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Livestock Physiology and Nutrition [and Discussion]

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Livestock physiology and nutrition

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Intensive methods of nutrition and husbandry for pigs and poultry have already been developed and implemented by the farming community over the last few decades. Similar intensive techniques in the nutrition and husbandry of cattle and sheep are currently being developed as a result of economic pressures, but their acceptability will depend upon consumer attitude as well as economic justification. The physiological, genetic and nutritional constraints on increasing animal productivity are briefly described, and biological and economic ceilings likely to prevail in the middle 1980s are presented, for each livestock class in turn. The major limiting factors to achieving biological ceilings are dealt with, and it will be shown that very different percentage achievements of maximum biological ceiling are likely to be obtained in practice. New possibilities for animal production in cattle and sheep are briefly considered. The implications of these advances in terms of human food production and natural resource utilization are discussed.

Introduction

This paper is confined to the subject of animal production in the context of providing products acceptable as human food, particularly meat, milk and eggs. This restriction is an important one, since there are many systems, particularly in the developing countries, where animals are kept for very different purposes, such as draught (e.g. horse and mule), hides and skins (e.g. cattle and goats in Africa), hair (e.g. Mohair goats in South Africa), fuel (e.g. excreta of camels in north Africa), wool (e.g. sheep in Australia and, historically, in England).

Early examples of animal intensification

Intensification may be described as the maintenance of a large number of animals on a small area of land in a highly productive state. The intensification of animal production systems for human food is not new. One of the earliest systems to be developed was the food cycle, human excreta → fish ponds → fish production → pig production based on fish protein feeding → pork for human consumption, as practised by the Chinese over 3000 years ago. It is noteworthy that, although fish farming is one of the first intensive animal systems to be developed by man, research, development and practice of efficient fish farming in this country is only now receiving detailed attention, and the proportion of fish protein in our diet obtained in this manner is very small.

Fish provide a good example of the interaction of animal productivity with physical attributes of the environment. Thus Nikolsky (1963) showed that the incubation of trout eggs was not time dependent, but was related to the number of 'degree days' as shown in table 1.

TABLE 1. EFFECT OF WATER TEMPERATURE ON INCUBATION PERIOD OF TROUT OVA (NIKOLSKY 1963)

water temperature/°C	duration of incubation period/days	no. of 'degree days'
2	205	410
5	82	410
10	41	410

More work along these lines could increase the food protein yield from fish, without necessarily altering the nutritional and genetic constraints to fish productivity.

THE CONCEPT OF BIOLOGICAL CEILINGS

In the case of the traditionally accepted agricultural animals, intensification has progressed to a high level with poultry, is currently progressing with pigs and cattle, and will make steady progress with sheep by the 1980s. Such a statement of the obvious requires closer definition. I have therefore attempted to compare the present and future levels of biological efficiency of different classes of farm livestock in relation to the assumed potential or maximum biological efficiency, which I define as 'biological ceiling'. The term biological ceiling is therefore used to denote the maximum genetic improvement of which the class is capable, with the removal of all environmental constraints which normally limit the expression of genetic potential. Animals fail to reach their biological ceilings because of numerous biological limitations, the chief of which are: (*a*) reproductive efficiency; (*b*) longevity; (*c*) growth rate; (*d*) feed conversion; (*e*) disease.

To these five might be added an oft-neglected biological factor – man. The 'social limitations' to technological advance are very great and may indeed outweigh certain of the other factors in importance. Thus widespread reaction to so-called 'factory farming' may well prevent more biologically efficient production systems from being implemented.

In addition to these biological limitations there are a series of important economic limitations, since it is rarely, if ever, profitable to keep animals in a biologically optimal physical environment.

(*a*) *Reproductive efficiency*

Table 2 presents data for the probable existing standards, and possible biological ceilings, for this factor.

It will be seen that those animals capable of producing litters fail to approach their biological ceilings on two counts. First, the number of offspring produced during each pregnancy is less than half the biological maximum, and secondly, the number of pregnancies per annum is below the ceiling figure.

Table 2 deals only with efficiency of the female. The efficiency of the male can be dramatically increased by the use of artificial insemination (a.i.) and this technique is now common practice

TABLE 2. EXISTING STANDARDS AND BIOLOGICAL AND ECONOMIC CEILINGS FOR FEMALE REPRODUCTIVITY EFFICIENCY

(After Wilson 1968.)

	cow	ewe	sow	hen
existing standard				
(1) no. of offspring/litter	1.0	1.5	9	n.a.
(2) no. of offspring/year	0.9	1.5	18	220
biological ceiling				
(3) no. of offspring/litter	2.0	5.0	20	n.a.
(4) no. of offspring/year	2.2	10.0	44	365
2 as percentage of 4	41	15	41	60
economic constraint, 1985				
(5) no. of offspring/litter	1.2	3.0	14	n.a.
(6) no. of offspring/year	1.2	4.5	31	300

n.a. = not applicable.

with cattle and feasible with all other livestock classes. Further developments in the efficiency of a.i. for non-bovines, and in techniques for oestrus control and the long-term storage of semen for all classes of livestock, should further increase the male's reproductive efficiency.

The economic importance of increasing fecundity in the ewe has been stressed by Blaxter (1968), who showed that as a litter size increases, so also does the overall efficiency with which feed is converted into lean meat. Similarly, as litter size increases, there is a corresponding decline in the relative production of obligatory by-products (mutton protein and wool) compared with the main end-product (lamb protein). The pertinent data are summarized in table 3.

TABLE 3. EFFECT OF FECUNDITY OF SHEEP, ON FEED REQUIREMENTS, ON PRODUCTION OF LEAN, AND ON RATIO OF OBLIGATORY PRODUCTS TO MEAT

(After Blaxter 1969)

no. of lambs/litter	% of total lean which is mutton meat	kg wool per kg lean from lamb	kg cereals to produce 1 kg lean meat
1	36	0.86	59
2	19	0.35	38
3	12	0.22	30
4	9	0.16	27

Female reproductive efficiency is capable of further improvement by the transfer of fertilized ova from top-quality donors to lower quality recipients, so as to obtain greater productivity from the resultant offspring. This subject, however, is trespassing on to the ground of Professor Donald's paper, since the chief implications are genetic rather than physiological.

Reference back to table 2 shows that the current reproductive efficiency of the hen is 50% greater than that of the sow and cow, which are in turn, $2\frac{1}{2}$ times greater than that of the ewe. By the 1980s, the relative position will probably have altered, with modest improvements with the hen and sow, but with significant and substantial improvement with the ewe. The dairy cow will probably show little or no change by that time, but a proportion of beef cows, according to Blaxter (1973), are likely to be physiologically manipulated so as to produce a regular incidence of twinning, with the result that their relative efficiency will be much improved, approaching that of the hen in the percentage of biological ceiling achieved.

(*b*) *Longevity and productive lifespans*

The longer a reproductive animal is maintained in a productive state the smaller becomes the 'amortization cost' of the animal through its non-productive stages. Unfortunately, it is often deemed economically expedient to dispose of a reproductive animal before the end of its productive life in order to replace it by a superior animal or to reduce the chances of loss, due to death or disease (e.g. cull cows are currently worth about £200).

Most animals are currently maintained for a small proportion of their potential working lives, as can be seen from table 4.

Poultry have possibly reached the economic limit of lifespan, since the maintenance of pullets into a second laying year may be uneconomic if there is a significant break between the first and second laying periods. The economic constraint for the pig is put at 5 years. Breeding from older sows results in a marked reduction in litter size. The economic constraint for the cow is estimated at 10 years, representing an improvement of over 4 years over the current level. During later lactations, milk yield will fall, but the eighth lactation yield should not be significantly below that of the first, or heifer, lactation so the case for frequent replacement of cows by heifers is invalid on this score. Unlike all other species, the cow does not produce a saleable end-product before about 2 years of age, when the first calf is produced and lactation commences. Thus a reduction in the percentage of non-productive heifers and an increase in the proportion of cows-in-milk is clearly desirable.

Table 4. Existing standards, and biological and economic ceilings, for animal longevity (years)

(After Wilson 1968.)

	cow	ewe	sow	hen
(1) existing average life	6	4	3	$1\frac{1}{2}$
(2) biological ceiling	25	10	15	4
(3) economic restraint 1985	10	7	5	$1\frac{1}{2}$
1 as percentage of 2	24	40	20	38
1 as percentage of 3	60	57	60	100

Table 5. Existing standards, and biological and economic ceilings, for liveweight gain (g/day)

(Wilson 1973.)

	broiler	lamb	steer	porker
(1) existing l.w.g.	32	114	1140	636
(2) biological ceiling	46	456	2500	912
(3) economic restraint 1985	36	184	1590	773
1 as percentage of 2	70	25	46	70
1 as percentage of 3	89	62	72	82

Table 6. Comparison of 1929, 1954 and 1969 standard U.S.A. formulations under identical conditions

	1929 ration	1969 ration	% improvement 1969 over earlier ration	mean annual rate of improvement (%)
pigs				
l.w.g./kg (lb) per day	0.535 (1.18)	0.663 (1.46)	25	0.62
f.c.e. (kg feed/kg grain)	3.29	2.92	11	—
broilers				
weight at 2 wks/kg (lb)	0.141 (0.31)	0.227 (0.50)	61	1.5
weight at 6 wks/kg (lb)	0.708 (1.56)	0.584 (2.65)	70	
weight at 8 wks/kg (lb)	1.09 (2.40)	1.63 (3.60)	50	
	1954 ration	1969 ration		
beef cattle (feed lot)				
days fed	169	140	17	—
l.w.g./kg	1.07 (2.35)	1.44 (3.18)	35	2.3
final weight/kg (lb)	442 (974)	462 (1018)	5	—

(*c*) *Growth rate time to sexual maturity or slaughter*

The data for growth rate are presented in table 5. A similar pattern emerges as for the other factors examined, with the broiler at present growing at 70 % of its biological ceiling, pork pigs and steers 70 and 46 % respectively, with lamb production currently trailing at only 25 % of the possible maximum.

All productive indices of livestock efficiency are influenced by interacting genetic and environmental factors, and normally it is not possible to partition the causes of improvement between them. However, it has been possible to assess the effect of certain improvements in applied nutrition by comparing American diets made up to past and current standard formulations and to compare their performance on groups of livestock, to which they are fed, in a contemporary comparison. The data are summarized in table 6.

The disproportionate timescales between species are unfortunate but unavoidable, since intensification in beef cattle occurred after intensification in the pig and poultry sectors.

The overall average improvements, due solely to advances in applied nutrition, varied from 2.3 % per annum in feed-lot beef cattle to 0.6 % per annum in pigs, with broilers intermediate at 1.5 % per annum. If these rates of improvement are applicable under U.K. conditions, and assuming that they can be continued between now and 1985, pigs will reach 89 % of their economic ceilings by 1985 and beef cattle 93 %.

Since significant contributions are also to be expected from the breeder and physiologist, it follows that intensification in livestock production will enable poultry, pigs and beef cattle to approach close to their economic ceilings by the 1980s, leaving only milk cattle and sheep with room for substantial improvement, probably continuing well into the next century. Obviously, any error in the estimates, or 'guesstimates', of ceiling values will alter the position, for we may yet live to see chickens producing two eggs and not one egg in a day, but in this paper I have endeavoured to give the best assessment of the situation based on current knowledge and past trends.

(*d*) *Food conversion*

The efficiency with which livestock convert food protein inputs into end-product protein outputs, taking into account the inputs to the breeding female as well as to her saleable offspring, is of paramount importance. A study of this aspect of livestock intensification shows that the rank order of efficiency for the different livestock classes is capable of little variation when comparisons are made on a constant basis.

Table 7 gives a rank order of eight livestock classes, including fish and rabbits as well as the traditional farm animals.

The milk cow comes first with a protein conversion efficiency of 38 %. Both forms of poultry, layer and broiler, rank equal with 31 %. Fish, rabbits and poultry form an intermediate group with efficiencies between 15 and 20 %. Ruminant meat animals come last, with single figure efficiencies.

Table 7 assumes high levels of productivity currently achieved by only the top 5 % of enterprises. Thus the overall protein conversion of sheep is calculated assuming that ewes lamb down twice a year with litters of three lambs. If more average levels of productivity are taken all the figures would fall to appreciably lower levels, although as stated previously the order of ranking would not change significantly.

However, if the basis of the calculations is changed, such as by considering energy inputs to protein or energy outputs, then a very different picture emerges. This point has been clearly made by Holmes (1970) using the calculations illustrated in tables 8 and 9.

Using production data closer to those currently obtained in the average herd or flock, Holmes calculated the same rank order for protein conversion as that already presented. However, when the energy input to protein output ratio is considered, poultry rank equal at 11 % efficiency and are marginally more efficient than milk production. When the basis is changed again to an energy input:output ratio, pork production ranks first at 20 % with milk production second at 16.5 %. Poultry now take third place with an overall average of 12 %. However, in all these calculations the ruminant meat animals occupy bottom place with percentage efficiencies in single figures.

Table 7. Conversion of food protein to product protein

(Wilson 1968.)

livestock class	production level	annual c.p. consumed / kg (lb)	annual c.p. produced / kg (lb)	efficiency of conversion / (%)
cow	6800 l (1500 gal)	586 (1290)	222 (490)	38
hen	300 eggs	7.3 (16)	2.3 (5)	31
broiler	1.8 kg (4 lb) carcass	3.6 (8)	1.1 (2.5)	31
fish	0.4 ha (1 acre) warm pond stocked with carp	3400 (7500)	680 (1500)	20
rabbit	4 litters of 10	48 (105)	8 (18)	17
porker	2¼ litters of 12	840 (1850)	123 (270)	15
lamb	2 litters of 3	125 (275)	11 (24)	9
steer	295 kg (650 lb) carcass at 1 year	568 (1250)	34 (75)	6

c.p., crude protein.

Table 8. Efficiency in whole farm situations

(After Holmes 1970.)

farm system	edible energy / m.e. consumed %	edible energy / g.e. consumed %	edible protein / m.e. consumed %	edible protein / c.p. consumed %
dairy	21	12	10	23
pigs	23	17	6	12
broiler	13	10	11	20
eggs	15	11	11	18

Table 9. Efficiency in whole farm situations

(After Holmes 1970.)

farm systems	edible energy / m.e. consumed %	edible energy / g.e. consumed %	edible protein / m.e. consumed %	edible protein / c.p. consumed %
dairy	21	12	10	23
dairy + beef	20	11	9	20
beef	7	4.5	2.6	6
sheep	3	1.7	1.3	3

m.e., metabolizable energy; g.e., gross energy.

Having considered all livestock systems in general terms, the individual enterprises will now be discussed. In these sections of the paper, attention will be focused on protein conversions, since this parameter is sensitive to economic change, and since farm livestock are most likely to be valued in future for their contribution to protein food for human consumption rather than for their energy value (Blaxter 1968; Coop 1967; Holmes 1970).

Possible future improvements in livestock productivity 1973–85

(*a*) *Dairy cows*

Advances in our knowledge of the nutrition of the dairy cow are likely to be considerable. Improvements will probably take place on two fronts. First, the allocation of nutrients differentially through the lactation so that the plane of nutrition varies to suit the changing physiological requirements of the cow. Secondly, the definition of critical balances between the various minerals, of minerals with vitamins, and of metabolizable energy with digestible protein, will enable diets of optimal nutritional density to be formulated. These improved diets will supply critical nutrients in such a manner that problems of palatability and intake are progressively removed, thereby enabling the nutritional constraint on the expression of milk yield potential to be overcome.

The protection of nutrients, especially proteins and fats, from rumen fermentation and hydrogenation is likely to become of practical importance, and by removing certain of the obvious disadvantages of ruminant digestion, such as the loss of methane from the rumen and the inherent difficulty in ascertaining amino acid requirements for milk synthesis, the overall feed conversion efficiency of the dairy cow is likely to be raised.

The chief problem with the dairy cow, as with all ruminants, is whether it is desirable to adapt an animal with a compound stomach, capable of digesting low-quality fibrous roughages, to a monogastric digestion pattern by employing such systems as liquid feeding, complete diet feeding or offering fats or proteins in such a form that they are protected from ruminal digestion and pass to the abomasum relatively unchanged.

The assessment of the nutritional status of a dairy herd, by an extension and improvement of techniques such as metabolic profiling, is likely to further increase standards of nutritional efficiency and hence of reproductive and lactational efficiency. Nutrient re-allocation and metabolic profiling will demand the harnessing of sophisticated computerized control and monitoring techniques to the dairy herd, and a new dimension in stockmanship will be called for, in which the computer output is recognized as being complementary to, and not a substitute for, the eyes and ears of the good husbandryman.

The need for increased longevity of the dairy cow has already been mentioned, and the sum total of all these improvements should be to raise milk yield by the 1980s well over the 5000 kg per annum mark, and to increase protein conversion efficiencies to over 30 %, (see table 10).

It will be noted from table 10 that the biological ceiling for protein conversion of the dairy cow is set at the very high level of 46 %.

TABLE 10. COW–PROTEIN CONVERSION PERCENTAGES

(After Wilson 1973.)

	4100 kg milk	6800 kg milk	18000 kg milk
4 lactations	28	35	45
16 lactations	31	37	46

(b) *Beef cattle*

Intensification in beef cattle is likely to be dramatic but there will continue to be a large number of different, but viable, systems of beef production to meet the different environmental conditions in different parts of the British Isles. The advent of twinning in beef herds, as envisaged by Blaxter (1973) will considerably increase the output per breeding cow, but important, if less spectacular, improvements are likely to be brought about by breeding for lean meat production through the use of imported breeds such as the Charolais (see table 11), or by using progeny and performance tested bulls from the leaner British breeds (e.g. Red Poll, Devon, Sussex).

The use of bulls, instead of steers, for beef will further increase the production of lean meat, as has been clearly shown by numerous studies, such as that by Prescott & Lamming (1964) summarized in table 12.

The effect of these improvements is likely to raise the current level of conversion of feed protein into edible lean meat from beef systems from 6 to about 8%, as indicated in table 13.

Table 11. Breed comparison: the percentage tissue in the third quarter

item	Charolais × Friesian	Hereford × Friesian	significance
bone	14.1	13.6	n.s.
fat	16.0	23.3	n.s.
lean	65.4	58.7	significant at $P = 0.01$
bone: lean ratio	0.216	0.232	not tested

Table 12. Comparison of bulls and steers

(After Prescott & Lamming 1964.)

factor	bulls	steers	significance
l.w.1 (16/day)	2.28	2.00	significant at $P = 0.01$
pre-slaughter weight/kg (lb)	404 (890)	378 (832)	
kidney fat %	2.08	3.39	
% muscle in tenth rib	64.2	51.8	significant at $P = 0.001$
% fat in tenth rib	16.8	29.2	

Table 13. Meat ruminants–protein conversion percentages

(After Wilson 1973.)

production standard	sheep	beef
current level	4	6
improved level	9	8
ceiling level	12	10

(c) *Sheep*

Improvements in sheep production are likely to come, mainly by closer attention to fecundity than to radical alterations in nutrition or breed choice. In the past, selection *against* fecundity has been practised, since it was not deemed prudent to select twin ram lambs for breeding and since many upland and hill farmers regarded one lamb per ewe per annum as being the correct production level to aim at under harsh conditions of out-wintering.

A move to inwintering, thereby enabling the carrying capacity of spring and summer grass to be better exploited by increased stocking rate, would enable dramatic and rapid increases in sheep productivity to be realized, as had been clearly demonstrated by Spedding and his co-workers (e.g. Spedding 1969). However, the limitation to improvements in this area is likely to be social rather than technological, since traditional methods die hard on hill and upland farms. The increase in sheep productivity by 1985 is therefore very difficult to predict, but the vast scope for major increase is clearly demonstrated in table 13, which suggests that improvement in fecundity could double the protein conversion percentage of sheep by 1985.

(d) *Poultry*

The current and possible future situation for both laying and meat poultry is set out in table 14.

It would be theoretically possible to raise the protein conversion efficiency of laying hens to levels close to those for high-yielding dairy cows by extending the laying period for a further year, with or without an intervening moulting period. There are some indications that such a trend is already taking place, and recent estimates of the proportion of the national flock kept on into a 'second year of lay' are 20 to 25 %. If this trend continues and if the productivity during the 'second year' increases, either by higher egg yields in equal time or by extending the profitable portion of the laying period from 30 to 40 weeks or more, then the overall protein conversions could be raised to a maximum ceiling of 33 %.

TABLE 14. POULTRY–PROTEIN CONVERSION PERCENTAGES

(After Wilson 1973.)

production standard	layer	broiler
current level	20	20
improved level (1985)	30	28
ceiling level	33	31

It would also be theoretically possible to increase protein output, and hence improve protein conversion, by selecting for larger eggs of greater protein content. The current trend, however, is to choose the lighter weight bird of lower maintenance requirement and replacement cost, and under these conditions the aim is to enable a larger percentage of the egg crop to achieve the minimum requirements for 'large' size rather than to produce 'very large' eggs at the expense of 'standard' eggs.

Current average standards of broiler production, at which birds at 1.6 kg weight are raised in 56 days with an overall feed utilization efficiency of 2.5, provide a protein conversion efficiency identical to that of laying hens at 20 %. By increasing the feed utilization to a figure of 2.0 to 1, already achieved under experimental conditions, and by increasing the liveweight of the finished broiler to 2.0 kg, the efficiency can be increased to about 30 %.

This improvement, in either greater weight at same age or equal weight at a lower age, is most likely to be achieved by the use of diets with improved amino acid balance and with optimal relationships between micronutrients. Further substantial improvements are to be expected by treating male and female broilers as separate crops and formulating different diets for the two sexes, as suggested by Filmer (1970).

The use of additives, such as growth promoters, may be extended with both classes of poultry, but in general the inclusion of additives will be directed specifically to disease prophylaxis or therapy, and as such this area lies outside the ground covered in this paper. However, recent work has shown that medicinal additives, such as coccidiostats, may interact both with other nutrients and with sex in such a manner that advantage can be taken of unexplained, but significant, synergisms and, conversely, unproductive antagonisms can be avoided by appropriate changes to diet specification.

(*e*) *Pigs*

It is important to differentiate between pigs kept for pork, for bacon and for 'heavy hog' production. The former type alone is considered in this paper, since world trends in pigmeat production favour the porker rather than the baconer, and it is probable that this trend will continue as total world *per caput* consumption of pigmeat continues.

The current and future projection for protein conversion for pork pigs are set out in table 15.

For interest, data for the rabbit are also shown in table 15, since the efficiency standards for this important meat animal are very similar to those for pork pigs.

Current levels of animal productivity in the pork industry are such that sows are maintained for an effective life of about 3 years, during which about four litters are produced from which a total of about 30 porkers are grown to carcass weights of approx. 40 kg. At this productive level the protein conversion is approximately 12 %, depending very greatly on the breed or strain of pig and its lean content at this carcase weight.

TABLE 15. NON-RUMINANT MAMMALS–PROTEIN CONVERSION PERCENTAGES

(After Wilson 1973.)

production standard	rabbit	porker
current level	11	12
improved level (1985)	17	16
ceiling level	20	18

Earlier weaning techniques, and especially very early weaning immediately after colostral feeding, would enable the farrowing index to be reduced and hence $2\frac{1}{4}$ litters could be born each year. Such early weaning systems would need to be coupled to efficient techniques to enable the sow to be successfully mated within one month of farrowing, possibly by endocrinological intervention to stimulate early post-partum ovulation.

The sow is capable of producing over 20 ova at each ovulation and the number of ova fertilized is usually greatly in excess of the number of livebirths, due to re-absorption of embryos in the Fallopian tube or uterine horns. If more of the embryos would be carried to full term, litters of 20 piglets are theoretically possible and have been achieved in practice, but average litter sizes of 12 reared to maturity are already practical with the top 5 % of producers.

The two next most important factors determining protein conversion are the growth rate and feed utilization of the growing and fattening pig. Current levels of gain average about 0.4 kg per day, and for feed utilization about 2.9:1. These levels could be readily raised to 0.6 kg and 2:1, equal to the standards achieved on the top 5 % of pork producing farms. Elevation to these levels is dependent upon both genetic and nutritional improvement. It is likely that extra lean breeds, such as the Pietrain, and the separate feeding of the two sexes with diets differing in both amino acid composition and nutrient density, will have a part to play. At these higher levels of productivity the protein conversion can be raised from 12 to about 16 %.

EFFLUENT – AN OBLIGATORY BY-PRODUCT OF ANIMAL PRODUCTION

No discussion of intensification in the animal industry is complete without a brief mention of effluent. The production of large quantities of effluent, possibly contaminated with medicaments and high levels of minerals such as copper, is likely to act as a major limiting factor to increased intensification, especially in geographical areas close to urban development.

Animal effluent can only be dealt with in one of two ways: (1) it can be applied to agricultural land where it has a value as an organic manure; (2) it can be treated by some appropriate method so as to render the end-product either inocuous or to transfer it into an accepted saleable by-product. The former method requires large areas of land able to accept untreated effluent at rates up to 50 tonnes of effluent per hectare. Wilson (1972) has calculated the areas of land required for different highly intensified systems, each occupying one half a hectare of building space. The respective areas are: broilers and intensive dairy cows 40; battery caged layers 65; beef-lot finishing yards 190 and cage-housed porkers 211 hectares.

It is clear that intensification will therefore either require farming enterprises to be diversified, so that extensive arable production is complementary to intensive livestock production, or else large capital sums will have to be supplied, probably financed from sources outside agriculture, to enable complex treatment plants to be established alongside intensive units.

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Discussion

J. C. Bowman (*Department of Agriculture, University of Reading*). In general terms, I agree with Dr Wilson's survey of the current biological efficiencies of animal production, of the 'ceiling' biological efficiencies and of the likely efficiencies obtaining in 1985 as a consequence of the biological and economic factors of the time. It is highly appropriate to consider the implications, if any, of these comparisons both for the future of animal production and for the determination of research and development policy.

Man is frequently in a situation of limited resources. In this regard I wish to refer to the need to establish priorities so that available resources for agricultural research and development can be devoted to the most important and relevant problems. Also, because the amount of feed available to support animals is limited and may in some cases be equally suitable for direct human consumption, it is important to realize which species could make best biological use of this major input into animal production.

My view is that biological efficiency, irrespective of the inputs required, is not a good criterion upon which to decide the future of animal production. From Dr Wilson's comparisons it is notable that the forms of animal production which are, and are likely to be, the most efficient biologically are those which rely most heavily on feed which could be consumed directly by humans and involve the most land and labour intensive systems, giving rise to the major problems of waste disposal and concern for animal welfare. However, I would like to suggest that these forms of animal production, chiefly poultry production and intensively fed dairy cows, may assume less importance in the future and should receive less attention than hitherto from research and development workers.

Several comparisons have shown conclusively that on land where arable farming is possible the yield of crude protein per unit area is much higher from crops than from any form of animal production. It seems likely that one of man's future objectives, particularly in the developed part of the world, will be to maximize production of protein from both plant and animal sources and simultaneously provide a supply of human feed which is varied in origin, flavour and appearance. Those concerned with animal production should therefore turn their attention to those systems of production which rely on feed, mostly high in cellulose and fibre and often the by-product of an arable crop, which cannot be consumed directly by humans and which are carried out on land not suitable for arable cropping, such as extensive grazing situations. These systems on Dr Wilson's calculations are not biologically the most efficient, but coupled with arable farming they make most efficient use of the limited land resource.

Finally there is some evidence that the efficiencies of the domesticated species may be less than some currently wild species. Since it is probably largely by chance that man has domesticated the few species used in farming from among the many species which are available to him, I suggest that more attention be paid to, and investigation started on, wild species which might be suitable for domestication.

I should be interested to know if Dr Wilson agrees with these comments on the implications of his efficiency comparisons.

P. N. WILSON. Professor Bowman is correct in stating that the yield of crude protein per unit area of land is in general higher from crops than from stock, and I agree with his contention that an important future objective should be the complementary production of protein from both plant and animal sources. I would not, however, agree that dairy cows and poultry should receive less attention than heretofore merely because they can sometimes compete with man for limited supplies of foods of similar quality.

The ruminant animal, whether domesticated, or wild, can utilize lignified plant materials which are of little or no use to man. Such materials do not have to be consumed *in situ*, and can be used as part of the raw material of compound diets fed to high yielding dairy cows (e.g. cotton seed). Again, the crude protein inputs to the dairy cow do not require to be a balanced assortment of essential amino acids, but can be in the form of non-protein nitrogen, such as urea or biuret. Recycled nitrogenous wastes could in future be used in this respect, and such materials are unlikely to be acceptable to man.

Since man is essentially an omnivore and not a vegetarian it follows that social attitudes will continue to dictate that meat is an important component of his diet. It may well be that beef and mutton will in future increasingly be produced in the more extensive areas, and be obtained from species not previously domesticated. However, there will still be a social need for some degree of self sufficiency for meat for overcrowded urban communities with little extensive land available for 'ranching'. In these situations the data presented in my paper show the marked biological superiority of poultry over both pigs and intensively fed ruminants for purposes of meat production. Poultry meat consumption is therefore likely to continue to increase for some considerable time, at least into the mid 1980s which is the period under review at this meeting.

On one important general point I am in complete agreement with Professor Bowman. As I stated in my paper, man is a vital but oft-neglected biological factor governing the rate of advance in animal production methods. Biologically optimal systems are likely to be substantially modified for both economic and social reasons. The rank order of biological efficiency is therefore unlikely to be highly correlated to the rank order of world supply of the different animal products. It is, however, impossible to deal with this aspect within the confines of a paper dealing only with physiology and nutrition.