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Nutrition of farmed rabbits

By G. G. Partridge, *Rowett Research Institute, Bucksburn, Aberdeen AB2 9SB*

Current status of rabbit production world-wide

The rabbit is now recognized as one of the world's major livestock species, with an estimated global yield of one million tonnes/year of rabbit carcass (Lebas *et al.* 1986). Europe remains the centre of world meat-rabbit production with the USSR, France, Italy and Spain supplying approximately two-thirds of this estimated world production. In the UK the industry has failed to grow significantly over the past 10 years, and it is currently estimated that UK production is around 6000 tonnes/year, with consumption values of 0·2 kg/head per year (1988; Commercial Rabbit Association, personal communication). The major consumers in Europe are France, Italy and Spain at 3–3·5 kg/head per year.

Interest in the production of wool from the Angora rabbit has also seen a resurgence over the past 10 years. Currently world production is estimated at 6000 tonnes/year, with China (5000 tonnes), Chile (450 tonnes) and Argentina (300 tonnes) established as major producers and Italy, Hong Kong and Japan as the principal importers of Angora wool for the fashion and medical garment trade (1987; F. McClure, personal communication).

The rabbit's biological potential

The ability of the rabbit to utilize predominantly forage-based diets, and so not compete with man, is seen as its major attribute in developing countries with chronic protein deficiencies (Owen *et al.* 1977; Schlolaut, 1985). Its relatively small size is advantageous, as it is effectively a 'biological refrigerator', obviating the need for carcass storage in hot or humid environments, or both. Rabbit meat itself is also subject to few religious taboos (Lebas *et al.* 1986).

In societies where there is concern over the possible detrimental effects of excessive consumption of animal fats the rabbit's inherently low-fat carcass is a marketing bonus (80 g fat/kg saleable carcass on conventional diets). The rabbit's potentially high reproductive rate per unit body size also results in the energetic efficiency of rabbit production being considerably higher than that of sheep, cattle or pigs (Dickerson, 1978).

Definition of nutrient requirements

Considerable advances have been made over the last 20 years in our understanding of the rabbit's nutrient requirements in both intensive and extensive production systems. The present paper attempts to draw together information obtained from a number of studies, principally over the last 5–10 years, and is intended to complement rather than reiterate information given in the reviews of Davidson & Spreadbury (1975), Lang (1981) and Lebas *et al.* (1986). Emphasis has been given to advances in our knowledge of the protein and energy requirements for growth, pregnancy and lactation. Information on vitamin and mineral needs is given in the publications of the National Research Council (1977) and Lang (1981).

The digestive physiology of the rabbit

Detailed descriptions of the gross anatomy of the rabbit are given elsewhere (Lang, 1981; Lebas *et al.* 1986). The practice of caecotrophy is a physiological–behavioural

Table 1. *Typical composition (g/kg dry matter) of soft and hard faeces in the rabbit (from Hörnicke, 1981; Lebas* et al. *1986)*

(Range in parentheses)

	Soft	Hard
Dry matter (g/kg)	271 (180–370)	583 (480–660)
Crude protein*	295 (210–370)	131 (90–250)
Crude fibre	220 (140–330)	378 (220–540)
Fats	24 (10–46)	26 (13–53)
Minerals	108 (60–108)	89 (31–144)
Nitrogen-free extract	351 (290–430)	377 (280–490)
Volatile fatty acids (mmol)	180	45
Sodium (mmol)	105	40
Potassium (mmol)	260	85

*N × 6·25

peculiarity of the rabbit, and is shared with some other species, e.g. hares (*Lepas* spp.), lemmings (*Lemmus* spp.), koalas (*Phascolarctos cinereus*). It would seem appropriate, therefore, to consider whether caecotrophy sets the animal apart from other non-ruminants with respect to nutritional requirements.

Caecotrophy-mechanism and nutritional significance

The rabbit produces two distinct kinds of faecal pellets, soft ones (caecotrophes) which are reingested directly from the anus, and hard ones which are voided. The formation of each type alternates in a precise circadian rhythm, with caecotrophy usually beginning around sunrise and continuing until early afternoon. The caecotrophes are packages of caecal contents surrounded by a mucus envelope, and have a high content of vitamins, protein and minerals. In contrast, hard faeces are lower in minerals and protein and have a relatively high fibre content (Table 1). The differences in composition are a result of retardation and retrograde transport of fine particles (including micro-organisms and water-soluble substances) which takes place in the proximal colon, sweeping these particles back into the caecum while large particles (>0·3 mm) continue towards the anus (Björnhag, 1981). The site of secretion of the mucus envelope has not been unequivocally demonstrated but appears to lie in the caecum itself, or the distal colon (Lang, 1981).

Caecotrophes account for approximately one-third of the total daily faecal dry-matter output (soft plus hard) and when reingested provide 5–18% of total daily dry-matter intake and up to 35% of the daily nitrogen intake. Thus young, fast-growing rabbits consuming about 20 g dietary crude protein (CP; N × 6·25) daily recycled approximately 3 g CP (1·3 g true protein) as soft faeces (Spreadbury, 1978). Animals of a similar body size consuming a barley diet (5·4 g CP/d) re-cycled 2·6 g CP each day by caecotrophy (G. G. Partridge, unpublished results). Despite this contribution to the animals' N economy the gross requirements for amino acids for optimal growth are not markedly different from those of other non-ruminants, such as the pig or chick (Table 2). Caecotrophy appears, therefore, to be somewhat of an evolutionary relic which aids the animal, particularly during times of nutritional adversity. In production situations (e.g., growth, lactation) with relatively high protein and energy intakes, its contribution to overall N requirements is relatively small (Spreadbury, 1978; Lebas *et al.* 1986).

Table 2. *Current estimates (g/MJ digestible energy*) of the crude protein (nitrogen × 6·25), digestible crude protein and amino acid requirements of growing rabbits, and a comparison with estimates for the growing pig and chick (from Adamson & Fisher, 1971, 1973; Spreadbury, 1978; Agricultural Research Council, 1975, 1981; Lebas, 1985; Lebas* et al. *1986)*

	Rabbit (g/kg diet)	Rabbit (0·8–2·5 kg)	Pig (15–50 kg)	Chick (4–8 weeks)
Crude protein	160	15·2	12·0†	12·0
Digestible crude protein	120	11·4	—	—
Lysine	7·5	0·71	0·84	0·62
Methionine + cysteine	6·0	0·57	0·42	0·52
Tryptophan	2·0	0·19	0·12	0·12
Threonine	5·5	0·52	0·50	0·41
Leucine	10·5	1·00	0·84	0·82
Isoleucine	6·0	0·57	0·46	0·49
Valine	7·0	0·67	0·59	0·55
Histidine	3·5	0·33	0·28	0·28
Arginine	6·0	0·57	—	0·58
Phenylalanine + tyrosine	12·0	1·14	0·80	0·89

*Assuming a 'typical' digestible energy of 10·5 MJ/kg air-dry diet (rabbit) and 13 MJ/kg air-dry diet (pig and chick).

†As 'ideal protein'.

Protein and energy requirements for growth

The importance of protein quality in rations for rabbits is now well recognized. Many studies over the last 15 years have highlighted the fact that, like other simple-stomached species, the rabbit has a reduced growth rate and food consumption when offered proteins with an unbalanced amino acid profile (Adamson & Fisher, 1971, 1973; Spreadbury, 1978).

Current recommendations for the requirements for essential amino acids are given in Table 2. It should be stressed that the estimates for lysine, the sulphur-amino acids and arginine are derived from a synthesis of several studies, whereas estimates for other amino acids are based on levels found acceptable in commercial practice, rather than by definitive experiments. Both the chick and the rabbit appear to have a higher requirement for S-amino acids than the pig, presumably a reflection of the relatively greater need for feather and fur growth in these animals.

De Blas *et al.* (1981, 1985) investigated the relationships between protein:energy ratio and growth rate, digestible energy (DE) intake and mortality for a series of commercial diets. They found that each of these relationships was curvilinear over the range 8–12 g digestible CP (DCP)/MJ DE, and identified an optimum at 10·2 g DCP/MJ DE. Maintenance needs for DCP have been estimated at 3·9 g DCP/kg body-weight$^{0·75}$ per d (Partridge *et al.* 1989).

The growing rabbit is able to adjust its voluntary food intake in response to changes in the energy density of the diet. DE intakes by commercial breeds up to conventional slaughter weights (2·0–2·5 kg) are commonly about 920–1000 kJ/kg body-weight$^{0·75}$ per d. It has been shown that when the DE of the diet falls below approximately 9·3 MJ/kg, by the addition of more fibrous materials, then total DE intakes are depressed and the corresponding growth rates reduced (Lebas *et al.* 1986; Partridge *et al.* 1989). Maintenance energy requirements of growing animals have been estimated at approximately

400 kJ DE/kg body-weight$^{0\cdot75}$ per d (Partridge *et al.* 1989). During fast growth, therefore, young commercial rabbits are consuming about 2·4 times their maintenance requirements. Comparative values for the growing pig (20–70 kg) and chick (0–9 weeks) are four and 2·2 times maintenance requirements respectively (Agricultural Research Council, 1975, 1981).

On typical commercial rations (i.e., without fat supplementation) the efficiency of utilization of dietary energy for body energy retention above maintenance ranges from 0·45 to 0·53 kJ retained/kJ DE intake. The partial efficiencies of utilization of DE for protein and fat retention have been estimated at 0·39 and 0·65 respectively (De Blas *et al.* 1985; Partridge, *et al.* 1989).

Fats as an energy source in rabbit diets

Results of several studies on the merits of fat supplementation of grower diets to increase daily energy intake are equivocal (Lang, 1981). Partridge *et al.* (1986*b*) found that supplementation up to 100 g/kg, with increasing levels of either grade B tallow (a mixed animal fat) or soya acid oil (a by-product of the margarine industry) significantly decreased dry-matter intake, with no effect on growth rate. Daily DE intakes on fat-supplemented diets were maximal at 1120 kJ DE/kg body-weight$^{0\cdot75}$, compared to 995 kJ DE/kg body-weight$^{0\cdot75}$ on the control ration, and body fat depots were significantly increased in weight after fat additions. Apparent digestibility of both fat sources was high (1·00).

Aside from the economic considerations, the supplementation of rabbit rations with fat to increase the energy density may be particularly appropriate in diets designed for lactating females kept under intensive rebreeding programmes, where demands for energy are particularly high (see p. 98).

The importance of fibre in rabbit rations

Many studies have confirmed that the rabbit has a relatively limited ability to digest dietary fibre. Digestibility coefficients for crude fibre and acid-detergent fibre are commonly less than 0·20 (Spreadbury & Davidson, 1978; Partridge, 1980). The exceptions are non-lignified fibre sources such as citrus or beet pulps where digestibilities of >0·60 have been reported (Carmona *et al.* 1980; Maertens & De Groote, 1984).

Feeding low-fibre diets to rabbits is, however, often detrimental to animal health and performance. The young rabbit, in particular, has a physiological requirement for some indigestible bulk in its diet to prevent caecal-colonic hypomotility, which appears to predispose to diarrhoea (Laplace, 1978). For this reason current recommendations suggest that levels of 'indigestible' fibre should be 100–120 g/kg diet (Lebas *et al.* 1986). Future work in this area should aim to define fibre requirements more precisely with respect to dietary polysaccharide content and its relationship to enteric disease in the growing animal.

Extent of hindgut fermentation in the rabbit

Hoover & Heitmann (1972), using in vitro incubation methods, estimated volatile fatty acid (VFA) production rates equivalent to 87–94 kJ/d in growing animals offered lucerne (*Medicago sativa*)-based diets. This corresponded to 10–12% of the animals' basal metabolic requirement (BMR, where BMR (kJ) = 293 body-weight$^{0\cdot75}$). Parker (1976), using in vivo sampling, reported slightly higher values of 269 and 194 kJ/d when adult animals were offered a standard laboratory diet at restricted (100 g/d) or *ad lib.* levels respectively. Thus, VFA supplied approximately 40·5 and 29·2% respectively of BMR in these adult animals.

Protein and energy requirements for pregnancy and lactation

Pregnancy. Few studies have been carried out on the specific protein and amino acid requirements for pregnancy in the rabbit. Requirements are met commonly in commercial practice by feeding restricted quantities of an all-purpose ration designed for breeding females or, more frequently in the UK, for all classes of stock. Moreover, in intensive rabbit production pregnancy is often concurrent with lactation, hence recommendations for nutrient levels in diets must, wherever possible, take account of effects on reproductive performance over the total breeding life of the doe, rather than over one isolated breeding cycle.

Most short-term studies on protein and energy needs during pregnancy have simultaneously changed both protein and energy intake (Hafez *et al.* 1967; Lebas, 1975; Partridge *et al.* 1986*a*). Where significant effects on litter birth weight have been reported, energy intake during pregnancy appeared to be the principal causal factor, rather than protein intake *per se*. Partridge & Allan (1982) offered isoenergetic diets at three levels of CP (122, 158 and 190 g/kg) and found no significant effects on pup birth weight over two successive reproductive cycles. They estimated that at the lowest level of protein offered (122 g/kg) approximately 84% of retained protein was utilized for conceptus growth.

Maintenance energy requirements of pregnant and non-pregnant does have been estimated in calorimetry studies (Partridge *et al.* 1986*c*): 335 and 310 kJ ME/kg body-weight$^{0\cdot75}$ per d respectively. The maintenance requirement for pregnant does includes a component of energy requirement for conceptus growth.

Lactation. (1) *Milk yield and composition.* Commercial does of the Fauve de Bourgogne breed produced 5·28 kg milk over a 28 d lactation, i.e., 189 g/d, or 1·72 kg milk/kg body-weight$^{0\cdot75}$ per lactation (Lebas, 1968). Slightly higher lactation yields of 190–210 g/d have been reported in other studies using New Zealand White × Californian crossbreds offered high-protein diets (CP $>$ 180 g/kg; Partridge & Allan 1982, 1983).

Typical values for doe milk composition at peak lactation, about day 18, are shown in Table 3.

The fat content of does' milk is influenced by the incorporation of supplemental fat in the diet to increase energy density. Partridge *et al.* (1983) offered a diet containing 50 g maize oil/kg and reported milk fat levels of 145 g/kg at peak lactation. Similarly, does accreting large amounts of body fat during pregnancy had higher levels of fat in their milk during the subsequent lactation (115 g/kg *v*. 99 g/kg for controls; Partridge *et al.* 1986*a*).

(2) *Protein and energy requirements.* There is little information in the literature on requirements for specific amino acids for optimum milk production in the doe. It is

Table 3. *Chemical composition of does' milk at peak lactation (g/kg) (from Lebas, 1971)*

Total solids	Protein (N × 6·38)	Fat	Ash	Lactose	Energy* (MJ/kg)
267	131	102	24	10	7·3

Amino acid composition (g/kg): Alanine 4·2, Arginine 6·1, Aspartate 8·3, Cysteine 2·2, Glutamate 19·4, Glycine 1·9, Histidine 3·1, Isoleucine 5·4, Leucine 10·6, Lysine 7·9, Methionine 2·3, Phenylalanine 5·4, Proline 9·6, Serine 5·2, Threonine 5·6, Tyrosine 6·2, Valine 6·9 (from Schlolaut, 1982).

*Calculated using gross-energy values for protein, fat and lactose of 23·6, 39·5 and 16·0 MJ/kg respectively.

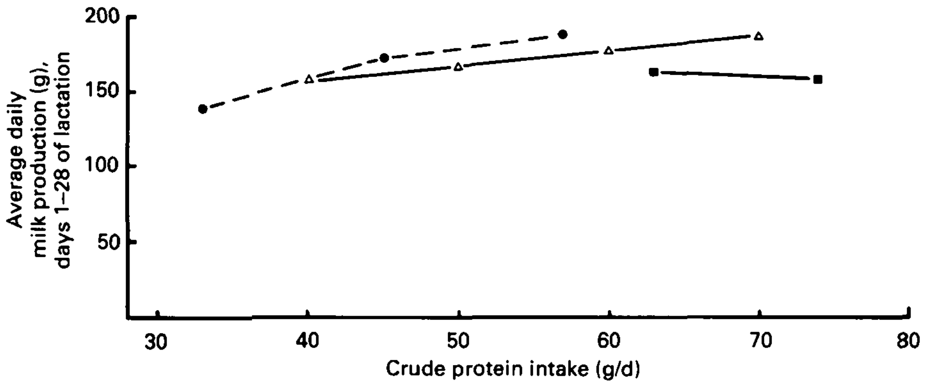

Fig. 1. The relationship between daily crude protein (nitrogen × 6·25) intake and milk production in the doe. Values obtained from three studies: Partridge and Allan (1982), (● - - - - ●); Partridge & Allan (1983), (△——△); Sanchez *et al.* (1985), (■——■). Data points from Partridge & Allan (1983) were calculated from the predictive equation: milk production (g/d) = 17·6+0·985 crude protein intake (g/d) + 30·3 digestible energy (DE) intake (MJ/d), where DE intake is 3·31 MJ/d.

assumed, therefore, that the amino acid balance for milk production is similar to that required for growth (Table 2).

The effects of the level of CP in the diet on milk yield have been investigated in some studies (Partridge & Allan, 1982, 1983; Sanchez *et al.* 1985), and the results from these experiments are summarized in Fig. 1. In our studies, decreasing the level of protein in the diet, by dilution of the basal protein with maize starch, invariably resulted in decreases in voluntary food intake and thereby DE intake. For this reason DE was included as a covariate in the summarizing equation (Fig. 1). Does consume about 1·26 MJ DE/kg body-weight$^{0\cdot75}$ per d during lactation (Lebas *et al.* 1986), which is approximately four times the non-pregnant animals' maintenance requirement (Partridge *et al.* 1986*c*). To supply 60 g CP/d (Fig. 1) from a 'typical' commercial ration containing 10·5 MJ DE/kg would, therefore, require a CP concentration of 180 g/kg.

Offering low-protein diets (109 g CP/kg) during lactation results in high rates of pup mortality due to insufficient milk production (47·3% mortality *v.* 10·9% mortality on a control diet containing 185 g CP/kg; G. G. Partridge, M. F. Fuller, D. Valaydon and J. Wilkins, unpublished results).

Under intensive breeding systems, where does are remated immediately post partum, late pregnancy and the fourth week of lactation coincide. In this situation does divert nutrients away from milk production towards the nurture of the developing litter *in utero* (Figs. 2 and 3; Partridge *et al.* 1986*c*).

Interactions between doe nutrition and long-term reproductive performance

Unfortunately few studies have critically examined the long-term effects of different dietary energy and protein intakes on reproductive performance over successive breeding cycles. Sanchez *et al.* (1985) compared the performance of does offered isoenergetic diets containing 175, 190 or 205 g CP/kg over a 12-month period. Few significant treatment differences were observed, although there was a tendency for optimum economic performance to be achieved on the diet containing 190 g CP/kg.

Lamb (1985) compared reproductive performance over three successive reproductive cycles in does mated 1 or 14 d post partum, and offered either high- or low-energy-dense

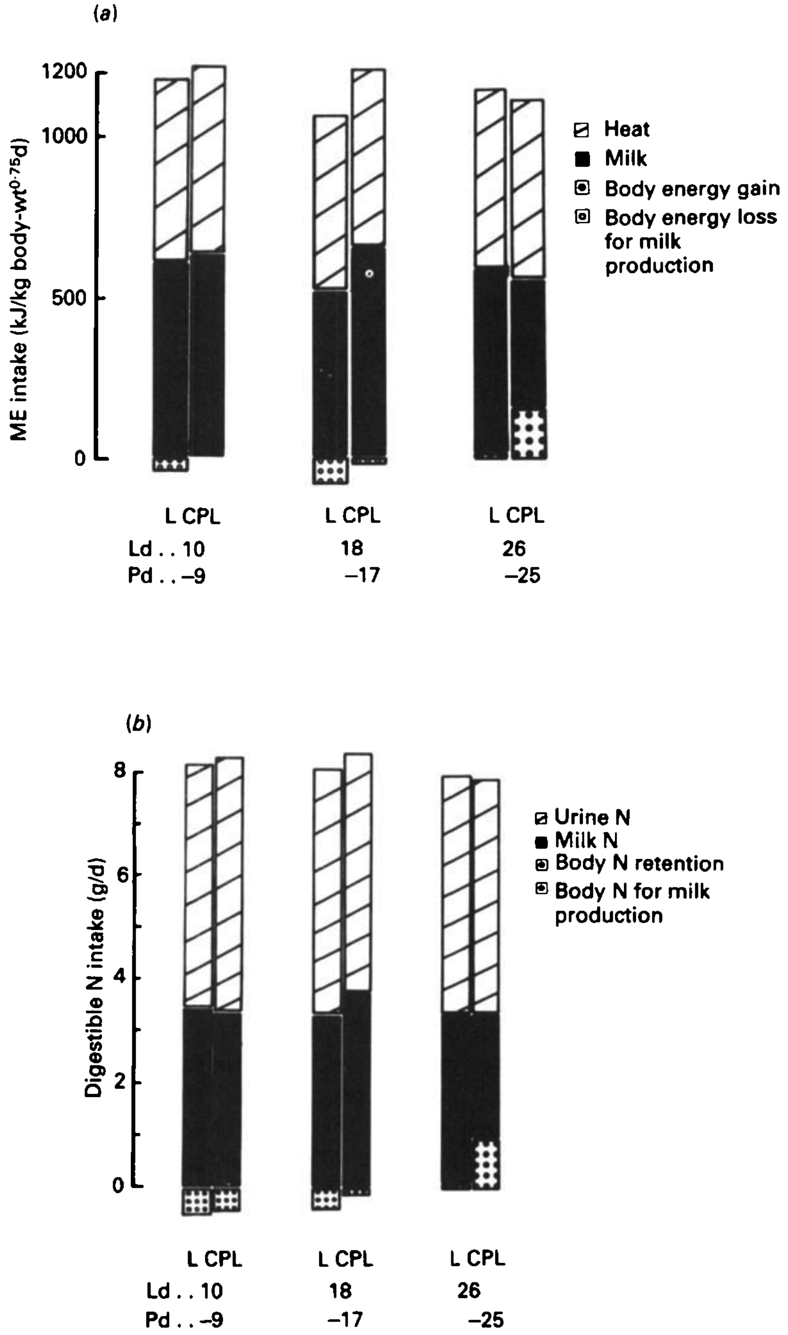

Fig. 2. The partition of (*a*) daily metabolizable energy intake and (*b*) digestible nitrogen intake into different components by lactating (L) and concurrently-pregnant and lactating (CPL) does. Ld, day of lactation; Pd, day of pregnancy (for CPL animals).

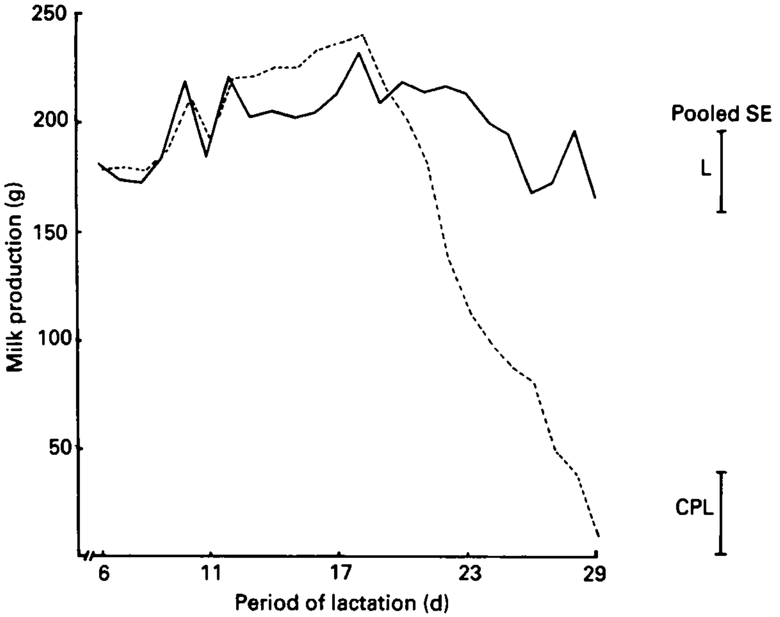

Fig. 3. Milk production curve for lactating (L; ———) and concurrently-pregnant and lactating (CPL; - - - - - -) does.

diets (15·4 and 8·5 MJ DE/kg dry matter respectively). DCP:DE values were held constant at 14·8 g/MJ. Nutritional regimen had no effect on any of the fertility indices measured (e.g., conception rate, ovulation rate, implantation rate), but litter weaning weights were significantly heavier on the high-energy diet, suggesting greater milk yield in these does. Further research on these aspects would be particularly valuable in the future to assist in defining optimum protein and energy requirements for various production systems.

Utilization of forage and agricultural by-products by rabbits

The rabbit is only likely to become a significant producer of meat in developing countries if it can thrive on indigenous plant species and agricultural by-products, and thereby be truly non-competitive with man. Lebas *et al.* (1986) cite a variety of wild and cultivated plants that can be used successfully in rabbit rations. Cheeke (1986) and Raharjo *et al.* (1986) describe studies on a number of temperate and tropical legumes and grasses. In general, many tropical grasses (e.g., bread grass (*Brachiaria brisantha*), elephant grass (*Pennisetum purpureum*), Guinea grass (*Panicum maximum*)) are relatively poorly utilized with dry-matter digestibilities ranging from 0·12 to 0·46, and CP digestibilities of 0·06–0·65. These materials will only be of use in rabbit rations to provide the indigestible-fibre component which appears essential for normal gastrointestinal function (see p. 96). In contrast, however, most legumes studied (e.g., Brazilian lucerne (*Stylosanthes guianensis*), sesbania (*Sesbania sesban*), leucaena (*Leucaena leucocephala*)) were far better utilized (dry-matter digestibility 0·43–0·79, CP digestibility 0·53–0·84), and could form the major component of successful rabbit rations. Information on the long-term productive performance (i.e., growth + reproduction) on these various foodstuffs is, however, still relatively rare and remains an important goal for research over the next 10 years.

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