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Choosing between animals

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Consideration is given to possible changes in emphasis in the ratio of crops to animal products, and in the contribution from different animal products to Britain's food supplies.

Basic factors affecting the biological and economic efficiency with which animals convert feedstuffs to food for man are considered with emphasis on lifetime performances of whole populations.

Estimates are made of the efficiency with which current commercial farm animal systems provide food, with brief reference to less conventional animals. Attention is focused on the range of ruminant systems whether heavily dependent on forage, or on grain and other concentrated feeds. Capital, labour and support energy needs of various animal systems are considered briefly.

The results are evaluated in relation to other recent studies and to the long term problems of food policy planning.

Objectives

It is possible that a reduction in the importation of feeding stuffs, an increase in the degree of self-sufficiency in food and a decline in the contribution of animal foods to the human diet may be necessary even in the short term in Britain if our economic troubles persist, and probably worldwide in the long term as population presses on resources. Some choice between animals may therefore be necessary so that the best use of resources is achieved individually and nationally. The purpose of this paper is to consider the criteria upon which choice can be based, the components of the efficiency with which animals convert feedstuffs into food and other products of value to man, taking account not only of feed efficiency but also of the adaptation of various animals and systems to available resources. Comparisons will be drawn both between species and between alternative systems within species.

The paper does not consider either the choice of better animals for breeding or the evaluation of different breeds within a species. There are well organized procedures for recording performance, for the selection of breeding stock and for the evaluation of breeds or strains. If these continue to be applied and improved, animals or breeds of higher productivity will be selected.

Components of efficiency

The estimation of feed efficiency of any animal system is concerned essentially with the lifetime yield of the useful animal product in relation to the total inputs of feed resources. It is helpful to consider the components which contribute to this overall figure.

Reproductive index

Breeding populations are needed to provide the raw material as animals for meat production or to yield milk or eggs. Reproductive performance is therefore important. This includes the aspects summarized in table 1. Earliness of breeding, length of the reproductive cycle, regularity of breeding, number in the litter and peri-natal mortality (important with some of the larger breeds of cattle), are all important. These factors have been included in a reproductive index in table 2 where the typical values for the annual mass of live young born or hatched are compared with typical masses of the dam. Since the maintenance cost of the animal varies with metabolic body size ($W^{0.75}$) the values expressed per kilogram$^{0.75}$ are probably more appropriate than those based on $W^{1.0}$. On the basis of metabolic body size poultry clearly show much higher reproductive indices than mammals, but within the mammals all values fall within the range attained by the cow bearing a single calf or bearing twins.

Table 1. Reproductive efficiency

(1) Age at first breeding
(2) Length of reproductive cycle
(3) Regularity of breeding
(4) Number in litter
(5) Peri-natal mortality

Table 2. A reproductive index

	typical mass of dam (kg)	$W^{0.75}$ ($kg^{0.75}$)	mass of progeny at birth (kg)	no. of progeny per year	mass of progeny per year (kg)	reproductive index per kg	reproductive index per $kg^{0.75}$
chicken	2.5	1.99	0.05	100	5.0	2.0	2.51
				150	7.5	3.0	3.77
				250	12.5	5.0	6.28
turkey	10	5.62	0.10	50	5.0	0.5	0.89
				80	8.0	0.8	1.42
rabbit	4.5	3.09	0.05	20	1.0	0.22	0.32
				40	2.0	0.44	0.65
sow	170	47.1	1.5	12.0	18.0	0.11	0.38
			1.2	24.0	28.8	0.17	0.61
ewe	70	24.2	4.5	1.0	4.5	0.06	0.19
			4.0	2.0	8.0	0.12	0.33
			3.0	3.0	9.0	0.13	0.37
cow	500	105.7	42	1.0	42	0.08	0.40
			35	2.0	70	0.14	0.66

Replacement index

The cost of maintaining and replacing breeding stock also affects feed efficiency. A replacement index based on the average breeding life of the female and annual number of progeny is shown in table 3. Replacements clearly increase from a very small proportion with the chicken to some 25 % of the total progeny with the cow and the sheep.

Productive efficiency

Similarly productive efficiency is affected by a number of factors (table 4). Obviously the maintenance of health is vital. This is the subject of another paper. Productivity in relation to maintenance requirement is dominant and in addition to gross productivity, the nature and composition of the product are most important. Productivity can again be expressed most usefully, for comparisons between species, on the basis of metabolic body size. Table 5 expresses growth rates as a proportion of the mid weight expressed as metabolic body size. Milk yields and egg yields can also be expressed per $kg^{0.75}$ and indeed all forms of production can be compared in terms of yield of protein per unit metabolic body size (table 6).

The data in table 5 show that while the maximal growth rates per kg W vary inversely with W, expression of growth per $kg^{0.75}$ reduces the range and values of 30–40 $g/kg^{0.75}$ are attainable by all species, with lamb showing even higher values but turkey lower.

TABLE 3. A REPLACEMENT INDEX

	typical breeding life (yr)	replacements per year	typical progeny per year	replacement index†
broiler	1	1	120	0.0083
turkey	1.5	0.66	60	0.011
rabbit	1.5	0.66	20	0.033
			40	0.0165
pig	2.5	0.4	12	0.033
			24	0.017
sheep	4.0	0.25	1.0	0.25
			2.0	0.125
suckler cow	5.0	0.20	1.0	0.2
milk cow	4.0	0.25	1.0	0.25

† Calculated as female replacements divided by total progeny.

TABLE 4. PRODUCTIVE EFFICIENCY

(1) Control of mortality and disease
(2) Lifetime production relative to the maintenance requirement
(3) Proportion of product utilized
(4) Composition of product

TABLE 5. TYPICAL RELATIVE GROWTH RATES OF MEAT ANIMALS

	birth or hatch mass (kg)	final mass (kg)	mid mass (kg)	mid mass ($kg^{0.75}$)	days to finish	daily gain (g)	r.g.r. (g/kg)	r.g.r. ($g/kg^{0.75}$)
broiler	0.05	2.0	1.02	1.02	60	32	32	31
duck	0.05	2.9	1.48	1.34	56	51	34	38
turkey								
stag	0.06	12.6	6.33	3.99	161	78	12	19
hen	0.05	7.6	3.33	2.46	147	51	15	21
rabbit	0.05	2.0	0.97	0.98	60	32	33	33
	0.05	3.2	1.63	1.44	98	32	20	22
pig								
pork	1.5	64	32.8	13.70	115	540	16	39
bacon	1.5	90	45.8	17.60	165	540	12	31
hog	1.5	104	52.8	19.58	198	520	10	26
sheep:								
early lamb	4.0	35	19.5	9.28	70	440	23	47
late lamb	4.0	50	27.5	12.0	210	210	8	18
cow:								
veal calf	42	180	111	34.2	131	1050	10	31
cereal beef	42	407	225	58.0	349	1050	5	18
18 month beef	43	475	259	64.6	569	760	3	12
24 month beef	43	513	278	68.1	722	650	2	9
red deer	4.0	60	32	13.4	365	153	5	11

Table 6 shows an even narrower range between the animals when performance is expressed as protein yield per day per $kg^{0.75}$. The highest value is shown for milk production, and rapidly growing mammals exceed poultry in rate of protein production per unit metabolic body size.

TABLE 6. TYPICAL VALUES FOR DAILY FORMATION OF PROTEIN RELATIVE TO BODY WEIGHT

	mid mass	daily gain or production	carcass	protein	protein production	protein production
	$kg^{0.75}$	g	%	g/kg	g/day	$(g/day)/kg^{0.75}$
eggs	1.68	41		102	4.18	2.5
broiler	1.02	32	63	113	2.27	2.3
duck	1.34	51	60	118	3.61	2.7
turkey:						
stag	4.0	78	79	144	8.86	2.2
hen	2.5	51	79	144	5.85	2.4
rabbit	1.0	32	60	160	3.12	3.1
	1.4	32	60	160	3.07	2.2
pig:						
pork	13.7	540	77	110	45.7	3.3
bacon	17.6	540	78	105	44.2	2.5
heavy hog	19.6	520	80	90	37.4	1.9
sheep:						
early lamb	9.3	440	45	130	25.7	2.8
late lamb	12.0	210	45	120	11.3	0.9
cow:						
veal calf	34.2	1050	58	140	85.3	2.5
cereal beef	58.0	1050	54	140	79.4	1.4
18 month beef	64.6	760	54	140	57.4	0.9
24 month beef	68.1	650	52	140	47.3	0.7
red deer	13.4	153	58	145	12.9	1.0
milk	105.7	11230	—	33	370.6	3.5

With the carcass animals, efficiency is affected not only by growth rate but also by the proportion of the live animal which is regarded as carcass, the carcass or killing out percentage, the proportion of the carcass and of the offal which is edible, and the composition of the edible carcass. There is great variation in these figures because of differing conventions and differing tastes. When composition of the edible product is considered it should be noted that poultry, rabbit and game tend to yield meat of high protein content and less than 10% fat while the conventional farm animals tend to yield carcasses in which at least 25% of the edible carcass is fat. Changing human dietary demands, the possible health risk from high fat diets and the high food cost of fat deposition have all led to increased interest in the possibility of using game animals for meat production and in the use of some of the less selected breeds such as Soay sheep (McLelland, Bonaiti & Taylor 1976) and Limousin cattle (Limousin Simmental Tests Steering Committee 1977).

Farm or game animals also provide skins and hides which are of commercial value and the wool sheep yields additional protein in its fleece which may equal in one year the total yield of edible protein from the carcass.

Intermediary metabolism

Much work has been done in recent years to evaluate the digestibility and metabolizability of feeding stuffs, and to estimate the net availability of metabolizable energy for various animal processes. Reid (1974) has summarized current estimates. Perhaps it is not widely enough appreciated that while these indicate the upper limits of net energetic efficiency for particular processes, the upper limit of gross efficiency which is more important in practice depends to a great extent on the relative feed capacity of the animal, i.e. its feed intake relative to maintenance requirement. This conclusion emphasizes the importance of current studies to understand and control the voluntary appetite of farm animals.

Current estimates of the efficiency of food conversion by farm animals

Recorded levels of commercial farm production reported by the Meat and Livestock Commission (1976), the Milk Marketing Board (1974), Moran & Orr (1969), Moran, Orr & Lamond (1970), Salmon (1974) and gleaned from a wide range of other technical sources have been used to estimate the efficiency with which farm animals in practical conditions convert their feed to edible energy or protein.

The quantities of feed consumed have been converted to metabolizable energy (m.e.) and crude protein on the basis used by M.A.F.F. (1975). For gross energy, average values of 20.5 MJ/kg d.m. for concentrates and 18 MJ/kg d.m. for grass and forages were assumed. The carcass percentages and proportions of lean meat in the carcass have been based on the sources noted, on data of the Limousin Simmental Tests Steering Committee (1977) for cattle, and on Lean, Curran, Duckworth & Holmes (1972) for pig meat. The assessment of the composition of the edible meat was based on dissection data, on Callow's (1947) estimates of calorific and protein content of meats and, particularly for poultry, on unpublished data kindly provided by Dr Southgate.† With the milk cow where milk and a calf are joint products, the feed of the cow has been allotted to milk and the calf was regarded as a by-product. In the data for broilers, duck and turkey the skin has been included in the edible meat; this may considerably exaggerate the proportion eaten by many consumers.

These estimates are all based on the best estimates available to the author but considerable variations occur in each component of the estimates. A standard deviation of $\pm 10\%$ might reasonably be applied to all the following efficiency estimates.

Efficiencies have been calculated as the proportion of feed protein, feed metabolizable energy (m.e.) and feed gross energy (g.e.) which is returned as edible nutrient. In addition, since protein is the major animal product but energy supply is normally the limiting factor, the yields of protein per MJ of m.e. and of g.e. have been calculated.

Single animals

Calculations of efficiency were first made on single animals from hatching or birth to slaughter for meat animals, from the beginning of lay for chickens and from the beginning of lactation for milking animals. These are shown in detail in appendix 1 and summarized in table 7.

The highest efficiency of protein conversion is shown by young mammals (pork, early lamb and veal) and by egg production while the lowest efficiencies occur with less intensive meat production. The pattern is similar for energy conversion but turkey, with a low energy content in the meat, yields rather low values similar to those from beef production.

† Personal communication based on data to be published in *The composition of Foods*, by McCance, Widdowson, Paul & Southgate.

When protein yield is expressed per MJ of energy there is close similarity between all the more intensive forms of livestock production, with poultry, rabbit, pork and bacon, early lamb, veal, milk and egg production all yielding 2.5–3.4 g protein per MJ m.e. When gross energy is considered the non-ruminants yield the higher values because of the higher metabolizability of gross energy in their diets, and milk production yields the highest return from ruminant animals.

Table 7. Measures of feed efficiency for single animals from hatching, birth, beginning of lay or lactation

	edible protein†	edible energy‡	edible energy§	efficiency: g protein/MJ of m.e.	efficiency: g protein/MJ of g.e.
eggs	25	21	14	3.2	2.1
broiler	19	16	11	2.9	2.1
turkey	20	9	6	3.1	2.2
rabbit	17	13	8	3.2	1.9
pork	27	31	20	3.4	2.2
bacon	22	25	17	2.6	1.8
heavy hog	15	22	15	1.7	1.1
early lamb	28	28	25	3.3	3.0
late lamb	10	15	9	1.3	0.8
veal	25	12	10	2.9	2.2
cereal beef	12	10	6	1.3	0.8
18 month beef	11	10	6	1.3	0.7
24 month beef	9	10	6	1.1	0.6
milk, with 900 kg conc./cow	20	21	11	2.5	1.4
milk, with 1650 kg conc./cow	21	23	13	2.8	1.5

† As a percentage of crude protein eaten.
‡ As a percentage of metabolizable energy eaten.
§ As a percentage of gross energy eaten.

If the efficiency, expressed as g protein per MJ of metabolizable energy, is compared with the estimates of relative growth rate (table 5) or of relative protein production (table 6) there is a strongly linear relation:

$$\text{g protein per MJ of m.e.} = 0.57 + 0.066\ \text{r.g.r.}\ (\text{g d}^{-1}\ (\text{kg}^{0.75})^{-1})$$
$$(n = 10;\ p = 0.001;\ r = 0.84;\ \text{r.s.d.} \pm 0.50); \quad (1)$$

$$\text{g protein per MJ of m.e.} = 0.77 + 0.72\ \text{protein}\ (\text{g d}^{-1}\ (\text{kg}^{0.75})^{-1})$$
$$(n = 13;\ p = 0.001;\ r = 0.83;\ \text{r.s.d.} \pm 0.47); \quad (2)$$

where n = number, r = correlation coefficient, and r.s.d. = residual standard deviation.

Populations

While the efficiencies for single animals provide a basis for comparison of species, inclusion of the food costs for rearing the chicken to egg laying and the cow to calving, for maintaining the dam and rearing her replacement, and credit for the carcass value of the culled breeding animals are essential for a comprehensive evaluation. Such calculations are shown in appendix 2 and summarized in table 8. (Male animals are few in number and their requirements have been ignored.)

These estimates indicate that for efficiency of protein conversion, eggs, milk, milk plus beef, poultry and pig production yield high values while breeding populations of sheep or beef cattle yield low values. Egg production, milk production, pig meat production and broiler production also show high efficiencies of conversion of m.e. and of gross energy. The trends are again similar for the yield of protein in relation to m.e. For the production of protein per unit of g.e. the poultry, whether for meat or egg production, yield the highest returns because poultry feeds contain a higher proportion of m.e. in the gross energy.

Table 8. Measures of feed efficiency in breeding populations

	edible protein†	edible energy‡	edible energy§	efficiency: g protein/MJ of m.e.	efficiency: g protein/MJ of g.e.
eggs	22	19	12	2.9	1.9
broiler	17	14	10	2.6	1.9
turkey	18	8	6	2.8	2.0
rabbit	13	10	6	2.4	1.4
bacon:					
12 piglets/year	14	16	11	1.7	1.1
24 piglets/year	18	19	13	2.0	1.4
sheep:					
1.4 lambs/year‖	4.0	6.0	3.3	0.5	0.3
2.8 lambs/year	6.2	9.3	5.2	0.9	0.5
suckler cow:					
0.9 calves/year‖	4.4	5.2	2.8	0.6	0.3
1.8 calves/year	7.4	7.3	4.1	0.9	0.5
milk with low concentrates	19	20	11	2.4	1.3
milk and 18 month beef	16	17	9	2.1	1.1
milk and 24 month beef	16	16	9	1.9	1.1
milk with high concentrates	20	21	12	2.5	1.4
milk and veal	20	20	12	2.5	1.4
milk and cereal beef	18	18	10	2.2	1.3
milk and 18 month beef	18	18	10	2.2	1.2

† As a percentage of crude protein eaten.
‡ As a percentage of metabolizable energy eaten.
§ As a percentage of gross energy eaten.
‖ Normal levels of prolificacy – for pigs the intermediate value of 16 per year is normal.

If the population values are compared with those for single animals the differences are small for poultry or for milk production. Moreover inclusion of by-product veal, or beef production with milk production, results in a relatively small loss of efficiency.

However, where replacement rates are high and reproductive indices are low, as for sheep and suckler beef cows, efficiency by any measure is reduced to half or less the figure for the single animal, and even with prolific animals like the pig or the rabbit the cost of maintaining the dam is substantial. For the pig, the sheep and the cow, where good husbandry, exogenous hormone application or, with cows, the fostering of an additional calf from the dairy herd, make possible an increase in the young reared per year, two estimates have been made. For the sheep and the cow doubling the number of progeny increases efficiency by about 50%. With the pig, however, with larger numbers of progeny, the improvement in feed efficiency from a doubling of piglets reared is of the order of 25%.

It should of course be stressed that within any animal system higher performance, the result of improved genotypes, better feeding and management, is likely to increase efficiency. For example (table 7) the higher milk yields associated with more liberal feeding of concentrates resulted in a small increase in all measures of efficiency; whether higher yields are commercially worth while depends primarily on the ratio of feed price to product price and on the magnitude of the non-feed costs.

Table 9. The yield of product, edible protein and edible energy which can be obtained from breeding populations fed from the produce of 1 hectare

	product/kg		edible protein	edible energy
	carcass	eggs	kg	MJ
eggs	85	1250	138	8900
broiler	1225†	—	137	7500
turkey	1000‡	—	144	4200
rabbit	730	—	118	4800
bacon				
12 piglets/year	745	—	80	7700
24 piglets/year	900	—	98	9300
sheep				
1.4 lambs/year	268	—	32	3500
2.8 lambs/year	423	—	50	5500
suckler cow				
0.9 calves/year	255	—	35	2800
1.8 calves/year	365	—	50	4100
		milk		
milk with low concentrates§	60	3940	138	11500
milk and 18 month beef‖	166	2800	116	9500
milk and 24 month beef‖	162	2600	110	9400
milk with high concentrates¶	52	4100	142	11790
milk and veal‖	100	3900	144	11500
milk and cereal beef‖	135	3100	120	9700
milk and 18 month beef	150	3000	120	9900

† Skin is included. If excluded, values are reduced to about 70% of the values shown.
‡ Skin is included. If excluded, values are reduced to about 80% of the values shown.
§ Low concentrates, 900 kg/year per cow.
‖ The calves surplus to these needed to replace the milking herd are reared for veal, cereal beef, etc.
¶ High concentrates, 1650 kg/year per cow.

Production per hectare for feed production

The population data were used to calculate the quantity of edible protein and energy which could be derived from the various animal systems, per hectare required to produce the feed. For this purpose it was assumed that concentrates based mainly on barley were derived from crops yielding 4000 kg per hectare (at 860 g d.m./kg) and that grazing and conserved grass were obtained from crops yielding 6000–7000 kg utilized d.m./ha (the higher figure in dairy herds).

The results are given in table 9 and the details included in appendix 2. These calculations show that milk and egg production give the highest yield of protein per hectare and milk the highest yield of edible energy. Poultry meat, provided all the skin is consumed, gives similar high yields of protein but lower yields of energy. Milk combined with beef production exceeds in yield pig meat production, while sheep and suckler cows give the lowest yields of edible nutrients per hectare. The outputs per hectare from milk, whether achieved with high or low levels of concentrated feeds, are similar implying that the effective productivity of cereals and grass at typical yields is similar.

These figures over-simplify the comparisons. Beef cattle and sheep can utilize grazing lands of low productivity. In such circumstances the production per hectare might be lower but the alternative uses might be forestry, waste or amenity land. Cattle and sheep can also utilize by-products on arable farms and industrial by-products, and so may raise overall productivity.

Moreover these data compare non-ruminants, such as pigs and poultry which are conventionally fed diets based almost entirely on concentrates, with ruminant cattle and sheep which can utilize cellulose, non-protein nitrogen and the products of grassland, although in current British practice cattle generally derive 20–40 % of their metabolizable energy from concentrates (cereal beef cattle derive 95 %). Only sheep (with about 6 % from concentrates) are truly grassland animals.

Table 10. Average yields of animal product per tonne of concentrate

	edible protein kg
eggs	34
broiler	34
turkey	36
rabbit	46
bacon	21
sheep	98
suckler beef	37
cereal beef	17
milk, low concentrates	123
with 18 month beef	83
milk, high concentrates	85
with 18 month beef	68
milk (marginal response)	33

The effect of a change in concentrate use

If the use of concentrated feed for livestock were to be reduced where would a reduction have the least impact? Clearly, with the livestock dependent on concentrates alone, a decline in availability would result in a corresponding decline in total output because either production would be impaired or the population would be reduced. With pigs and rabbits, however, a greater proportion of the feed might be derived from forage or by-products and with ruminants there is certainly the possibility of replacing some of the concentrates with forage. There is considerable evidence on the marginal responses in milk production to concentrated feeds (Craven 1973; Leaver, Campling & Holmes 1968). However, with beef production, because more concentrated diets tend to accelerate maturity and reduce final carcass mass, there is apparently a negative marginal response to concentrate feeding.

The data in table 10 show average yields of animal product per tonne of concentrate and for milk production the marginal responses to concentrates. It is noticeable that the marginal response for milk is similar to the overall response for poultry and that the overall returns from concentrates when fed at low levels for milk production far exceed the yield from other stock.

Other considerations affecting choice of animals

The use of fossil fuel is considered elsewhere in this conference. Leach (1975) has compared various forms of animal production and has illustrated the low fuel efficiency of all intensive animal systems. They all yield less edible energy than the fossil fuel energy used.

The economics of animal production are so confounded by politics at present that it did not prove practicable to make any full evaluation. Suffice it to observe that in general, as fixed capital increases, working capital in stock and feed tends to decline, and capital turnover is more rapid. With longer term operations based on ruminant animals for meat production, fixed capital expenditure may be low, but since capital is locked up in livestock for up to 2 years, the rate of turnover is low.

The available estimates of the return on capital (Nix 1976) have shown no strong trend between species although within the ruminant species those with a more rapid turnover such as milk or semi-intensive beef production usually give the best financial return (M.L.C. 1976).

Successful animal production is heavily dependent on good stockmanship, and improved capital equipment may be necessary in some circumstances to provide satisfactory conditions and to economize on labour.

The choice of animal systems will be made by the individual farmer on the basis of his preferences, the conditions peculiar to his farm and his estimate of the satisfaction and profit which he can derive from different enterprises. He will also be affected by the consumers' choice which will be influenced by quality, including nutrient composition, shape, size, convenience and price of the product.

Towards yet greater efficiency

The general theme of this meeting is the management of inputs for yet greater agricultural yield and efficiency. It appears that in all species, production relative to body size has a dominant influence on feed efficiency. A high reproductive rate and low replacement rate are also important. It is difficult to visualize a new farm animal which would satisfy these criteria better than existing species which have survived and developed under domestication for many generations. In the tropics it is possible that goats (Wilson 1958; Devendra & Burns 1970) and buffalo (Cockrill 1974) could be more widely used. In some harsh environments wild ungulates are better adapted than any of the conventional farm animals (Ledger 1968; Blaxter, Kay, Sharman & Cunningham 1974) but the problems of harvesting and marketing are substantial.

With regard to reproductive performance there is little scope for further improvement in feed efficiency from increased prolificacy in birds or in the most prolific mammals, but the reduction of neonatal mortality, in pigs for example, is desirable. With sheep and cattle the planned achievement of multiple births could have a beneficial effect. Doubling of the average of 1.4 lambs reared per ewe would increase yield from 0.5 to 0.9 g protein per MJ m.e. Similarly, doubling the output from suckler cows (which could be done by double suckling as well as by achieving multiple births) raises yield from 0.6 to 0.9 g protein per MJ m.e.

Where the replacement index is high the modification of herd structure offers some scope for improvement. Allen (1976) has estimated that by taking one calf crop before slaughter of beef heifers the calf crop from a cow population would be increased by 22 % and feed efficiency reduced by only 5 %.

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With regard to potential efficiency, Wilson (1973) has shown that current levels may be greatly exceeded. An objective estimate of maximal efficiency can be made from a knowledge of efficiencies of use of metabolizable energy and of relative feed levels. Reid (1974) summarized estimates of the efficiency of use of metabolizable energy for maintenance, growth, lactation or egg production in the most important species of farm animal. Relative feed level (intake as a multiple of the requirement of metabolizable energy for maintenance) ranges from less than 2 for growing ruminants on medium quality diets to more than 3 for growing pigs and lactating cows. Since net efficiency is determined by the biochemical reactions involved in the formation of body tissues and secretions it is not subject to variation (although because of the technical difficulties estimates of its magnitude vary). An exception occurs in ruminant nutrition where efficiency of use of m.e. for growth and lactation is influenced by the relative proportions of the volatile fatty acids which in turn depend on dietary quality (Blaxter 1962). Within a given dietary régime, however, net efficiency is biochemically determined and the only opportunity for increasing gross efficiency lies in the discovery and application of methods of management which maximize appetite on the available feed.

The greater growth rate of entire male cattle and lambs and pigs is now regarded as a way towards greater efficiency. However, practical considerations of consumer attitudes and government regulations do not encourage its widespread adoption with bulls. Much of the advantage from the use of male animals is associated with a desirable reduction in the fat content of the animal at slaughter. A general reduction in the level of fat content at which most animals are slaughtered and the selection of breeds of low fat content could effect a material improvement on feed efficiencies.

More efficiency in land use can come from increasing the productivity of feed crops, the choice of more productive feed crops and from the better use of crop residues and by-products.

That grassland can be more productive and better used has been known for at least 40 years. There has indeed been an increase of about 80 % in average grassland productivity in the U.K. since 1938 (Wright 1940; N.E.D.O. 1975) and recent data both on beef and milk production show that even now the better farmers are harvesting through their cattle 20–30 % more grass than the average recorded farmer (M.M.B. 1975; M.L.C. 1976).

By-products can be processed to yield satisfactory animal feeds and this subject is considered in another paper in this conference (Foot, this volume).

Lastly, and most important, is the impact of extension or advisory work. If optimal technical methods have been devised it is vital that they be made known to the farmer by the most effective means.

Comparison with other estimates of efficiency

Insofar as they are comparable, the estimates of efficiency are not dissimilar to the early estimates of Leitch & Godden (1942). The values calculated in this paper from fresh data agree in general very closely with the author's own earlier estimates (Holmes 1970) although they are more favourable and, it is considered, more correct in respect of sheep and pig production. Allowing for the possible errors in such studies there is also good agreement with estimates made by Reid (1970) and Balch & Reid (1976) and close agreement with the lifetime estimates of Wilcke (1969).

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Conclusions

In broad terms the conclusions of this survey are that the common farm animals are all capable of attaining similar levels of feed conversion efficiency as single animals. In practice, however, lower than maximal growth rates and efficiencies are commonly accepted especially with ruminant animals for meat production.

Where breeding populations are considered, the high cost of rearing and maintaining a female which produces only a small number of progeny severely reduces feed efficiency, and steps to increase prolificacy would yield substantial improvements. The milk cow is an exception to this generalization because of its concurrent high level of milk production. The rabbit, which is sometimes proposed as a meat animal deserving further exploitation, does not appear to have any outstanding merit.

Under normal farm conditions milk production, even with associated beef production, gives high yields of human food per hectare, equalled or exceeded by egg production and by meat poultry only if a high proportion of the carcass including the skin is in fact consumed. When the response to the use of concentrated feeds is considered, the dairy herd again yields the greatest return especially when fed at a modest level of concentrates.

These conclusions will influence the farmer only to the extent that they are supported by economic conditions. If, however, it is accepted that economic conditions in agriculture are much affected by governmental action what guidance do these figures give?

The efficiency of farm animals must be considered both in relation to human dietary requirements and the resources available. Alternative sources of animal protein are probably exchangeable to the majority of consumers depending on price and convenience, but the nation's land resources are less flexible. Much of our land is unsuitable for conventional arable cultivation. Recent estimates suggest that some 5.5 million ha might be cultivated but there would remain 6.5 million ha of lowland grass and 6 million ha of upland rough grazing (Blaxter 1975; H.M.S.O. 1975; Holmes 1975). An important aspect of agricultural policy must remain the encouragement of the effective use of these grasslands.

Much will depend on the future economic circumstances of the United Kingdom, but if it or any other country with large areas of grass or potential grassland found that the supply of concentrated animal feeds was reduced, it would be appropriate to allot these supplies in limited amounts (say 1 t per cow) to dairy herds, to efficient poultry units and in limited amounts to pig herds. Dairy herds with associated beef units would then be encouraged to make fuller use of grassland, pig herds to supplement their concentrate supplies with vegetable products, lower grade feed and food wastes, and the beef cattle and sheep enterprises to make full use of the pasture resources which cannot otherwise be utilized. Unless cheap energy sources can be found it might also be necessary to adopt policies which encouraged the use of natural sources of fertility by recycling of animal excreta and the exploitation of leguminous pastures which laid less emphasis on chemical fertilizers.

Throughout this paper an objective, almost mechanistic, attitude to animal production has been maintained. But there is a widespread unease about so-called factory farming. Even if animal production must be made more efficient, it is most important that it be conducted in such a manner and on such a scale that the personal attention of the husbandman and the individual initiative and satisfaction of the farmer in the care of his livestock is encouraged, while pollution from animal residues is not allowed to become a major problem.

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Appendix 1. Efficiency of production of single animals from birth, or the beginning of laying or of lactation

		nutritive value of concentrates			nutritive value of forage dry matter		total feed input			product		composition of product		edible yield		efficiency				
	concentrates fed (kg†)	crude protein (g/kg)	metabolizable energy (m.e.) (MJ/kg)	forage dry matter fed (kg)	crude protein (g/kg)	m.e. (MJ/kg)	crude protein (kg)	m.e. (MJ)	gross energy (g.e.) (MJ)	carcass (kg)	lean meat (kg)	edible protein (g/kg)	edible energy (MJ/kg)	protein (kg)	energy (MJ)	edible protein‡	edible energy§	edible energy‖	g protein/MJ total m.e. in feed	g protein/MJ total g.e. in feed
broiler	3.75	200	13	—	—	—	0.75	49	68	1.25	0.72	113	6.1	0.14	7.62	18.8	15.5	11.2	2.88	2.06
turkey:																				
stag	35.0	200	13	—	—	—	7.0	455	630	10.0	5.2	144	4.2	1.44	42	20.6	9.2	6.7	3.16	2.28
hen	22.0	200	13	—	—	—	4.4	286	396	6.0	3.1	144	4.2	0.86	25.2	19.5	8.8	6.4	3.00	2.17
rabbit	3.0	220	12	2.5	160	9	1.1	58	99	1.2	0.84	160	6.5	0.19	7.8	17.4	13.3	7.9	3.24	1.92
pork pig	133	150	12	—	—	—	20.0	1600	2394	49	23.5	110	10.0	5.4	490	27.0	30.6	20.5	3.37	2.26
bacon pig	234	140	12	—	—	—	32.8	2810	4212	70	32.9	105	10.0	7.4	700	22.5	24.9	16.6	2.63	1.76
hog pig	375	130	12	—	—	—	48.8	4500	6750	83	37.4	90	12.0	7.5	990	15.4	22.1	14.7	1.67	1.11
early lamb:																				
10 weeks	10¶	300	31	28	150	11	7.2	620	684	15.8	8.8	130	11.0	2.05	174	28.4	28.1	25.4	3.31	2.99
late lamb:																				
30 weeks	10¶	300	31	170	140	10	26.8	2010	3240	22.5	12.4	120	13.0	2.7	293	10.1	14.6	9.0	1.34	0.83
veal	230¶	250	22	—	—	—	57.5	5060	6600	104	63.6	140	6.0	14.6	624	25.4	12.3	10.0	2.88	2.19
cereal beef	1870	130	11	240	60	9	260	23000	37980	220	132	140	10.0	31	2200	11.9	9.6	5.8	1.34	0.82
18 month beef	1120	140	11	1550	120	9.5	340	27000	48060	256	141	140	11.0	36	2820	10.6	10.4	5.8	1.33	0.75
24 month beef	1000	140	11	2500	110	9.5	420	36000	63000	268	147	140	14.0	38	3750	9.0	10.4	5.9	1.06	0.60
milk:										milk										
low conc.	900	140	11	4000	120	9.5	600	48000	88200	3700	—	33	2.7	122	10000	20.3	20.8	11.3	2.54	1.38
high conc.	1650	140	11	3600	120	9.5	680	52400	94500	4400	—	33	2.7	145	11900	21.3	22.7	12.6	2.77	1.53
chicken	40	155	12	—	—	—	6.2	480	720	eggs 15	—	102	6.8	1.53	102	24.7	21.2	14.2	3.19	2.12

† 860 g d.m./kg.
‡ As a percentage of total crude protein in feed.
§ As a percentage of total m.e. in feed.
‖ As a percentage of total g.e. in feed.
¶ milk, dry matter.

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Appendix 2. Lifetime efficiencies of breeding populations

(*a*)

	input				edible output			efficiency			output per hectare required to grow the feed		
	concentrates fed / kg	area to grow feed / ha	crude protein / kg	total m.e. / MJ	product / kg	protein / kg	energy / MJ	edible protein†	edible energy‡	g edible protein/total MJ of m.e. in feed	product / kg	protein / kg	energy / MJ
egg chicken					eggs						eggs		
production	40	0.01	6.2	480	15.0	1.53	102	—	—	—	1250		
replace 1	8	0.002	1.4	96	carcass						carcass		
cull 0.8					1.0	0.12	5	—	—	—	83		
total	**48**	**0.012**	**7.6**	**576**	—	**1.65**	**107**	**22.2**	**18.6**	**2.86**	—	**137.5**	**8920**
broiler (100)													
production	375	—	75	4900	125	14.0	762						
cull dam 0.0083	35	—	5.6	450	—	—	—						
total	**410**	**0.102**	**80.6**	**5350**	**125**	**14.0**	**762**	**17.4**	**14.2**	**2.62**	**1225**	**137**	**7470**
turkey (10)													
production 285	285												
cull dam 0.0166	35												
total	**320**	**0.08**	**64**	**4160**	**80**	**11.5**	**336**	**18.0**	**8.1**	**2.76**	**1000**	**144**	**4200**
rabbit	5.5		1.06	58.5	1.2	0.19	7.8						
0.0286 dam	2.3		0.43	23.8									
replace dam 0.0165	0.2		0.04	2.4									
cull dam 0.015	—		—	—	0.05	0.01	0.3						
total	**8.0**	**0.0017**	**1.53**	**84.7**	**1.25**	**0.20**	**8.1**	**13.1**	**9.6**	**2.36**	**735**	**117.6**	**4764**
bacon, 12/year	234		32.8	2810	68	7.4	700						
sow share 0.0833	127		17.8	1520									
replace sow 0.033	23		3.2	270									
cull sow 0.025	—		—	—	3.5	0.3	35						
total	**384**	**0.096**	**53.8**	**4600**	**71.5**	**7.7**	**735**	**14.3**	**16.0**	**1.67**	**745**	**80**	**7656**
bacon, 24/year	234		32.8	2810	68	7.4	700						
sow share 0.0417	63.5												
replace sow 0.02	14												
cull sow 0.016	—	—	—	—	2.2	0.2	22						
total	**311.5**	**0.0779**	**43.5**	**3738**	**70.2**	**7.6**	**722**	**17.5**	**19.3**	**2.03**	**901**	**98**	**9271**

† As a percentage of total crude protein in feed.
‡ As a percentage of total MJ of m.e. in feed.

APPENDIX 2. (*cont.*)

(*b*)

	input					edible output			efficiency			output per hectare required to grow the feed		
	concentrates fed (kg)	forage d.m. fed (kg)	area to grow feed (ha)	crude protein (kg)	total m.e. (GJ)	product (kg)	protein (kg)	energy (MJ)	edible protein†	edible energy‡	g edible protein/total MJ of m.e. in feed	product (kg)	protein (kg)	energy (MJ)
sheep														
1.4 lambs/ewe	45	600	0.113	—	—	31	3.7	402						
replace 0.25	—	150	0.025	—	—									
cull 0.2	—	—	—			6	0.7	78						
total	**45**	**750**	**0.138**	**110**	**8.0**	**37**	**4.4**	**480**	**4.0**	**6.0**	**0.55**	**268**	**32**	**3500**
2.8 lambs/ewe	60	700	0.131	—	—	60	7.2	780						
replace 0.25	—	150	0.025											
cull 0.2	—	—	—	—	—	6	0.7	78						
total	**60**	**850**	**0.156**	**127**	**9.2**	**66**	**7.9**	**858**	**6.2**	**9.3**	**0.86**	**423**	**50**	**5500**
suckler cow														
0.9 calf/cow calf finished in 18 months	1000	4000	0.90	620	48.0	230	32	2540						
replace 0.2	—	1000	0.16	120	10.0									
cull 0.16	—	—	—	—	—	40	5	500						
total	**1000**	**5000**	**1.06**	**840**	**58.0**	**270**	**37**	**3000**	**4.4**	**5.2**	**0.64**	**255**	**35**	**2830**
1.8 calves/cow calf finished in 18 months	1500	5000	1.21	810	66.5	460	64	5100						
replace 0.2	—	1000	0.16	120	10.0									
cull	—	—	—	—	—	40	5	500						
total	**1500**	**6000**	**1.37**	**930**	**76.5**	**500**	**69**	**5600**	**7.4**	**7.3**	**0.90**	**365**	**50**	**4090**
milk														
low conc.	900	4000	0.80	600	48.0	3700	122	10000						
rear 0.2	160	600	0.14	90	7.0									
cull cow (0.16)	—	—	—	—	—	40	6	560						
surplus calves 0.75/cow	—	—	—	—	—	16	2.2	220				60 carcass 3940 milk		
total	**1060**	**4600**	**0.94**	**690**	**55.0**	**—**	**130**	**10780**	**18.8**	**19.6**	**2.36**		**138**	**11470**
calves for 18 month beef beef 0.7/cow	780	1085	0.38	238	18.9	179	25	1970				166 carcass 2800 milk		
total	**1840**	**5685**	**1.32**	**930**	**74.0**		**153**	**12530**	**16.4**	**17.4**	**2.06**		**116**	**9490**
calves for 24 month beef beef 0.7/cow	700	1750	0.47	294	25.2	188	27	2630				162 carcass 2600 milk		
total	**1760**	**6350**	**1.41**	**984**	**80.0**		**155**	**13190**	**15.7**	**16.5**	**1.94**		**110**	**9350**
milk														
high conc.	1650	3600	0.94	680	52.4	4400	145	11900						
rear 0.2	160	600	0.14	90	7.0									
cull cow (0.16)	—	—	—	—	—	40	6	560						
surplus calves 0.75/cow	—	—	—	—	—	16	2	220						
total	**1810**	**4200**	**1.08**	**770**	**61.4**		**153**	**12680**	**19.9**	**20.6**	**2.49**		**142**	**11740**

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Appendix 2*b*. (*cont*.)

	input					edible output			efficiency			output per hectare required to grow the feed		
	concentrates fed / kg	forage d.m. fed / kg	area to grow feed / ha	crude protein / kg	total m.e. / MJ	product / kg	protein / kg	energy / kg	edible protein†	edible energy‡	g edible protein/total MJ of m.e. in feed	product / kg	protein / kg	energy / MJ
calves for veal 0.75/cow	161	—	0.04 (0.33)§	40	3.54	73	10	440						
total	**1 970**	**4 200**	**1.12** (**1.42**)§	**810**	**64.9**		**161**	**12 900**	**19.9**	**19.86**	**2.48**		**144** (**113**)	**11 520** (**9 080**)
calves for cereal beef 0.7/cow	1 310	168	0.36	182	16.1	154	22	1 540						
total	**3 120**	**4 370**	**1.44**	**950**	**77.5**		**173**	**14 000**	**18.2**	**18.06**	**2.23**		**120**	**9 722**
calves for 18 month beef 0.7/cow	780	1 085	0.38	238	18.9	179	25	1 970						
total	**2 590**	**5 285**	**1.46**	**1 008**	**80.4**		**176**	**14 430**	**17.5**	**17.94**	**2.19**		**120**	**9 883**

† As a percentage of total crude protein in feed.
‡ As a percentage of total MJ of m.e. in feed.
§ If the area to produce the milk powder is included.