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Supplementation of cereal straws with different protein feeds: *In vivo* studies

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SUMMARY - Three feeding trials with growing lambs were carried out in order to evaluate the protein value of some common protein feeds in the supplementation of wheat straw in complete pelleted diets. The protein feeds were: soya bean meal (SBM), sunflower cake (SFC), coconut cake (CNC), brewers yeast (BY), meat meal (MM), fish meal (FM), blood meal (BM) and a commercial product based on blood meal integrated with lysine and methionine and protected with calcium soaps to escape the rumen. The results confirm that wheat straw is a potentially good source of energy, provided it is associated with a slowly degradable protein source. SBM was the best feed of plant origin and comparable with feeds of animal origin. SFC was the worst feed in this respect. When a fraction of the protein of SBM is replaced by a protected protein, the crude protein level of the diet can be lowered from 16-18% down to 13% on the DM basis. The statistical "response surface analysis" was a unique tool to show the best combinations between ingredients.

Key words: Wheat straw, protein feeds, associative effect, growing lambs.

RESUME - *"Supplémentation des pailles de céréales avec différents aliments protéiques : Etudes* in vivo*". Trois essais d'alimentation d'agneaux en croissance ont été conduits pour évaluer la valeur protéique de quelques aliments protéiques communs comme suppléments de la paille de blé dans des diètes complètes en pellets. Les aliments protéiques étaient : tourteau de soja (SBM), tourteau de tournesol (SFC), tourteau de coprah (CNC), levure de brasserie (BY), farine de viande (MM), farine de poisson (FM), farine de sang (BM) et un produit commercial avec sa protéine protégée par des savons de calcium. Les résultats confirment que la paille de blé est une bonne source d'énergie, pourvu qu'elle soit associée avec un aliment protéique lentement dégradable. SBM était le meilleur aliment végétal, comparable avec les aliments d'origine animale. SFC était le plus mauvais à cet égard. Quand une fraction de la protéine du tourteau de soja est remplacée par la protéine protégée, le niveau de protéine brute de la diète peut être baissé de 16-18% à 13% sur la MS. L'analyse statistique "response surface analysis" a été un instrument unique pour mettre en évidence les meilleures combinaisons entre aliments.*

Mots-clés : *Paille de blé, aliments protéiques, effet associatif, agneaux en croissance.*

Introduction

In the area of Mediterranean countries of South-Europe a huge amount of fibrous agricultural residues, mainly from cereal cultures, are available as roughage resources. All this material is often misused or wasted because it is believed that its poor nutritive value cannot be easily upgraded. It is a matter of lack of information on its correct use. Besides that, the poor fibrous residues, namely by-products of cereals and legume crops, may represent a serious pollution problem for the surrounding environment. The higher the production of grains from cereals and pulses, the higher the amount of fibrous residual by-products. According to our experience from previous experiments, the nutritive value of fibrous feeds can be upgraded both by chemical and physical treatments and by adequate associations with the proper concentrates within complete, balanced diets. As a consequence of all this, the objectives of the project may be summarized in the following points:

(i) The study on the contribution of different protein feeds to the improvement of the nutritive value of wheat straw, by means of recorded measurements of the animals' performances.

(ii) The proposal of some mathematical-statistical model to describe the possible associative effects between ingredients within the diets.

Expected results and achievements of the project are higher sheep farming profits which can be reached by producing high quality products such as sheep and goat typical cheeses, high quality lamb and kid carcasses. Better profits may contribute to keep rural populations in place, with all the consequential benefits.

We do believe that the results and information got with small ruminants may be applicable to large ruminants as well. A better knowledge of the actual nutritive value of Mediterranean fibrous poor feeds and the know-how to treat them and/or how to include them in complete balanced diets in order to upgrade their poor nutritive value, both in terms of energy and in terms of nitrogen content, must be considered a valuable means to increase farming incomes. We feel that there is a lack of technical information on how the nutritive value of poorly digestible fibrous agricultural residues can be improved simply by changing quantitatively and qualitatively feed ingredients in practical diets and how these changes can affect the quantity and quality of final productions. As a matter of fact, little is known on how to use poor fibrous feeds of Mediterranean origin in order to upgrade at the maximum level their nutritive value as feeds for the ruminant animals: feed tables available in the literature usually don't consider the important aspect of associative effects that can be dramatically important with poorly digestible fibrous roughage.

Material and methods

First and second trials (1994 and 1995)

In each of the first two trials, thirty-two 50 d old Apennine lambs, 16 males and 16 females, with initial average body weight 14.7 kg, standard deviation 2 kg, were kept in individual pens on a peat bedding and individually fed *ad libitum* 4 different complete diets, administered in the form of pellets, with 8 replicates (4 with male lambs and 4 with female lambs) per diet. The pelleted form was adopted not to allow the animals to select feeds and leave orts with a different composition from the offered rations.

The initial reference composition of the lambs' bodies was estimated by using the following regression equations, calculated by means of data from previous trials:

Dry matter (DM) (%) = 26.051 + 0.352 BW
Crude protein (CP) (%) = 84.718 - 1.989 BW
Gross energy (GE) (MJ kg^{-1} DM) = 18.5 + 0.487 BW

where BW is the empty body weight, devoid of the gastro-intestinal content.

All the 32 lambs in each experiment were slaughtered at the end of the 50 d period of growth and their whole bodies (blood, fleece, hooves included) minced and sub-sampled for the analysis of CP and GE contents. By difference with the estimated initial reference composition, the amounts of energy and nitrogen retained (RE and RN) by the lambs within their bodies were measured and scaled to metabolic liveweight, according to the directions of the comparative slaughter technique (Thomson and Cammell, 1979a,b, 1980). The ratios RE/RN were also considered as good indicators of the diet balance (Antongiovanni, 1994). During the growth period, individual DM intakes and BW gains were recorded. The apparent digestibilities of organic matter (DOM), of energy (DE) and nitrogen (DN) were also measured *in vivo* by using acid insoluble ash (AIA) as the internal marker (according to van Keulen and Young, 1977). The efficiency of metabolic utilization of nitrogen was estimated by means of the two parameters "protein efficiency ratio" (PER), i.e. the ratio of BW gains to CP intakes and "metabolic utilization of absorbed nitrogen" (MUN), i.e. the percent ratio of retained nitrogen to absorbed nitrogen. All data were submitted to the analysis of variance and to the Duncan's multiple-range test between means (Steel and Torrie, 1960). Male lambs were not analysed versus female lambs because, obviously, male lambs perform better and because aim of the trial was a test on diets.

Results from previous trials (Antongiovanni, 1993, 1994) indicated that the most suitable CP level to be adopted in pelleted complete diets, based on untreated wheat straw as the roughage, and fed to Apennine growing lambs is around 18% on the DM basis. This level was therefore adopted in the present experiments, with the aim of upgrading a poor fibrous feed like straw. The first experiment was meant to study 4 diets, based on wheat straw (40%) and including soya bean meal (SBM), meat meal (MM), sunflower cake (SFC) and coconut cake (CNC). The second experiment was designed as the continuation of the previous one carried out in 1995, for the same project, and dealt with brewers yeast (BY), fish meal (FM) and blood meal (BM), as the protein sources. Goal of the two trials was the comparison of 7 different protein feeds, when included within complete pelleted diets for growing lambs, to be evaluated in terms of efficiency of metabolic utilization of their energy and nitrogen contents. One of the tested diets (SBM) served as the reference diet to allow us to merge the results of the two experiments. In order to achieve this main goal, the same experimental protocol was adopted in the two experiments. For the ingredient composition and chemical composition of the diets of the first two experiments, see Table 1.

Table 1. Ingredient and chemical composition of tested diets in the first two experiments

	1994				1995			
	SBM	MM	SFC	CNC	SBM	BY	FM	BM
Ingredients (%)								
Wheat straw	40	40	40	40	40	40	40	40
Maize meal	25	27	18	–	25	23	21	34
Soya bean meal	30	15	15	15	30	15	15	15
Meat meal	–	13	–	–	–	–	–	–
Sunflower cake	–	–	22	–	–	–	–	–
Coconut cake	–	–	–	40	–	–	–	–
Brewers dried yeast	–	–	–	–	–	17	–	–
Fish meal	–	–	–	–	–	–	9	–
Blood meal	–	–	–	–	–	–	–	6
Minerals & vitamins	5	5	5	5	5	5	5	5
Nutrients (% DM)								
Dry matter	87.8	87.6	87.7	88.4	89.8	90.0	89.8	90.0
Crude protein	19.4	19.1	19.0	18.0	19.0	20.7	19.2	19.8
Ether extract	2.0	3.8	1.8	3.6	2.3	2.2	2.8	1.8
Crude fibre	16.1	16.1	20.3	19.4	13.0	14.4	16.6	13.6
Ash	9.6	10.7	8.9	9.9	12.5	11.5	11.3	10.4
NDF[†]	33.6	41.0	40.2	50.3	31.3	37.1	35.0	37.0
ADF[††]	21.3	23.4	26.7	31.0	16.5	19.9	20.4	19.4
ADL[†††]	3.4	4.4	5.3	5.4	2.5	2.8	2.6	2.9
AIA	2.0	2.2	1.8	2.1	2.0	2.2	2.5	1.8
Ca	1.6	2.0	1.7	1.5	2.5	2.0	2.0	1.6
P	0.7	1.0	0.8	0.7	0.7	0.7	0.8	0.6
GE (MJ kg^{-1} DM)	17.92	20.28	18.08	18.02	17.10	17.40	17.70	17.85

[†]NDF: neutral detergent fibre
[††]ADF: acid detergent fibre
[†††]ADL: acid detergent lignin

Third trial (1996)

In the third experiment, thirty-two 50 d old Apennine male lambs, with initial body weight 16.3 kg, standard deviation 2.3 kg, were kept in individual wooden pens on a peat bedding and individually fed *ad libitum* 16 different complete diets, administered in the form of pellets, with 2 replicates per diet.

The diets were designed to have 4 increasing levels of crude protein (13, 15.5, 18 and 20.5% on the DM basis) and 4 increasing levels of an industrial product based on blood meal enriched with methionine and lysine and protected with calcium soaps to by-pass the rumen. This protected protein feed was included in the diets so that it could replace increasing amounts of the crude protein of soya bean (0, 15, 30 and 45%). The ingredient composition of the 16 diets is showed in Table 2. It was compulsory to adopt such a small number of replicates per diet because, unlike the previous trials, this time the response surface model was employed to statistically analyse the results. When a continuous regression model is adopted, it is not important the number of replicates but the number of observations. But furthermore, the analysis of covariance on initial body weight was also carried out, considering both the crude protein level and the replacement level. In this case 8 replicates per level were available.

Table 2. Ingredient composition of diets (%) of the third experiment

Diet	Straw	Soya bean	Cereals†	MVS††	PR†††	PR (% CP)	CP (% DM)
1	40	17.4	37.6	5	–	0	13.0
2	40	24.3	30.7	5	–	0	15.5
3	40	31.3	23.7	5	–	0	18.0
4	40	38.2	16.8	5	–	0	20.5
5	40	13.4	37.3	5	4.3	15	13.0
6	40	19.6	30.3	5	5.1	15	15.5
7	40	25.7	23.3	5	5.9	15	18.0
8	40	31.9	16.3	5	6.8	15	20.5
9	40	9.4	37.0	5	8.6	30	13.0
10	40	14.8	30.0	5	10.2	30	15.5
11	40	20.2	22.9	5	11.9	30	18.0
12	40	25.6	15.9	5	13.5	30	20.5
13	40	5.4	36.7	5	12.9	45	13.0
14	40	10.1	29.6	5	15.3	45	15.5
15	40	14.7	22.5	5	17.8	45	18.0
16	40	19.3	15.4	5	20.3	45	20.5

†Maize plus barley 50:50
††MVS: mineral vitamin supplement ($CaCO_3$ 30%, $CaHPO_4$ 30%, NaCl 10%, trace elements 15%, vitamins A, D, E 15%)
†††PR: protected protein (soya bean meal 70%, blood meal 10%, methionine 1%, lysine 0.5%, fat 18.5%)

Table 3 shows the scheme of the analysis of covariance. The chemical composition of the diets is in Table 4.

Table 3. Scheme of the analysis of covariance (third experiment)

Replacement level (% of CP)	Crude protein level (%)			
	13.0	15.5	18.0	20.5
0	Diet 1	Diet 2	Diet 3	Diet 4
15	Diet 5	Diet 6	Diet 7	Diet 8
30	Diet 9	Diet 10	Diet 11	Diet 12
45	Diet 13	Diet 14	Diet 15	Diet 16

Table 4. Chemical composition of diets (% DM) of the third experiment

Diet	DM	CP	EE†	CF††	Ash	NDF	ADF	ADL	AIA
1	88.4	13.3	1.8	17.8	9.7	41.3	25.3	4.5	3.6
2	89.5	16.5	2.1	18.2	10.0	40.7	26.3	4.3	3.7
3	87.3	17.6	1.5	19.2	10.8	43.8	28.1	4.8	3.8
4	88.1	20.1	2.0	18.9	11.1	45.9	28.7	4.5	3.1
5	87.3	14.1	2.5	16.7	10.3	39.7	23.0	5.0	4.1
6	88.8	15.4	2.6	16.2	11.1	39.7	25.6	4.2	3.6
7	88.4	18.2	3.0	18.2	11.5	43.0	26.1	4.1	4.2
8	88.5	20.5	2.8	19.0	12.0	45.8	27.7	4.7	4.1
9	89.5	13.1	3.2	16.3	10.8	42.5	24.9	4.6	3.7
10	89.2	16.3	3.2	17.7	11.7	43.5	26.3	4.3	4.5
11	89.3	17.9	3.7	19.0	11.9	42.8	26.4	4.4	4.1
12	88.4	21.1	3.6	17.5	12.9	42.7	27.3	4.5	5.1
13	88.2	12.4	2.6	19.4	10.7	42.3	25.5	3.6	3.7
14	89.5	15.4	3.0	17.1	11.7	38.0	24.5	3.5	4.0
15	89.7	18.8	3.3	17.1	11.5	38.1	24.5	3.3	4.2
16	88.0	20.8	3.8	16.9	13.7	40.8	26.9	3.5	3.9

†EE: ether extract
††CF: crude fibre

The initial reference composition of the lambs' bodies was estimated by means of the following new regression equations, calculated with data from previous trials:

Equation	R^2	RSD
EBW (g) = -4,937.57 + 0.7889 BW + 71.0 SC	0.994	353.2
CaW (g) = -572.04 + 0.5000 BW	0.976	382.6
DM (g) = -7,410.21 + 0.247 BW + 71.79 SC + 4.744 WH	0.990	190.5
CP (g) = -3,005.9 +0.0842 BW + 6.938 SC	0.978	126.8
GE (kJ) = -129,718.5 + 8.2256 BW + 1,362.05 SC	0.980	6,875.5

where EBW is the empty body weight, devoid of the gastro-intestinal content; BW is the body weight at slaughter; SC is the shank circumference; CaW is the carcass weight and WH is the height at withers.

As usual, all the 32 lambs in experiment were slaughtered at the end of the 50 d period of the growth trial and their whole bodies (blood, fleece, hooves included) minced and sub-sampled for the analysis of crude protein (CP) and gross energy (GE) contents.

All data were submitted to the analysis of covariance on initial body weight and to the response surface analysis of Toyomizu *et al.* (1982, 1993) and Rousch *et al.* (1979), by a multiple regression procedure (SAS, 1988).

Results

First trial (1994)

The performance results from all the three trials are referred to the following items: (i) dry matter intakes (DMI); (ii) average daily empty body weight gains (BWG); (iii) digestibility of energy (DE);

(iv) digestibility of nitrogen (DN); (v) retained energy (RE); (vi) retained nitrogen (RN); (vii) protein efficiency ratio (PER); and (viii) metabolic utilization of absorbed nitrogen (MUN).

For the first trial, the results relative to the major performance traits are reported in Table 5. DMI were not different between diets. It means that the introduction of protein feeds different from soya bean into the diet had no influence on palatability and on the filling capacity. BWG were highest with diet SBM and lowest with diet SFC ($P < 0.01$). This means that the protein fractions of SBM were best utilized and those of SFC were worst utilized for growing purposes.

Table 5. Performances of lambs in the first two experiments

	Diets 1994				Diets 1995			
	SBM	MM	SFC	CNC	SBM	BY	FM	BM
DM intakes (g d^{-1})	1207	1186	1193	1159	1250	1374	1275	1236
BW gains (g d^{-1})	204^{A}	194^{a}	147^{Bb}	179	225	262	257	267
DE (%)	61.2	60.8	64.4^{a}	59.2^{b}	82.7	79.7	80.7	80.1
DN (%)	71.7^{Aa}	64.1^{B}	75.2^{A}	67.3^{Bb}	86.7	84.8	86.4	86.1
RE (kJ d^{-1} kg^{-1} $BW^{0.75}$)	274^{Aa}	270^{A}	200^{B}	234^{Bb}	285	320	308	317
RN (mg d^{-1} kg^{-1} $BW^{0.75}$)	616^{a}	600^{a}	494^{b}	584^{a}	574	607	647	676
PER	0.88^{a}	0.86^{a}	0.67^{b}	0.83^{a}	0.97	1.04	1.09	1.19
MUN (%)	21.3^{a}	23.7^{A}	16.2^{Bb}	22.7^{A}	27.7	28.2	32.6	34.1
RE/RN, actual	0.44	0.45	0.40	0.40	0.50	0.53	0.48	0.47
RE/RN, ideal	0.45	0.44	0.42	0.44	0.47	0.48	0.48	0.48

^{A,a,B,b}Means within columns with different lower case superscripts differ at the $P < 0.05$ level; those with different capital superscripts differ at the $P < 0.01$ level

In the same Table 5 the apparent *in vivo* digestibility coefficients of energy and nitrogen can be found as well. From digestibility data, the diet based on SFC resulted the most highly digested, especially if nitrogen is considered ($P < 0.01$ in comparison with MM and CNC; not different from SBM). It therefore resulted the best diet in terms of digestibility, but also the worst one in terms of metabolic utilization of its nutrients. In other words, it was metabolically badly balanced. The retained amounts of energy and nitrogen together with the two parameters PER and MUN, dealing with the efficiency of metabolic utilization of nitrogen, are reported. Again, the diet based on SBM was the most efficient in terms of retainable energy ($P < 0.01$), not different from the one based on MM and, again the SFC diet was the least efficient, this time not different from the diet based on CNC. RN and PER values resulted quite similar to RE ones: SBM was more efficient than SFC ($P < 0.05$) and MM and CNC were not different; SFC was the least efficient. The protein biological value MUN, that is the percent ratio of metabolically utilized nitrogen (retained nitrogen) to absorbed (digested) nitrogen, gives us clear indications of how efficiently absorbed dietary nitrogen was utilized in building up body proteins: absorbed protein from SBM, MM and CNC were statistically comparable, whereas the digested protein fraction from SFC was decisively less efficiently anabolized ($P < 0.01$ in comparison with MM and CNC; $P < 0.05$ in comparison with SBM).

If we look at the measured actual RE/RN figures of Table 5 and we compare them with what we consider ideal for the recorded BWG (Antongiovanni, 1994), we can see that both diet SFC and diet CNC could be improved by simply considering that energy is the limiting factor.

Second trial (1995)

DMI were very close with one another and all around 1300 g DM $head^{-1}$ d^{-1}. The introduction of other protein feeds to substitute for half of the soya bean had no influence on DMI, that is on palatability and/or filling capacity. The same finding was pointed out in our previous experiment with reference to MM, SFC and CNC. This time the observation is even more important, in our opinion, because untasty ingredients such as fish meal or blood meal were introduced into the formulation of diets.

BWG were all statistically not different. The diet SBM'95 allowed higher gains than the same diet SBM'94, even if with a statistically not significant difference, probably due to the lower fibre fractions level.

As far as the apparent *in vivo* digestibility coefficients of energy and nitrogen were concerned, the extent of digestion of the reference SBM diet was significantly much higher in 1995 than in 1994. This is probably due to the different composition of basal straw, with less fibre (13% vs. 16% CF; 28.5% vs. 34.2% NDF; 16.3% vs. 21.7% ADF). Since the "trial effect" is not considered, digestibility coefficients of the other three diets must be compared with those of SBM diet and they were not different.

Again, with the retentions of energy and nitrogen and the two metabolic parameters PER and MUN, no statistically significant difference between diets, that is between protein feeds, could be detected, even if some trend can be pointed out. All the three tested diets other than SBM appeared to allow slightly better performances than the reference SBM'95 diet. Particularly, the nitrogen fraction seemed to be better utilized: better PER and better MUN. But, it must be stressed again, this is only a trend. For sure, BY, FM and BM can adequately replace half of the SBM in straw-based diets, allowing at least comparable performances. The fibrous fraction of straw can supply the same extent of energy for the metabolic utilization of the nitrogenous fractions.

Finally, if we look at the figures which represent the actual measured RE/RN, in comparison with the figures of the second line, that we consider as the ideal for balanced diets and for the recorded BWG (Antongiovanni, 1994), we may observe that SBM 1994, the reference diet of the previous year was better balanced than that of the 1995 experiment, which is, according to our method, limited by nitrogen. If we compare the other three diets with each other, BY is also short of nitrogen, whereas FM and BM are adequately balanced between energy and nitrogen.

Third trial (1996)

Data referring to the first three performance traits are reported in Table 6, according to the analysis of covariance. The only thing to be observed in this table is that when CP was increased from 13% up to 15.5%, DMI increased as well from 967 g d^{-1} up to 1126 g d^{-1} ($P < 0.05$). The presence of the protected protein was of no use. On the contrary, if we look at Table 5, the 15% level of replacement with the protected protein was of some use in enhancing the amount of retained energy. No interaction between the level of crude protein and the degree of replacement could be detected. When we move to the two metabolic traits which deal with the utilization of nitrogen, PER and MUN, we realize that the level of dietary protein is very critical: the higher the protein, the poorer the metabolic utilization.[l] For PER only, the 0.02 level of statistical significance for the interaction between crude protein and protected protein was found.

Table 6. Performances of lambs in the third experiment

	Level of dietary crude protein (% DM)				Level of protected protein (% CP)				Interact
	13.0	15.5	18.0	20.5	0	15	30	45	
DMI	967^{A}	1126^{B}	1096^{B}	1091^{B}	1086	1148	992	1053	NS†
BWG	163	198	190	187	183	201	167	188	0.14
DE	61.6^{A}	60.5^{A}	63.9^{B}	66.8^{C}	59.3^{A}	63.5^{B}	63.8^{BC}	66.2^{D}	0.0001
DN	62.3^{A}	67.7^{B}	71.5^{C}	77.6^{D}	67.9^{A}	68.9^{A}	69.9^{AB}	72.3^{B}	0.009
RE	186	223	227	223	200^{A}	253^{B}	195^{A}	213^{AB}	NS
RN	435	510	512	507	531	542	385	507	NS
PER	1.28^{A}	1.11^{B}	0.96^{C}	0.83^{D}	1.01	1.04	1.01	1.11	0.02
MUN	34.0^{A}	26.2^{B}	22.7^{BC}	17.9^{C}	28.5	25.7	20.6	26.5	NS

†NS: non significant

A,B,C,DMeans within columns with different superscripts differ at the $P < 0.05$ level

The *in vivo* digestibilities of both energy and nitrogen, shown in Table 6, were markedly affected by either the crude protein of the diet or the replacing protected protein, with quite a strong significant interaction: the higher the crude protein or the protected protein, the better.

From the reading of Table 7 is then clear that neither the crude protein nor the protected protein in the diet had an influence on the body condition of lambs at slaughter.

Table 7. Chemical composition of the lambs' bodies (DM and CP as %, GE as kJ kg^{-1})

	Level of dietary crude protein (% DM)				Level of protected protein (% CP)				Interact
	13.0	15.5	18.0	20.5	0	15	30	45	
DM	33.1	34.8	34.9	34.7	34.0	35.6	33.5	34.5	NS†
CP	17.3	17.3	17.9	17.4	17.9	17.5	16.9	17.6	NS
GE	8725	9115	9163	9196	8751	9517	8885	9047	NS

†NS: non significant

The last part of the "results" deals with the response surface graphs illustrated in Figs 1 to 6. Figure 1 depicts the behaviour of DMI as a function of the crude protein level in the diet (CP, from 20.5% down to 13.0%) and the percentage of replacement of dietary CP with the protected protein (PR, from 0% up to 45%). DMI had a maximum around 18% CP, whatever the PR level, but changed linearly, even if not significantly, with increasing amounts of PR. Figure 2 depicts EBW gains, which behaved exactly like DMI. Figures 3 and 4 refer to *in vivo* digestibilities of energy and nitrogen. The surfaces are actually tilted planes sloping up towards the highest CP and the highest PR. Figure 5 shows the PER surface. PER was higher at the lowest CP and highest at the highest PR. Lastly, Fig. 6, which deals with MUN, had a behaviour similar to that of PER, but the effect of PR was not linear, with a depression in the middle.

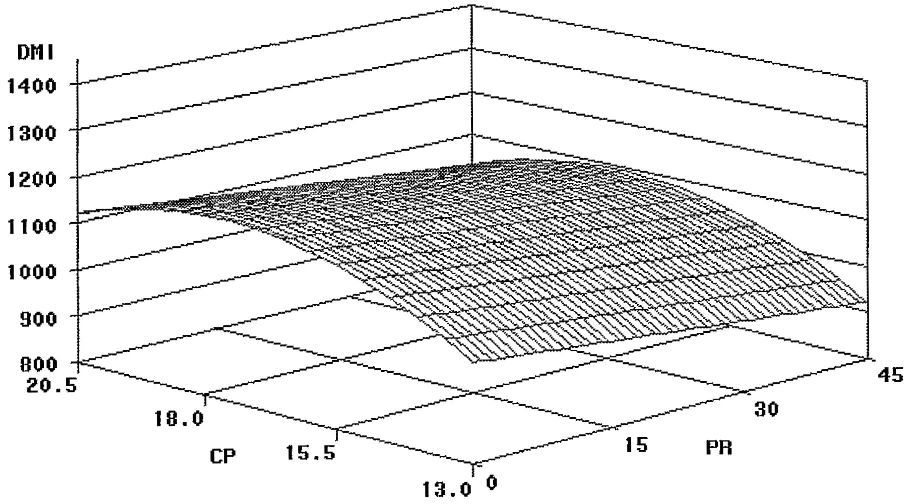

Fig. 1. Response surface of dry matter intake (DMI).

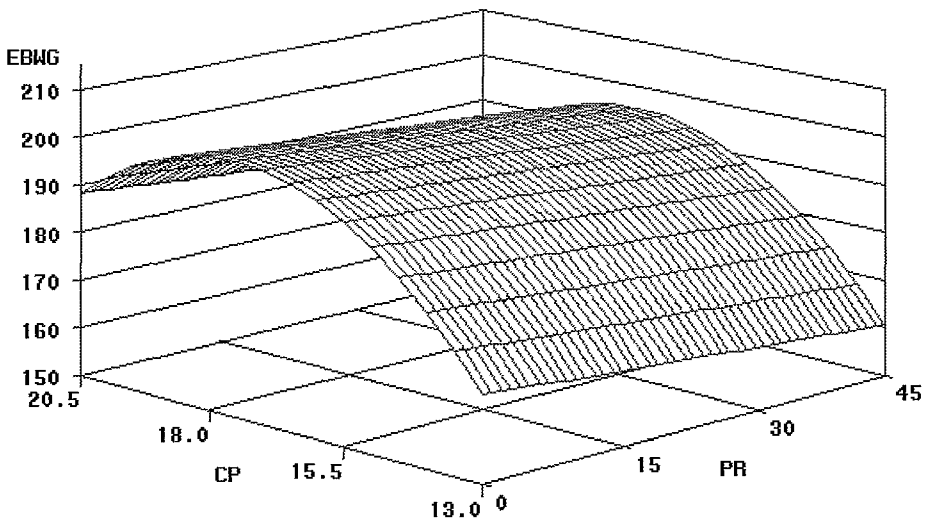

Fig. 2. Response surface of empty body weight gains (EBWG).

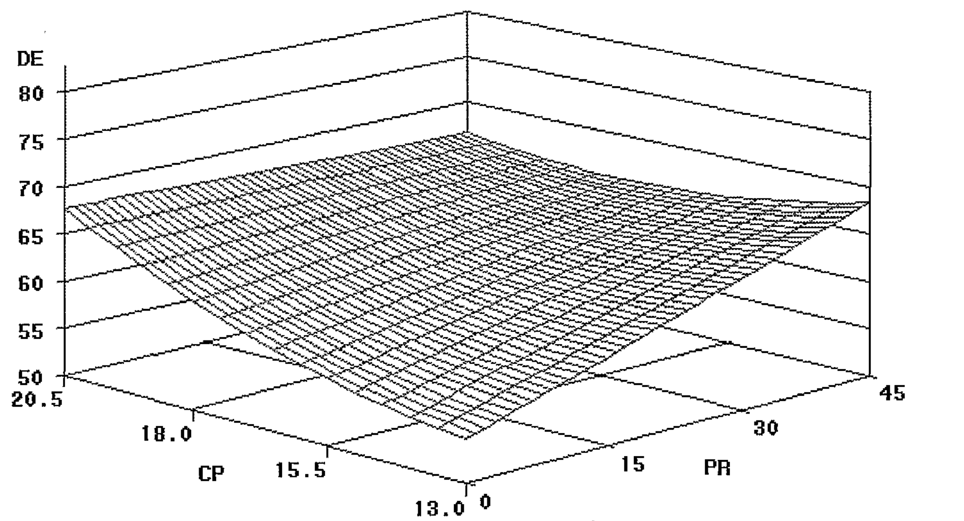

Fig. 3. Response surface of gross energy apparent *in vivo* digestibility (DE).

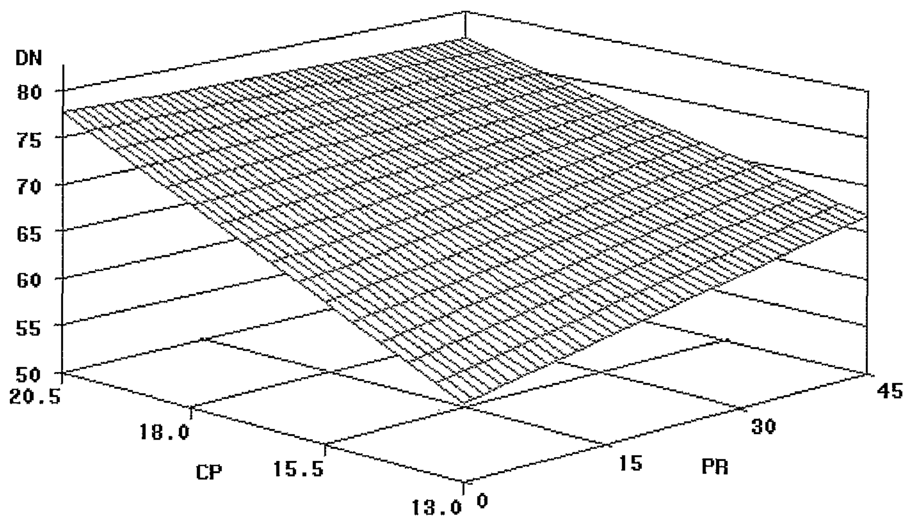

Fig. 4. Response surface of nitrogen apparent *in vivo* digestibility (DN).

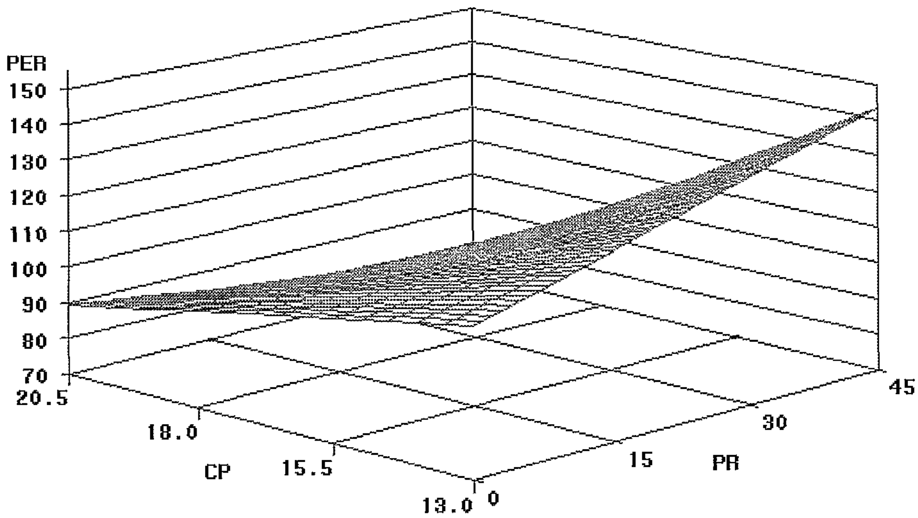

Fig. 5. Response surface of protein efficiency ratio (PER).

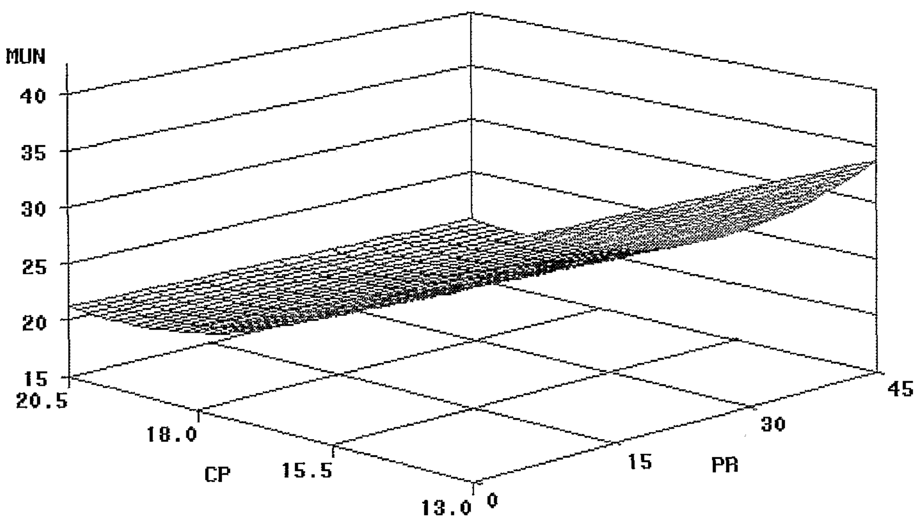

Fig. 6. Response surface of metabolic utilization of absorbed nitrogen (MUN).

Discussion

First trial (1994)

The discussion of results can be summarized in the following points:

(i) SBM resulted the best protein feed of the four tested, comparable with MM.

(ii) SFC was the worst protein feed as far as the measured performance traits were concerned (BW gains, feed conversions, retained amounts of energy and nitrogen).

(iii) SFC was the most digestible diet, but its high digestibility did not compensate for the poor performances of lambs.

(iv) Both SFC and CNC were short of energy as compared with nitrogen and, therefore, the diets could be improved.

(v) SFC could probably be improved also by adjusting the amino acid pattern.

Second trial (1995)

The discussion of achieved results can be summarized in the following points:

(i) SBM remained at the top of quality as a protein feed, comparable with BY, FM and BM.

(ii) It must be paid attention to the fibre fractions of the whole diet: the reference SBM diet of 1994 was richer in cell wall constituents than the one of 1995, that means that it was richer in slowly fermentable carbohydrates, and its energy was used more efficiently together with a slowly degradable protein like that of heated soya bean. In fact, RE figures are comparable (274 vs. 285 kJ d^{-1} kg^{-1} $BW^{0.75}$), but RN figures clearly demonstrate that the nitrogenous fraction of SBM 1994 was more efficiently retained (616 vs. 574 mg d^{-1} kg^{-1} $BW^{0.75}$).

(iii) The same can be said of diet BY, but not of diets FM and BM, which appeared more adequately balanced.

Third trial (1996)

If we look again at tables and figures, we can summarize our comments in the following points:

(i) DMI and BWG were influenced by the CP level of the diet, with a maximum around 15.5%, but were not by the degree of replacement with protected protein. This point will be commented together with the digestibility figures.

(ii) The higher the CP and the protected protein levels, the higher the digestibilities of both energy and nitrogen. It is well known that digestibility is one of the major factors which influence voluntary intake: if a diet is highly digestible, the flow rate through the rumen is fast and the animal eats more. But in the ruminant animals the apparent overall digestibility comprises the degradability that occurs in the rumen. And, if the nitrogen content of the diet is too much, the rumen pH may change and restrain the activity of microbes. This is the reason why, most probably, DMI increased along with CP up to a maximum and then decreased. BWG is a direct consequence of DMI. Protected protein appeared not to have any effect on DMI because it is protected and, therefore, undegradable.

(iii) The shape of the surfaces of PER and MUN clearly indicates that the efficiency of utilization of digested nitrogen at the metabolic level was proportionally affected by the amount of protected protein present in the diet.

In conclusion it was confirmed that if a poor fibrous roughage like wheat straw is to be utilized as the sole forage of a diet, it must be associated with a slowly degradable source of protein, best if a protected one. Furthermore, if the protein feed is very well protected (in our case it was protected with a thin layer of fat) it is not necessary to have high level of crude protein in the diet. On the contrary, the best results are achieved with low levels (in our case with 13%).

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