentrés. *Reproduction, Nutrition et Développement* suppl. 2: *169s–170s.*

De Boever, J.L., B.G. Cottyn, J.M. Vanacker & Ch.V. Boucqué, 1994. An improved enzymatic method by adding gammanase to determine digestibility and predict energy value of compound feeds and raw materials for cattle. *Animal Feed Science and Technology* 47: 1–18.

Lopez S., J. France & M.S. Dhanoa, 1994. A correction for particulate matter loss when applying the polyester-bag method. *British Journal of Nutrition* 71: 135–137.

Nocek, J.E. & S. Tamminga, 1991. Site of digestion of starch in the gastro intestinal tract of dairy cows and its effect on milk yield and composition. *Journal of Dairy Science* 74: *3598–3629.*

Orskov, E.R. & I. McDonald, *1979.* The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *Journal of Agricultural Science (Cambridge)* 92: 499–503.

Tamminga, S., P. Van der Togt, C.J. van der Koelen, C. Meliefste, M. Luttikhuis & G.D.H. Claassen, 1989. The behaviour of starches in the rumen of dairy cows (In Dutch). Mededeling 14, IDLO Research Institute for Livestock Feeding and Nutrition, Lelystad, 29 pp.

Tamminga, S., W.M. Van Straalen, A.P.J. Subnel, R.G.M. Meijer, A. Steg, C.J.G. Wever & M.C. Blok, 1994. The Dutch protein evaluation system: the DVE/OEB-system. *Livestock Production Science* 40: 139–155.

Tamminga, S., A.M. Van Vuuren, C.J. Van der Koelen, R.S. Ketelaar & P.L. Van der Togt, 1990. Ruminal behaviour of structural carbohydrates, non-structural carbohydrates and crude protein from concentrate ingredients in dairy cows. *Netherlands Journal of Agricultural Science* 38: 513–526.

Van Gelder, A.H., E.M. Te Brinke, J.W. Cone, H.J. Van Lonkhuijsen, J.M. Jetten & W.J. Lichtendonk, 1992. Protocol for the analysis of non-starch polysaccharides (nsp) (In Dutch). Kwaliteitsreeks nr. 19, Produktschap voor Veevoeder, 's-Gravenhage, 52 pp.

Van Straalen, W.M. & S. Tamminga, 1990. Protein degradation of ruminant diets. In: J. Wiseman & D.J.A. Cole (Eds.), Recent advances in animal production, Butterworths, London, pp. 55–72.

Vik-Mo, L. & E. Lindberg, *1985.* In sacco degradability of protein (N) and dry matter in samples of individual feeds or combinations, tested with diets medium or high in protein. *Acta Agriculturae Scandinavica* 35: 117–128.

Wainman, F.W., P.J.S. Dewey & A.W. Boyne, 1981. Compound feedingstuffs for ruminants. Third Report, Department of Agriculture and Fisheries, Feedingstuffs Evaluation Unit, Aberdeen , 49 pp.