BIOLOGICAL ENERGY PROCESSES IN ANIMAL PRODUCTION

G N LOUW, Rumevite (Pty) Ltd

Introduction

The oil crisis of the past few years had a more far reaching influence on the agricultural industry than one would have thought at the first instance. In the highly mechanized agriculture of the present time the expenditure of fossil fuel energy per hectare is often substantially greater than the energy yield embodied in the food produced, and the gap is ever widening. Variable costs are increasing in all sectors of industry with a direct influence on cost of food production, as well as the purchasing power of the consumer.

Agriculture, and especially the animal industry, are hit very hard from both sides. Economic recessions in especially the beef industry have consequently been occurring in most developed countries.

As a result of this new awareness of a threatening energy shortage it is conceivable that animal scientists should endeavour to improve energy utilization by farm animals. Man is omnivorous and obtains his food directly from plants or indirectly from them by consuming animal products. The utilization of plants is the most direct form of utilization of solar energy. The efficiency of solar energy being stored by plants in the form of carbohydrates is about one or two per cent. Each time this energy is transferred to another organism (such as when a steer grazes) a 90 to 95 per cent loss occurs. This means that the further man moves away from plants as a source of food, the higher the real cost.

It is, however, true that man cannot utilize roughages which consist mainly of cellulosic material. The ruminant, on the contrary, is ideally suited to feed on such materials. It is for this particular reason that these animals have been living in such close association with homo sapiens through the ages and will continue to do so.

The efficiency with which farm animals utilize food energy will have a large bearing on decisions as to what animal production systems should be employed. The figures in Table 1 may serve as an indication of the relativity in this connection.

From Table 1 it seems logical that efficiency of energy utilization for food production will in future enjoy more attention. However, it will always be against the background of the monogastric, which competes with man for food, versus the ruminant, which lives in complete harmony with man.

Investigation of the reasons for these differences necessitate a closer look at the energy metabolism of these animals.

TABLE 1 Efficiency of production of food protein and energy by domesticated animals (Reid, 1970)

Food	Production of	
	Protein (g/MJ of DE*)	Energy (as % of DE*)
Pork	1,46	18
Eggs	2,41	12
Broiler	2,84	12
Milk (3 600 kg/year)	2,51	22
Milk (5 400 kg/year)	3,06	27
Beef	0,69	6

*DE =digestible energy ingested

Aspects of energy metabolism

When animals ingest food it has to be masticated, digested and absorbed before any of the nutrients of which it is composed can be metabolised in the body. All these processes involved in food utilization require energy and many induce substantial energy losses. Ingested energy thus follows a multitude of biological pathways before it is expended.

The best way of illustrating the major pathways is by means of Figure 1.

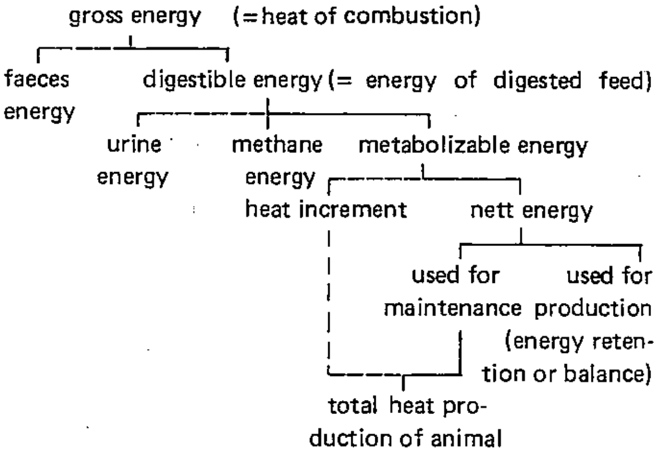

FIG 1 The partition of food energy in the animal (MacDonald, Edwards and Greenhalgh, 1973)

Gross energy is the heat of combustion of the ingested food, while digestible energy is actually its apparent digestible energy content. During the process of digestion much gas is produced in the alimentary tract as a result of microbial activity. In monogastrics this activity is relatively low, but in ruminants the fermentation process in the paunch is rather active. The total energy lost in the form of gasses from the rumen amounts to approximately eight per cent of gross energy ingested.

The processes essential for food digestion and metabolism require a certain amount of energy, which in terms of animal productivity is actually lost. This energy fraction is known as the specific dynamic action or heat increment of a food, and varies among foods.

Nett energy is that fraction of gross energy which is finally available for maintenance and production.

The major key to energy utilization in the body is adenosine triphosphate (ATP). Energy is released when this product is split into adenosine diphosphate (ADP) and phosphoric acid. The ATP must be resynthesized continuously and there are no appreciable stores in the body. It is actually resynthesized from its products as soon as it is broken down.

The energy needed for the latter process is derived from the splitting of creatine phosphate, which also has to be resynthesized continuously. Energy for this activity is derived from combustion of food, measured by the consumption of oxygen, and glycolysis which is the break-down of glycogen resulting in the formation of lactic acid. The second of these processes is reversible in so far that with an input of energy from food combustion, lactic acid is reconstituted to glycogen.

The loss of energy as heat is about 56 per cent when glucose is oxidised in the formation of ATP, while the efficiency of free energy capture is only 44 per cent. The ingestion of carbohydrates and fats increases the body's resting energy output by about five per cent. This is a relatively low value which might be due to the synthesis of glycogen from glucose.

The heat increment of proteins is much higher. After the ingestion and break-down of proteins (unaccompanied by fats or carbohydrates) the energy output is increased 20 to 30 per cent above that of intake. Amino acids like phenylalanine, glycine, alanine and glutamic acid have very marked calorigenic action, in contrast to arginine and histidine which produce a low dynamic action. Apparently the extra energy is required by the liver for deamination of amino acids and the formation of urea.

As concerns protein synthesis, the linking of one amino acid to another requires the expenditure of three pyrophosphate 'high energy' bonds, and if the ATP which provides these is obtained through glucose oxidation, about 2 500 kJ of energy will be lost as heat for each kg of protein formed. (MacDonald *et al*, 1973; Burton, 1965).

The practical implications of this physiological phenomenon is that, apart from other aspects of protein metabolism, a well-balanced supply of amino acids in rations for monogastrics is imperative for maximum energy utilization.

In monogastrics sugar form the major source of energy. In ruminants, however, energy is absorbed mainly in the form of volatile fatty acids produced in the rumen by anaerobic fermentation. The most important acids produced are acetic, propionic and butyric acids, which occur in varying proportions, depending on the type of ration being ingested. Long roughage promotes the production of acetic acid, while concentrate feeds result in lower acetic acid and higher propionic acid levels.

The significance of these acids in ruminant nutrition is reflected by the fact that some 70 per cent of the gross energy of nutrients which pass the gut wall consist of volatile fatty acids (Blaxter, 1962). In this context it is interesting to note that a cow can produce 1,5 kg acetic acid per day.

The magnitude of energy loss through gas production as a result of the anaerobic fermentation taking place in the rumen is significant. According to Blaxter (1962) the amount of methane produced by cattle can approach 400 litres/24 hours, while sheep can produce up to 50 litres, amounting to 10 per cent of gross energy ingested. It is for this reason that metabolizable energy is presently being introduced as the more popular criterion for expressing the energetic value of feeds.

The heat increments, and thus the efficiency of utilization, of steam volatile fatty acids differ appreciably. Blaxter (1962) provided data in this connection.

From Table 2 it seems that there is a synergistic effect between propionic and butyric acids, while acetic acid makes no such contribution. It was also proved that if a mixture of propionic and butyric acids, in a ratio of 3:2, is added to acetic acid, the efficiency of utilization of acetic acid for maintenance over a range of molar proportions of 0 to 90 per cent varies very little. It is apparent that propionic acid, even in relatively very small quantities, is necessary to facilitate this action of acetic acid.

TABLE 2 The calorimetric efficiencies of utilization for maintenance of some end-products of ruminant digestion (Blaxter, 1962)

End-product	Calorimetric efficiency
Acetic acid	59,2
Propionic acid	86,5
Butyric acid	76,4
Propionic + butyric acids, 60:40	90,7
Acetic + propionic + butyric acids, 75:15:10	85,6
Acetic + butyric acids, 90:10	65,0

The fatty acids produced in the rumen tend to be specific for the production of various hydrocarbon products in the body. It seems that acetic acid is essential for milk fat production and that propionic acid provides carbon skeletons for glycerol, lactose and glycogen.

These aspects of energy metabolism have a profound influence on practical animal production. It dictates the formulation of rations for milk production, growth and fattening of steers and lambs and consequently of the efficient use of available feed resources. It is now clear why ruminants are the poorest converters of feed to meat.

Farm animals are hometherms, which means that they attempt to keep their body temperature constant. As a rule heat is lost through convection, radiation and conduction. Isolation of the body by hair or a fat layer underneath the skin are the most common ways of protecting the animal and thus of preserving its energy resources. It is, however, of much practical importance that the heat increment of food plays an important part in stabilising the energy resources of the body under cold conditions.

When an animal starts to lose heat its primary defence is to restrict the flow of blood from the interior of the body to the skin. As a second stage it starts to shiver in an attempt to produce sufficient heat for maintaining the equilibrium. The environmental temperature below which heat production is increased, is known as the critical temperature.

MacDonald *et al* (1973) used the following example to illustrate the mechanism employed by a pig to maintain body temperature. When a pig is being fasted it will start shivering at an environmental temperature of 20°C. If, however, the pig is fed the heat increment of the food will result in the animal maintaining heat equilibrium until environmental temperature has dropped to 5°C, meaning a difference of 15°C. This lower level of temperature at which the self protecting mechanisms of the body come into operation is known as the effective critical temperature.

The effective critical temperature will vary with the quantity of food consumed and the efficiency with which it is metabolised.

In the case of ruminants it is important to note that the heat of fermentation in the rumen contributes largely to the heat increment. The practical implication of this is that well-fed animals can withstand cold much better than hungry ones. This applied particularly to winter conditions when food is scarce and the digestibility of the grass low.

On the contrary, however, the effect of the heat increment of feeds and the ability of animals to dissipate excessive body heat have significant depressive effects on tropical livestock farming. In tropical regions grazings are fast growing and mature quickly. The heat increments of these materials are relatively high and contribute much to create heat stress in unadapted animals.

Excessive build-up of heat in the animal results in various physiological deviations which suppress productivity. Bond (1973) cites literature which indicate that under hot climatic conditions the manifestation and intensity of oestrus are decreased and miniature calves are born. It is necessary that livestock should be adapted to warm climates, and that excessive body heat, which includes the heat increment, should be dissipated as effectively as possible.

The young animal tends to store more energy in the form of protein than does older ones. In young calves, for instance, approximately 35 per cent of the energy retained is stored as protein, whereas in older animals this value is only 15 per cent. (Mac Donald *et al,* 1973).

It was indicated in Table 1 that the high producing dairy cow is the most efficient converter of energy into food, while the beef animal rates the lowest. This also applied to the utilization of metabolisable energy for fattening. In trials with dairy cows the conversion of metabolisable energy of food given in excess of requirements for maintenance needs was coverted to milk with an efficiency of 70 per cent. When the same foods were given to fattening animals the average efficiency with which they were converted to body fat was 58 per cent only (Blaxter, 1962). This applied to a limited range of rations only. According to various other literature the efficiency of milk secretion may exceed that of fattening by as much as 20 per cent.

With regard to the efficiency of energy utilization by dairy cows while lactating or dry, MacDonald *et al* (1973) states the following:—

"The combined efficiency of tissue gain and loss in the lactating cow is 61,6 per cent. The process of laying down body tissue during lactation, and its subsequent mobilisation for milk production is thus only marginally less efficient than direct milk production from dietary energy. Tissue gain in a non-lactating cow, followed by mobilisation of milk production, has a much lower combined efficiency of 49,1 per cent."

It is on account of these findings that the practice is sometime propogated that cows should be put in good condition before being dried off. Putting on condition during the dry period before calving might be less economical.

The practical implications of all this is that the animal industry will be forced towards the production of milk as farming becomes more intensified and feeds more expensive. As regards red meat production the only way out will be to rely more on natural grazings and low quality crop residues. In this connection the feeding of NPN and the treatment of roughages with NaOH can contribute much.

Considerations regarding some energy sources for the future

Similar to industrial fuel the demand for biological fuel will become more critical as time moves on. The depletion of fossil fuel reserves might call on agriculture to produce energy sources for essential traction items like ploughing and harvesting. Competition for food by man will then not only be restricted to monogastrics. Machines might prove to be more gluttonous than any number of chickens or swine.

It is therefore necessary that stock should be taken in time about potential energy sources. In terms of agricultural involvement it means harnessing solar energy, which requires soil, water and fertiliser. The question may be posed whether the economy of fertiliser production will warrant such projects.

However, as far as animal production is concerned, it is logical that the ruminant will regain its historical position as man's closest ally in converting plant material into food. It cannot be accepted that the luxury of feeding high quality grains and oil cakes to monogastrics can last for ever.

As concerns the future of ruminant nutrition, it promises to have much interesting aspects in store. During the last 25 years the use of NPN as a source of crude protein for these animals has been exploited to an almost optimum level. It has brought about a revolution in the utilization of veld grazings under extensive conditions. However, as far as rumen stimulation is concerned, NPN has limitations. Since its effect is based completely on biological activity the bound energy in low quality roughages could never be made available to the animal to the fullest extent. Fermentation systems have their limitations and in the case of typical winter grass or crop residues rumen stimulation by NPN supplementation can at its best assure maintenance of the animal. Digestibility of these materials can as a rule only be increased from approximately 36 to 45 per cent.

The advent of PVC production in our country has now opened a completely new field in the technology of animal production. For the first time NaOH will be available at an acceptable price and the adapted method of Beckmann for roughage treatment may become a proposition.

Hofmeyr and Jansen (1976) estimate the readily available crop residues in South Africa to be in the order as given in Table 3.

The addition of four to five per cent NaOH to any of the materials indicated in Table 3 increase their digestibility by about 75 per cent. Should the necessary NPN protein and minerals be added to correct for certain deficiencies, the final product will still be cheaper than grain, with which it will compete to some extent.

TABLE 3 Production and possible availability of low quality roughages in South Africa. (Average for period 1970/71 to 1974/75) (Hofmeyr and Jansen, 1976)

	Produced (tons)	Available (tons)
Oat straw	104 000	78 000
Barley straw	35 000	26 250
Rye straw	6 000	4 500
Wheat straw	1 656 000	1 242 000
Maize straw	8 671 000	6 503 000
Sorghum straw	503 000	377 250
Bagasse	2 720 256	2 720 256
	13 695 256	10 951 506

Conclusion

Animal production, and particularly that of ruminants, is closely integrated with the nutrition and clothing of mankind, and will remain so. In order to keep pace with population growth greater demands will be put on the animal industry to supply in these needs. This necessitates more research on animal and plant performance, as well as highly effective methods of education in order to put new knowledge in practice. The role of the fertiliser industry in this regard cannot be emphasized too much.

References

BLAXTER, K.L., 1962. The energy metabolism of ruminants. London: Hutchinson.

BOND, J., 1973. Environment and reproduction. Factors affecting calf crop. Edited by Cunha, T., Warnick, A. & Koger, M. Gainesville: Univ. Florida Press.

BRODY, S., 1945. Bioenergetics and growth. New York: Hafner Press.

BURTON, B.T., 1965. The Heinz Handbook of Nutrition. New York: McGraw-Hill.

HOFMEYR, H.S. & JANSEN, T.H., 1976. Die moontlikheid van bytsodabehandelde ruvoere vir veeproduksie. *S. Afr. Tydskr. Veek.* 6., 147–154.

MACDONALD, P., EDWARDS, R.A. & GREENHALGH, H.F.D., 1973. Animal Nutrition. Edinburgh: Oliver & Boyd.

ORTEN, J.M. & NEUHAUS, O.W., 1970. Biochemistry. St. Louis: C.V. Mosby Co., U.S.A.

REID, J.T., 1970. The future role of ruminants in animal production. Physiology of digestion and metabolism in the ruminant. Edited by A.T. Phillipson, Oriel Press.