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ANIMAL BREEDING OBJECTIVES: BALANCING PRODUCTIVITY AND ECOLOGICAL IMPACT

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SUMMARY

The livestock industry is faced with the challenge to meet the growing demand for animal product while at the same time reducing the environmental impact. This requires an improvement of the efficiency of production, robustness of animals and quality of animal products. This paper concentrates on the definition of the breeding objective and how environmental constraints should be incorporated. The discussion on how to best incorporate the environmental impact has many similarities with the discussion at the end of the last century on the perspective to be taken in calculating economic values. A summary is presented of that discussion and the unifying concepts that resulted from it. Subsequently, these concepts are extended to include environmental constraints in deriving weight of traits in the breeding objective. The principles are illustrated with a numerical example on dairy cattle in the Netherlands and a constraint on methane emission. It is concluded that methane emission expressed per kg of product and not per animal should be used to evaluate the consequences of animal breeding on methane emission.

INTRODUCTION

On a global level, we are faced with increasing demands on natural resources from a growing population. To meet the growing demand, the food production needs to double in the coming 30 years while halving its environmental impact. Not only more and higher quality food is needed, but also renewable feed stocks for energy and other industrial uses are asked for. The modern bioeconomy has its roots in providing both food and non-food products from managed agricultural, aquaculture and forestry ecosystems (Becoteps, 2011). This paper concentrates on the contribution of the livestock industry to meet the increased demand for high quality food to feed the human population.

There are many individuals on this planet who live relatively healthy lives consuming little or no animal protein and many would argue that the challenge of feeding the human population could be met by reducing the amount of livestock products in our diet (Appleby *et al*., 1999). However, the demand for animal protein especially in developing countries is expected to grow as they become more affluent. Part the animals proteins are produced from feed such as grain that could be directly consumed by humans while another part is produced from feed that would not be available to humans such as grass and by-products from the human food industry. The challenge for livestock production is to meet the growing demand for animal product while at the same time reducing the environmental impact. This implies that the livestock production needs to improve the efficiency of production, robustness of animals and quality of animal products. Improvement of efficiency of animal production needs to focus on improving lifetime productivity which can be achieved by improving not only productivity but also by improving health, reproductive performance, length of productive life span, and robustness of animals (e.g. Hume *et al*., 2011). Robustness of animals refers to the ability of animals to handle variation in the environment and face climate change. The quality of animal products refers not only to the food safety and taste but also to animal welfare.

A breeding scheme aims at genetic improvement in the breeding goal through the selection of parents to produce the next generation. The breeding objective reflects the combination of traits

Table 1. Proportional changes (%) in greenhouse gas emissions and global warming potential (GWP_{100}) achieved through genetic improvement (1988-2007) as calculated by DEFRA (cited from Hume *et al.,* 2011)

	CH_4	NH_3	N_2O	GWP_{100}
Chickens-Layers	-30	-36	-29	-25
Chickens-Broilers	-20	10	-23	-23
Pigs	-17	-18	-14	-15
Cattle- dairy	-25	-17	-30	-16
Cattle- beef	0	0	0	0
Sheep	-1	0	0	-1

that the breeder aims at improving through selection. The amount of genetic improvement in the breeding objective (and the underlying trait) depends on the accuracy of the selection criteria, the intensity of selection and the generation interval.

Breeding in poultry, pigs and dairy cattle has not only resulted in increased productivity but also in decreased emission of greenhouse gasses per ton of animal product (Table 1). Bannink *et al*. (2011) used a mechanistic model to predict the methane emission by dairy cows from data on productivity and composition of the average ration in The Netherlands. They found that the average methane emission per cow per year increased from 110 kg in 1990 to 126 in 2010. Expressed per kg of milk, the methane emission decreased from 17.5 g in 1990 to 15 g in 2010. These results illustrate the importance of how environmental impact is expressed. Expressed per cow, methane production increased by 15% over the last 20 years while expressed per kg of milk, the methane production decreased by 14% over the last 20 years. In this paper, I argue that environmental impact should be evaluated per kg of product. Furthermore, I demonstrate that it is important to include not just the productive period but the entire life cycle of an animal in the evaluation. The discussion on how to best express the environmental impact has a lot of similarities with the discussion at the end of the last century on the perspective to be taken in calculating economic values. I will, therefore, start with a summary of the discussion on the impact on perspectives taken on economic values and present the unifying concepts that resulted from these discussions. Subsequently, I will apply the concepts to include environmental impacts in deriving the weight of traits in the breeding objective. I will use a simple numerical example to illustrate my findings.

BREEDING OBJECTIVE

The breeding objective can be thought of as the overall goal of the breeding program. The purpose of the breeding objective is to aid the following decision-making processes:

1) within-line or -breed selection, i.e. which animals to choose as parents;
2) across line or breed selection, i.e. which lines or breeds to use in the production system;
3) evaluation of investments in breeding programs and design of breeding programs, i.e. the breeding objective provides the criterion to quantify and maximize returns on investments in the breeding program.

An obvious and attractive economic breeding objective would be to maximize profit. Some people have argues that breeding objectives should be defined in terms of biological efficiency. More recently, a number of persons have argued that not only economic but also non-tangible effects should be incorporated in the definition of breeding objectives (Oleson *et al*., 2000; Kanis *et al*. 2005). Dekkers and Gibson (1999) reviewed how best to ensure that breeding objectives and selection criteria are used in practice by taking into account the perceptions and wishes of the breeders for whom they are designed.

Unless specified otherwise, I will concentrate on the maximization of profit in this paper as it serves to demonstrate the issues related to definition of breeding objective. But there are other issues that need to be resolved, such as whose profit is being maximized and how to incorporate constraints imposed on the size of production system like limited feed resources or environmental constraints. Already, Dickerson (1970) recognized some of these issues and concluded that in a competitive world, the only reasonable breeding objective was economic efficiency, defined as the ratio of production income divided by production costs. It is a measure that maximizes the difference between value and cost and it is independent of the size of the production system. But it still faces the problem that a breeding organization and their clients might have different objectives and it is not clear how it deals with constraints on size of production system. This issue will be addressed in this paper. Furthermore, attention will be paid to the relationship between maximum efficiency and profitability of the enterprise.

THE AGGREGATE GENOTYPE

The selection index approach, which was advocated by Hazel (1943), is generally accepted as the framework for deriving economic weights. In the selection index approach a linear aggregate genotype is used to derive a linear selection index. The aggregate genotype can be described as:

$$H = v_1g_1 + v_2g_2 + ... + v_ng_n$$

where g_i is the genetic value for trait *i*, and v_i the corresponding economic value. The purpose of the aggregate genotype is to describe genetic variation in the breeding objective as completely as possible in terms of a linear function of genetic values for biological traits, along with economic values for those traits.

Based on the definition of the aggregate genotype, the economic value of trait *i* is defined as the effect of a marginal (one unit) change in the genetic level of trait *i* (g_i) on the objective function (i.e. profit), keeping all other traits that are included in the aggregate genotype constant. For more complex situations, bio-economic models are the method of choice for deriving economic values. However, I will use profit equations because they provide more insight into elements contributing to economic values than bio-economic models. These insights can subsequently be incorporated in bio-economic models that deal with more complex situations.

Impact of perspective on economic values. In the literature there has been a lot of attention to four issues in the definition of the breeding objective:

1. From what perspective should the benefits of genetic improvement be viewed?
2. Should profit be expressed per farm, per animal, or per unit of product?
3. Should the breeding objective be to maximize profit (i.e. R-C) or to maximize economic efficiency?
4. Should the breeding objective be defined per farm, per animal, per unit of product, per unit of an input factor, or subject to any other constraint?

It was Moav (1973) who first noted that different perspectives can yield different profit functions and different absolute and relative economic weights in the aggregate genotype. Subsequent authors have discussed this problem, and I will illustrate it here with the example provided by Brascamp *et al.* (1985). They considered a meat production enterprise consisting of *N* breeding females, and producing *n* offspring for slaughter each year. A simple profit function for the production enterprise could take the form, $P = N(nwr - nc_1d - c_2)$ where *w* is the weight of meat produced per offspring, *r* is the returns per unit product, *d* is the number of days to slaughter, c_1 the cost per day, and c_2 the cost of maintaining each female for one year. There are three traits under genetic control, *n*, *d* and *w* and economic values can be calculated for four perspectives, i.e. (1) profit per enterprise, (2) profit per breeding female, (3) profit per slaughter pig, and (4) profit per kg of meat. The relative economic weights for *n*, *d* and *w* are the same for perspectives 1 and 2, the absolute values differing only by a scaling factor, the number of females. Thus, these two perspectives result in equivalent economic weights. However, relative economic weights for *n*, *d*, and *w* do differ for other perspectives. This is disturbing, since it implies that different perspectives in the industry would lead to different aggregate genotypes and hence different desired directions of genetic change. Brascamp *et al*. (1985) demonstrated that it is possible to develop a consistent set of economic values which has the same relative weight for every perspective. To obtain the consistent set of economic values they including normal return on investment as a cost, such that current profit equals zero. Following that paper, also other authors showed that consistent set of economic values can be derived by imposing the same constraint on the profit equations for all perspectives (Goddard, 1998). For example, Smith *et al*. (1986) showed that the same set of consistent economic values can be obtained by applying rescaling, and imposing a restriction on the size of the enterprise or by defining the objective as economic efficiency (profit per kg of output). This implies that it should not matter from which perspective economic values are derived. However, it does not mean that considering one perspective is sufficient to obtain the consistent set of relative economic values. It is important to apply the conditions that result in a consistent set of economic values across perspectives, e.g. restriction on profit or the use of prices that correspond to a normal profit situation.

Deriving economic values from profit equations. I assume a simplified situation in which profit of a cow depends on productivity, expressed as kg of milk produced during one lactation (M), and the longevity, expressed as the number of lactations (L). Profit per cow during her lifetime is equal to:

$$P_L = L[M(r_m - c_m) - C_L] - C_R$$

where r_m is milk price, c_m is feed cost of one kg of milk, C_L is maintenance cost per lactation, and C_R is rearing cost of replacement heifer. Table 2 gives the economic values derived from three perspectives: profit per cow, profit per lactation and profit per kg of milk. Economic values are also expressed per cow per year to facilitate a more direct comparison. The relative economic values of milk production and longevity depend on the perspective taken. Using profit per kg of milk, the economic value of increased milk production results from spreading fixed costs (C_L and C_R) over more kg of milk and does not depend on the milk price. For the other two perspectives, the economic value of M is equal to the marginal net revenue of one additional kg of milk. For

Table 2: Economic values for milk production and longevity from three different perspectives expressed in unit of profit equation (lifetime, lactation, or kg milk) and expressed per cow per lactation

	Expressed per unit		Expressed per cow per lactation	
Perspective	Milk	Longevity	Milk	Longevity
Lifetime profit	$L(r_m - c_m)$	$M(r_m - c_m) - C_L$	$(r_m - c_m)$	$\frac{[M(r_m - c_m) - C_L]}{L}$
Lactation profit	$(r_m - c_m)$	$\frac{C_R}{L^2}$	$(r_m - c_m)$	$\frac{C_R}{L^2}$
Profit per kg M	$\frac{C_L}{M^2} + \frac{C_R}{LM^2}$	$\frac{C_R}{ML^2}$	$\frac{C_L}{M} + \frac{C_R}{LM}$	$\frac{C_R}{L^2}$

longevity, the economic value resulted from increased production of milk when lifetime profit is used while for the other two perspectives, the economic value of increased longevity results from spreading rearing costs over more years.

The differences in the relative economic values of M and L between the three perspectives disappear when the concept of rescaling is applied (Smith *et al*., 1986) which is equivalent to imposing a restriction on the total amount of milk that is produced by the herd. This can be shown by formulating the profit equation at herd level, i.e. the level at which the restriction applies. The equation for profit at herd level expressed per year can be written as a function of the profit per cow per year and the number of cows (N_{cow}):

$P_{herd} = N_{cow}\left\{\left[M(r_m - c_m) - C_L - \frac{C_R}{L}\right]\right\}$ where $N_{cow} = \frac{Q}{M}$ and Q is a constant reflecting the fixed herd milk production. Note that under this restriction, not only profit per cow per year but also number of cows is a function of M. Taking the first derivative of this profit equation results in the same economic values as those obtained from profit per kg milk. For this case, we again find that the differences between the three perspectives disappear by introducing a restriction on output and secondly that the relative economic values are equal to those obtained from the equation reflecting profit per kg of milk. The latter can be interpreted as economic efficiency expressed per unit of output. Efficiency can also be expressed per unit of input for example feed. In the equivalent equation for herd profit in that case, the number of cows is a function of the average feed consumption of a cow. Also this profit equation will result in a consistent set of economic values for all three perspectives and those will be equal to those derived from profit expressed per unit of input. However, the economic values derived from efficiency per unit of output will not be the same as the economic values derived from efficiency expressed per unit of input. Dickerson (1970) proposed to use economic efficiency defined as the ratio of production income divided by production costs. The implicit assumption in that efficiency measure is that total production costs are restricting the size of the production system. The choice of the efficiency measures requires identification of the factor that is limiting the size of the production system, i.e. total input of feed , total input of production costs, or total output of milk.

INCORPORATING ECOLOGICAL CONSTRAINTS

The framework presented for the calculation of economic values can be extended to incorporate ecological constraints on animal production. This will be illustrated by extending the profit equations to include methane emission from dairy cows. The profit equation in which the number of cows in the herd is a function of the methane emission per cow can be used to derive economic weights that correspond to a situation in which the total methane emission from the herd is constant and –as a consequence- determining the size of the herd. The economic values are equivalent to those derived from profit expressed per unit of methane emission. The total methane emission from a herd (TOT_{ME}) can be calculated from the number of cows (N_c) and the methane emission per cow (ME_{cow}):

$TOT_{ME} = N_c ME_{cow}$ From this it follows that $N_c = \frac{TOT_{ME}}{ME_{cow}}$.

Bannink et al. (2011) showed that the emission of enteric methane by a cow can be predicted by considering characteristics of the diet, dry matter intake, live weight, milk production and composition of milk. Ignoring variation due to live weight and dry matter intake, the methane production of lactating cow with a production level of M kg of milk per year can be represented by the following simplified equation: $EM_{cow} = 56.8 + 0.0086M$ (kg CH_4/cow/yr). In this equation, variation in methane emission between cows due to variation in milk composition, live weight or dry matter intake is ignored. The parameters reflect an average lactating dairy cow in The Netherlands in 2008 with an average production of 8335 kg of milk and an average emission of enteric methane of 128 kg. The methane production during the rearing period needs to be considered also in order to obtain the total annual methane emission from the dairy herd. The methane production during the two-year rearing period is assumed to be 40 kg per replacement heifer which can be spread over L years, where L is the longevity (expressed in productive years) of a cow. This leads to the following expressing for the annual methane emission of a lactation cow: $ME_{cow} = 56.8 + 0.0086M + \frac{40}{L}$. Given the average longevity of 3.5 years (Demeter et al., 2011), the rearing period accounts for 8% of the methane production of a lactating cow.

The economic values of traits in the aggregate genotype can be derived for a situation in which the total methane emission from the dairy herd is fixed. It has been shown previously that the resulting economic values are equal those obtained from profit expressed per kg of methane. We again consider the situation with only two traits, i.e. milk production per cow per year (M) and longevity (L). The profit of the herd is equal to:

$$\text{Profit}_{herd} = N_c\left[\text{Profit}_{cow}\right]$$

$$\text{where } N_c = \frac{TOT_{ME}}{ME_{cow}} = \frac{TOT_{ME}}{56.8 + 0.0086M + \frac{40}{L}}, \text{ and } \text{Profit}_{cow} = M(r_M - c_M) - C_L - \frac{C_R}{L}$$

The economic value of M can be obtained as the first derivative of the Profit_{herd} with respect to M divided by the number of cows. The last step is needed to obtain economic values expressed per cow rather than herd. The economic value for M (v_M) per cow per year is equal to:

$$v_m = \frac{\partial \text{Profit}_{cow}}{\partial M} - \text{Profit}_{cow}\left(\frac{\left(\frac{\partial ME_{cow}}{\partial M}\right)}{ME_{cow}}\right) = (r_M - c_M) - \text{Profit}_{cow}\left(\frac{0.0086}{ME_{cow}}\right)$$

In words, the economic value of 1 kg of milk is equal to the marginal increase in profit per cow minus the average profit of a cow times the reduction in the number of cows resulting from 1 kg higher production of the cow. The reduction is herd is equal to the methane production due to 1 kg higher milk production (0.0086) divided by the average methane production of a cow.

The economic value of longevity (v_L) expressed per cow per year is equal to:

$$v_L = \frac{\partial \text{Profit}_{cow}}{\partial L} - \text{Profit}_{cow}\left(\frac{\left(\frac{\partial ME_{cow}}{\partial L}\right)}{ME_{cow}}\right) = \frac{C_R}{L^2} - \text{Profit}_{cow}\left(\frac{\frac{-40}{L^2}}{ME_{cow}}\right)$$

From this expression it appears that increasing longevity will lead to an increase in the number of cows, which results from the methane production during rearing period of replacement heifer (40).

So far, it has been assumed that the total methane emission of the herd is constraint. However, an alternative approach is to minimize the methane emission per kg of milk of per unit of profit. Minimizing methane emission per kg of M leads to the following ecological values (kg CH4/unit) expressed per cow per year: $ve_M = 0.0086 - \frac{ME_{cow}}{M} = \frac{-\left(56.8 + \frac{40}{L}\right)}{M}$ and $ve_L = \frac{-40}{L^2}$. Both values are negative which reflects that methane emission per kg of M decreases with an increase in

M or L. The expression for the ecological value of M (ve_M) does not include the marginal increase in methane emission per kg of milk (0.0086) but includes the emission per lactation which is independent of milk production.

NUMERICAL EXAMPLES

Table 3 presents economic values derived from profit equation in which herd size was constrained by total milk production or by total methane emission. For an average Dutch dairy herd, the economic value of M was 249 and of L was 90 with a constraint on herd methane emission, and the economic value of M was 223 and of L was 79 with a constraint on herd milk production. The economic value of M was 278 and of L was 122 when using profit per lactation, i.e. with constraint on herd size. Imposing a restriction on herd output in terms of milk or methane (Table 3) resulted in reduction of absolute economic value M and M and in an increase of the relative economic value of L compared to M. When average milk production was reduced by 20% (M-20%), the economic value for M (and also L) was very similar for the three different perspectives. This similarity is caused by the fact that the average profit of a cow was close to zero at that herd production level (-€10/cow/yr). When $Profit_{cow}$=0, the expressions for v_M and v_L for constraint on methane emission from the herd are equal to expression for constant herd size (lactation perspective in Table 2). These results demonstrate that average profit per cow plays an important factor in determining the impact of changes in herd size that result from changes in M or L. The fact that the average profit at M-20% is zero, however, should not be taken as a general result but more as a result of the simplified equation which was used to reflect profitability of the herd.

The ecological value (in kg CH_4/cow/year) for the average situation is -7.74 per 1000 kg increase in M and -3.27 per year increase in L. The ratio of ecological values is (2.37) is smaller than the ratio in economic values in Table 3, which reflects a higher relative value of L.

Table 3. Economic value of lactation milk production (v_M)[1] expressed per 1000 kg of milk, economic value of longevity (v_L)[2] for Dutch dairy herd[3] with different production levels derived from profit equation where herd size is constrained by total milk production or by total methane production

	Fixed herd milk production			Fixed herd methane emission		
	v_M	v_L	v_M/v_L	v_M	v_L	v_M/v_L
Average	223	79	2.82	249	90	2.76
M -20%	279	79	3.52	279	79	3.52
M+20%	186	79	2.35	226	99	2.27
L-20%	231	124	1.87	254	138	1.84
L+20%	218	55	3.96	246	64	3.88

[1] expressed per 1000 kg of milk (€/1000 kg/cow/yr)
[2] expressed per year longevity (€/yr/cow/yr)
[3] production parameters, prices and costs were taken from Demeter et al. (2011)

DISCUSSION

The discussion on how to best express the environmental impact in deriving a breeding objective has many similarities with the discussion at the end of the last century on the perspective to be taken in calculating economic values. The differences in economic values between perspectives disappear when using the same basis of calculation. It is shown that the same principles apply when incorporating an ecological constraint on herd size. Profit expressed per kg of methane emission leads to exactly the same economic values as profit of herd where herd size is constrained by a fixed total methane production. Maximizing profit per kg of methane leads to different relative weights of M and L than minimizing methane emission per kg of milk. This difference results from the difference in the implied assumptions. Maximizing profit per kg of methane refers to a situation where a maximum applies to the emission of methane from dairy herds. Minimizing methane emission per kg of milk refers to a situation where a fixed amount of milk is being produced. It is not easy to choose the perspective that best represents the actual and future situation. We need to deal with that uncertainty. However, it is very important to be explicit in the choice of the perspective in deriving economic weights and the consequences of the choice.

The equations in this paper are a very simple representation of reality. For example, the equation for methane emission from a cow depends not only on M but also on other factors such as live weight and milk composition (Bannink *et al.* 2011). Information on some of these relations is scarce. Further, profit not only depends on milk production, as assumed here, but also on fat and protein production and the relation between feed costs and milk production is non-linear which is also ignored.. When expressed in CO_2 equivalents, methane is the most important but not the only greenhouse gas. The other contributions also need to be included. A full assessment of the environmental impact requires the quantification of the emissions and resource use during the entire life cycle (De Vries and De Boer, 2010). The short comings of the profit equations used in this paper can be overcome be using more detailed bio-economic models to calculate components of the economic values. The simple equations, however, are sufficient to show the how ecological constraints on animal production should be incorporated in determining the breeding objective. To conclude with the answer to the question from the introduction: methane emission expressed per kg of product rather than per animal should be used in evaluating the ecological consequences of animal breeding.

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