Forage intake and secondary production in extensive livestock systems in páramo

A. M. Schmidt and P. A. Verweij

International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands

Abstract. Three different estimates are presented of average dry matter intake, in terms of quality and quantity, by adult cows grazing in the bunchgrass páramo of Parque Nacional Natural Los Nevados, Colombia. Plant and animal variables were measured and used in different equations to determine total forage intake. Total dry matter intake per cow, with a live weight of 417 kg, is estimated at 13.8, 10.1 (± 1.8), and 11.4 kg per day for methods based on grazing behavior, fecal excretion, and maintenance and production requirements, respectively. The latter two figures are considered most reliable. For an average adult cow a productivity index of 35 kg per 100 kg of body weight per year is derived, which is low compared to other extensive grazing systems. Based on field observations of grazing behavior, the botanical composition of cattle diet was determined. Average forage digestibility and crude protein content are 52% and 7.5%, respectively. Differences in forage quality of the consumed plant groups correspond with the Ivlev's electivity index as a quantitative measure of forage selection. Short grasses, forbs, and ground-covering species are preferred to bunchgrasses.

Resumen. Se presentan tres estimaciones de ingestión promedio de materia seca, en términos de calidad y cantidad, por vacas que pastan en el páramo de pajonal del Parque Nacional Natural Los Nevados, Colombia, obtenidas a través de diferentes métodos. Se midieron variables de planta y de animal, utilizándose estos datos en diferentes ecuaciones para llegar a una aproximación de la ingestión total de forraje. La ingestión total de materia seca por vaca con un peso vivo de 417 kg se estima en 13.8, 10.1 (± 1.8) y 11.4 kg por día, con métodos basados en los hábitos de pastoreo, la excreción fecal y los requerimientos de mantenimiento y producción, respectivamente. Las dos últimas cifras son consideradas las más confiables. Para una vaca adulta de peso promedio se derivó un índice de productividad de 35 kg por 100 kg de peso corporal por año, lo cual es bajo para un sistema de pastoreo extensivo. La composición botánica de la dieta del ganado se determinó con base en las observaciones de campo de los hábitos de pastoreo. La digestibilidad promedio y el contenido promedio de proteina cruda del forraje son 52% y 7.5%, respectivamente. Las diferencias de calidad del forraje de los grupos de

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plantas consumidas corresponden con el Indice electivo de Ivlev como una medida cuantitativa de selección de forraje. El ganado muestra preferencia por los pastos cortos, hierbas y especies cubridoras del suelo en comparación con los pastos de macolla.

Introduction

An extensive cattle grazing system was studied, within the framework of a research project, concerned with monitoring and modelling of human impacts on vegetation dynamics in the páramo of Parque Nacional Natural Los Nevados (Pels and Verweij, 1992; Verweij and Budde, 1992; Verweij and Kok, 1992). Our general objective was to determine, for a páramo ecosystem, the forage consumption and production of cattle, and to relate their grazing behavior and spatial distribution to effects on vegetation and microrelief. This contribution concentrates on estimates of cattle feed intake, in terms of quantity and diet composition, and an estimate of secondary production.

In many Andean páramo ecosystems, grazing by domestic animals, such as cows, mules, horses, and sheep, plays an important role in determining vegetation structure and composition. Few estimates of consumption and secondary production by cattle at high elevations are known from the literature. In Colombia, extensive livestock production systems have been studied predominantly in lowland areas and lower mountain belts up to elevations of about 3200 m (Díaz, 1985; Koeslag, 1985). At these altitudes cultivation of improved grass species is possible, whereas in the extreme climatic conditions of the páramo, this is not feasible according to farmers' experiments in the study area. The diet of grazing animals in the páramos consists of a selection of species from the (semi-)natural vegetation. An important component of this vegetation is made up of perennial bunchgrasses which are a major ingredient of the feed of ruminants. The bunchgrasses, mostly of the genera *Calamagrostis* and *Festuca*, are known to be low in nitrogen content (Verweij and Beekman, in press). In view of the fundamental differences in forage quality, ultimate care has to be taken when extrapolating data from lower and more intensively managed grazing systems to the traditional livestock system of the páramo.

In the heterogeneous páramo bunchgrass vegetation, the composition of animal diet, as influenced by selection, is an important parameter in the estimation of the amount of forage consumed (Mannetje, 1974). The ratio between energy (considered to be equal to digestible dry matter) and protein content of the feed determines to what extent the intake requirements can be fulfilled (Breman and De Ridder, in press). In this study, digestibility and crude protein or nitrogen content are used to evaluate quality of cattle diet in relation to total intake. Differences in forage quality of plant species are related to animal preference (Van Dyne *et al.*, 1980). Besides forage quality, selection is conditioned by the spatial distribution and relative abundance of the preferred fraction of the forage (Arnold and Dudzinski, 1978).

Materials and methods

The study area is located in the Parque Nacional Natural Los Nevados in the central cordillera of Colombia (4°35–60'N, 75°10'W). The altitudinal range is 3900–4100 m. Mean average temperature is about 7.5°C and mean annual precipitation is approximately 1300 mm, with a bimodal distribution. The characteristics of the ecosystem and an initial grazing gradient are described by Verweij and Budde (1992). Cattle roam freely over extensive areas controlled by each farmer. The cattle are cross breeds between Normando and Red Poll. As Normando bulls are always crossed with the mixed breed, the breed possesses mainly Normando characteristics, thus facilitating comparison with those in the literature. Burning of the bunchgrass vegetation is practiced at intervals of several years in order to stimulate growth of young grass shoots of higher forage quality.

Total forage intake was estimated according to three different methods: 1) field observations on bite counts per time unit, 2) measurement of the daily fecal excretion, and 3) indirect estimations based on requirements for growth, milk production, and reproduction.

A representation of the different ways for arriving at an assessment of intake is shown by the grazing model in Figure 1.

Grazing behavior. Free-ranging animals were observed in order to note their grazing and resting rhythm and the relative abundance of different plant species composing their diet. The grazing behavior of six cows was followed during an average observation period of eight hours. Bite counts per unit of time were made and bite sizes estimated. With intervals of 15 minutes, the number of bites of one cow was recorded during five minutes. Additionally, it was registered to which of the following plant groups the bites corresponded: bunchgrasses, short grasses, or ground-covering species, mainly *Lachemilla orbiculata*. In order to enable a quantitative comparison of intake of different cows, they were observed in areas with similar forage of mainly bunch- and short grasses (floristic type C, Verweij and Budde, 1992). Bite sizes were simulated by two observers harvesting the amounts approximately consumed of each plant group in one bite. These artificial bites were harvested at bite depth (Ungar and Noy-Meir, 1988), with a cylindric shape for bunchgrasses and an elliptic shape for short grasses. The bite frequency of each animal was calculated over the entire active grazing period observed. The number of bites was then extrapolated to 24 hours using this frequency. The total dry matter intake was assessed by multiplying bite size with bite frequency and grazing time (Forbes, 1986).

Selection and forage quality. By interviewing local farmers, additional information was collected about cattle preference for certain plant species. For the most abundant species in the cattle's diet, digestibility was analyzed using the modified Van Soest method (Van Soest, 1982) of *in vitro* organic matter digestibility. This method simulates animal digestion, using rumen fluid. Of the same plant samples, crude protein content was determined according to the Weende analysis based on nitrogen content. Nitrogen content was determined using a Carlo Erba 1106-Elemental Analyzer.

A quantitative measure of food selection is Ivlev's electivity index (Ivlev, 1961; Jacobs, 1974), defined as the relative difference between the fraction of a given forage type in the animal diet (r) and the fraction of the same forage in the vegetation (p). A differentiation into five plant groups was made as follows: green tussock leaves, dead tussock leaves, short grasses, ground-covering species together with forbs, and shrubs. At this level of detail, the groups could clearly be distinguished during field observations of grazing behavior. Biomass data of 39 plots of one square meter were used to assess the contribution of the different plant groups to the to-

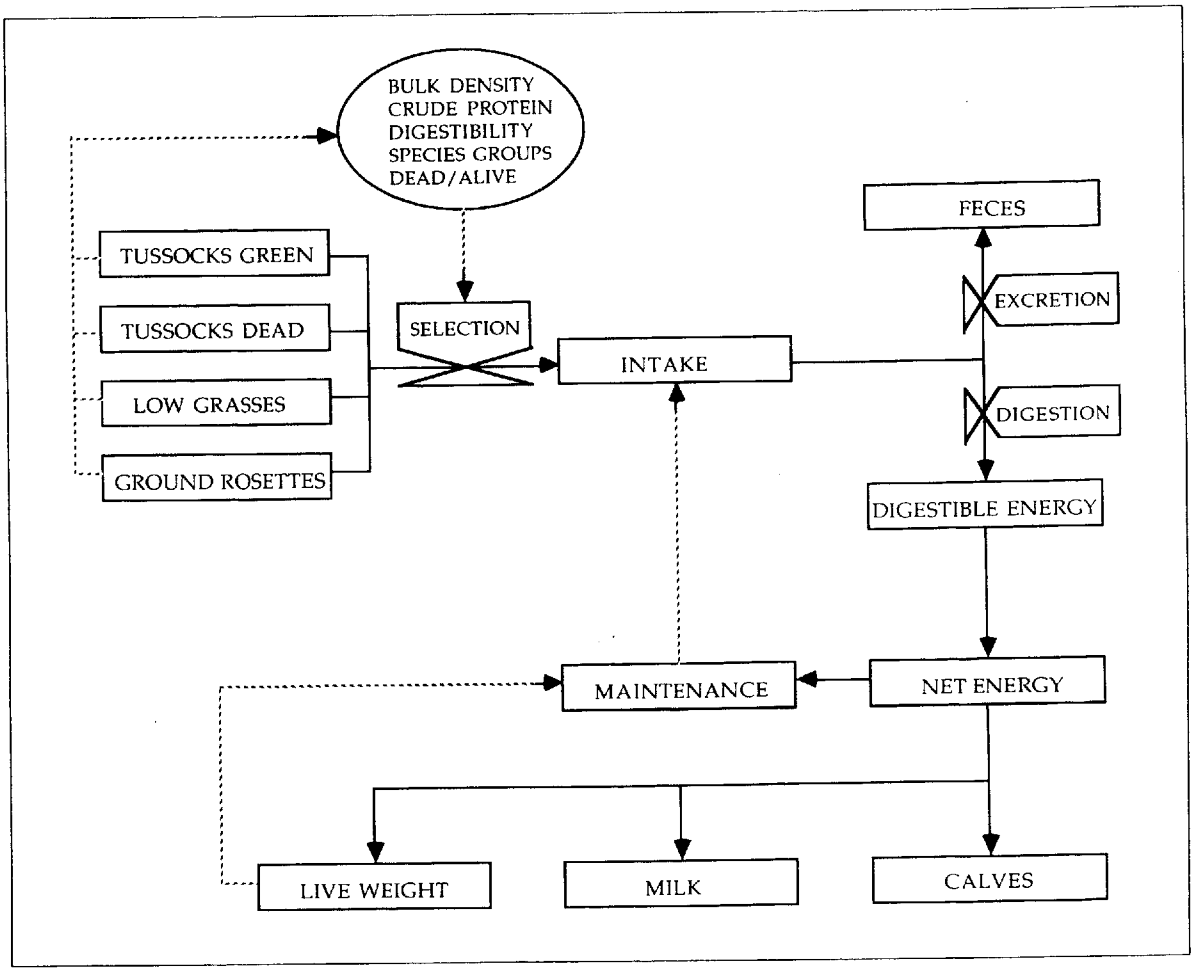

Figure 1. Model of the grazing system, showing the factors determining cattle intake. Derived from Mannetje and Ebersohn (1980).

tal aboveground phytomass, excluding litter and dead leaf bases. The Ivlev's electivity index E, where $E = (r-p)/(r+p)$, determined for each of the five plant groups, varies from −1 to 0 for negative selection and from 0 to +1 for positive selection. It was determined whether selection corresponds to differences in forage quality among the groups.

Fecal excretion. Four adult cows were kept in an enclosure during 7, 14, 24, and 24 hours, respectively. Feces produced within each time interval were collected and weighed. An equation used in calculating forage intake, based on dry matter digestibility of the forage and fecal excretion, is given by Van Dyne *et al.* (1980) as:

$$F = 100 \times E/(100 - D) \quad (1)$$

where D = digestibility of dry matter (%); E = fecal excretion, dry weight (kg/day); F = forage intake, dry weight (kg/day).

Nutritional requirements. A third method for estimating intake is the summation of requirements for maintenance and secondary production of cattle; maintenance is a function of body weight. As derived from Barrett and Larkin (1974), maintenance requirements correspond to 33 g digestible dry matter and 0.46 g nitrogen per unit of metabolic (body) weight, which is equal to body weight to the power 0.75.

Live weight gain was estimated for different age classes by measuring body weight changes of 50 cows within a time interval of four months. Heart girth was used to assess live weight (Vos and Vos, 1967). These measurements were calibrated experimentally by establishing the relationship between heart girth and body weight on a modern farm where a balance for weighing of cows was available. In this way an average live weight gain per day was determined. The equation expressing dry matter intake for growth, as a function of live weight gain, is given by Breman and De Ridder (in press). Energy content of the feed is assumed to be the limiting factor for growth. Dry matter intake used for growth is then:

$$DMIg = LWG \times 12.1/(D \times 18.4 \times 0.49) \quad (2)$$

where DMIg = dry matter intake used for growth (kg); LWG = live weight gain (kg/d); 12.1 = energy content of 1 kg live weight gain (MJ) for an average adult cow (Balch *et al.*, 1980); 18.4 = energy content of dry matter (MJ/kg) (Barret and Larkin, 1974); 0.49 = transformation efficiency to net energy (Barrret and Larkin, 1974).

Live weight gain was measured under different management conditions and compared with the general conditions in Colombia (Geoffray, 1981), which are considered to be more favorable. The management conditions differ in terms of forage quality, reproduction system, and environmental stress. As discussed above, forage of cattle in the páramo exists by a selection of the natural vegetation. At Finca Normandía (3600 m) adjacent to Parque Nacional Los Nevados, improved grass species, such as *Anthoxantum odoratum, Dactylis glomerata, Lolium perenne,* and *Phalaris* sp., are cultivated. In addition, concentrates are used as supplementary feed. Another important difference is that artificial insemination is used at Finca Normandía to control reproduction. At the higher elevation of the páramo (4000 m), however, environmental stress is more severe than at Finca Normandía. Besides maintenance and growth, milk production, and reproduction require extra nutrients.

According to Barret and Larkin (1974), energy and nitrogen requirements per kg milk of 4% fat are 332 g digestible dry matter and 8.4 g nitrogen, respectively. Daily milk production was determined for seven randomly chosen cows in different lactation periods. Dry matter intake used for milk production was then calculated. In a similar way, dry matter intake used for reproduction was assessed, based on energy and nitrogen requirements. In the last 2–3 months of gestation, 27 g digestible dry matter and 0.43 g nitrogen are required per unit of metabolic weight (Barret and Larkin, 1974).

The reproductive cycle was studied in order to define the time fraction during which intake of an average cow from the herd is elevated due to lactation or reproduction requirements. By interviewing local farmers, information was collected about management practices and herd structures. Questions about age at first calving, calving interval, cow viability, calf viability, and lactation period were asked.

Calving percentage of the herd was calculated from herd composition, by dividing the total number of calves born in one year by the total number of breeding females (Wagenaar and Kontrohr, 1986).

Environmental effects on voluntary intake occur at temperatures below 15°C (NRC, 1981; Fox, 1986); an adjustment of +3% of dry matter intake between temperatures of 5–15°C is appropriate. Mannetje and Ebersohn (1989) indicate an adjustment of about +20% for grazing activity. Because the cattle walk over relatively large distances in this extensive area, and due to relief differences, extra energy will be required. Hafez and Dyer (1969) report a daily energy requirement of 79 kcal/100 kg/mile for walking and 207 kcal/100 kg/1000 ft extra for ascent. All corrections were applied in the final calculation of forage intake.

Secondary production. A cow productivity index was computed as the product of cow viability (%) × life weight gain (kg) + cow viability (%) × calving percentage (%) × calf viability (%) × calf weight at 1 year (kg) + cow viability (%) × calving percentage (%) × lactation milked out yield (kg)/9 (Trail and Gregory, 1981). This productivity index was expressed in kg per cow per year and in kg per 100 kg of adult cow maintained per year, to provide a basis for comparison with productivity of other extensive livestock systems.

Results

Grazing behavior. From field observations in the study area and interviews with the local farmers, it can be concluded that the cattle graze from 5 or 6 o'clock in the morning until 8 or 9 in the evening. A mean active grazing time of 60% was found, including resting periods shorter than 15 minutes. This implies that cattle graze approximately nine hours, with four or five resting periods amounting to six hours. In general, cows graze from 4–9 hours per day with more time spent on rangelands than when on dense pastures (Van Dyne *et al.*, 1980). The cattle of the páramo apparently have to make a considerable effort to meet their nutritional requirements by grazing long periods over large areas, which confirms the extensive nature of the grazing system.

The simulated bite sizes were assessed at 1.06 ± 0.44 g dry weight (± s.e., n = 20) for short grasses and 1.29 ± 0.68 g (± s.e., n = 50) for bunchgrasses. Results of intake estimations based on bite counts are presented in Table 1. According to this method, total intake was estimated at 13.8 kg dry matter per day.

Botanical composition and forage quality of cattle diet. From observations of grazing behavior, it was concluded that most of the cattle diet consists of short grasses (with sedges included) of mainly *Calamagrostis coarctata* and *Carex tristichia*. Bunchgrasses of *Calamagrostis* and *Festuca* and the ground-covering species *Lachemilla orbiculata* are important components. Of the forbs, the dominant species are *Trifolium repens, Rumex acetosella, Castilleja fissifolia,* and *Bartsia pedicularioides,* but in comparison with grasses they play a minor role in the cows' diet. Shrubs are hardly consumed. Remarkably, cows sometimes eat the inflorescence of the stem rosette *Espeletia hartwegiana*. Table 2 shows the relative contributions of different plant groups to dry matter intake of cattle. The average nitrogen

Table 1. Intake estimates based on bite counts during the active grazing period of cattle in the páramo of Parque Nacional Natural Los Nevados. Grazing period 9 h; bite size of bunchgrasses and short grasses 1.29 g and 1.06 g dry weight, respectively.

Cow	Bite rate (per minute)		Average intake (kg per day)		Total intake (kg per day)
	bunch-grasses	short grasses	bunch-grasses	short grasses	
1	12.1	13.5	8.4	7.8	16.2
2	6.4	17.8	4.4	10.2	14.6
3	7.3	15.7	5.1	9.0	14.1
4	6.4	10.4	4.5	6.0	10.4
					mean 13.8

Table 2. Botanical composition of cattle diet in the páramo of Parque Nacional Natural Los Nevados. D = *in vitro* digestibility, N = nitrogen content.

Plant group	% of diet	Dominant species	D (%)	N (%)
bunchgrasses	30 ± 5	*Calamagrostis effusa* green	33.7 ± 1.1	0.8 ± 0.14
		Calamagrostis dead	20.7 ± 3.9	0.2 ± 0.12
		Calamagrostis recta green	29.9 ± 2.3	0.9 ± 0.05
		Calamagrostis dead	19.2 ± 1.3	0.3 ± 0.10
		Festuca sublimis green	39.9 ± 6.6	0.8 ± 0.08
		Festuca sublimis dead	20.7 ± 9.5	0.3 ± 0.09
short grasses	40 ±5	*Calamagrostis coarctata*	62.8	0.9
		Carex tristichia	52.8	1.8
		Agrostis tolucensis	71.1	
ground cover	20 ±5	*Lachemilla orbiculata*	61.8	1.2
		Lupinus microphyllus	59.7	2.2
		Satureja nubigena	62.8	1.3
forbs	10 ±5	*Rumex acetosella*		1.6
		Trifolium repens	79.2	3.1
		Castilleja fissifolia	68.5	1.5
		Bartsia pedicularioides	62.6	1.5
shrubs	< 1	*Baccharis genistelloides*	66.7	0.8
		Escallonia myrtiloides	54.0	1.4
Esp. flowers	< 1	*Espeletia hartwegiana*	45.8	1.6

Table 3. Comparison of forage quality and forage preference using Ivlev's electivity index E (Ivlev, 1961), defined as the relative difference between the fraction (*r*) of a given forage type in the animal's diet and the fraction (*p*) of the same forage in the vegetation [$E = (r-p)/(r+p)$]. Quality is expressed as *in vitro* digestibility (D) and nitrogen content (N) of consumed plant groups (weighed averages according to species preference) and of total cattle diet.

Plant group	Fraction of diet r (%)	D (%)	N (%)	Fraction of vegetation p (%)	Fraction of vegetation p (g)	E = (r-p)/(r+p)
bunchgrasses	30	29.4	0.7	82	602 ± 85	−0.47
green	21	33.4	0.8	25	184 ± 26	−0.09
dead	9	20.1	0.3	57	419 ± 59	−0.73
short grasses	40	58.8	1.4	9	64 ± 51	+0.63
ground cover	20	61.7	1.3	7	48 ± 34	+0.62
forbs	10	70.1	1.9			
shrubs	<1	60.3	1.1	2	15 ± 16	–
total diet	100	52.0	1.2			

content and *in vitro* digestibility of total diet were determined at 1.2% (N) and 52% (D), respectively (Table 3).

Our observations confirmed that the cows select leaf over stem and green over dead material as was reported by Mannetje (1974) and Mannetje and Ebersohn (1980). Green tussock leaves have a significantly higher nitrogen content and digestibility than dead material (Table 2). The same holds true for short grasses which make up only small part of total biomass (9%) and are preferred to bunchgrasses. In Table 3, the quality per distinguished plant group is given in terms of digestibility and nitrogen content, and compared to Ivlev's electivity index as a quantitative measure of selection. Ivlev's electivity index appears to correspond well with differences in forage quality. This is shown in Figure 2, where relative differences from the average digestibility and nitrogen content are plotted against Ivlev's electivity index. A linear relationship is suggested.

Fecal excretion. Mean daily excretion of feces was assessed at 4.9 (± 0.9) kg

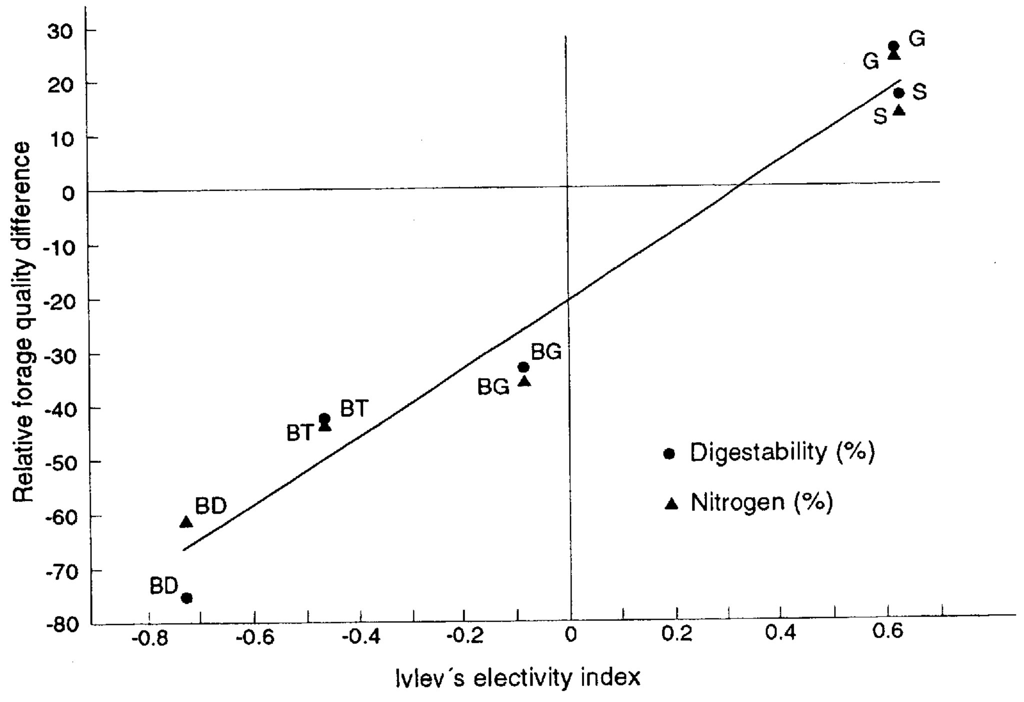

Figure 2. Relation between the forage quality of plant groups as relative difference from the mean forage quality of the total diet and the Ivlev's electivity index as a measure of food selection. Relative forage quality difference from the mean is calculated as (%N of plant group – 1.2% N)/1.2% N, or as (%D of plant group – 52% D)/52% D. BD = bunchgrasses, dead parts; BG = bunchgrasses, green parts; BT = bunchgrasses, total; G = ground-covering species and low forbs; S = short grasses.

dry matter (± s.e., n = 4). The average digestibility of the consumed dry matter was estimated at 52%. Using equation (1) the following estimate of forage intake could be derived: 10.1 ± 1.8 kg dry matter per day.

Nutritional requirements and secondary production. As mentioned above, forage intake is highly dependent on the ratio of energy to nitrogen content of the feed. The critical level of crude protein, below which voluntary intake of dry matter by beef cattle is depressed, is 7% (FAO, 1991). In this study, nitrogen content was found to be the limiting factor exclusively for milk production. In the case of all other feed requirements, such as maintenance, live weight gain, and reproduction, energy was found to be limiting.

Results of measurements on live weight gain are presented in Table 4. In the páramo and at Finca Normandía, growth is apparently most reduced in age class 1–3.5 years, but continues longer. This indicates that cattle reach maturity later than under more favorable conditions, which is confirmed by the age of the animals at first calving which is 3.5 against 3 years under more favorable management. In the páramo, lower growth rates throughout result in lower adult weights. Average body weight of an adult cow was determined at 417 kg and its mean live weight gain at 1.2 kg per month. Dry matter intake used for growth was determined at 0.1 kg per day.

According to local farmers the mean calving interval is 12 months, unsuccessful gestations not taken into account. Calving percentages of 78%, 59%, and 56%, respectively, were calculated for the three different herds. Mean daily milk production of páramo cows is assessed at 5 kg milk per cow of which 1 kg is consumed by the calf. The lactation period lasts seven months. The lactation yield within this period is assessed at about 1100 kg milk.

Taking into account a mean calving percentage of 64%, an average cow from the herd requires 0.6 kg dry matter per day for reproduction and

Table 4. Weight and growth per age class of Normando cows in different management conditions: standard favorable conditions in Colombia (Geoffray, 1981), medium conditions at Finca Normandía (3600 m), and the more extreme páramo (4000 m).

Management conditions	favorable	medium	páramo
Weight (kg)			
at birth	38–40	38–40	30–40
1 year	190	165	165
3.5 years	490	387	360
adult (6 years)	532	459	417
Growth (kg per month)			
0 – 1 year	12.5	10.5	10.5
1 – 3.5 years	8.9	7.4	6.5
3.5 – 6 years	1.4	2.4	1.9
3.5 – 12 years	–	1.2	1.2

1.3 kg per day for milk production.

Dry matter intake used for maintenance is assessed at 5.9 kg per day. Summing maintenance and production requirements, dry matter intake is estimated at 7.9 kg per day. Besides normal grazing activity, the cattle walk about 5 km extra per day with an estimated ascent of 50 m. After adjustments for walking, grazing activity, and environmental stress, a total dry matter intake of adult cows (live weight 417 kg) of 11.4 kg per day was obtained. A cow productivity index of 144 kg per adult female per year was calculated, which is equal to 35 kg per 100 kg live weight per year.

Discussion

Of the three final estimates of daily dry matter intake by cattle, the one derived by the second method (bite counts) is probably an over-estimation. The outcome of 13.8 kg dry matter per day is above the 2–3% of live body weight generally taken as a rule of thumb to roughly estimate daily intake. Simulated bite size is highly variable; nevertheless, it is a critical parameter in the intake calculations based on bite counts. A general remark concerns the simplicity of this method brought about by using continuously variable parameters as single means or totals (Hodgson, 1982). However, the method is useful to derive information on the plant composition and quality of the cattle diet. This information is an essential input in the other intake estimates and can be related to processes of selection and to changes of the natural vegetation due to grazing.

The other outcomes are of a similar order of magnitude (10.1 and 11.4 kg per day) and are considered to be more reliable. The result of the intake estimate, based on maintenance and production requirements, can be validated partly, using the general intake equation for steers (Minson and McDonald, 1987). The prediction of dry matter intake for a steer of 417 kg live weight and a growth of 0.04 kg per day is 7 kg per day, with a coefficient of variation of 8.7%. According to our calculations, an average cow of the páramo would need 7.2 kg dry matter per day for maintenance, growth, and normal grazing activity alone, which is within the range predicted by Minson and McDonald (*l.c.*).

Indices of cow productivity are given by Trail and Gregory (1981) for extensive grazing systems in the Kenyan highlands at elevations of 1800–2200 m. Climate there is semi-arid (yearly rainfall 610–680 mm) and the breed concerned is Sahiwal cattle and its crosses with *Bos taurus* and indigenous *Bos indicus*. Cow productivity indices of six different herds range from 32–68 kg per 100 kg live weight per year. Our estimate of cow productivity of 35 kg per 100 kg per year thus corresponds to the lower side of these reported figures on extensive grazing systems.

It appears that if forage quality of a plant group is higher relative to the average diet quality, the animal preference for this plant group expressed as Ivlev's electivity index increases in a linear way. Increasing height, bulk density, and cover are mentioned by Ungar and Noy-Meir (1988) as possibilities to maximize intake rate. In spite of their lower height, lower bulk density, and lower cover, the short grasses and ground-covering species are preferred to the bunchgrasses. This suggests that forage selection in the studied páramo bunch grasslands is controlled by quality factors rather than the spatial organization of herbage.

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