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The ability of faecal nitrogen to predict digestibility for goats and sheep fed with tropical herbage

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SUMMARY

Faecal indices were evaluated to assess organic matter digestibility (OMD) for small ruminants fed with *Digitaria decumbens*. A continuous digestibility trial was conducted with five Creole bucks and five Black-belly rams, fed with fresh cut *Digitaria decumbens* from 15 to 70 days of re-growth. The amount of herbage offered, the refusals and the faeces were weighed daily for each animal during 55 days. Herbage and faeces samples were kept to determine dry and organic matter (DM and OM), crude protein (CP), neutral and acid detergent fibre (NDF and ADF) and lignin contents (ADL). OMD was calculated per week and per animal. Predictive regressions of OMD were calculated for each species, from all the faecal components measured (CPf, NDFf, ADFf and ADLf), using linear or curvilinear models. Regressions from CPf had the lowest residual standard error ($<0{\cdot}028$) when calculated for each species, compared with regressions from the other faecal components. Among the regressions from CPf, the lowest standard error of the predictive parameters was obtained with a model in the form of a-b/CPf, for each species. The latter allows prediction of OMD at pasture, consistent with theoretical energy requirement for both goats and ewes grazing a *Digitaria decumbens* based sward.

INTRODUCTION

Grazing systems are prevalent in tropical areas. However, knowledge of nutrition at pasture of various ruminant species is too limited to suggest appropriate rules of grazing management. This is partly due to a lack of accurate and usable methods to study the intake and nutritive value of grazed herbage.

Methods based on the chemical composition of faeces are attractive because they allow the prediction for individual animals of diet quality at pasture (Corbett & Freer 1995). Faecal indices were tested to predict digestibility and intake for Creole cattle fed with a tropical stoloniferous grass *Dichanthium* spp. (Boval *et al*. 1996*a*). The faecal crude protein (CPf) content was the most accurate predictor of digestibility, using a model based on a biological relationship between digestibility and CPf content, of Lancaster (1949). That method permitted an estimation of individual values of digestible intake at pasture, that were consistent with the average daily gains measured simultaneously for tethered heifers grazing herbages varying in quality in different experiments (Boval *et al*. 1996*b*, 2000, 2002).

Previous studies of faecal crude protein as an indicator of digestibility have shown that single-sward regressions are more accurate than those embracing a great variety of herbage (Minson & Raymond 1958; Greenhalgh *et al*. 1960; Streeter 1969). Therefore to predict in small ruminants the digestibility of *Digitaria decumbens*, another stoloniferous grass, a new experiment was conducted to test digestibility prediction from CPf. The current paper describes the testing of this method for Creole bucks and Black-belly rams all fed with *Digitaria decumbens*. The relevance of the predictive regression established was evaluated for goats and ewes grazing a *Digitaria decumbens* pasture.

MATERIALS AND METHODS

Location

The experiment was carried out in Guadeloupe in the French West Indies (16°16′N, 61°30′W) at the experimental station of the National Institute for Agricultural Research (INRA). Temperatures ranged from 21 to 31 °C and the annual mean rainfall is 3000 mm.

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Experimental design, diets, animals and feeding

Five Creole bucks (3 years old and with a live weight (LW) of 41·71 ± 2 kg) and five Black-belly rams (2 years old and 46·14 ± 6 kg LW) were fed with *Digitaria decumbens* when confined in individual pens. The herbage was fertilized once, at the beginning of the re-growth, with 90 kg of nitrogen per hectare as ammonium nitrate (NH_4NO_3). The grass was cut daily at 06.00 h and chopped (5 cm length) before being offered twice daily (08.00 and 13.00 h) to the animals. The animals were adapted to be fed with this grass at 14 days of re-growth for 2 weeks. Afterwards, the re-growth stage of *Digitaria decumbens* varied continuously from 15 to 70 days for all the animals. The amount of forage provided was 1·15 times the animal's voluntary intake estimated during the period of adaptation. The animals were watered *ad libitum* and had continuous access to salt. They were weighed weekly.

Intake and digestibility measurements

Following a 14-day period of adaptation to the grass, the amount of herbage offered, the refusals and the faeces were weighed for each buck and ram every day (except Sunday) in a continuous digestibility trial lasting 8 weeks. Intake and faecal output per animal were calculated daily. Digestibility was calculated per week and per animal. Representative samples (300 g) of faeces and herbage offered and refused were kept daily. The samples were then pooled per week and per animal.

Chemical analytical methods

Dry matter contents of both herbage and faeces samples were determined by drying at constant weight at 60 °C in a forced-draught oven. The samples were then ground (0·75 mm) prior to chemical analysis. The OM content was measured after a 10 h pyrolysis at 550 °C. Dried herbage and faeces samples were used to determine the NDF, ADF and ADL contents following the method of Van Soest *et al.* (1991) and the nitrogen concentration was determined using the Kjeldahl method. The CP content was calculated by multiplying the nitrogen content by 6·25.

Statistical analyses

Statistical analyses were performed on data collected through 8 weeks for 5 bucks ($n=40$) and 5 rams ($n=40$). Data were subjected to analysis of variance using the General Linear Model procedure of SAS (1989).

The herbage data were analysed according to a model including the re-growth stage effect. Animal data collected for the bucks and the rams were analysed according to the following model:

$$Y_{ij} = \mu + W_i + I_j + e_{ij}$$

where μ is the mean, W_i is the week effect ($i=1$–8) within each species, I_j is the individual effect ($j=1$–5) within each species. Partial R^2 was calculated to quantify the variance explained for each effect, by dividing the sum of squares of the effects by the sum of squares of the corrected total.

Predictive models of OMD were calculated for each species from data collected per animal and per week ($n=40$). In a first step, the covariates considered were faecal components as CPf, NDFf, ADFf and ADLf contents, alone or combined. In a second step the faecal and herbage components (DMh, OMh, CPh, NDFh, ADFh and ADLh) were combined as covariates. Linear or curvilinear models (logarithmic, quadratic and hyperbolic models) were tested. Predictive models were calculated by the REG procedure using the MAXR (Maximum R^2 Improvement) method of SAS (1989). This procedure allows the comparison of each independent parameter with all others, until the best n-parameter model (n fixed by user) is obtained as that producing the highest R^2. The individual effect was tested on the predictive parameters following the model:

$$Y_i = a + bX + I_i + I_i \times b$$

where a is the intercept, b the slope, I_i the individual effect ($i=1$–5) and $I_i \times b$ the interaction between the individual effect and the slope. The models for which at least one predictive parameter was not significant were not presented.

Estimation of OMD and OM intake (OMI) for grazing goats and ewes, from the regression established

The relevance of the predictive regressions of OMD from faecal components, determined in metabolism cages, was evaluated with Creole goats and Black-belly ewes grazing a *Digitaria decumbens* sward.

Grazing trials were carried out on a *Digitaria decumbens* based sward with four dry goats (4 years old and 28 ± 2·1 kg LW) and four dry ewes (4 years old and 45 ± 2·4 kg LW). The goats and the ewes were tethered, and grazing simultaneously on the same sward, for two grazing cycles each of 28 days. Each grazing cycle comprised two 10-day adaptation periods each followed by a 4-day measurement period. Each female had a defined area to graze daily (representing around 3 kg of DM) and was moved every morning to a fresh area. Each area received an application of 80 kg/ha of a 27–9–18 N–P–K fertilizer and was cut individually 28 days before being grazed. Faecal OM output was measured by collecting, twice daily, all faeces excreted by each animal in individual bags, over the 4-day measurement period. The entire amount of faeces over the 4-day measurement period was weighed, mixed and homogenized. A subsample of 300 g was taken to determine chemical composition (DMf, OMf, CPf, NDFf and ADFf). Samples of herbage offered were also kept at each grazing cycle, to determine chemical composition (DMh, OMh, CPh, NDHh and ADHh). Each animal was weighed weekly.

OMD was estimated for goats and ewes from the chemical components of the faecal subsample taken for each grazing female, using the significant regressions established in metabolism cages. OMI was estimated from OMD estimated and faecal OM output measured for the grazing females, as: (faecal OM output/(1 − OMD)) and the energy supply expressed in UF (Unité Fourragère) according to the French Feed Unit Systems (Vermorel 1978). The energy supply (UFs) with the grass grazed was estimated per day using a predictive regression from OMD for tropical grass at different stages of re-growth (Aumont *et al*. 1995):

$$\mathrm{UFs} = (1{\cdot}55 \times \mathrm{OMD}) \times \mathrm{OMI}$$
$$(R^2 = 0{\cdot}98;\ \text{R.S.E.} = 0{\cdot}009)$$

UFs values were then compared with the energy required (UFr) for the goats and the ewes. UFr was estimated to be 0·396 and 0·56 UF/day, respectively for the goats and the ewes according to Jarrige (1988), taking into account their live-weight changes (respectively −2·8 and −1·8 kg per grazing cycle) and their grazing activity (energy required was increased by 20%).

RESULTS

Diet composition of the housed bucks and rams

The composition of the grass offered is reported in Table 1. The rising stage of re-growth affected mainly CPh and ADLh, for which greater coefficients of variation were measured. The mean decreases per day of re-growth for CPh and ADLh were respectively 4 and 0·8 g/kg OM.

OMD, intake and faecal components

The main source of OMD variation was the stage of re-growth of the herbage. OMD decreased by 0·0018 and 0·0021 per day of re-growth, respectively for the bucks and the rams (Table 2). For each species, OMD varied significantly between individuals, on average by 0·0038 and 0·0024, within the bucks and the rams.

OMI decreased significantly per day of re-growth, by 0·26 and 0·44 g OM/kg $\mathrm{LW}^{0{\cdot}75}$ respectively for the bucks and the rams. The individual effect was also significant for OMI. Re-growth stage and individual effects were significant for all the faecal components.

Table 1. *Chemical composition of* Digitaria decumbens *offered to Creole bucks and Black-belly rams*

	Mean	R.S.D.	Range	Re-growth stage effect (Pr > *F*)	R^2
DMh (g/kg)	248	1·0	205–280	**	0·98
OMh (g/kg DM)	912	3·8	902–924	**	0·83
CPh (g/kg OM)	77	1·6	63–96	**	0·98
NDFh (g/kg OM)	864	5·6	846–884	**	0·84
ADFh (g/kg OM)	457	4·5	445–483	**	0·87
ADLh (g/kg OM)	62	6·2	51–71	**	0·58

R.S.D.: residual standard deviation.
Significance: ** $P < 0{\cdot}01$.

OMD prediction from faecal components

Among the faecal parameters tested, CPf alone predicted OMD with a residual standard deviation (R.S.D.), lower than 0·03, for both animal species (Table 3). Predictive models of OMD from NDFf or ADFf were not significant. Among the predictive models from CPf, greater R^2 and lower R.S.D. were reached with the hyperbolic model than with the linear model, for both the bucks and the rams (model 1, Table 3). Other models with CPf in quadratic equations had non-significant predictive parameters and were not presented. Adding a herbage characteristic as CPh to CPf (models 3 and 4), improved the OMD prediction for the bucks and the rams, with R.S.D. below 0·025. Individual effects were not significant for any predictive parameters of the different models.

Estimation of OMD, OMI and energy supply for grazing goats and ewes, from the regression established

For the grazing goats, OMD values predicted with the models 1 and 3 (OMD1 and OMD3) were similar, 0·71 on average (Table 4). Compared with the latter estimations, OMD2 was greater by 0·04, and OMD4 was lower by about 0·03. OMI and UFs estimations with the four models varied in the same way as OMD estimations. UFs1 was the closest to UFr, whereas UFs2 was largely higher than UFr.

For the ewes, OMD1, OMD2 and OMD4 were close, about 0·70 on average, whereas OMD3 was lower by 0·02. OMI and UFs estimations were all similar, about 541 g OM per day and 0·586 on average. UFs1 and UFs3 were the closest to UFr.

DISCUSSION

Nutritive value of Digitaria decumbens

The chemical components contents are in accordance with those previously cited by Minson (1984),

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Table 2. *Organic matter digestibility (OMD) and intake (OMI), and chemical composition of faeces for Creole bucks and Black-belly rams fed with* Digitaria decumbens

	Mean	R.S.D.	Range	Re-growth stage effect Pr > F	Re-growth stage effect p.R^2	Individual effect Pr > F	Individual effect p.R^2
Creole bucks							
OMD	0·65	0·22	0·61–0·71	**	0·41	**	0·46
OMI (g OM/kg $LW^{0·75}$)	44	3·4	36–51	**	0·28	**	0·63
CPf (g/kg OM)	119	9·5	92–154	**	0·71	**	0·17
NDFf (g/kg OM)	849	18·5	819–884	**	0·48	**	0·22
ADFf (g/kg OM)	475	12·4	449–518	**	0·72	**	0·13
ADLf (g/kg OM)	207	11·0	180–265	**	0·84	*	0·08
Black-belly rams							
OMD	0·63	0·18	0·59–0·71	**	0·73	**	0·20
OMI (g OM/kg $LW^{0·75}$)	54	3·4	43–67	**	0·70	**	0·22
CPf (g/kg OM)	117	4·4	98–160	**	0·96	NS	
NDFf (g/kg OM)	833	18·6	801–910	**	0·63	**	0·17
ADFf (g/kg OM)	491	19·1	442–569	**	0·69	**	0·11
ADLf (g/kg OM)	213	14·1	178–275	**	0·89	NS	

R.S.D.: residual standard deviation.
p.R^2: partial R^2 = sum of square of the effects/sum of square of the corrected total.
Significance: * $P<0·05$; ** $P<0·01$; NS: non-significant.

Table 3. *Predictive regressions of OM digestibility from faecal crude protein content, calculated for Creole bucks and Black-belly rams all fed with* Digitaria decumbens

Predictive models	R.S.D.	R^2
Creole bucks (D.F. = 39)		
1. $0·816_{(\pm 0·065)} - 19·864_{(\pm 6·987)}/\text{CPf}$	0·0265	0·79
2. $0·475_{(\pm 0·061)} + 0·143_{(\pm 0·054)}\ \text{CPf}$	0·0269	0·79
3. $0·672_{(\pm 0·225)} - 13·477_{(\pm 12·765)}/\text{CPf} + 0·119_{(\pm 0·151)}\ \text{CPh}$	0·0243	0·86
4. $0·429_{(\pm 0·055)} + 0·103_{(\pm 0·086)}\ \text{CPf} + 0·124_{(\pm 0·131)}\ \text{CPh}$	0·0225	0·88
Black-belly rams (D.F. = 39)		
1. $0·866_{(\pm 0·073)} - 26·623_{(\pm 8·371)}/\text{CPf}$	0·0295	0·74
2. $0·441_{(\pm 0·072)} + 0·164_{(\pm 0·059)}\ \text{CPf}$	0·033	0·68
3. $0·532_{(\pm 0·185)} - 11·140_{(\pm 10·740)}/\text{CPf} + 0·258_{(\pm 0·132)}\ \text{CPh}$	0·0235	0·87
4. $0·341_{(\pm 0·065)} + 0·063_{(\pm 0·060)}\ \text{CPf} + 0·282_{(\pm 0·116)}\ \text{CPh}$	0·0235	0·87

R.S.D.: residual standard deviation.

Aumont *et al.* (1995) and Archimède *et al.* (2000) for *Digitaria decumbens*. The fibre contents are high compared with those of temperate grass and hardly vary with the re-growth stage. Conversely, the CPh content is lower than 80 g/kg OM and decreases sharply with the stage of re-growth of the grass.

The OMD and OMI values measured for the housed Creole bucks are close to reports by Chenost (1975), respectively about 0·656 and 42·8 g OM/kg $LW^{0·75}$ on average for *Digitaria decumbens*, from 28 to 77 days of re-growth. Our rams' OMD and OMI values were close to estimations reported by Minson (1984, 1990) and Archimède *et al.* (2000), concerning sheep fed indoors with *Digitaria decumbens*.

OM digestibility prediction from CPf content

The faecal crude protein content is the best indicator of digestibility for the two ruminant species. The precision of prediction ranged from 0·027 to 0·033 and may permit an acceptable error less than 10% for OM intake estimation. The hyperbolic and linear models had similar R.S.D., and the two models could allow similar estimations of OMD at pasture.

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Table 4. *OMD and energy supplied* (*UFs*) *estimated for grazing Creole goats and Black-belly ewes on a* Digitaria decumbens *sward, from regressions established for Creole bucks and Black-belly rams fed with chopped* Digitaria decumbens *in metabolism cages*

	Goats ($n=16$)	Ewes ($n=16$)
Measured variables at pasture (mean ± S.D.)		
Faecal output (kg OM/day)	0·11 ± 0·035	0·163 ± 0·044
CPf (g/kg OM)	142·53 ± 15·06	127·11 ± 8·01
Average LW (kg)	28·23 ± 2·1	44·77 ± 2·4
LW loss/28 day (kg)	−2·59 ± 0·45	−1·76 ± 0·60
Estimations from regressions in Table 3		
OMD1	0·705[b]	0·697[b]
OMD2	0·750[a]	0·699[b]
OMD3	0·717[b]	0·679[a]
OMD4	0·677[c]	0·713[ab]
OMI1 (kg OM/day)	0·368[b]	0·536[a]
OMI2 (kg OM/day)	0·433[a]	0·541[a]
OMI3 (kg OM/day)	0·386[ab]	0·510[a]
OMI4 (kg OM/day)	0·335[c]	0·577[a]
UFs1 (/day)	0·401[b]	0·578[a]
UFs2 (/day)	0·502[a]	0·586[a]
UFs3 (/day)	0·429[b]	0·538[a]
UFs4 (/day)	0·349[c]	0·643[a]
Theoretic UFr (/day)	0·396	0·550

OMD1 to OMD4 for the goats and the ewes were calculated from regressions presented in Table 3.
OMI1–4 = (faecal output)/1 − (OMD1–4).
UFs: estimation of energy supply from the grass consumed at pasture by the goats and the ewes, from OMD predicted with regressions reported in Table 3.
UFr: estimation of energy required according to Jarrige (1978).
Values with different superscripts within columns for goats or ewes are significantly different ($P<0·05$).

However, this was not the case when we used these two regressions to estimate OMD for grazing goats. The linear model predicts a greater OMD by 0·045, than the hyperbolic one, inducing a greater estimation of energy supply, by 0·10 UF. According to the theoretical energy requirement of the grazing goats, the hyperbolic model allows more reliable estimation than the linear one, as the linear model overestimates. It may be due to the greater CPf range of the grazing goats, than of the CPf range of the housed bucks. So, the linear model seems convenient for reliable prediction inside a CPf range close to the one in which it was established. In return the hyperbolic model appears as usable outside its range of establishment. Thus, as illustrated in Fig. 1 for the Creole bucks, for CPf up to 140 g/kg OM, the linear model has a tendency to predict higher OMD than the hyperbolic model (Fig. 1). For the sheep the CPf ranges at pasture and in cages were similar, which explains why linear and hyperbolic models predict similar values for OMD and energy supply. The relevance of the hyperbolic model for prediction at pasture has already been put forward for Creole cattle (Boval *et al.* 1996*a*). A hyperbolic model predicting OMD from CPf for housed steers was more precise than linear or quadratic models. Moreover it was more reliable when used at pasture to predict OMD and OMI from CPf and faecal output for heifers grazing the same grass.

There are fewer published hyperbolic models (Lancaster 1949; Wehausen 1995) than linear or quadratic models predicting OMD from CPf (Langlands *et al.* 1963; Greenhalgh *et al.* 1966; Streeter 1969; Thomas & Campling 1976; Barthiaux-Thill & Oger 1986). However, the hyperbolic model may be based on a biological relationship between digestibility and metabolic faecal protein (MFP), as first proposed by Lancaster (1949). MFP is one of the main faecal fractions, consisting of digestive cells, digestive secretions and system microbes, and it has been shown that a constant amount of MFP is excreted per 100 g of OMI (Jarrige 1965; Mason 1969). This is not the case for undigested feed protein (UF), the other main faecal fraction, composed of dietary cell wall constituents, which may vary for a same amount of OMI, depending on the nature of the diet.

The constant relationship between the amount of MFP and OMI may be presented as follows:

$$MFP/OMI = b \quad (1)$$

Or as follows:

$$[MFP] \times FO/OMI = b \quad (2)$$

where MFP is expressed as a content and FO is the amount of faeces.

Looking at it another way, knowing that:

$$FO = (1 - OMD) \times OMI \quad (3)$$

It can be deduced from the expressions 2 and 3 that:

$$[MFP] \times (1 - OMD) = b \quad (4)$$

and

$$OMD = 1 - b/[MFP] \quad (5)$$

MFP content is proportional to faecal CP content, being both contents of faeces not more submitted to any digestive process. Thus expression 5 is equivalent to the following: $OMD = 1 - b/CPf$, as developed in the current paper, where CPf is the faecal CP content and b may reflect the amount of MFP for 100 g of OMI, or per kg of OMI, as expressed in Table 3. The hypothesis of Lancaster (1949) seems indeed to be

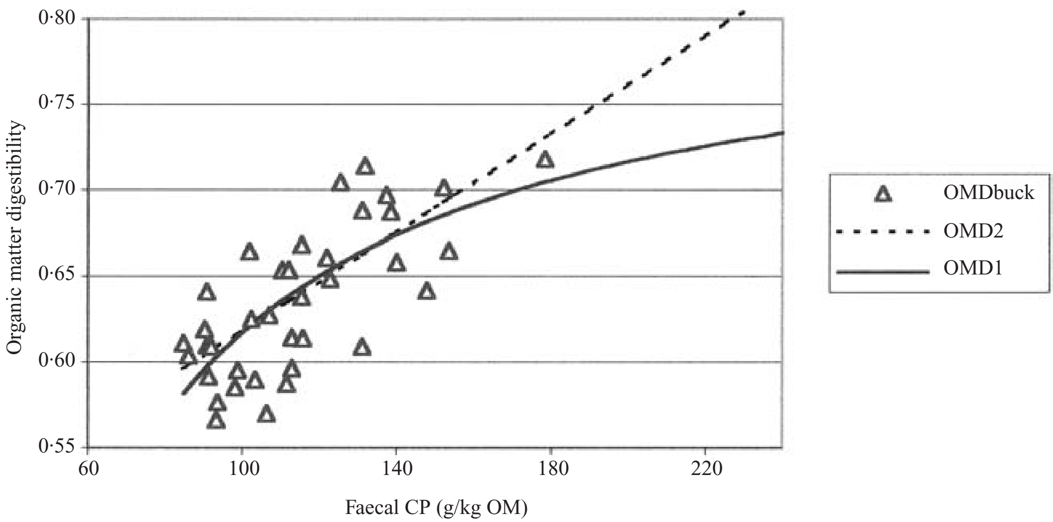

Fig. 1. Relationships between organic matter digestibility measured (OMD) or predicted with hyperbolic (OMD1) or linear (OMD2) models, and faecal crude protein content (CPf) for Creole bucks fed with *Digitaria decumbens*. OMD1 = 0·8161 − 1·9864/CPf; OMD2 = 0·4748 + 0·0143 CPf.

plausible for the current programme for the bucks and the rams. For goats, MFP values of 13·75 and 25·63 g/kg DM intake were cited by Devendra (1982) and Majumdar (1960). Based on these references, calculation of MFP per kg of OMI for our Creole bucks (calculated from Table 2) gives 15 and 28 g per kg of OMI. The *b* value of the hyperbolic model predicting OMD from CPf for Creole bucks ranges between the latter two estimates. For sheep, considering that MFP excreted is about 50·7 or 54% of total faecal CP, according to Bruchem *et al.* (1997) and Krawielitzki *et al.* (1999), and that the Black-belly rams excreted 43 g per kg of OMI (calculated from Table 2), an estimation of MFP gives 22 or 23 g per kg of OMI. These values are again close to the *b* values of the hyperbolic model predicting OMD from CPf for Black-belly rams (Table 3). However, further investigation is needed to estimate MFP in tropical conditions, and to check if MFP is a constant ratio to OMI for a given grass, for goats and sheep. If this hypothesis is verified, predicting OMD may be feasible directly from MFP estimation in the future, saving expensive digestibility trials.

Adding a herbage characteristic such as CPh to predictive regressions of OMD, decreases the R.S.D., and this may permit more reliable estimation of OMD at pasture. However, such models are not necessarily convenient for prediction at pasture. Indeed, the composition of the diet selected at pasture may be very different from that of the pasture on offer (Arnold 1981), in contrast to housing situations. Thus, for example, model 4 predicts values for OMD and UFs for grazing goats that are too low when compared with their theoretical requirements. The CPh of the whole herbage proposed at pasture was used and it is probable that the CPh of the herbage really consumed is higher. As a consequence, it would be necessary to study which appropriate characteristics, common to *in situ* living grass available at pasture and to chopped grass distributed in metabolism cages, could really improve OMD prediction at pasture. However, the gain in prediction should be meaningful, because the lower the number of predictors, the better it is for the cost of estimation in grazing trials.

Previous studies reported common equations for sheep and for cattle predicting OMD from CPf (Langlands *et al.* 1963; Thomas & Campling 1976). The predictive parameters of regressions established in the current programme for the rams show similarity with those for the bucks. It may be possible that under similar conditions of feeding, sheep could be used to derive a faecal CP prediction equation for use for another ruminant species. This would be of great interest for grazing studies, allowing a greater applicability of a regression established for one ruminant species to other ruminant species fed in similar conditions.

CONCLUSIONS

The current programme has shown that CPf is a reliable index to predict OMD in tropical conditions. A predictive model in the shape of a-b/CPf proposed first in 1949 is of great interest, because it allows reliable estimation for grazing animals, even if the CPf range at pasture is greater than the range used to establish it. Further digestibility trials measuring simultaneously MFP values, OMD and CPf would be relevant to assess the connection between MFP and the slope of hyperbolic regressions between OMD and CPf. Moreover it would be helpful to estimate the evolution of the parameters of a hyperbolic relationship between OMD and CPf, first for different ruminant species fed with the same grass and second, for different grasses.

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