SOME FACTORS INFLUENCING THE EFFICIENCY OF FEED UTILISATION BY RUMINANTS WITH SPECIAL REFERENCE TO THE TROPICS

R.A. Leng*

SUMMARY

The efficiency with which metabolisable energy of feeds is used for productive purposes in ruminants is highly variable. It depends upon:

* the nutrients in the feed that are available in the rumen for use by the microbial milieu and the balance of nutrients that arise from fermentative digestion and from nutrients of dietary origin that are absorbed from the intestines.

* whether the animal is heat stressed which in turn depends on solar radiation and climatic conditions.

* the previous dietary history of the animal and the composition of body tissues.

* the previous health history as it affects the protein status of the animal.

As many of the factors that effect the efficiency of use of metabolisable energy are reactions of the animal to the feed and the environment, prediction of the value of a feed by chemical analysis are of little value. A new approach to forage evaluation is needed which is based on animal response.

INTRODUCTION

Although Kleiber observed in early 1960 that

> "Metabolisable energy is not a homogenous entity, instead it represents an assembly of nutrients or metabolites each of which is used with a specific efficiency for a particular purpose' (Kronfeld, 1976)

scientists are still observing to their apparent surprise that

> "a further description of the nature of the ME will be required if animal responses are to be predicted accurately from a knowledge of the diet consumed" (Beever et al., 1988).

The concept of metabolisable energy of a feed being an index of its feeding value is at the best a crude approximation and at worst positively misleading. It is most misleading when applied to pastures.

*Department of Biochemistry, Microbiology and Nutrition, University of New England, Armidale, New South Wales, Australia.

Some of the reasons for this relate to technical aspects. For example the method of estimating ME is to take a pasture sample from a field and estimate digestible energy using *in vitro* fermentation. The digestible energy is then multiplied by 0.81 to allow for the energy in methane and loss of heat to estimate ME. Then regression equations are used to calculate the potential productivity from that feed.

It is fairly obvious that animals select their diet from a mixed grazing, and the feed that is left in a paddock is that which has not been consumed. Digestibility measured in *vitro* are often inaccurate and the factor of 0.81 is purely arbitrary.

A survey of the literature soon turns up many contradictions in terms of ME. Selected examples are given in Table 1 where growth rates of lambs on 40% digestible straw based diets or cottonseed hulls supplemented with protein meals are often similar to those on 65-80% digestible pastures (rye grass) of high protein content even where the pasture is cut and carried to the animal (see Table 1). Grain based diets are also used inefficiently without protein meal supplements (see Table 1).

Table 1. Live-weight gain (LWt) and feed conversion ratio (FCR) of lambs fed high and low quality diets.

Basal	Quality status	Approx. digest. (%)	Growth rate (g/d)	FCR	
				g/g LWt	g DOM/g LWt
Cottonseed hulls (CSH)[1]	low	40	75	16:1	6:1
CSH + formal-casein (BP)[1]	low	40	138	8:1	3:1
Ricestraw (RS)[2]	low	42	-53	50:1	21:1
RS + 120 g CSM + UMB[2]	low	42	90	8:1	3:1
Clover/ryegrass[3]	high	80	143	8:1	6:1
Grain/hay[3]	high	80	130	6:1	5:1
Grain/hay + fishmeal[3]	high	80	253	5:1	4:1
Barley + urea[4]	high	80	224	4:1	3:1
Barley + fishmeal[4]	high	80	332	3:1	2:1

[1]Davis and Leng (1989); [2]Sudana and Leng (1986); [3]Geenty *et al*. (1987); [4]Ørskov *et al*. (1972).

The future use of metabolisable energy requires a correction for efficiency of utilisation of energy which is variable and at the present time not predictable. This efficiency of utilisation of the feed depends on: intake, the efficiencies of fermentative digestion, the composition of the rumen microbial populations, the amount of bypass protein in the feed, the previous health and dietary history of the animal and the environmental temperatures and humidity.

The most important reason for ceasing to use metabolisable energy values is that it relegates feeds such as tropical pastures, straw, cottonseed hulls etc. to being of no feeding value other than providing diluents for grain based diets or to provide for maintenance. Bow inaccurate this is, is shown by the data in Table 1. In this table, sheep fed cottonseed hulls (about 40% digestible) supplemented with cottonseed meal grew at the same rates as sheep fed low protein grain based diets (80% digestible) (Davis and Leng, 1987; Geenty et al., 1987). Feed conversion efficiencies are similar on grain or forage based diets despite lower rates of gain on the latter.

Another major effect of the unquestioning acceptance of the concept of metabolisable energy is that thin animals on dry forages are invariably deemed to be 'energy deficient'. Recommendations therefore emphasise supplementation with energy dense supplements such as grains which tend to substitute for the basal forage diets and often are detrimental. This is particularly so where the basal diet is deficient in nitrogen to supply adequate quantities of ammonia for the rumen organisms (see Lee et al., 1986). The organisms degrading the starch lower rumen ammonia levels still further and reduce the (less palatable) straw intake.

This widely accepted but wrong concept that 'energy' is a primary limitation to production on forage based diets, particularly those of digestibilities below 55%, has been highly detrimental to progress.

Examples of the conflict of primary energy deficiency vs. balanced nutrient and efficiency of feed utilisation

Silage/starch based diets. A prime example of the approach recently appeared in the literature (Thomas et al., 1988; Beever et al., 1988). In these studies, the effects of feeding concentrate (barley) on cattle growth rates on late-cut ryegrass silage was studied (Fig. 1). The cattle in this case were restricted to an intake of 18g/kg liveweight. Presumably the rationale was that energy density of the silage based diet was the primary constraint to growth. In studies in our laboratories, it has been hypothesised that it is the ratio of amino acids to energy yielding substrates (i.e. VFA) in the nutrients available for absorption (i.e. the P/E ratio) that is the primary constraint. Supplements of a cottonseed meal pellet (a bypass protein) stimulated cattle growth rates to a much greater extent than barley (Fig. 1).

In Canadian studies (Veira et al. 1985) with cattle fed grass silage, comparisons were made between feeding small quantities of barley (energy) or fishmeal (bypass protein) on growth and efficiency of feed utilisation. Clearly from a comparison of these results (Fig. 1) it is the balance of nutrients which is the primary limitation to production and energy density is a secondary consideration.

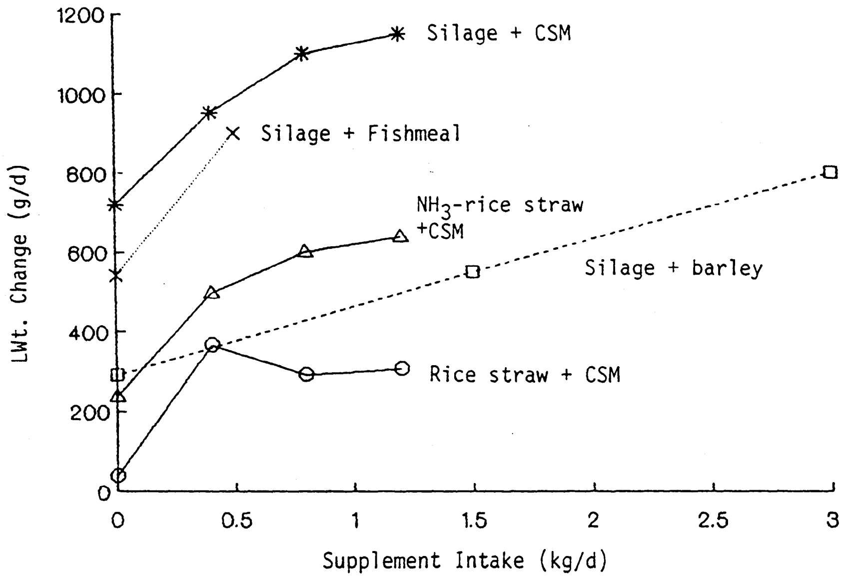

Fig. 1. The effects on live-weight gain of feeding "energy" to cattle on silage based diets as compared to balancing nutrition with bypass protein (Beever et al., 1988; Griffiths and Leng, 1989; Veira et al., 1985). Data for cattle fed straw based diets are also included for comparison (Perdok, 1987).

An explanation of the differing responses of cattle to supplements (Fig. 1) is as follows: On silage based diets it is the low protein to energy ratio in the nutrients absorbed that is the primary constraint to feed conversion efficiency and therefore growth rate. Supplemental bypass protein corrects this; the animal becomes more efficient; reduces heat production and uses more of the available nutrients for tissue synthesis. On the other hand, supplementation with barley substitutes for silage intake and although it increases the total metabolisable energy intake marginally and increases the quantity of nutrients absorbed, the ratio of protein to energy remains unchanged. However, a higher propionate production in the rumen (glucogenic substrate) may be the reason for the improved efficiency of feed utilisation for growth resulting from the addition of barley to the silage even though growth rate is not as substantially improved as with bypass protein supplements (see Table 2).

Table 2. The effects of supplementation of a late-cut ryegrass silage with barley on the growth and utilisation of feed by cattle (Beever et al., 1988).

Diet	ME intake (MJ/d)	Lwt gain (g/d)	FCR	
			(g/g gain)	(MJ ME/g gain)
Silage	58.9	369	16.2	160
Silage 72% Barley 28%	65.3	582	10.5	112
Silage 44% Barley 56%	69.6	798	8.0	87

The main point of this discussion is to emphasise that metabolisable energy value of feed can be highly misleading and that by supplementation to balance nutrients, the efficiency of feed utilisation is stimulated and production increases result largely from nutrients being used for energy and anabolic purposes that had previously been "burnt off".

Forage/sugar diets. A further example of the difficulties of predicting production from metabolisable energy values of feeds has been reported from these laboratories (Navas and Leng, 1989). With sheep allowed ad lib. intake of four diets (Diet 1 straw, Diet 2, straw + 15% sucrose, Diet 3 straw + 30% sucrose and Diet 4 Straw + 45% sucrose) which also contained 10% cottonseed meal, urea and minerals, the intake of the diets increased by more than 50% by the addition of the highest level of sugar. As the major dietary components are fermented in the rumen it can be assumed the availability of microbial cells and VFA increased with metabolisable energy intake but the protein to energy ratio in the nutrients absorbed would remain constant.

Wool growth was stimulated by the increased metabolisable energy intake but the efficiency of feed utilisation for fattening however was reduced. Animals on the basal straw diet gained weight, whereas those on the sugar with 50% more metabolisable energy intake lost weight (Fig. 2). In these studies the source of bypass protein (i.e. cottonseed meal) was kept constant and protozoal numbers in the rumen increased. Both these changes would have lowered the P:E ratio in absorbed nutrients (see Bird and Leng, 1985). .

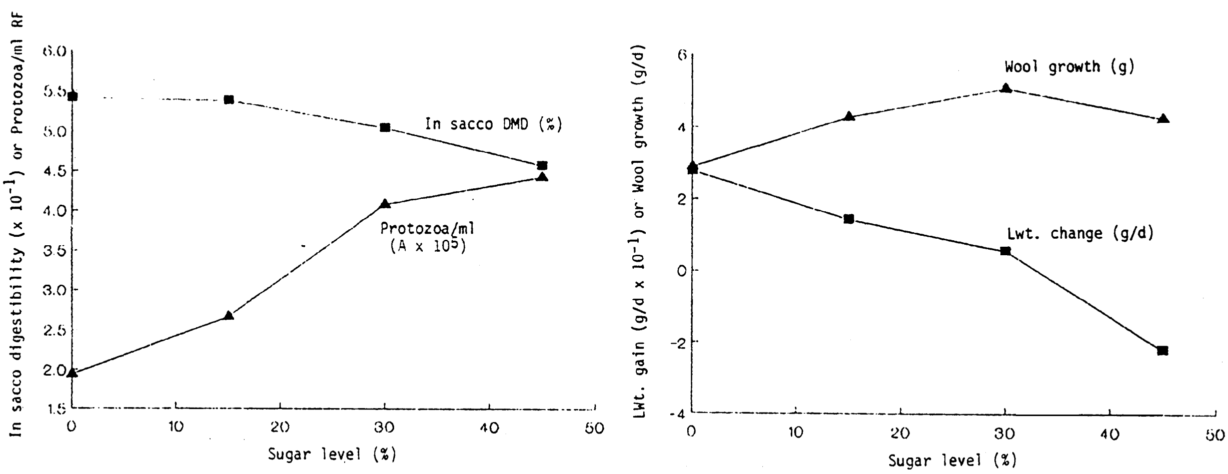

Fig. 2. The effects of increasing "energy" in a diet of straw on intake and production of sheep (Navas and Leng, 1989 - this symposium). Sheep were fed a mixture of straw-chaff/sugar plus urea/minerals and 5% cottonseed meal.

This research clearly suggests that it is the P:E ratio in the nutrients absorbed that governs productivity and not the metabolisable energy content of the feed.

Environmental factors affecting the requirements for bypass protein

Factors that affect the protein to energy ratio in the nutrients available to ruminant have been discussed previously in this series (Leng, 1985). In the discussion now'presented, some important factors that affect the requirements for protein relative to energy are detailed.

Effects of previous dietary and health history Fattet et al. (1984) showed that sheep on 'low quality' diets when supplemented with a bypass protein (fishmeal) partitioned their nutrients differently and grow at a faster rate than unsupplemented animals. The supplemented sheep deposited protein whereas the control sheep lost body protein and much less fat was mobilised in the animal given a bypass protein supplement.

This illustrates that balancing the dietary nutrients has a considerable effect on body composition.

Elliot and O'Donovan(1971) in Zimbabwe showed large carry-over effects from supplementing young cattle grazing in the dry season which affected the efficiency of feed utilisation when these animals were being finished on high maize diets following the wet season which lasted 196 days.

In their work Elliot and O'Donovan(1971) examined the responses of young cattle to graded amounts of cottonseed meal in the dry season (100 days). In the wet season (196 days) all animals were grazed together without supplementation and there was apparent compensatory gain in the group that had not been supplemented in the dry season. However , the carry-over effects of supplementation in the dry season were manifest as increased efficiency of feed utilisation when the cattle were in the feedlot on high maize based diets (see Table 3).

There appears to be only two factors which could explain these responses. The cattle that received supplements had a considerable reserve of body protein and could maximally use the nutrients arising from a maize diet. The second is that compensatory gain in the wet season does not represent a true gain of tissue dry matter and is the result of increased water retention. The apparent compensatory gain that occurs in cattle following removal of ticks appeared to be largely an increase in water content (Springell et al., 1971).

Table 3: Cattle growth rates through the dry season in Zimbabwe (120 days) when pastures are of low quality and supplements of cottonseed meal were given, then through the wet season (196 days) when abundant green pasture was available (no supplementation) followed by fattening in the feed-lot on high maize diets. The initial body weight was 215 kg and the animals were marketed when they reached 430 kg liveweight (Elliot & O'Donovan, 1971).

Dry Season		Wet Season	Feed Lot	
Supplement intake (kg/d)	Lwt gain (g/d)	Lwt gain (g/d)	Lwt gain (kg/d)	Feed/carcass gain (kg/kg)
0	-213	633	1.0	8.4
0.45	114	520	1.1	7.3
0.90	243	429	1.4	5.6
1.35	326	423	1.2	5.8

Heat Stress. Undoubtedly ruminants are more prone to environmental heat stress than other animals including humans. The following reasons are given for making this statement:

a. Fermentative digestion of forage produces more heat than the digestion of carbohydrates in monogastric animals.

b. The inefficient metabolism of the nutrients that are absorbed from forage based diets induces considerable metabolic heat production. Heat production from this source can be, at times , extremely high.

c. In cattle, as environmental temperature increases, heat loss by vaporisation of water increases and sensible heat loss (i.e. by radiation, conduction and convection) is decreased. At high temperatures in cattle, evaporative heat loss from the respiratory tract is only 20-30% of the total evaporative heat loss from the body (Blaxter, 1962).

d. Cattle, because of their lack of eccrine sweat glands, cannot vaporise water from their skin at anywhere near the capacity of humans. However, panting clearly indicates a heat stress in these animals as only 25-35% of heat is lost via this route. Cattle can only evaporate water to 1800-2400 kcal/m^2/24h. Humans, in a comparable environment can vaporise about 5 times this amount (Blaxter, 1962).

e. It may be assumed therefore under high environmental temperatures and humidity that grazing ruminants are often heat stressed. Ruminants can store considerable heat in the body and the overall rise in the mean body temperature may be 6oC under certain conditions. However, as shown by Blaxter and his colleagues (1962) that as the environmental temperature increases, fat is the major substrate that is oxidised to promote heat production (Fig. 3). In the zone of thermal neutrality (i.e. where heat production and heat loss are balanced) fat oxidation is negligible. At the upper critical temperature an increase in the heat production stimulates metabolic rate and therefore additional heat generation. The increased heat production appears to be from protein catabolism (Fig. 4). In sheep, a 7oC rise in body temperature would double basal metabolic heat production.

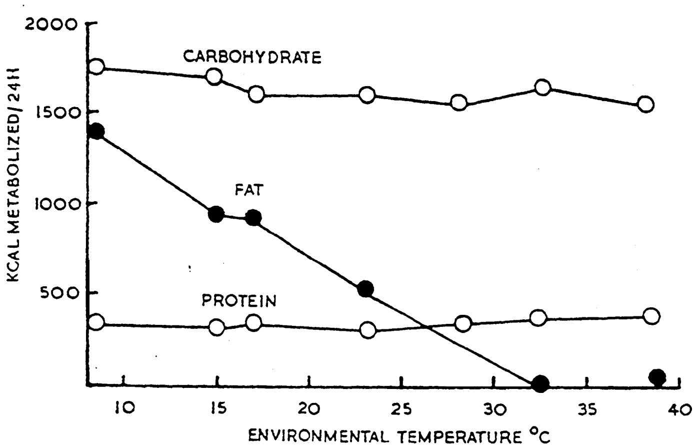

Fig. 3. Utilisation of nutrient with increasing environmental temperature in closely shorn sheep (Blaxter, 1962).

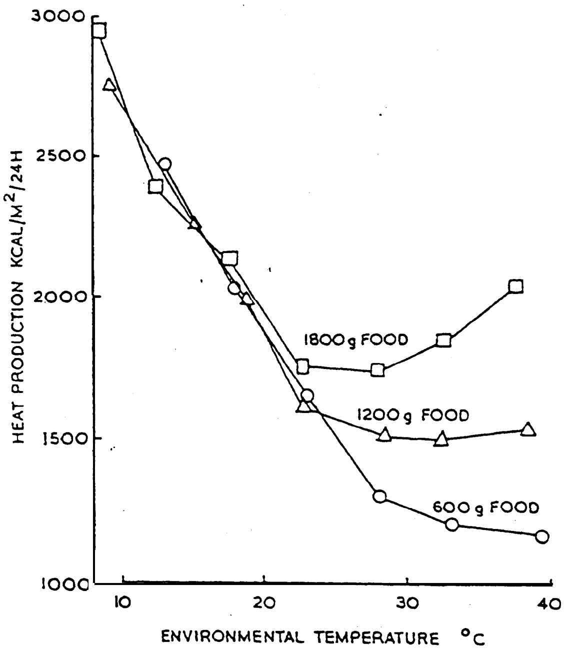

Fig. 4. Effects of high environmental temperature on protein utilisation of sheep (Blaxter, 1962).

Quite clearly from the research of Blaxter and his colleagues, cattle and sheep are prone to heat stress, particularly on low quality pastures and heat stress in itself increases the requirements for protein.

The only defense the ruminant has to combat heat stress is to reduce feed intake.

The net effect of the above factors is that the higher the environmental temperatures/humidities the lower will be the feed intake of ruminants on "low quality feeds" and the greater the percentage increase in intake that will result from balancing the nutrients available closer to those required. Therefore feed intake should be stimulated to a greater extent when both urea and a bypass protein are supplemented to animals that are in hot environments.

Feed intake of ruminants on low N, low digestibility forage based diets will be further reduced if their protein status has been lowered by parasites and/or they have been through previous periods of protein undernutrition. As may be expected therefore there are marked differences in reported responses to supplementation of cattle on low quality feeds between results from research in the tropics/subtropics and that from temperate areas (see Fig. 5).

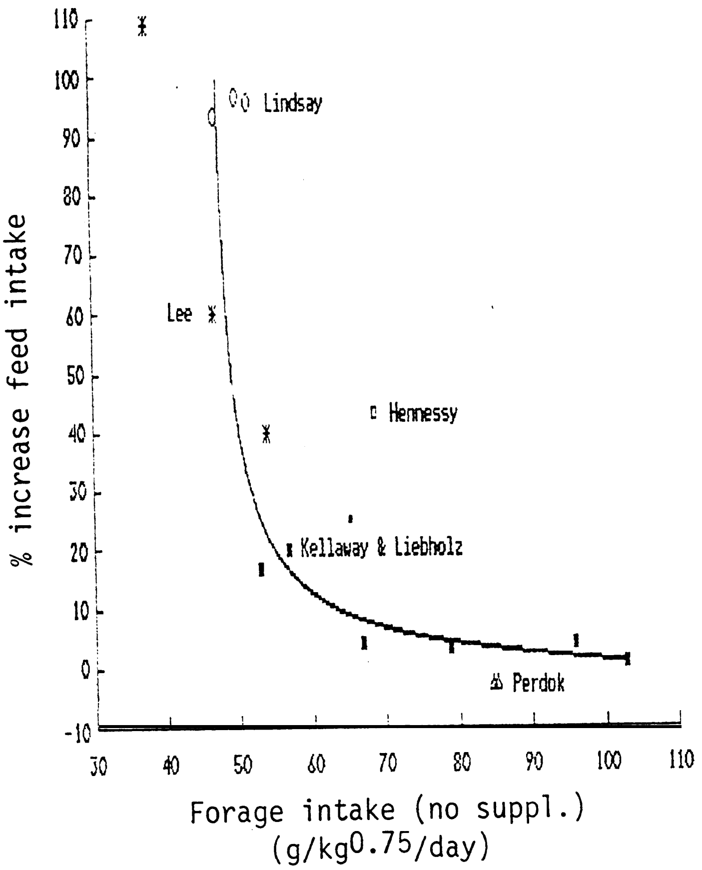

Fig 5. Intake of low digestibility forages by cattle either unsupplemented or supplemented with bypass protein or bypass protein and urea (Lindsay and Loxton, 1981; Lindsay et al., 1982, Hennessy, 1984, Perdok, 1987; Kellaway and Leibholz, 1981).

The effects of supplementation on feed intake has been a contentious issue for some time. For example, the feed intake of cattle on low digestibility feeds (44-55%) varied between 37 and 110 $g/kg^{.75}$/day (Fig. 5). There was no response in forage intake to supplements of protein when on the supplemented diet intake is relatively high (although these diets contained urea) but when the intake of forage without supplements was less than 60 $g/kg^{.75}$/day large increases in intake resulted to urea and to urea plus bypass protein. This effect suggests that there is an overriding factor that decreases feed intake which is rapid in its onset.

The most probable mechanism for this is the heat stress that is promoted by a high metabolic heat production coupled with a high environmental temperature and/or radiation load and which can be ameliorated by a reduction in metabolic heat generation.

<u>Influence of internal and external parasites</u>. In the tropics ticks and flies are the major ectoparasite of ruminants. With the tick that is present in Australia (*Boophilus boophilus*) it

has been calculated that they can take from 0.6-1.5 ml of blood per day. Assuming an animal is infested with 200 ticks then on a daily basis the animal may lose 200 ml of blood or 40 g protein (assuming blood is 20% protein). An increase in requirements for protein of 40 g could be met by feeding 150 g cottonseed meal or from microbial protein produced in the rumen from 250 g of digestible carbohydrate. The requirements for amino acids is therefore increased by parasitism and cattle will be more imbalanced for their nutrients during and for sometime after treatment for parasites. Protein depleted animals are likely to produce more heat,, and the utilisation of metabolisable energy will be decreased.

CONCLUSIONS

The general conclusion drawn from this discussion is that the protein status of an animal (the amount of protein in the live weight) will effect the animal's requirements for additional amino acids other than those arising from rumen fermentative digest ion. In summary, the requirements for a bypass protein supplement will be increased on a low protein diet if bddy protein reserves have been depleted by:

1. tick infestation and/or flies.
2. intestinal parasites.
3. heat stress due to high environmental temperatures/humidity.
4. heat stress due to absorption of unbalanced nutrients superimposed on an environmental heat stress.'
5. previous periods of protein undernutrition.

The second major conclusion is that the response to supplementation of cattle on N-deficient forages will be much higher at high environmental temperatures. Conversely the effects of imbalanced diets on feed intake will be much more detrimental on cattle in the tropics and sub-tropics then in temperature.

The efficiency of utilisation of metabolisable energy is the factor most effected by the constraints discussed above. This decreases confidence in any pasture evaluation system that is based on metabolisable energy values. The discussion also emphasised the need for caution when extrapolating from laboratory to the field.

It is apparent that the benefits of supplementation to balance nutrient availability will have much larger effects in the tropical countries than in temperate areas.

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