Breeding goal definition

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Introduction

Sections 1 and 2 introduce the users to the area of genetic improvement in general and in particular to the role breeding goal definition has in the management of animal genetic resources. The process guiding the user through the decision-making when defining breeding goals (see 2.3.) starts with Section 3.

- Users for which these guidelines provide a first entrance in the area of breeding goal definition are advised to go through Section 1 and 2 in detail (including Annexes), to get the basic principles of genetic improvement and breeding goal definition.
- Users of these guidelines familiar with genetic improvement and breeding goal definition may wish to go to Section 3 directly; these people are advised to read the (double framed) boxes from Sections 1 and 2, as these boxes include the headlines of the sections.

Section 1. Why genetic improvement in managing farm animal genetic resources?

1.1 Helping to achieve the development objective

Genetic improvement aims for an active use of the genetic variation available, both within breeds and between breeds[1] of livestock. The animal genetic variation can be used to accommodate interests and wishes of farmers to make livestock even more efficient in using available resources to produce human food and other agricultural products. Genetic improvement focuses at a directional improvement in genetics of animals in coming generations such that they will produce the desired products more efficiently under the (expected) future economic, social and ecological production environment. This direction of the improvement is formalised in a 'breeding goal'. The breeding goal is to serve the farmers and the community in a broader sense in establishing the development objective for agricultural production in their country. The development objective will (traditionally) include economic variables, but it should be extended to also accommodate aspects like ethics and other social aspects of human welfare and well being.

[1]All words underlined refer to terms used in these guidelines for which a description is given in Annex VII.

Genetic improvement helps to achieve the development objective

• Defines what is the 'best' animal	- Breeding goal
• Identifies the best animals by recording	- Breeding value
• Uses the best animals	- Breeding structure

1) Breeding goal definition is the first step to be made in designing genetic improvement strategies. The breeding goal identifies the animal traits that farmers would like to be improved. To be able to identify the animal traits, the development objective of agricultural production in the country is to be defined and the animal production system is to be characterised.

2) Then, a second step is to implement a structure of gathering information, a recording system, to identify those animals that have the highest breeding value for traits in the breeding goal. This step of identifying high genetic merit animals is called ‘breeding value prediction’.

3) A third step is to make a well-organized structure for:
   - the use of animals with highest predicted breeding value; and
   - the dissemination of superior genes through the population, a quick and widespread use of selected animals.

It is apparent that the second and third steps involve a lot of costs, especially the second step of recording. Investments will have to be recovered by the genetic improvement giving increased sustainability of production in future generations. Development of breeding strategies that will be effective is of great importance for the management of animal genetic resources.

Breeding goals focus on
- saving inputs of resources
- achieving sustainability
- dynamic genetic improvements
- accommodating local production environments

Saving inputs of resources

Animal production is a means to producing human food, other agricultural products for human consumption (like fur or coats, or biogas) and intermediates to be used as inputs for plant production (dung as fertiliser, draft). Animal production also serves human interest in different other ways, like banking and social status. Animal production is a means to creating human welfare and well being by converting lower valued resources (production factors, labour, land and capital) to higher valued products.

Genetic improvement involves a technological development to improve output and quality of animal production. Genetic improvement aims at saving input of resources per unit of output and a change towards the use of cheaper resources. These two statements imply:

- firstly, that genetic improvement should be based upon farmers' perceptions and wishes; this will enhance acceptability and implementation of developed technology;
- secondly, that the value of genetic improvement is in the alternative use of saved resources.

Farmers want to save on resources because there are additional opportunities to use these resources, either to expand the production of the animal activity or to use them in another (animal) activity.

Sustainability

Development objectives should consider sustainable development of agricultural production. Sustainable agricultural production permits conversion of available resources to human food and other agricultural products without diminishing the future availability of those resources or causing environmental degradation. Livestock is a critical part of sustainable agricultural production because of unique abilities to utilise a spectrum of renewable resources. Genetic improvement is an important tool in achieving sustainability when used to improve these unique abilities of livestock.

Dynamic genetic improvement

Genetic improvement is not aiming at an optimum; genetic improvement is dynamically searching for improvements. Given animal genetic variation (within or between breeds), there is always a means of improvement. In fact, this approach of farmers is originating from the historical and continued natural processes of re-establishing genetic variation (i.e. mutations). This genetic improvement approach is also an incentive to conserve genetic variation during the process of selection.

Breeding goal definition is an important area of decision-making; genetic change is lasting and therefore valuable. The state of the future generation will depend partly on the state of the current generation and so on. For this reason, genetic improvement is an important tool in the realisation of the development objective

A third dimension to the dynamics of breeding goals is the uncertainty about the future. Breeding goals ought not to change according to seasonal or cyclic variation of circumstances. As soon as structural and lasting changes are observed, breeding goals should be adjusted in order to avoid losses. Breeding goal definitions should be robust, but also continuously requiring reconsideration of economic and social developments.

Accommodating local production environments

There is not ‘a worldwide standard’ or even ‘a country standard’ breeding goal. Differences in economic, social and ecological production environment give rise to different approaches and desires in what human welfare and well being is. These differences give rise to different development objectives. A diversification of breeding goals is important to serve farmers facing different local situations. A diversification of breeding goals according to local production environments will help to conserve the diversity in genetic resources. A diversification of breeding goals according to local production environments will support genetic improvement towards locally adapted breeds.

Wise use is the best form of *in situ* conservation

About these guidelines

Breeding goal definition involves a decision-making process. To provide a helpful tool, the decision-making process in breeding goal definition is broken down in sequential steps and users will be guided step-by-step, following logical flow charts. For each step or decision:

- examples are used to illustrate the step;
- background information is given as why this step is important;
- it is indicated how to find data to make a sound decision; and
- drawbacks of not making the decision or of making a poor decision are denoted.

After some decision-making steps, an incentive is given to go back some steps to reconsider decisions made earlier.

Forms are provided to fill in to help systematically putting the information together. A list of terms used is given in Annex VII.

1.2. Links to other guidelines for development of farm animal genetic resource management plans

The purpose of the FAO guidelines is to assist countries to develop Farm Animal Genetic Resource (AnGR) Management Plans that will become both components of the Diversity Plan and a basis for developing livestock breeding policies. In the FAO guidelines, management of AnGR includes identification and description of AnGR, the active utilisation of AnGR to increase food production (including animal productivity and product quality) and other agricultural production, the conservation of endangered livestock breeds for possible future use, access to AnGR and the monitoring and reporting.

These guidelines help policy-makers, field technicians and farmers to define breeding goals for genetic improvement to manage animal genetic resources. These guidelines account for a broad range in country capacity and are applicable to all important animal species and production environments.

For domestic species, issues of utilisation and conservation cannot be separated; both are critical components of management of AnGR. Most AnGR reside in developing countries where the need to increase food production and to reduce poverty are greatest. The breeds that farmers use today are different from those used in the past and from those that will be used in the future.

Management of livestock AnGR seeks to ensure that appropriate genetic material is used and developed and will be available to meet future challenges of changing environments and human preferences. The most important use of these guidelines is for setting priorities for the design and implementation of AnGR management activities thereby better targeting country needs and for establishing and maintaining cost-effective activities. In addition, the guidelines will assist in describing the countries' AnGR to the global community.

Section 2. What is genetic improvement?

2.1. What is a breeding goal?

Farmers always like the animals to perform better in order for:
- dairy cows to give more milk and live longer;
- young stock to grow faster;
- the suckler cows to reproduce regularly and to give birth more easily;
- sheep to produce more meat and wool with a better quality;
- chickens to lay more eggs without a loss in egg weight.

Each farmer will come up with several traits. The breeding goal lists these traits and gives each of these traits a value. By giving each trait of the breeding goal a value, a weighed analysis of traits is made, an aggregate genotype to be improved.

An example. Goal traits in genetic improvement of chickens
- General
    - Disease resistance
    - Adaptation to heat stress
    - Utilisation of poor quality feeds
- Breeding stock
    - Productive life
    - Fecundity
    - Quality of eggs (fertilisation, hatchability)
- Growers
    - Growth rate
    - Feed conversion
    - Carcass quality

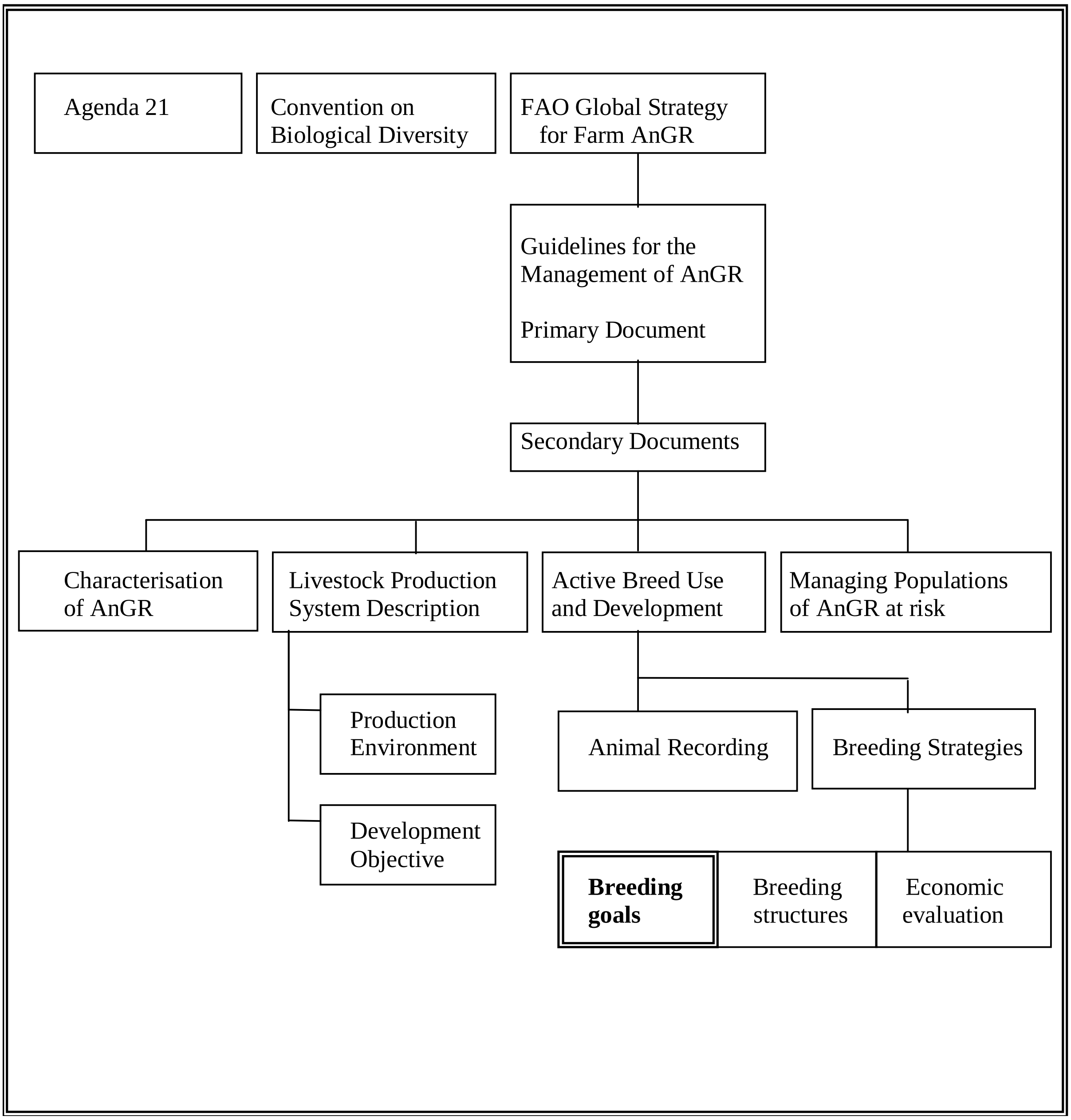


Figure 1.1. Breeding goal guidelines in the context of Farm Animal Genetic Resource (AnGR) Management Plans.

The choice of the list of traits is to be based on the development objective of agricultural production and the characterisation of the animal production system. The values used for making the calculation are generally called 'economic values' or 'economic weights'. In these guidelines they will be called 'goal values for genetic improvement' or simply 'goal values'. The term 'goal values' emphasises that these values fit the overall development of the agricultural production in a country, accommodating not only economic environment, but also the social and ecological environment. The goal value of a trait denotes the contribution of its improvement to the realisation of the development objective. The list of breeding goal traits and their goal values will be used for within-breed selection, but also help to choose between breeds to be used in the animal production system.

Breeding goal

- the breeding goal is a list of traits the farmer would like to be improved genetically;
- this list is based on the development objective of agricultural production and the characterisation of the animal production system;
- each trait in the breeding goal is given a 'goal value', indicating the contribution of the improvement of the trait to the realisation of the development objective.

The breeding goal is not the final criterion or tool used in selection. The tool used in deciding on which males and females will become parents of the next generation is the 'selection index'. The selection index is a summary of observations, information on measurements and scores. In the selection index weighing is performed by co-efficients. These index co-efficients also account for:

- the genetic possibilities of improvement (by considering the genetic and phenotypic parameters in the population, such as (co)variances and correlations); and
- the number of observations on the animal and its relatives.

As breeding goal traits differ in genetic possibilities of improvement and in ease of recording (directly or indirectly) and as observations generally do not give complete information, index co-efficients are generally not equal to goal values and they differ markedly.

This selection index approach is described in Annex I: the breeding goal is the aggregate genotype to aim for and the tool to reach the goal is the selection index. The good thing about this approach is that the tool is optimised given the goal. Index co-efficients are calculated in such a way

An example. Goal traits in genetic improvement of yak

- milk yield;
- beef yield – big body;
- wool yield – rich, thick hair;
- draught – body strength, good feet and legs;
- tame and gentle;
- fertile;
- disease resistance;
- grazing, feed intake from pasture.

Selection index

- the selection index is a tool that lists all the observations for making the selection decisions;
- in the selection index observations are weighed by their index co-efficients;
- these index co-efficients are calculated to maximise the correlation between the breeding goal and the selection index.

An example. Using the selection index approach

A farmer wishes to select male goats for improved milk production and carcass quality. Of course, he cannot measure milk production on the male and he will not slaughter the (potential) breeding males. Therefore, he uses milk production records on the dam and full sisters of the male and carcass quality information on slaughtered full brothers.

Breeding goal = goal value milk * genotype value milk + goal value carcass quality * genotype carcass quality
(where genotype is the unknown true breeding value)

Selection index male =
index co-efficient milk dam * milk performance dam
+ index co-efficient milk full sisters * milk performance full sisters
+ index co-efficient carcass quality full brothers * carcass quality full brothers

Alternatively – a simplification generally used in practice (see Annex I):

*Selection index male = goal value milk * PBV milk*
*+ goal value carcass quality * PBV carcass value*

where PBV milk is the predicted breeding value for the male based on corrected and weighed performance of the dam and full sisters; and PBV carcass value idem performance full brothers to maximise the correlation between goal and tool. This maximisation considers the assigned goal values, the genetic and phenotypic population parameters and the observations available. The selection index approach simultaneously gives optimal co-efficients to observations on different groups of animals and on different traits. In fact, the aggregate genotype is the true breeding value to improve; the selection index is the predicted breeding value. The calculation of the index co-efficients is detailed in Annex I.

The correlation between goal and tool is also called the 'reliability' of the predicted breeding value. The more observations included in the selection index, the higher the reliability of the predicted breeding value. Notice that the observations included in the selection index are to be measured in the setting of the breeding structure. Of course, these can be measurements that are also used for other management decisions, like feeding strategy.

Nowadays, breeding value prediction uses sophisticated statistical techniques, all based upon Best Linear Unbiased Prediction (BLUP) applying mixed model methodology, as developed for livestock selection by Henderson in the 1960s. This mixed model methodology uses exactly the same optimal index co-efficients to weigh observations from different sources (i.e. individual itself, or a relative) and to observations on different traits. In fact, mixed model equations are used to calculate selection indexes.

Two advantages of using mixed models methodology in genetic improvement are:

- it is much more flexible: mixed models simultaneously consider calculation of index co-efficients when potential selection candidates have different numbers of observations available for breeding value prediction; and
- it directly corrects for the (disturbing) environmental contributions to observations: mixed models use the available performance data to simultaneously give an estimate of the environmental contribution to observations (while the selection index assumes that these environmental effects are known without error from external sources).

The mixed model prediction of breeding values disentangles the genetic and environmental contributions to observations. More details on mixed model methodology are in Annex II.

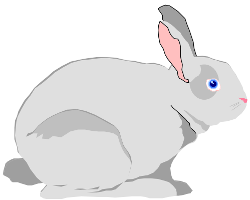
2.2. What genetic changes are addressed?

Before starting to take action, the user has to get an idea what the result of the genetic improvement strategy might be. What is meant by improving genetics?

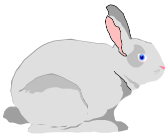
The observed performance of an animal, its phenotype (P), is a result of genetic (G) and environmental (E) contributions. The DNA of the animal forms the genetic contribution; the environmental contribution is formed

An example

Why is a rabbit growing fast? Is it due to housing, feeding or genetics?



= lots of feed + excellent genotype + good housing



= little feed + excellent genotype + bad housing

by husbandry: feeding, health care, climatic influences and so on. The genetic and environmental contributions are often considered to act independently (additive). However, there can also be a G*E interaction meaning that particular genotypes of animals will not be best in all husbandry practices. All contributions give rise to deviations from the (overall) mean performance

$$P = meanP + G + E + G*E.$$

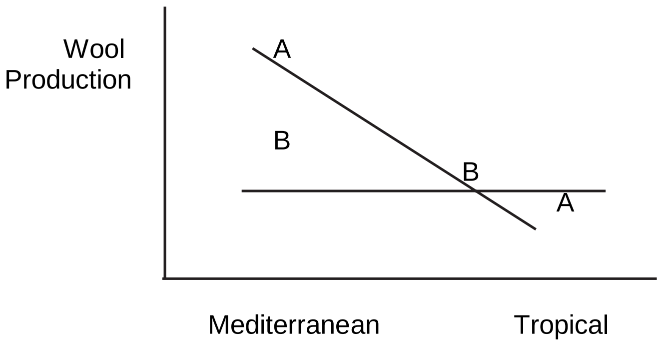
The farmer aims to improve the genetic contribution; G is in the breeding goal. The selection index is built up by phenotypic observations. What selection index and mixed model methodology in fact do is to disentangle G and E in order to predict G from P.

Differences in phenotypic observations among animals result from differences in genetic contributions G, differences in environmental contributions E and differences in interactions G*E. In addition, higher or lower variances in phenotypes may occur because of co-variances between components. For example, a decrease in phenotypic variation is observed when higher genetic merit animals are kept in better environments.

The genetic material, DNA, of an individual is a very complex structure. Part of the DNA codes the genes for production of enzymes. Enzymes act within the metabolism of the animal. Livestock species have thousands of genes. All important domestic livestock species are diploid, so they have two (homologous) copies of each gene, one inherited from the sire and one inherited from the dam. Genes may have variants, called alleles. All

An example. Genotype*Environment interactions

Performance levels in terms of wool production by daughter groups of two different rams A and B



Under Mediterranean environments the daughters of ram A out-perform the daughters of ram B. Under tropical environments production levels for both daughter groups are lower but less for B than for A; now the daughters of ram B perform better than the daughters of ram A.

alleles of a given gene code form an enzyme with the same function, but the alleles may differ in the speed of processing the enzyme, or may give slightly different enzymes that, for example, give rise to other blood plasma levels of the enzyme. When considering the effect of an allele on a single metabolic process:

- the allele may act independently of the others (additivity; A);
- the allele may interact with the other allele at the homologous gene (dominance; D);
- the allele may interact with any other allele of any other gene (epistasis or interaction effect, I).

$$G = \text{mean}G + A + D + I.$$

Within breed improvement of quantitative traits is generally focussing on improvement of additive genetic effects. Cross-breeding is especially trying to exploit dominance effects. Adaptive fitness is a complex of G*E and I effects. Adaptive fitness is merely thought to evolve from keeping animals over many generations in the same environment; the animals with the favourable G*E and I effects will have a higher fitness, which literally means have a higher genetic contribution to the next generation (i.e. more offspring). Performance testing in recording in the local environment will enhance adaptive fitness and so will the definition of a complete breeding oal, including trait definition according to local environment.

An example. Differences in layer performance

full sib hens I x x x x x x x xx x

full sib hens II x xxx x xx xx x → performance

Observations on two full sib groups of layer hens were plotted. Differences within each full sib group are found and also differences between full sib groups. Each full sib group was housed in one back yard pen, but the pens were in two different villages. The differences within each full sib group will be due to genetic differences between the hens. It is unclear whether the differences between groups I and II are due to genetic differences or due to the different feeding in the different pens.

Identification of higher genetic merit animals requires disentangling the environmental contribution from the phenotypic observation – this is accomplished by the **breeding value prediction** using mixed model methodology.

Selecting the animals with better genotypes means selecting animals that have the favourable variants or alleles. A generally adapted model is that when selecting on (predicted) G or A of quantitative traits and combinations as a whole, the number of genes involved is very large, the so called ‘infinitesimal’ model. Due to this very large number of genes involved, allele frequencies of individual genes in the population will hardly change. Selecting for individually identifiable alleles at specific loci (e.g. polledness or milk protein variants) does give a directional change in allele frequencies. Please notice these selection procedures according to type of observations used do not change the breeding goal, but they do change the selection index.

2.3. Strategies for genetic improvement– steps and stages involved

The ultimate goal of genetic improvement strategies is to get improved genotypes for the traits of importance in order to help to achieve the development objective of agricultural production. There is a direct relationship between the chosen definition of the breeding goal and the future realisation of genetic gain of traits of importance.

Setting up strategies for genetic improvement involves breeding goal definition, designing recording systems for routinely observing animal performances for breeding value prediction and optimising a structure for using the best animals (see Section 1.1.). Figure 2.1 gives a more detailed, overall picture of this plan process for genetic improvement strategies.

Adaptive fitness
A nation's locally adapted livestock breeds are a result of the selective forces imposed by the production environment(s) and management systems of the nation and by the preferences of the nation's farmers and consumers. As nations change, their livestock breeds likewise evolve in response to changing conditions and demands. Historically, these changes have been gradual, permitting genetic changes within the nation's breeds to keep pace with the changing needs of the people. The result has been an array of slowly evolving livestock breeds that are generally well adapted to the specific production conditions, management systems and markets of the nation.

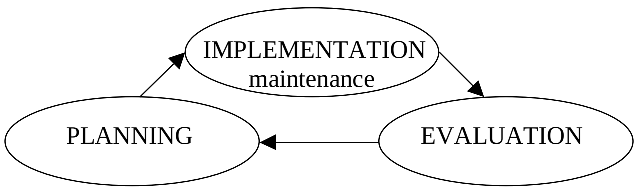
This overall picture highlights the position of the definition of breeding goals.

These guidelines will help the user to perform the subsequent steps to set up a breeding strategy with special reference on the breeding goal definition. Subsequent steps are to:
Section 3
- define the development objective of the agricultural production in the country;
- characterise the animal production system for the animal species of interest;
- identify breeds to be (possibly) used and improved by selection;
- identify a list of breeding goal traits; and

Section 4.
- derive goal values for each of the breeding goal traits.

The characterisation of breeding structure and the choice of breeds involved, the estimation of population genetic parameters, the choice of information sources for breeding value prediction and the evaluation of the (economic) efficacy of breeding strategies are subject to other AnGR breeding strategy documentation. Selection index calculations, resulting in index co-efficients and genetic gain, are described in Annex I. Calculation of geneflow for future expression of genetic superiority in offspring of selected parents (dissemination of superior genes) is described in Annex III.

Genetic improvement, as any other management area, involves planning, implementation and evaluation



Planning, implementation and evaluation is a continuous process. Evaluation is necessary to identify drawbacks and bottlenecks of the strategy and to find new opportunities that give rise to new planning and implementation. New planning and implementation with regard to breeding goals is especially of importance when (long-term) changes in production environments are to be encountered. Users of these guidelines may be in the position of:

1. having to define a breeding goal in a population as part of setting up a whole new breeding strategy; or
2. having to re-think and possibly revise the current breeding goal in a running breeding strategy.

The users in the first position need to pay specific attention to the fact that their breeding goal is embedded in the development objective of agricultural production in the country. As an example; there is no need for increasing milk production output of the system, when there is no demand for more milk. Recording of traits to implement selection is to be embedded in a broader structure of trying to improve husbandry practices as well. When planning and implementing the breeding goal and breeding strategy, the users will have to involve farmers in making the decisions.

Developing breeding strategies is a process of continuous refining; after initial planning and implementation of the strategy (breeding goal, breeding value prediction and breeding structure), evaluations will pinpoint opportunities for improvement giving rise to renewed planning and implementation.

Also during the initial planning, the user will realise that when starting from 'scratch' it is better first to use well-defined but simple breeding goals and selection indexes (e.g. only two to three traits) rather than to complicate these on fore hand. As an example, in these guidelines the breeding goal will first be split up into several sub-goals for different groups of traits. This helps to find solutions and provides a way of obtaining results more quickly. Subjective assignment of values to different (groups) of traits is adopted, which is especially useful in the case of missing information. In other words, even before implementing a first strategy, the use will have to go through several 'iterations', when appropriate, this will also be indicated in the guidelines.

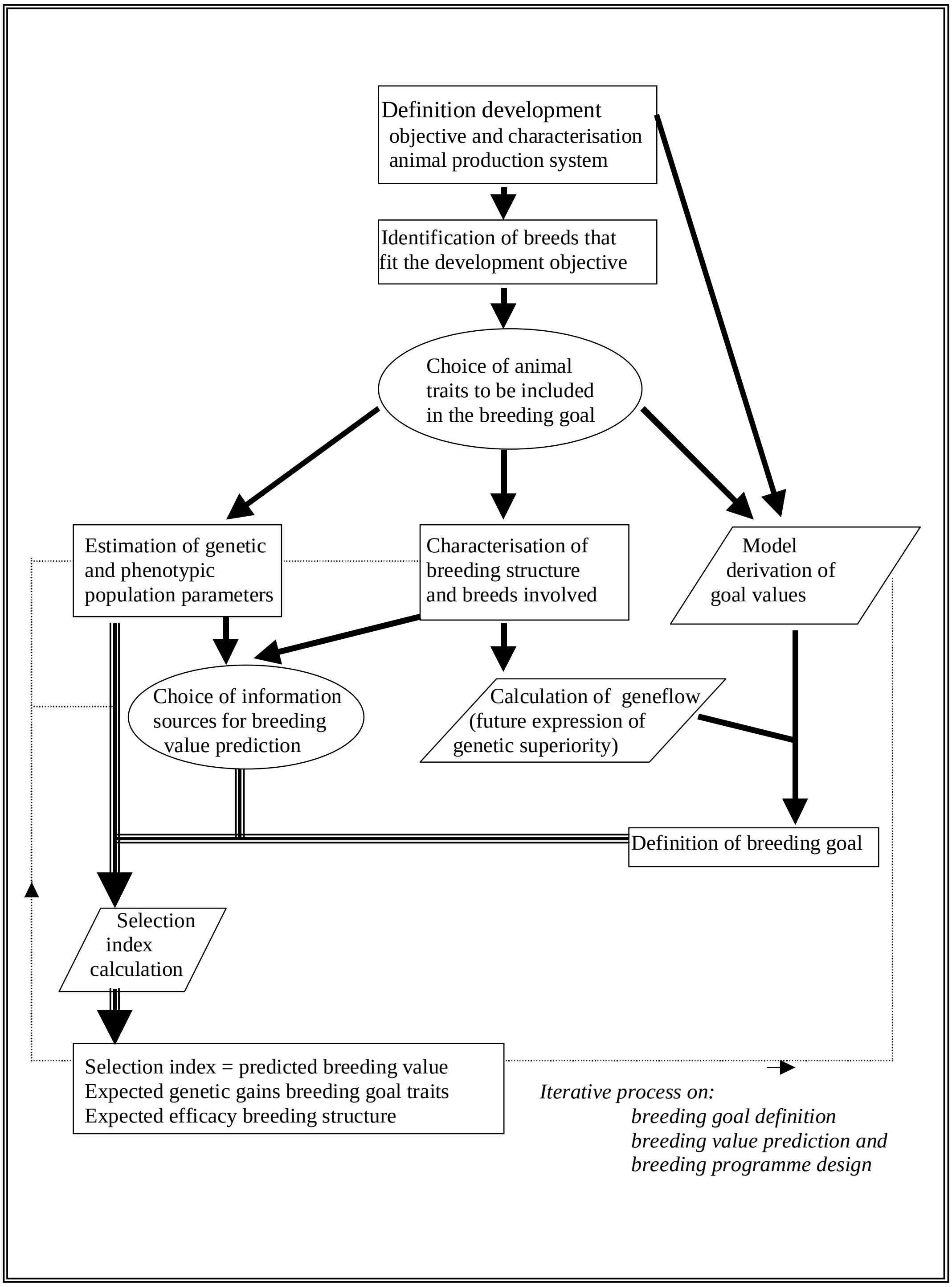


Figure 2.1. Planning genetic improvement strategies.

User guidance

Section 3 helps the user to identify the breeds and the breeding goal traits that fit the animal production system and the development objective of the farmers and the community in a broader sense.

- *Users not familiar with genetic improvement strategies and breeding goal definition* are instructed first to get an impression of the end terms of this chapter (by superficial reading) and then to carefully read the whole chapter following the different steps one by one. By going through the chapter several times, the users can iteratively refine their model of the production system before starting with Section 4.
- *Users familiar with breeding goal definition who want to refine or renew the breeding goals currently applied* should first document the model of the production system used for the current breeding goal and then use this as a starting point when going through Section 3.
- *Users already having made a definite choice on the breed and breeding goal traits and who are interested in the objective derivation of goal values* had best roughly identify the main ideas from Section 3 by studying the flow charts and then go to Section 4.3 directly. When working step by step from section 4.3 on, these users need information that others gather during Section 3.

Section 3. Development objective in agricultural production and characterisation of the animal production system

The aim of this chapter is to provide guidelines for the definition of a complete list of animal traits of interest to farmers to improve efficiency of production. The definition of this list of animal traits is to be based on:

- definition of the development objective of agricultural production in the country;
- characterisation of the animal production system for which the breeding goal is defined;
- choice of relevant breeds for the animal production system.

The list of animal traits serves as an entrance to the choice of breeding goal traits. This list of breeding goal traits should be complete, comprehensive and mutually exclusive. In this section focus is on making a complete list. A lot of the information gathered in this section is used again in deriving goal values (Section 4).

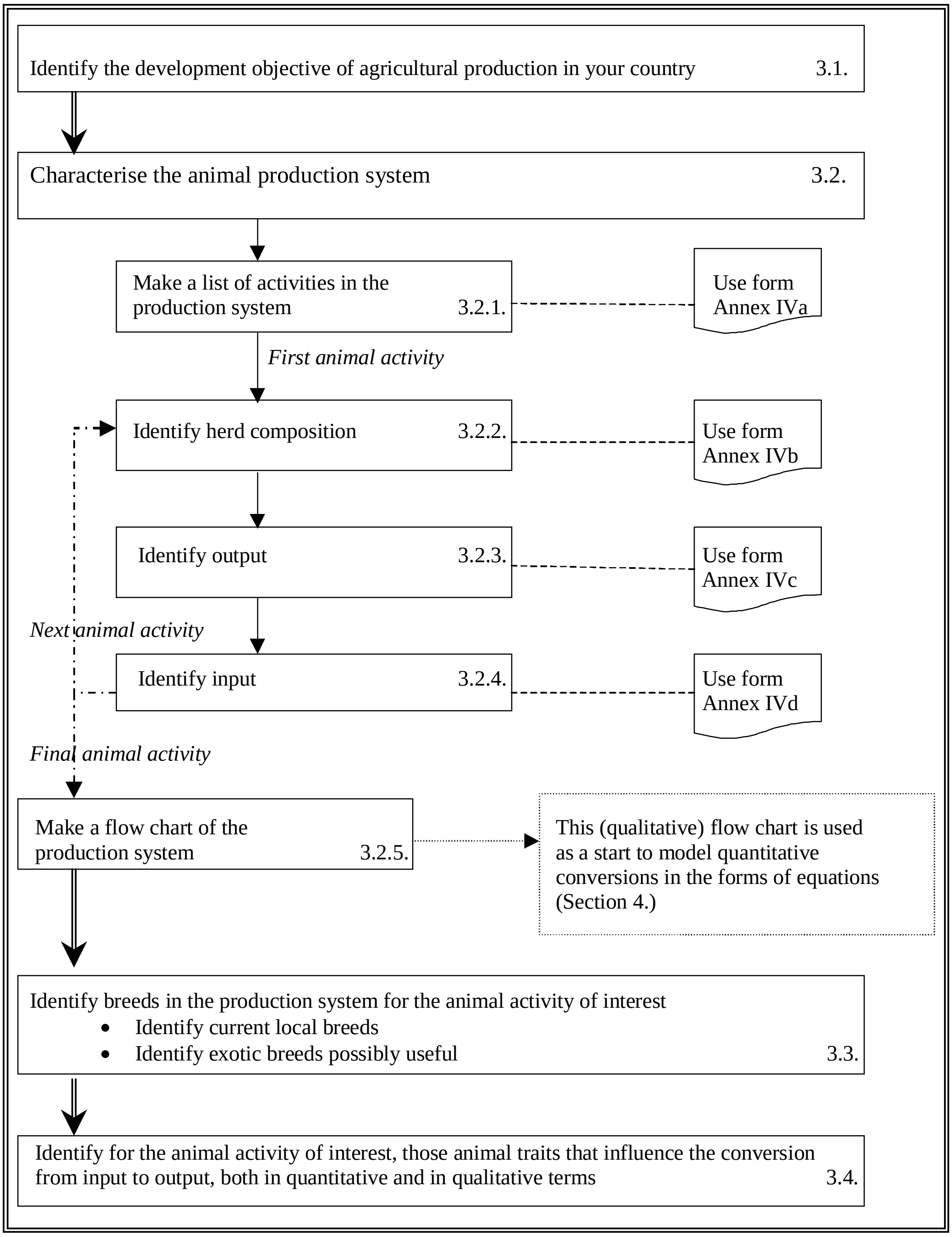


Figure 3.1. Stepwise characterisation of the animal production system and the development objective for agricultural production in the country.

User guidance
In these guidelines first the definition of the development objective in agricultural production in your country is established and next the characterisation of the animal production system (as a part of agricultural production in your country).

- First read this section on the development objective and then the section on the characterisation of the animal production.
- Then more carefully read this section and define a 'draft' development objective.
- Then more carefully read the next section and characterise the animal production system.
- Finally reconsider the 'draft' development objective and proceed with the choice of breeds.

A thoughtful definition of the breeding goal may require several 'iterations' (re-thinking to combine new ideas) on the underlying starting points like the development objective in agricultural production and the characterisation of the animal production system.

3.1 Defining the development objective in agricultural production

Genetic improvement is an important tool to achieve the broader development objective of agricultural production. This means that in order to make genetic improvement a suitable tool, we need to define the development objective as a starting point.

In Chapter 1, it was generally stated that the development objective focuses on sustainable agricultural production: conversion of available resources to human food and agricultural products without diminishing the future availability of those resources or causing environmental degradation. Genetic improvement can add to saving of resources (per unit of production) offering opportunities to alternative use of these resources. Now according to local environments the breeding goal should emphasise saving of one or more of these resources. For example, when pasture is very expensive or only available in a limited amount, emphasis is on reducing pasture required per animal. Again according to local environments, the saved resources are used to either expand production (in case of need for more human food), or are used for other purposes, not agricultural production (for example, saved labour is used by having a family member work in a local factory).

To conclude: to decide upon the breeding goal (traits included and goal value per trait), the user first needs to establish in what direction the agricultural production in the country is to change, the development objective of agricultural production. Before doing so, two important dimensions of decision-making in agricultural production ‘level’ and ‘time horizon’ are discussed.

Decision-making level
When you ask a national policy-maker in what direction agricultural production should change, you will get a different answer than when you ask an individual farmer. It certainly is not true that one of the answers will be wrong, but it simply is the case that the national policy-maker and the individual farmer take other points of view. Logically, the national policy-maker will be concerned with the availability of food for all inhabitants and national economics. On the other hand, the individual farmer will be more concerned with the interest of his own family and the profit of his own farm. To conclude: the interest in decision-making will depend upon whom you ask and the **level** or the scope that this person will take.

Decision-making time horizon
Suppose a veterinarian goes to a farm and asks the farmer what can be done for the farmer that day. The farmer will probably say that there is an ill animal that needs direct treatment because a bacterium is causing a clinic infection. When the veterinarian finished the treatment, the farmer is offered veterinary help for the next month and the farmer may choose what is to be done. Then the farmer will probably say that the animals in the herd are regularly suffering from the bacterium, endemically present in the herd and the farmer wants the veterinarian to have a look at all animals to determine which animals suffer sub-clinically from this bacteria. The next month the veterinarian does so and together with the farmer, the veterinarian sets up a scheme for preventing the bacterium to cause clinical infections again. At the end, the veterinarian asks the farmer what the farmer would like to do in the future to prevent the bacterium from causing damage again. The probable answer of the farmer to this last question will be to breed resistant animals. To conclude: the interest in decision-making will depend upon the **time horizon** taken for solving the problem.

Development objective:
- in what direction should agricultural production change?
- what opportunity is used when having available (saved) land, labour and capital?

The interest in decision-making will depend upon whom you ask and the **level** or the scope that this person will take.

The interest in decision-making will depend upon the **time horizon** taken for solving the problem.

Consider the long-term and a broad, national level in decision-making: what is the function of agricultural production? What purpose serves agricultural production in your country? Food production is certainly number one. But what else? What role does agricultural production serve in rural development, maybe in the tourist sector or nature conservation, or maybe it is an important sector in employment of people?

Given this role, would policy-makers in your country have preferences for the development of agricultural production in a certain direction? For example, in The Netherlands, policy-makers would like agricultural production to become more environmentally healthy and the Dutch Government gives subsidies to farmers when they take management measures to preserve nature and when they start activities in the tourist sector. In addition to political points of view, what do you think citizens in your country consider important for agricultural production? Consider not only economic factors, but also social and ethical factors.

When you are not sure about the long-term function of agricultural production in your country, or about the political issues, you should ask around and talk with policy-makers and citizens. Have a look at recent subsidies for agricultural production.

The **development objective** for your country:

Development objective of ....:

Future functions of agricultural production:

....

....

....

Changes in agricultural production looked for:

....

....

....

Discuss the development objective with many people, policy-makers, citizens and farmers. Try to find out if there is consistent thinking on this development objective, e.g. do policy-makers and farmers agree on the development objective. One way to check this is as follows. It was mentioned that genetic improvement can add to saving of resources (per unit of production) offering opportunities to alternative use of these resources. Ask a policy-maker what he would like farmers to do when there is land available (or labour or capital) and also what would the farmers do.

Putting things the other way around, the wish to develop a country in a certain direction will lead to market demand for production factors and to (relative) prices for the production factors that express their (relative) need for (alternative) opportunities. **Look up long-term price developments and check if the defined development objective is consistent with current developments in your country.**

Decision-maker

There is one more thing to find out with respect to breeding goal definition in relation to the development objective: who is the decision-maker in genetic improvement? In the selection process, who is making the final choice in deciding which sire is to be mated to which dam? Is it the farmer (owner of the animal) or other family members, is it a supplier of genetic material (e.g. commercial farmer) or is it some regional or governmental institution? It may be that the farmer is deciding within a limited list of alternatives offered by the commercial farmer, then it is still the farmer who decides. It may also be that the actual mating of a sire with a dam is not under direct control because several sires are within a group (flock or herd or whatever); then there is still someone who decides which sires are allowed in the group.

The decision-maker in genetic improvement:

Decision	Person
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..

Warning: this can be a very delicate point in the context of social structure! This question relates to the social status and influence of people. Make sure that you make a correct choice. Do not only ask the landlord who is making the decisions, but also the farmers. Do not only ask the head of the family, but also ask the women and herdsmen in the field.

3.2. Characterising the animal production system

This paragraph will guide the user to make the decisions on the first five steps of the characterisation of the animal production system.

1) The user's interest for these guidelines may have been to set up a breeding structure with breeding goal for a specific species. However, it is important to consider that farming systems will commonly involve more than one species. For example, farming systems in Ethiopia involve grazing cattle, sheep and goats. In China small farming systems have chickens, cows and pigs. Generally, the husbandries of these different species compete with each other, e.g. for feed or labour. Consider a separate activity for each animal species in the production system. Decide upon the relevance of taking many details for all species or only species of interest.

2) In developing countries, agricultural production is commonly in mixed farming systems. Plant and animal activities interact to make production as a whole more efficient. Also a mix of animal activities is used to enhance the efficient use of resources. For example, cows graze in longer grass and only eat the grass, while the goats eat the shorter grass and eat a lot of herbs; together they make better use of the pasture and the pasture will produce more feed. Although, the interest is in setting up a system structure for animal species, the whole of the production system in which the animals are kept is considered.

3) In characterising the production system, a lot of information is needed. Make sure that information from all kinds of sources is acquired: have a look at descriptive books and database statistics available, talk with specialists (people from extension services and researchers) or go out and have a look at the practical system and talk with farmers.

3.2.1. Activities

1) The first step in characterising the animal production system is to identify the different activities within the system; to break down the system into separate, but dependent, interacting entities. Use the form in Annex IVa to list the activities and have a look at the supplied example.

2) The identification should not be limited to animal activities only, but it should also include manufacturing of agricultural products and activities to acquire resources.

Be precise. Identification of the different activities is important because it is a first step to identifying the flow of products and resources and their use in the system. Especially the identification of activities that use resources is important when assigning values and cost, as are the activities that use (final or intermediate) products. Ignoring activities means ignoring flows of products and resources, which in turn lead to ignoring animal traits that are meaningful for the efficiency of the animal production system. This may lead to erroneously not including these animal traits in the breeding goal.

An example	Plant production	Market
	Biogas production	Cattle
Chickens	Household	Milk manufacturing

3.2.2. Herd composition

For the identification of product output and resource input in animal activities, closely examine the composition of the herd or flock. When multiple species are involved in the animal production system, consider herd composition for each of them.

What can be the sources of information for the figures on herd composition? Refer to statistics on number of animals within a certain region for example from a private or national recording institute. If these are not available, make an inquiry for farmers and gather the information in the field. Ask enough farmers (ten to 20) to make sure that a reliable and representative figure is obtained.

1) Animals enter the herd within the production system either by birth within the system or when bought; leaving the herd is by death or selling. Death of an animal may be the decision taken by the farmer (slaughtering or sold for production with another farmer) or may be involuntary by illness or high age. The life span of animals will depend on their sex and their use within the herd. Specific categories can be reproducing female, breeding male and slaughtering male. When looking at the herd composition, one could start with drawing the life span of an individual animal within a certain category and with defining the age structure in the herd at a given moment.

2) When drawing the life span of an individual animal, consider an average animal. Consider all important events for this individual animal, starting with birth and ending with death, referring to both production and reproduction. Use Annex IVb and consider the examples below. Make a life span drawing for each category of animals, reproducing females and males, slaughter males and females.

3) There may be an apparent difference between what you would like an average animal to do and what an average animal actually does under

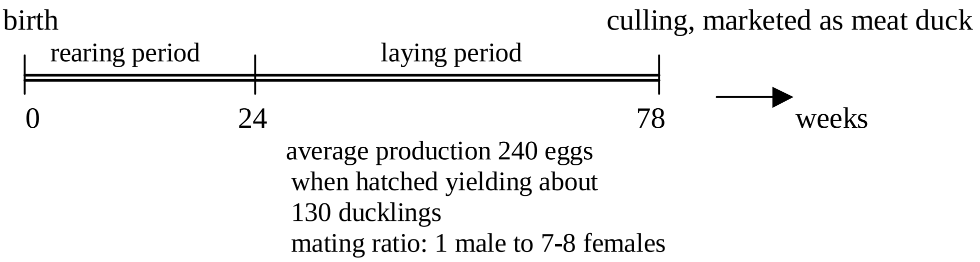
practical husbandry practices. At this stage consider an average animal under practical husbandry.

4) Consider average herd composition. Make categories of animals, for example, young animals in rearing, pregnant young animals, animals in first production cycle and so on. Do this for each animal category.

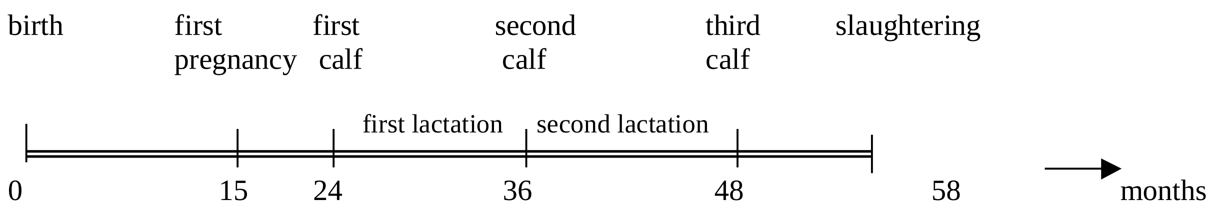
5) It is important to check consistency in the figures for life span and herd composition.
   - Calculate average age at leaving the herd from your average herd composition; this should be equal to the average age at slaughter / death in your life span drawing.
   - The number of animals born in the herd on a yearly basis should be equal to the number of animals leaving the herd on a yearly basis, at least in a herd of constant size.

Be precise. It is important to make a precise life span of the animals, with all important events included. These events relate to major requirements for inputs and major product outputs from the production system. These events also help to define efficiency of production over the life span of the animals. Ignoring events might lead to erroneously not including animal traits that influence efficiency of production in the list of important traits to be improved by selection.

An example - a typical Chinese duck: Jianchang Duck – dual purpose (meat, table eggs)



An example - an average buffalo cow in Egypt



An example – a buffalo herd in Egypt

Animal category		Age period (in months)	Number in the herd on average per year	Specification
Young stock for replacement and reproducing females				
	Rearing period year 1	0 – 12	20	
	Rearing period year 2	12-24	18	
	First lactation	24-36	15	
	Second lactation	36-48	10	
	Third lactation	48-60	8	
	Fourth > lactation	60 >	17	
Total			50	
Breeding males				
	Rearing period	0-12	3	This assumes natural mating
	Adult bulls	12-24	2	
Total			5	
Slaughter animals				
	Female veal calf	0-10	5	When considering the dairy herd, these animals are generally sold at an age of two weeks
	Male veal calf	0-10	22	
	Beef bull	0-16	0	
Total			27	

An example – a buffalo herd in Egypt

Average age of slaughtering.

- 15 – 10 = 5 animals slaughtered during first lactation at average age of 30 months
- 10 – 8 = 2 animals slaughtered during second lactation at average age of 42 months
- other animals (43) at average age of 62 months
- ⇨ average age of animals at slaughter [5*30 + 2*42 + 43*62]/[5+2+43]=58 months of age
- ⇨ this is consistent with the age of the average dairy cow in the life span

Number of animals sold or involuntary leaving the farm per year:

- 5+22 female and male slaughter animals
- 1+2 young and adult breeding bulls
- 2+3 young female stock during rearing period
- 5+2+8 dairy cows during first, second and later lactation

This makes 25 female animals and 25 male animals yearly leaving the herd, which is equal to 20 young female stock + 3 young breeding bulls and 27 slaughter animals entering the herd on a yearly basis.

3.2.3. Output animal production activities

1) Domestic animals provide a whole range of human foods and other agricultural products, like power and fertiliser (see box). Identify for your production system, per species, the output of the animal activities. Do not leave out any output or contribution of the animals. Use the box below and the assumed herd categories and age groups for screening if your list is complete. Also re-consider the listed activities in your system for screening; include all flows of products from animal activities to other activities in the system. Use the form in Annex IVc.

Domestic animals provide

Food	Fertiliser	Income
Fibre	Fuel	Security
Power	Transportation	

Also Include in Annex IVc the following information:

2) Which activity uses the outputs (household, within farming system, market)?

3) Where a shortage of the product output is compensated (taken from another activity in the household or farming system, or bought at the market); identify (market) values; identify limitations in buying products.
4) Where a surplus of the product output is used (kept in household as savings, expanding household or farming system, sold at market); identify (market) values, identify limitations in selling products.
5) Identify quality differentiation in the products; for example, egg size or colour, fat content milk, beef marbling.

Be precise. It is important to list outputs of the animal activities carefully. Common outputs of the activities are directly related to animal traits that influence efficiency of production (especially traits measuring productivity of animals). Ignoring outputs might lead to erroneously not including animal traits that influence efficiency of production in the list of important traits to be improved by selection.

3.2.4. Inputs animal production activities

1) Domestic animals consume resources or inputs to produce their outputs. Identify for the production system, per species, the inputs to the animal activities. Use the box below and the assumed herd categories and age groups to check if the list is complete. Also re-consider the listed activities in the system for screening; include all flows of products from all activities to animal activities in the system. Use the form in Annex IVd.

An example – a list of output of a chicken farm

Animal activity	Output	To activity	In case of surplus to activity	In case of shortage from activity	Use for	Price differentiation[i]
Chickens	Eggs	Household	Market	Market	Food	Yes
	Feathers	Household	-	-	Pillows	-
	Meat	Household	Market		Food	Yes
	Young poultry	Market	Household		Replacement stock	Yes
	Dung	Plant production Household	Market	-		

[I] Is there any payment for quality of the product? If yes, how much?

Also include in Annex IVd the following information:

2) Who provides the inputs, who is the owner of inputs (household, local community, veterinarian, bank, etc.)?

3) How would a shortage of input be compensated (taken from another activity in the household or farming system, or bought at the market) - identify (market) values; identify limitations in buying inputs?

4) How would a surplus of input be used (kept in household as savings, expanding household or farming system, sold at market) - identify (market) values, identify limitations in marketing inputs / production factors?

5) How is quality appraised for inputs and outputs - is their price differentiation in quality?

Domestic animals need

Labour:	family labour, hired labour
Land:	crop production, grazing, other feeds, water
Capital:	housing, veterinary care, equipment, etc.

Be precise. It is important to list inputs of the animal activities carefully. Common inputs of the activities are directly related to animal traits that influence efficiency of production. Ignoring inputs might lead to erroneously not including animal traits that influence efficiency of production in the list of important traits to be improved by selection.

An example – a list of input of a chicken farm

Animal activity	Input	From activity	In case of shortage input	In case of surplus input	Owner	Price differentiation[I]
Chickens	Corn	Crop production	No buying	Market	Farmer	Yes
	'Waste'	Household, crop production, other animal activities	No buying	Pigs	Farmer	No
	Labour	Household	Other family	Help other family	Farmer	Yes

[I]Is there any payment for quality of the product? If yes, how much?

3.2.5. Flow chart of the production system

1) Now all the information on inputs and outputs of animal activities in the production system is to be summarised. From the information gathered a flow chart is made. A flow chart systematically shows all the 'flows' of products and resources between the activities within the production system. When making the flow chart, use the information from Annexes IVa, IVc and IVd.

2) In doing so, the user might conclude that the annexes are not complete; just complete them when making the flow chart. Use the example in the following box as a guideline for making the flow chart.

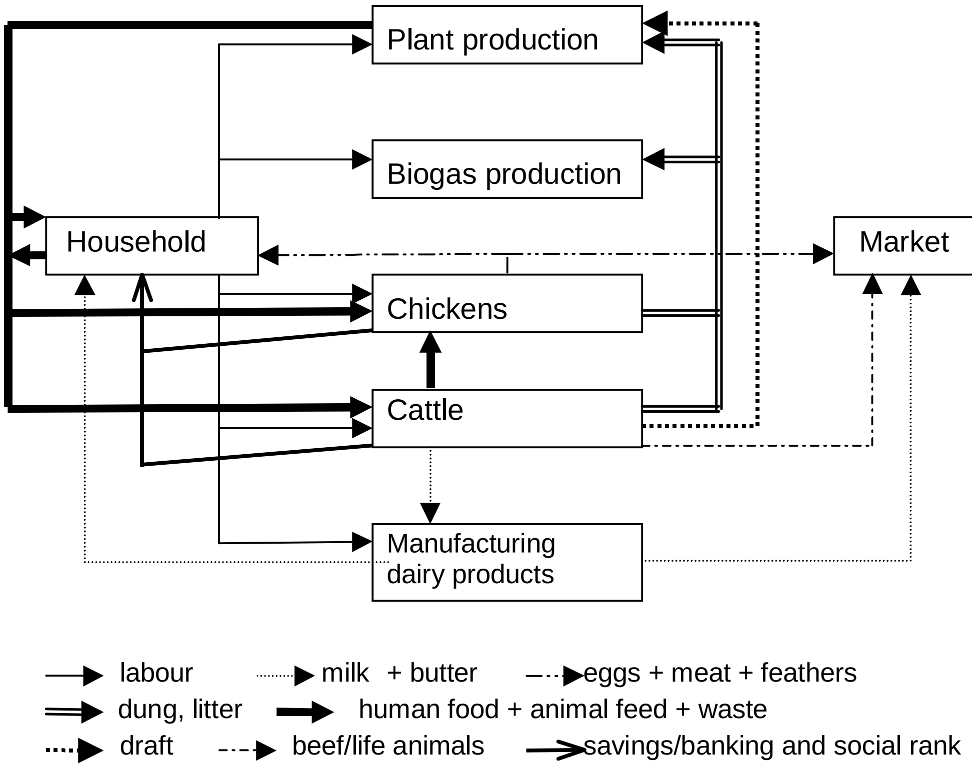
User guidance

The structure of the production system is assigned, a major step in the decision-making process. This structure is a starting point to:

- identify breeds that fit the development objective;
- choose animal traits to be included in the breeding goal; and
- identify the development objective of the production system.

This structure is also used for building a (mathematical) model to derive economic values (see Figure 2.1; Chapter 4.)
A lot of information on the animal production system is put together, the user might like to reconsider the definition of the development of agricultural production in the country.

An example – a mixed farming system



Interactions between activities in the production system

The approach taken is to decompose the production system in activities. Relationships between activities are considered by the flow of inputs and outputs. This approach is very helpful in understanding the production system; the variables and their relationships (mathematical functions) represent the activities and the flow of products and resources. It is however, important to realise that this approach is a simplification of the complex nature of life. It may be assumed that changing the genetic merit of the animals will not influence grass growth, dung composition or product quality, but in reality this will not always hold. It has always to be realised that the results of modelling are a direct consequence of the assumptions made.

3.3. Deciding on the breeds to use

Looking at livestock species, tremendous differences between individual animals are observed. A group of individuals 'more alike' (within the group) than others (outside the group) is called a 'breed'. The trait on which likeness is based can be anything from morphological trait (e.g. coat colour or hair type), to region of birth, to known breeding history (e.g. pedigree) or to production traits (e.g. suitability for pulling or meat yield). In general, breed definition is a composite of many likeness criteria.

When breeding, variation between individuals is exploited and in essence that part of the variation that has a genetic origin. In fact, generally a two-step procedure is followed:

1) choice of breeds used (this may be one breed, or multiple breeds in case of cross-breeding systems),
2) within-breed selection.

It is obvious that choices in both steps will deal largely with the same group of traits. In other words, when considering the choices that users have made in the past or would make in the near future, information is obtained on the traits to consider for within-breed selection. Therefore, this paragraph deals with the first step and in the next paragraph the traits for within-breed selection are considered.

① Identify the breeds of your current stock, use the box below. Also identify any other local breed used by other local farmers. List on what traits you define breeds and reveal the reasons why you keep the breeds you currently have.

Breed identification

Breeds of your current stock ……………….……………
Other local breeds ……………….……………
……………….……………

Characteristics used for breed definition ………………. ……………
………………. ……………
………………. ……………

Why do you have the breed you currently have?
……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

For information of the breeds and breed definition, ask the farmers. It is helpful to look at information provided by DAD-is.

② Look for any information available on local breeds, like mean production levels, disease resistance, product characteristics, etc. Some countries will have very good information on the breeds, other countries only poor information. Any information is welcome! Specify those characteristics, also based on the reasons given above, that make the local breeds especially adaptable to the local production environments and markets. Use the following box to characterise the local breeds, specifying per characteristic (if relevant) the level (e.g. growth, length calving interval, laying period, kg milk per lactation or hatchability of eggs).

Characterisation local breeds

Trait	Local breed				
	……				
……					

③ Put in the above box for each breed and characteristic a score: ++, +, 0, - or - -.

④ Make a choice on your two favourable local breeds.

⑤ A choice of breeds should start from the local breeds available, but should not be limited to those breeds only. Try to identify the weak points of the local breeds given the structure of the animal production system and the development objective of agricultural production. Look in the DAD-is system for other interesting exotic breeds that might be useful for you. Choose five breeds that might be useful and list the traits that complement your current local breeds and list the characteristics of the exotic breeds that are unfavourable relative to your current local breeds. From this list, decide upon whether or not you want to explore the possibility of using exotic breeds in improving your local breeds.

3.4. Listing animal traits

Make a list of animal traits for which genetic improvement might be important in order to realise the development objective of agricultural production in your country. Try to be complete. List anything important that comes into your mind when considering:

Characterisation exotic breeds

Exotic breed	Favourable traits	Unfavourable traits
……	……	……
…….		
…….		
…….		
…….		

- animal activities of the production system;
- inputs and outputs and the internal flows of commodities of the production system;
- development objective of agricultural production of the country;
- what the decision-maker in selection decisions will consider to be important;
- special characteristics of the local breeds and exotic breeds.

User guidance

After assigning the structure of the production system, we have now also defined the development objective of agricultural production and have identified breeds and traits we would like to be improved by selection to contribute to the development objective. Again a major step accomplished; we have gathered all the information we need for the more specific decision-making on the breeding goal. This is what we will do in the next chapter.

To make a start in breeding goal definition it is appropriate to start with a relatively simple situation. The user should be very careful with the implementation of results of (too) simplistic models.

- A sensitivity analysis is very useful: search for the major factors that determine the results of the modelling. Depending upon the outcome you might reconsider the assumptions for these major factors, or define a breeding goal that is relatively robust to the assumptions for the major factors.
- A sensitivity analysis can only be performed for modelling elements, not for factors that are not considered in the model. Therefore, reconsider the results of modelling from a broader perspective before applying results. Only when doing so, a relatively simple approach is a suitable and useful step in deciding on breeding goals. The more broad approach should include interactions between system activities and ecological effects of the production system on the society and world as a whole.
- It is advised, to apply an iterative approach: starting with a relatively simple, model and then stepwise expanding to a more complicated model.

A broader ecosystem

In this section, the entity of an animal production system was considered. The main objective was to assign outputs and inputs of the system that correspond to market commodities. This is an initial step, but it certainly cannot be the only step to be performed when defining breeding goals for sustainable production systems. It does not matter if the aim is for sustainable production by resource sufficiency or functional integrity, there is also a need to consider important criteria like nutrient leakage, gas production (NH_3, CH_4 and CO_2) and resource depletion rates. In other words, the broader ecosystem 'surrounding' the agricultural production system is to be considered.

User guidance

Section 4 helps the user to make a choice on the breeding goal traits and to assign goal values to each breeding goal trait.

- Users not familiar with genetic improvement strategies and breeding goal definition are instructed first to get an impression of the end terms of this chapter (by superficial reading) and then to read carefully the whole chapter following the different steps one by one. By going through the chapter several times, the users can iteratively refine the derivation of goal values.
- Users already having made a definite choice on the breed and breeding goal traits and who are interested in the objective derivation of goal values had best go to Section 4.3 directly. When working step by step from section 4.3 on, these users need information that others gather during Section 3.

Section 4. Breeding goal: defining goal traits and assigning goal values

This section guides the user in defining the breeding goal.

1) First a complete, comprehensive and mutually exclusive list of breeding goal traits is made.
2) The next step is to weigh the breeding goal traits, to give each goal trait a relative value expressing to what extent genetic improvement for the goal trait is needed: a goal value.

- The goal value of a trait determines the emphasis a trait will get in selection decisions. A higher goal value for a trait (relative to goal values of other traits) means that animals with a high predicted breeding value for the trait are generally more selected. Thus, with a higher goal value, the trait will be more genetically improved in the offspring.

- In other words, the (relative) goal values are very important because they determine the levels of genetic improvement of the traits in the breeding goal. These levels of genetic improvement should fit the development objective in agricultural production.

- In order to make breeding goals effective, the decision-maker in decision selection should indeed use the goal values to weigh the predicted breeding values. To enhance the practical implementation of breeding goals it is important to obtain a certain degree of commitment on the goal values with the farmers.

Goal values can be assigned in a subjective way or by an objective derivation based on normative modelling. When first defining the breeding goal, a subjective assignment is a meaningful step, because it forces the user to carefully think about the close relation between the development objective in agricultural production and the desired genetic improvement of traits. The objective derivation of goal values is a more advanced way of establishing the breeding goal based on concrete knowledge on the technical and socio-economic production environment.

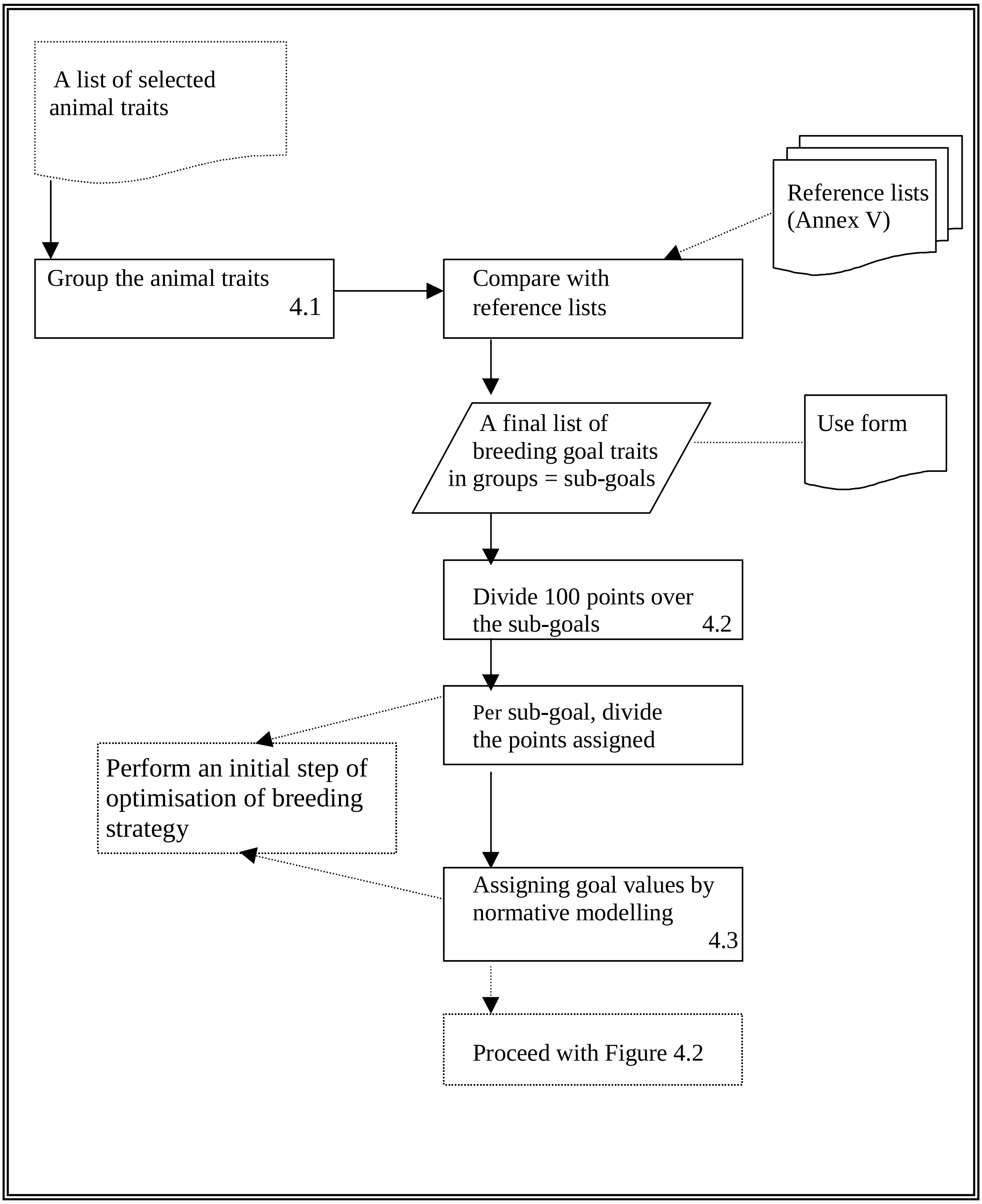


Figure 4.1. Stepwise procedure in listing breeding goal traits and assigning goal values.

4.1. Listing breeding goal traits

In Section 3.4, the user made a complete list of animal traits; a list that includes all traits that the user thought of when defining the development objective of agricultural production in the country, when describing the animal production system and when deciding on the breeds to be used.

With the complete list of animal traits as a starting point, a list of breeding goal traits is defined. The list of breeding goal traits should be complete but also comprehensive and mutually exclusive.

- **Complete** means covering the whole of traits of importance in helping to establish the development objective. Completeness means that the breeding goal is a suitable, helpful tool in establishing the development objective. Ignoring important traits means that these traits will not get the genetic improvement desired from the development objective; some traits might even deteriorate from erroneously ignoring them, leading to unfavourable side-effects from selection (e.g. fertility and health will deteriorate when selecting for production traits only). Completeness will also appeal to the decision-maker in selection of animals and give an incentive to indeed use the predicted breeding values on goal traits available.

- The breeding goal should be **comprehensive**. When dividing selection pressure over many traits, genetic improvement for each of these traits will be limited. When making a comprehensive breeding goal, with a limited number of traits, then genetic improvement for each of these traits is more readily obtained, showing that selection indeed can help to establish the development objective. Again, this point is an incentive for the decision-maker in selection to practically implement the selection on breeding goal traits. Also a comprehensive goal can be more easily explained to and understood by the farmers.

- The traits in the breeding goal should be **mutually exclusive**. This condition does not require complete absence of relationships between goal traits; that would even be practically impossible. This condition means, however, that from two traits that are highly correlated and in fact focus at the same characteristic of the animal, only one trait is to be included in the breeding goal. For example, it is better to include only weaning weight of piglets averaged over males and females as a breeding goal trait, not weaning weight for each sex separately. Another example in sheep, includes only female fertility in first and (averaged) later parity when it is known that the number of lambs born in first parity is a clearly different trait while all later parities genetically are the same trait.

① Consider the list of animal traits filled in of these guidelines. Group the traits according to
- production traits
- non-production traits.

- Production traits are traits that are directly linked to the output of an animal product like wool, meat, milk, draught; genetic improvement of a production trait will directly increase the production level per animal.

- Non-production are traits for which a genetic improvement will not directly increase production level of the animal, but a genetic improvement will lead to an increase in efficiency of production by lowering the input of resources per animal.

- *NB. The difference between production and non-production traits is not always straightforward, for example, when considering reproduction in animals for meat production. Do not worry too much; the difference between production and non-production traits is not a goal itself, but only a way to define the main groups of traits in the breeding goal.*

② Within the group of production traits, identify groups according to the product output that is increased. For some species only one product is relevant, for other species multiple products will be relevant. Sometimes it is desirable to distinguish only the main product from a larger group of by-products.

③ Within the group of non-production traits, identify groups according to:
- traits directly related to **health** of the animals, if wanted, distinguish traits for the most important disorders separately;
- traits directly related to **fertility and parturition,** if wanted, distinguish between traits for female and male fertility;
- traits directly related to **feed intake** (requirement) of the animals, for example feed intake capacity, body weight (as an indicator of maintenance requirements), or feed conversion;
- traits directly related to **workability** of the animals, like character (ease of handling), social behaviour and milking speed.

④ After steps ①, ② and ③, some traits may not fit into one of the groups: either remove the trait from the list when not considered important or assign a separate group for this trait.

⑤ Reconsider the groups; each group will represent a sub-breeding goal. Rule of thumb: use no more than six sub-breeding goals and no more than four traits per sub-breeding goal.

⑥ Compare the current list of breeding goal traits with the reference lists in Annex V. Again reconsider that the list is complete, comprehensive and mutually exclusive. Also reconsider that the list of breeding goal traits should correspond to the development objective of agricultural production, the animal production system and the choice of breeds to use.

⑦ Finalise the list of breeding goal traits by filling in the table in the next box and if convenient, list predictor traits per sub-goal.

- Removing traits from the list is important. Consider the following: is it important to improve the trait as such, or is it important to improve the trait because it helps to genetically improve another, underlying trait. For example, udder attachment in goats is an indicator trait for mastitis susceptibility: mastitis susceptibility is the breeding goal traits, not udder attachment. Udder attachment might be a good trait to include in a recording scheme and to use in an index for the prediction of the breeding value for mastitis susceptibility (see also Annex I).

- For the users own convenience these '**predictor**' or index traits can be listed separately.

- Notice, it is not necessary that breeding goal traits can be directly, routinely observed on selection candidates. For example, in pig breeding, selection is for fatness of the carcass. Fatness of the carcass is in the breeding goal, but is not observed on selection candidates, because this would mean that candidates have to be slaughtered, which means that they cannot be used anymore for breeding. As a predictor trait, a routine score on body condition is taken or sub-cutaneous fat thickness is measured ultrasonically.

A list of breeding goal traits

Sub-breeding goal
Other index traits for the prediction of breeding values

- Sub-division of the total breeding goal in groups of sub-goals is a useful way towards the practical implementation of selection of male and female parents. Sub-division allows the direct identification of the main characteristics looked after when genetically improving animals.
- Sub-division of the total breeding goal also enhances a stepwise assignment of goal values; a stepwise weighing of predicted breeding values.
  1. For each breeding goal trait, breeding values are predicted per selection candidate (from direct (= same trait) or indirect (= other predictor trait) observations).
  2. The traits within a sub-goal are weighed to give a predicted breeding value of this whole sub-group per selection candidate. Likewise for every sub-group.
  3. The predicted breeding values per sub-group are weighed to a 'total' breeding value per selection candidate.

This way, the sub-division allows an easy identification of the strong and weak points per selection candidate.

An example - A list of breeding goal traits in dairy cattle breeding

Sub-breeding goal					
Milk production	**Female fertility**	**Health resistance**	**Calving performance**	**Feed efficiency**	**Miscellaneous**
Milk yield Fat yield	Cycling/showing heat	Mastitis incidence	Direct effect Maternal effect	Body weight Feed intake capacity	Character Milking speed
Protein yield	Pregnancy rate		Still birth		
		Mobility		Body condition score	
Other index traits for the prediction of breeding values					
	Interval calving – 1st insemination	Cell count	Rump angle	Muscularity Body depth	
		Claw diagonal Rear legs set		Body width	

4.2. Subjectively assigning goal values

A helpful way to become familiar with the weighing of breeding goal traits is the subjective assignment of goal values. This can be done by an individual user of these guidelines, e.g. policy-maker or farmer, or can be done via a more extensive expert panel or survey.

① The set up is to first divide 100 points over sub-goals as given in the former table.

- Note, the scale is linear: twice as many points for a trait means that the predicted breeding value for the trait gets twice as much emphasis in the total index value of the animal. However, this does not mean that the genetic improvement for the trait will be twice as high. Remember that the level of genetic improvement will also depend on the genetic possibilities of improvement (considering the genetic and phenotypic parameters in the population, such as (co)variances and correlations) and the number of observations on the animal and its relatives.

- At this stage it is useful to perform a 'sensitivity analysis', referring to Figure 2.1. When (preliminary) information on the breeding structure is known and population parameters and discounted expressions (from gene flow) are available (or reasonable assumptions can be made), the user should perform selection index calculations to derive expected genetic gains for the breeding goal traits. By varying the subjectively assigned goal values (at constant other assumptions), a fair picture can be obtained to what extent changes in goal values will give rise to changes in expected genetic gains.

- Notice, that when performing the above steps, the user enters the stage of **optimising the breeding strategy**!

② Next, divide the points per sub-goal over traits within the sub-goal.

- Note, the scale is linear: twice as many points for a trait means that the predicted breeding value for the trait gets twice as much emphasis in the total index value of the animal. However, this does not mean that the genetic improvement for the trait will be twice as high. Remember (page 7) that the level of genetic improvement will also depend on the genetic possibilities of improvement (considering the genetic and phenotypic parameters in the population, such as (co)variances and correlations) and the number of observations on the animal and its relatives.

- At this stage it is useful to perform a 'sensitivity analysis', referring to Figure 2.1. When (preliminary) information on the breeding structure is known and population parameters and discounted expressions (from gene flow) are available (or reasonable assumptions can be made), the user should perform selection index calculations to derive expected genetic gains for the breeding goal traits. By varying the subjectively assigned goal values (at constant other assumptions), a fair picture can be obtained to what extent changes in goal values will give rise to changes in expected genetic gains.

- Notice, that when performing the above steps, the user enters the stage of **optimising the breeding strategy**!

4.3. Assigning goal values by normative modelling

This Section will guide the user to build a model for the objective derivation of goal values for the breeding goal traits. Figure 4.2 summarises the different steps involved. The next paragraphs give background information on each of these steps, especially on what information to base the choice, possible choices and effects of each choice. Referring to Figure 2.1**,** a lot of the information required is gathered during Section 3 when defining the development objective in agricultural production and the characterisation of the animal production system.

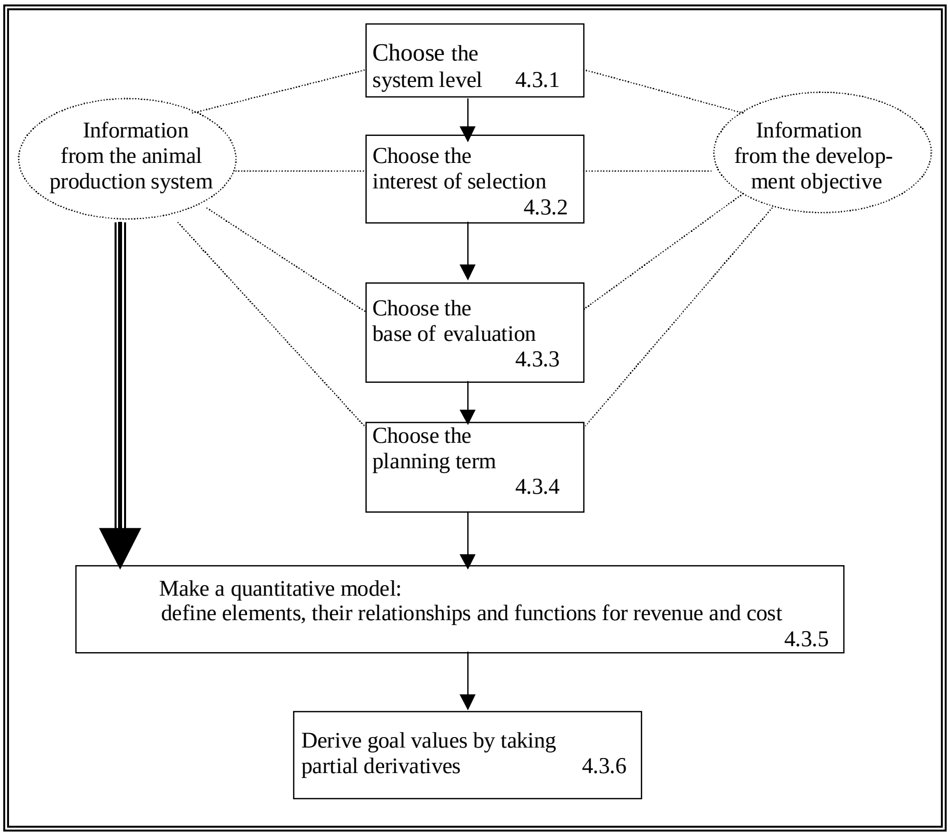


Figure 4.2. Stepwise assigning goal values by normative modelling.

4.3.1. System level

A model is an equation or a set of equations that represent the behaviour of a system. A model is not the complete, real system; it is generally less than complete because it should only include those elements of reality that are relevant for the study undertaken. A model is an 'abstract' of the real system in order to study the behaviour of the system. The behaviour of the system is the way in which the system reacts to endogenous or exogenous impulses. In fact, the interest is in finding out how the system reacts on an improvement in genetic merit of the animals in the system.

Figure 4.3. gives a general structure of animal production systems. Genetic merit is tied up to the level of an animal. Therefore, the animal level is the lowest level considered in deriving goal values, but higher levels may be considered as well. Notice, elements and their relationships chosen in a model on animal level depend on biological processes at even lower levels.

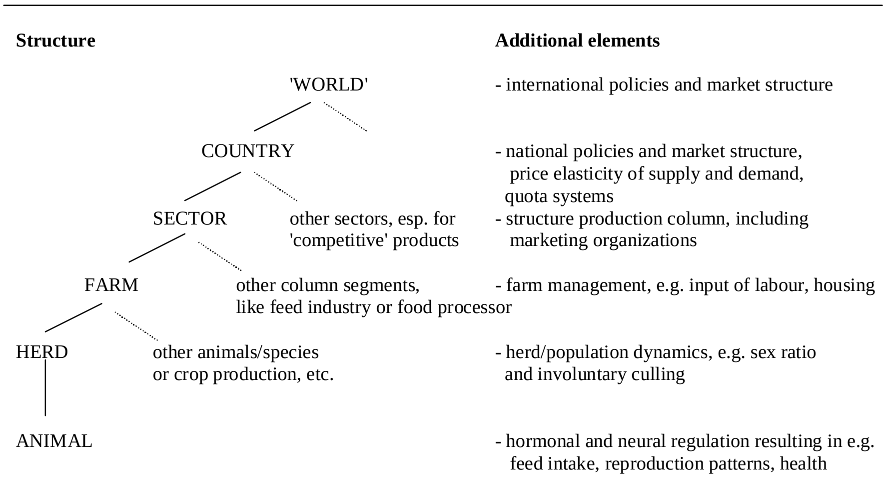


Figure 4.3. A general structure of animal production systems.

Improvement of genetic merit is a technological development; it increases the efficiency of production by saving resources per unit of output. Long-term effects of greater efficiency will be reflected in lower market prices. Yet, a cyclic interaction is observed. Future prices determine goal values; goal values determine genetic change per trait and genetic change per trait will influence future prices. Therefore, the derivation of goal values ideally requires knowledge on future levels of genetic improvement and their price effects.

Make your choice in system level to model. The advice is to consider farm level.

The theoretically appropriate level to be used in deriving goal values is the one for which limited resources and prices of products and resources are influenced by an improvement of the trait. This readily ends up at sector or national level. Although theoretically appropriate, national and sector level are rarely chosen because of methodological difficulties. The potential bias as a result of simplification made by modelling at herd or farm level can be tested by calculating goal values for several assumptions on market prices and production levels (sensitivity analysis).

4.3.4. Interest of selection

The interest of selection denotes the primary interest of the decision-maker. This primary interest will strongly depend upon the position that the decision-maker holds on the market. There are several types of markets, differing in the way that prices are determined and a (long-term) balance is found between total demand and supply for the product. Options for the interest of selection are:

- maximise revenues minus cost (profit maximisation);
- minimise cost per unit of product (or cost price minimisation); or
- maximise revenues per unit of cost (maximise return on investment).

The differences between these options probably do not look readily obvious and there is an overlap between these. For example, cost price minimisation will help to increase profits. Taking this even further, assuming certain market conditions, taking the average over farmers and overlooking the long-term, the approaches are equal. However, there are differences in these options that are interesting enough to consider when defining breeding goals from the point of view of an individual farmer.

The farmer generally deals with a market of free competition; there are many consumers and producers and an individual farmer has no influence on the price setting. In this situation, the interest of the individual farmer will be to maximise profit.

When breeding goals have been developed by and for producers or groups of producers, emphasis is therefore put on profit maximisation. In developing countries, markets are generally more local, but the same mechanism will apply (see example). It is therefore advised to opt for profit maximisation, unless there are clear reasons to deviate from this.

The question “why consider profit maximisation with a taxpayer-financed national breeding structure?” is very relevant. The government sets up the breeding structure and the main interest of the government is to reduce the cost per unit of food for the citizens. There are two possible answers. First situation: the government is in charge of the (national) breeding structure to test and make available good breeding animals. However, they still allow the farmer to make a choice in which breeding animals to use and there is even an option for the farmer not to use a breeding animal from the government. In this situation, the basic decision of which animal to use is still made by the farmer and the farmer will follow his interest of selection. Note the possibilities of governments to impose their interests on the individual producers by creating a social and economic production environment. Secondly, when the government is in charge of the (national) breeding structure and fully controls the decision-making in breeding, then cost price minimisation might be taken.

A commercial investor might also set up a breeding structure. An investor has money available for investments and will choose the branch that gives the highest return on investment. Well, the same type of answering holds as with the taxpayer-financed breeding structure; only with full control by the investor, return on the investment should be considered as the interest of selection. However, the investor (and also the government) will generally give responsibility of the decision-making to the individual farmer, maybe only for the sake of having the farmers involved in the structure.

[The effect of the chosen interest of selection will be presented after making the choice on the basis of evaluation.]

An example

At the market place in a small town in India, farmers (themselves or via merchandisers) are selling their chicken eggs. The people from the small town will generally first look around at the market place before deciding where to buy their eggs. An individual farmer asking too high a price (given a certain quality) will not sell his eggs. Of course, some people will try to buy at lower prices, but at a certain price level the farmer will stop selling his product. This is a market of free competition.

An individual, commercial farmer will try to maximise his profit; he will try to produce a number of eggs where the cost to produce an additional egg is fully compensated by the market price. Producing one more egg will have higher costs (e.g. from feed input) and for that egg, the market price will be too low. He will not produce one egg less, because that egg will have marginal costs that are lower than the market price; producing and selling this egg will give more benefit, i.e. profit.

An individual farmer with 'backyard' production of chicken eggs will probably reason in another way, because his costs of producing one more egg are not directly identifiable. However, the market principle is the same. Also this farmer will not sell his eggs at too low a price, because he will consider the alternative of having the eggs consumed by his own family.

4.3.3. Basis of evaluation

Another hard decision is still to be made: the basis of evaluation. The basis of evaluation is representing the strict limitations for the production system, i.e. the farmer's management over the planning term of decision-making in animal breeding. The system may face:
- a fixed input of a certain resource, e.g. feed, land or labour;
- a fixed output of a certain product, e.g. milk quota.

In the case where no fixed input or output is faced, the basis of evaluation will be:
- a fixed number of animals on the farm.

Limitations as applied at farm level are denoted here, but for the taxpayer and investor financed breeding structures and limitations at higher system level will apply. For example, a fixed amount of product output for a sector in the breeding structure.

Maybe it is not directly obvious why a basis of evaluation is to be chosen. Think of it in the way that somehow the size of the system is to be defined or restricted. When the system size is not constrained by an input or output component, it is convenient to define system size in terms of the number of animals.

Make a decision on the basis of evaluation. When the product output or the input of a certain resource (land, labour or feed) of an individual farm is restricted by legislation, consider this restriction as the basis of evaluation. Also when legislation places a very strict limitation on output of by-products or elements of environmental pollution, take this as the basis of evaluation. When the system is constrained for multiple products or resources, assume these multiple restrictions as the basis of evaluation. When the system size is not constrained by an input or output component, it is convenient to define system size in terms of the number of animals.

It might be that legislation is enforced that does not strictly constrain the input or output but applies levies on surpluses used or produced. For example, a normative figure for the loss of CO_2 to the environment is set per farm and when farms have a loss lower than the normative figure, no levy has to be paid. However, when the loss is higher, a levy must be paid. This situation with levies does not enforce a strict constraint to be considered in choosing a basis of evaluation. It introduces however, non-linearity of prices to be considered when deriving goal values.

What is the effect of a choice on the basis of evaluation? The effect will be considered together with the effect of a choice in the interest of selection.

This is one of the most difficult areas of breeding goal definition and it is a heavily debated area. The basic idea of the effects of the basis of evaluation and interest of selection is summarised in Table 4.1 in terms of economic perspectives.

Table 4.1. Economic perspectives in deriving goal values with different basis of evaluation and different interests of selection.

Basis of evaluation	Interest of selection	
	Maximisation of profit	Minimisation of cost price
Fixed number of animals	Marginal revenue[A] - Marginal cost	Average total cost [A] - Marginal cost [B]
Fixed input	Marginal revenue [A]- Average (revenue-fixed cost per animal)[C]	Average total cost [A] - Average fixed cost farm [C]
Fixed output	Average variable cost [A] - Marginal cost [B]	Average variable cost [A] - Marginal cost [B]

[A] Per δy units of product
[B] Per δy units of product, corresponding to δx_v units of production factor
[C] Per δx_v units of production factor

When maximising profit of the farm assuming a fixed number of animals on the farm, the general question is: are, per animal, the marginal cost of inputs lower or higher than the marginal revenue of outputs obtained? When marginal revenues are higher than marginal costs, a higher level of outputs per animal by genetic improvement is beneficial, i.e. the goal value of the trait is positive.

When minimising the cost price with a restricted output of the farm, the question is: is the marginal cost of additional inputs needed to increase the production of the animal by one unit, higher or lower than the average cost per unit of product? When the marginal costs are lower than an increase in product output per animal (while reducing the number of animals per farm), will it reduce the overall cost price per unit of product, i.e. the goal value of the trait is positive?

Details in Table 4.1 (examples on how these economic perspectives are derived and a discussion on differences and equivalencies) are in Annex VI. Here, it is important that the user of the guidelines understands that the different choices on the basis of evaluation and the interest of selection allows for the goal value to be derived from a different economic point of view. These different economic points of view enforce that different aspects of the (economic) production environment determine the goal values of traits. As an example, when maximising profit with a fixed number of animals, the price of the product becomes a major parameter as it determines marginal revenue. However, when minimising cost price with a fixed output, the price of the product plays no role at all. Another example, generally average variable costs are highly influenced by average production levels, while marginal revenue are not.

The user has already made a choice on the basis of evaluation and the interest of selection. **The advice is to hold on to the choices that were made and to start making a normative model for the derivation of goal values.** After finishing the model, the user should reconsider the choices made and perform a sensitivity analysis on important parameters, preferably when considering different interests of selection and different basis of evaluation. From this sensitivity analysis, the impact of choices made should be fully understood.

4.3.4. Planning term

In the choice of the planning term there are basically three options:

- < 1 year - short or operational term;
- 1-5 years - mid or tactical term;
- 5 years - long or strategic term.

The choice of a planning term should be included in deriving goal values regarding:
1) the choice of price parameters; and
2) the distinction between variable and fixed cost.

The choice of the planning term is also related to the choice of system level. For example, only in the long-term will the improvement of a trait influence limited resources and prices of products and resources at sector level.

For an individual farmer, the choice is primarily based upon his assessment of when revenues from breeding decisions are expected. This will largely differ between livestock species.

Make a decision on the planning term. The advice is to consider long-term price parameters and a clear distinction between cost variable and fixed time.

It is difficult to distinguish between mid- and long-term in estimating future prices. Try to analyse historic price trends over a long period and try to predict from these trends possible future prices. When considering that future prices will depend on a few basic assumptions, for example, regarding governmental policies, define different scenarios.

Selection sometimes has a major influence on the short-term efficiency of a single farm (e.g. value of new-born calf to be sold for beef production). Nevertheless, it is appropriate to consider long-term prices, because the major benefits from selection will appear in the longer term.

Modelling allows for the implementation of mathematical programming techniques to (re-)optimise management variables with changing levels of genetic merit. For example, dynamic programming can be used to determine the optimum replacement policies. Reducing involuntary (reproductive failure, health problems) disposal rates increased optimum voluntary disposal. Ignoring these changes in management variables would underestimate the economic advantage of reducing involuntary culling. Linear programming is used to derive goal values in dairy cattle according to environmental policies. Linear programming also allows easy handling of multiple restrictions. As for example, future governmental policies and their effects on farm structure are yet unknown, different alternatives can be studied and linear programming allows for the definition of optimum farm management for each alternative. In fact, linear programming allows for the best (given farm characteristics) use of saved resources, in others words, the appropriate choice of (marginal) prices for (marginal) feed requirements. Consider optimising farm management as a refinement when modelling for the derivation of goal values; a refinement that might be considered in a later iteration.

The question of optimising farm management given farm structure should not be confused with optimising farm structure. Animal breeding is part of long-term planning of production. Therefore, it is appropriate to consider all cost to be variable in time. However, costs may be fixed (constant or discontinuously variable) with respect to the size of the farm. Considering these fixed costs to be variable per unit of product requires an assumption on the (continuously optimum) size of the farm. However, structural developments in industry are then detached from improvements in the efficiency of production, which is not correct considering long-term effects of the implementation of new techniques. **Therefore, in deriving goal values, clearly distinguish between costs fixed and variable in size, independent or dependent on the level of genetic merit per animal.** For example, housing costs include variable costs per animal, but also fixed costs not related to the number of animals in the stable.

4.3.5. Elements of the model and their quantitative relationships

Choices on the level of the system, the interest of selection, the basis of evaluation and the planning term are now made, the user will make a set of equations, a normative model.

① Consider the flow chart of the animal production system. Define two equations, one for cost as a function of the inputs of the system and one for revenue as a function of the outputs of the system. Combine these two equations in one regarding the interest of selection of the system: profit = revenue – cost and cost price = amount of product / cost.

② Refine the broad equations for cost and revenue by splitting each term into two factors: one factor representing ‘amount’ and one factor representing ‘price’. It may be that a term combines multiple outputs (e.g. feed costs are from feeding grain and grass), then split each term likewise but per output component. When a product is sold with different qualities, consider the amount and price of each product separately. The same should be done for resources with different qualities.

③ While detailing the equations for the revenue and cost, make a listing of all input variables required, distinguish between:
- parameters to be derived from more detailed modelling, **internal parameters,** these parameters are usually variable;
- parameters to be assigned from external information, **external parameters** these parameters are usually considered fixed.

④ Now start detailing the equations further, internal parameter one-by-one, until for each internal parameter an (underlying) equation is derived based on external parameters only.

This is a laborious work that needs a lot of careful detailing. Work precise; write out the equations on paper. A direct transfer of the equations in a computer model (e.g. in a spreadsheet program) is very convenient. Make a good documentation of the model; make sure that other people can understand the model and that other people can retrace the origins of parameters assumed.

Below some literature examples of models in terms of a set of equations are given. Do not use these literature examples as ‘blue prints’ of the model to develop; these references are only given to help the user get started when detailing their own model.

Pigs: De Vries, A.G., 1989. A model to estimate economic values in pig breeding. Livestock Production Science, 21: 49-66.

Beef cattle: Hirooka, H., A.F. Groen and J. Hillers, 1998. Developing breeding objectives for beef cattle production. 1. A bio-economic simulation model. Animal Science, 66: 607-621.

Broilers: Groen, A.F., X.S. Jiang, D.A. Emmerson and A. Vereijken, 1998. A deterministic model for the economic evaluation of broiler production systems. Poultry Science, 77: 925-933.

Sheep: Simm, G. , M.J. Young and P.R. Beaton, 1987. An economic selection index for lean meat production in New Zealand sheep. Animal Production, 45: 465-475.

Dairy cattle: Groen, A.F., 1988. Derivation of economic values in cattle breeding: a model at farm level. Agricultural Systems, 27: 195-213.

⑤ Make a full list of all external parameters and distinguish between the following groups of external parameters:
- external parameters representing the social-economic production environment (e.g. product prices at the market place; levies and subsidies as part of governmental legislation, fixed and variable cost housing), **social-economic parameters**;
- external parameters that represent the technical production environment, (e.g. energy content of feed stuffs, energy requirement per kilogram product or labour requirement per animal), **technical parameters**;
- external parameters that represent the genotype of the animal, these will be the **breeding goal traits**.

The structure of the model should be such that it allows the clear identification of the breeding goal traits. As the user knows for which breeding goal traits goal values are to be derived, perform steps ① to ⑤ directed towards defining equations that relate the cost and revenue of the system to the (assumed levels of) breeding goal traits.

The derivation of goal values requires that the breeding goal traits can be varied independently.

> A model is an 'abstract' of the real system in order to study the behaviour of the system. The behaviour of the system is the way in which the system reacts to endogenous or exogenous impulses. In fact, the interest is in finding out how the system reacts on an improvement in genetic merit of the animals in the system.

⑥ Define for each external parameter (social-economic, technical and breeding goal) a level. Relate the levels to the animal production system (and its whole environment) and the choice of breeds in the system.

⑦ Use the levels of the external parameters to calculate all internal parameters and, as a summary of it all, the cost and revenue of the system and the interest of selection (profit or cost price).

⑧ Validate the outcome of step ⑦. Validation is perhaps the most difficult, but also the most crucial step of building a model. Validation requires both objective comparison of outcomes of the model to 'real life' data (and changing external parameters when necessary) and subjective, heuristic playing around with levels of parameters in order to get close to ‘reality’.

Validation of the model requires re-iteration on steps ② to ⑦ until a satisfactory outcome of the model is obtained.

> A model is not the complete, real system; it is generally less than complete because it should only include those elements of reality that are relevant for the study undertaken.

⑨ Finalise the model building by redefining the equations such that the interest of selection (i.e. profit or cost price) is a direct function of

$$(Factor_1 * Level\ trait_1) + \ldots\ldots + (Factor_n * level\ trait_n)$$

This way of expressing the equations is most helpful when deriving the goal values.

4.3.6. Taking the partial derivative

The final step in deriving normative goal values is now to observe how the modelled system reacts on an improvement of the genetic merit of the animals in the system.

① Calculate the level of profit or cost price of the system assuming all the base parameters of the model.
② Keep all base parameters constant except for the level of one breeding goal trait; increase the level of this trait by one unit (e.g. from 150 eggs to 151 eggs, from 100 g / day growth to 101 g / day, from 2 300 kg milk per year to 2 301 kg milk per year). Recalculate the profit or cost price of the system.
③ With the interest of selection being profit maximisation, define the goal value of the breeding goal trait as (profit ② - profit ①); with the interest of selection being cost price minimisation, define the goal value as (cost price ① - cost price ②).
④ Repeat steps ② and ③ for all breeding goal traits.
⑤ Validate the goal values. Consider if the goal values are logical and can be interpreted and explained to the farmers. Consider performing a sensitivity analysis, i.e. repeating steps ② and ③ with other base levels for external parameters. If this validation requires redefining the model of the system, do so.
⑥ Make a final list of goal values for each breeding goal trait.

At this stage it is useful to perform a ‘sensitivity analysis’, referring to Figure 2.1 on page 14. When (preliminary) information on the breeding structure is known and population parameters and discounted expressions (from gene flow) are available (or reasonable assumptions can be made), the user should perform selection index calculations to derive expected genetic gains for the breeding goal traits. By varying the goal values (at constant other assumptions), a fair picture can be obtained to what extent changes in goal values will give rise to changes in expected genetic gains.

Notice, that when performing the above steps, the user enters the stage of **optimising the breeding strategy**!

4.3.7. Advanced topics

Customised goal values

Breeding goals have to correspond to the individual farmer's interest of selection; the farmers for buying a certain stock (or semen or embryo) at a certain price, will be based upon his assessment of how animals will contribute to the efficiency of his farm. As farmers are confronted with different production environments (socio-economic, natural or technical), goal values may differ for different groups of farmers. This is the basis for a diversification of breeding goals among (groups of) farmers and the use of customised indices for (individual) farms. **The study on possible differences in goal values for different groups of farmers should be an advanced step in defining breeding strategies.** The final decision on a practical implementation of diversification of breeding goals or the application of customised indices requires careful consideration of aspects like effects on selection intensities (and thus future genetic improvement) in the breeding strategy and acceptance of the farmers to cooperate in the strategy.

Non-linear goal values

The goal value of a trait may depend on the level of the trait itself or on the level of other traits. **Evaluation of non-linearity of goal values can be performed by deriving goal values at different starting values for genetic merit of the animals.** When goal values are indeed found to be non-linear, regularly updating goal values according to new population averages is a strategy that gives satisfactory results and is easily understood by farmers.

For traits with non-linear goal values, it should be possible to increase the mean value of the objective function in the progeny by planned sire*dam matings. The advantage of planned matings will be greatest for traits with a high heritability and a population mean close to the economic optimum. Mating strategies are to be considered as part of breeding strategies.

Individual animal variation

Generally in modelling to derive goal values, it is assumed that all animals in the system have equal genetic merit. This is a simplifying assumption, because in a real system there will be variation among animals in a herd or flock. For the derivation of goal values for some traits (especially traits like involuntary culling of the animals) ignoring individual animal variation might bias resulting goal values. However, including individual animal variation in the model is a complicated advanced step. **Necessity should first be carefully considered for example by performing a sensitivity analysis on non-linearity of goal values with respect to genetic merit of the animals.**

Annex I. Selection index theory

The aggregate genotype and selection index

The choice of an aggregate genotype is the starting point in setting up breeding structures. The aggregate genotype is used to represent the genetic merit of an animal: the sum of its genotypes for several traits (assuming a distinct genotype for each trait), each genotype being weighted by the predicted contribution to the increase in the overall development objective. Usually, a breeding structure has different selection paths. A classical example is when four different selection paths are distinguished: SS (sires to breed sires), SD (sires to breed dams), DS (dams to breed sires) and DD (dams to breed dams). Selection paths differ in the generation interval (see later), the amount of information available for the selection decision and also in the intensity of selection (see later). Therefore, although the traits in the aggregate genotype are the same for each selection path, selection paths differ in the relative weighing of traits in the aggregate genotype.

In each selection path, selection for each genotype trait is on predictive observations (the phenotypic performance of the animal itself and of related animals). These observations maybe on the trait itself or on correlated traits. Observations will be combined in a selection index. The calculation of index co-efficients (or weighing factors, regression co-efficients) for observations in the selection index maximises the response to selection by maximising the correlation between genotype trait and index, considering:

- the number of observations in the index;
- the (family) relationship between the animal being evaluated and the source of information;
- the genetic and phenotypic (co) variances among the genotype trait and the index observations.

$$I_{ykl} = \mathbf{b}'_{ykl}\,\mathbf{x}_{yl} \qquad \mathbf{b}_{ykl} = \mathbf{P}_{yl}^{-1}\mathbf{G}_{yl}$$

where,

I_{ykl} is the selection index value of an animal for genotype trait y in situation k and selection path l (CU.animal^{-1});

$\mathbf{b}_{ykl}$ is an n x 1 vector with the index coefficients of n index traits for genotype trait y in situation k and selection path l [CU.(animal.unit)$^{-1}$];

$\mathbf{x}_{yl}$ is an n x 1 vector with the phenotypic performance for n index traits (unit) for genotype trait y, specified for a selection path l;
$\mathbf{P}_{yl}$ is an n x n matrix with the covariances between n index traits for genotype trait y, specified for a selection path l;
$\mathbf{G}_{yl}$ is an n x m matrix with the covariances between genotype trait y and n index traits, specified for selection path l.

The vector x should not contain the 'crude' observations on animals, but should contain the phenotypic performances as a deviation from a 'comparable average'. For example, when the milk production of a Zebu cow is 7 kg, while on average Zebu cows in the same herd on the same day at the same stage of lactation produce 6.5 kg, the observation on this individual cow is denoted as 7 - 6.5 is 0.5 kg.

In fact, the index value I_y is the predicted breeding value of the animal for trait y (PBV_y). When we use a full multi-trait approach, i.e. the vector $\boldsymbol{x}$ and the matrix $\boldsymbol{G}$ consider all observations used to predict genetic merit of all genotype traits, then the total index value I_T is a weighed summation of I_y 's:

$$I_{Tkl} = \mathbf{a}'_{kl} I_{ykl} \qquad \mathbf{a}_{kl} = \mathbf{c}_l \mathbf{v}_k$$

where,

$\mathbf{a}_{kl}$ is an m x 1 vector with the discounted goal values of m genotype traits in situation k and selection path l ($CU.animal^{-1}.unit^{-1}$; where unit stands for e.g. kg milk, egg number or kg growth);
$\mathbf{c}_l$ is an m x m diagonal matrix with the cumulative discounted expressions of m genotype traits in selection path l [$(animal.timeperiod).animal^{-1}$; timeperiod is e.g. week or year];
$\mathbf{v}_k$ is an m x 1 vector with the goal values of m genotype traits in situation k [$CU.(animal.timeperiod)^{-1}.unit^{-1}$].

The so-called cumulative discounted expressions (calculated from geneflow, Annex III) and the goal values determine this contribution. The goal value of a trait expresses to what extent the efficiency of production is improved at the moment of expression of one unit of genetic superiority for that trait. The cumulative discounted expression of a trait reflects time and frequency of the future expression of superior genes originating from the use of a selected individual in a breeding structure. Multiplying the goal values by the cumulative discounted expressions gives the discounted goal values.

In fact, the above description is a two-step procedure. First we predict genetic values (using bs and xs) and then we weigh predicted genetic values to aggregate the breeding goal, the aggregate genotype. When I_y are fully multi-trait prediction (i.e. all xs are used for each I_y then I_T as above is fully equivalent to the aggregate genotype H, as originally introduced in the selection index by Hazel (1943):

$$H_{Tkl} = \mathbf{a}'_{kl}\,\mathbf{g}_{kl} \qquad I_{Tkl} = \mathbf{b}'_{kl}\,\mathbf{x}_{l}$$

where H_{Tkl} is the (total) aggregate genotype of an animal in situation k and selection path l (CU.animal^{-1}) and g is an *m* x 1 vector with the (true) genetic superiorities of m genotype traits.

The two-step procedure is practically more appealing to breeders because it more clearly shows the predicted breeding values per trait (PBV_y) of interest and how the PBV_ys should be weighed in selection decisions.

In practice, PBV_ys tend not to be predicted by a fully multi-trait approach. In the predictions simplifications are made to reduce computational efforts. These simplifications usually include considering only single traits or small groups of traits to predict a PBV_y, e.g. only milk observations used to predict PBV_{milk} and only udder conformation traits used to predict $PBV_{mastitis}$. The error of this simplification is dependent on the accuracy of Iy (lower error with higher accuracies) and on the correlation structure G (lower error with less correlated traits).

Selection index theory

Breeding Goal			Symbol
	Also called:	Aggregate genotype	H
	Includes	Genotype traits	g
	weighed by	Discounted goal values	a
	In fact is	True breeding value	
Selection tool			
	Also called	Selection index	I
	Includes	Observations	x
	weighed by	Index co-efficients	b
	In fact is	Predicted breeding value	PBV

How well does the tool fit with the goal? - Accuracy of selection=correlation between breeding goal and selection tool; given by the ratio of the standard deviation on the index over the standard deviation on the goal.

Accuracy of selection

The variance on H among animals in a population is

$$\sigma^2_{H_{kl}} = \mathbf{a}_{kl}\mathbf{C}\mathbf{a}_{kl}$$

where,

C is a *m* x *m* matrix with the co-variances between *m* genotype traits.

The variance on I among animals in a population is

$$\sigma^2_{I_{kl}} = \mathbf{b}_{kl}\mathbf{P}_l\mathbf{b}_{kl}$$

The suitability of the selection index I to predict (true) genotype values in the aggregate genotype H is given by the correlation between I and H

$$r_{IH_{kl}} = \frac{\sigma_{I_{kl}}}{\sigma_{H_{kl}}}$$

When the correlation is 1, the variance in I is equal to the variance in H, denoting that the index can fully reveal the variation in true genotype values. This correlation between I and H is generally called the accuracy of the index (the quadrate being called the reliability of the index), or accuracy of the prediction.

Defining (co)variances matrices C, G and P

When defining co(variance) matrices, three different types of co-variances will be encountered:

1. (co)variance among animals (for the same trait);
2. (co)variance among traits (for the same animal);
3. (co)variances when multiple observations are considered.

Ad 1.

The co-variance among two animals A_1 and A_2 can arise from a common genetic background and from a common environmental background. The common genetic background is given by the additive genetic relationship between the animals. So,

$$Cov_{A_1A_2} = a_{12} \times \sigma^2_A + c^2 \times \sigma^2_P$$

where,

a_{12} is the additive genetic relationship between animals A_1 and A;

σ^2_A is the additive genetic variance (for a given trait);

c^2 is the common environmental variance as a fraction of the total phenotypic variance σ^2_P

c^2 is usually defined for a specific group of related animals, for example, full sib litter mates or mother and daughter producing in the same herd.

This equation ignores genetic covariances between animals other than additive genetic co-variances.

Another common way to write the same formula is:

$$Cov_{A_1A_2} = t \times \sigma_P^2$$
$$t = Rh^2 + c^2$$

where t is the intraclass correlation; R is another symbol for a_{12}; h^2 is the heritability of the trait, equal to the additive genetic variance as a fraction of the total phenotypic variance.

With 1 and 2 being the same animal, t is called the repeatability of the trait and c^2 denotes the permanent environmental variance as a fraction of total phenotypic variance; the co-variance between repeated measurements is then equal to the genetic variance plus the permanent environmental variance.

Ad 2.

Calculation of the co-variance between two traits y and z is based on the knowledge of the correlation co-efficient r_{yz}

$$\text{cov}_{yz} = r_{yz} \times \sigma_y \times \sigma_z$$

where, σ denotes the standard deviation on the trait. This principle can be applied for phenotypic, genetic and environmental correlations. With y and z being the same trait, of course the co-variance becomes the variance on the trait.

Ad 3.

Assume that we have n observations on trait y. Variance on the average of y is:

$$\sigma_{\bar{y}}^2 = \text{var}[(y_1 + y_2 + ... + y_n)/n] = \text{cov}[(y_1 + y_2 + ... + y_n)/n, (y_1 + y_2 + ... + y_n)/n]$$

So, the variance on the average of y is equal to $1/n^2$ multiplied by [n times the variance on the observation y_i itself plus n(n-1) times the co-variance between two observations y_i and y_j

$$\sigma_{\bar{y}}^2 = \frac{1}{n^2}[n \times \text{cov}(y_i, y_i) + n(n-1) \times \text{cov}(y_i, y_j)] = \frac{1}{n}[\sigma_y^2 + (n-1)t\sigma_y^2] = [(1 + (n-1)t)/n] \times \sigma_y^2$$

where t represents either the repeatability or the intraclass correlation.

Likewise it can be derived that the covariance between one observation on trait z and the average of n observations on y is:

$$\mathrm{cov}_{\bar{y}z} = \frac{1}{n} \times n \times \mathrm{cov}(y_i, z) = \mathrm{cov}_{y_i z}$$

Having these three types of co-variances, we can work out the (co)variance matrices C, G and P.

C-matrix, the co-variances between genotype traits, these will always be genetic co-variances, always considers the same animal (for which the genotype value is calculated) and does not deal with multiple measurements

- diagonal: same trait

$$\mathrm{cov}(g_y, g_y) = \sigma^2_{A_y}$$

- off-diagonal: other trait

$$\mathrm{cov}(g_y, g_z) = r_{A_{yz}} \times \sigma_{A_y} \times \sigma_{A_z}$$

G-matrix, the co-variances between genotype traits and index observations

- general

$$\mathrm{cov}(x, g_y) = a_{ij} \times r_{A_{xy}} \times \sigma_{A_x} \times \sigma_{A_y}$$

- special situations
  - same animal, same trait (i = j, x = y)

$$\mathrm{cov}(x, g_y) = \sigma^2_{A_x}$$

  - same animal, other trait (i = j)

$$\mathrm{cov}(x, g_y) = r_{A_{xy}} \times \sigma_{A_x} \times \sigma_{A_y}$$

  - other animal, same trait

$$\mathrm{cov}(x, g_y) = a_{ij} \times \sigma^2_{A_x}$$

P-matrix, the co-variances between selection index observations

- diagonal: same trait, same animal

$$\mathrm{cov}(x, x) = [(1 + (n-1)t)/n] \times \sigma^2_{P_x}$$

- off-diagonal:
  - same trait, different animals (a_{ij} now is the relationship between animals in the group for which the average is calculated)

$$\mathrm{cov}(x, x) = a_{ij} \times \sigma^2_{A_x} + c^2 \times \sigma^2_{P_x}$$

  - other trait, same animals

$$\mathrm{cov}(x, y) = \frac{1}{n} \times [r_{P_{xy}} \sigma_{Px} \sigma_{P_y} + (n-1)(a_{ij} r_{A_{xy}} \sigma_{A_x} \sigma_{A_y} + r_{e_{xy}} \sigma_{e_x} \sigma_{e_{yy}})]$$

$$\mathrm{cov}(x, y) = a_{ij} r_{A_{xy}} \sigma_{A_x} \sigma_{A_y}$$

- other trait, other animals

(Maybe you will also have to account for environmental correlations here, but environmental correlations between different traits on measured different animals are generally ignored).

Selection intensity

What is selection intensity? Assume a certain selection based on criterion c. Assume S_c to be the selection differential for the selection criterion c: the mean for c of the selected group of individuals. c is assumed to be distributed normally, with mean μ_c and variance σ^2_c. When standardising observations on c to x according to

$$x_i = \frac{c_i - \mu_c}{\sigma_c}$$

x_i will be distributed normally with mean zero and variance 1. Now, the selection intensity is equal to the standardised selection differential S_x, given as

$$i = S_x = \frac{S_c - \mu_c}{\sigma_c}$$

i can also be calculated as *i* = z / p, where z is the value of normal distribution with mean zero and variance 1 at culling point with fraction p selected. Thus, for any given p and corresponding z, i can be computed. Tabulated selection intensities for given fraction p are given for example by Falconer (1989). Note that in applying selection theory c = I and I ~ $N(0,\sigma^2_I)$.

It is important to mention that in calculating i as z / p it is assumed that selection is in a population of infinite size with the criterion for selection being normally distributed. Another assumption is that observations on the selection criterion are independent and originate from an infinite population. These aspects will generally not hold in animal breeding as populations of potentially selected animals are small and breeding values are derived using mixed model methodology (i.e. sire or animal models). Adjustments of i for both aspects can be made.

Selection response

After one round of selection, the genetic superiority (GS) of the selected animals for each genotype trait m is

$$GS_{klm} = (i_l / \sigma_{I_{kl}}) \times \mathbf{b}'_{kl} \mathbf{G}_m$$

where,

i_l is the intensity of selection in path *l*,
$\mathbf{G}_m$ is the m^{th} column of **G**.

A breeding goal is defined for the reference ‘predicted’ future situation and the corresponding ‘predicted’ discounted goal values. The obtained economic revenues are the sum of genetic superiority for all *m* genotype traits due to selection in all *l* selection paths, weighed by the ‘actual’ discounted goal values (‘actual’ denoting at the future moment of expression of the superiority). When the predicted goal values equal the actual goal values (i.e. predicted production circumstance equal actual production circumstances), optimum levels of improvement per trait and maximum economic revenues (MER, CU per animal in the population) of the breeding structure will be obtained

$$MER_k = \sum_l \left[i_l \times \sigma_{I_{kl}} \right]$$

This equation is equal to the formula by Rendel and Robertson (1950)

$$\delta GS_k = \frac{\sum_l GS_{kl}}{\sum_l L_l}$$

when all cumulative discounted expressions in all selection paths equal 1 over the sum of generation intervals (*L*) for all selection paths. This will hold when cumulative expressions are derived for an on-going breeding structure, evaluated over an infinite time term and are not discounted (or discounting rate is 0). In fact, δGS is the steady state predicted genetic gain per year when applying a certain breeding strategy (H, I and i) in a population. Calculation of MER is more flexible, as the cumulative discounted expressions included can deal with both discounting and irregular patterns of response to selection, especially in periods when starting a breeding structure (see Annex III).

Note that in calculating both MER and δGS it is assumed that variances of traits and other genetic parameters, as well as selection intensities are independent of each other and do not change over time, notwithstanding applied selection.

Annex II. Mixed model methodology

This is only a very short introduction to mixed model methodology, merely aiming at showing its equivalence to selection index theory.

In a mixed model, we assume observations to be influenced by fixed and random effects. In matrix notation, a mixed model can be expressed as

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zg} + \mathbf{e}$$

where,

y n x 1 vector with n observations;
b f x 1 vector with f fixed effect levels;
g s x 1 vector with s random effect levels (e.g., s is the number of animals a breeding value has to be derived for using the data);
e n x 1 vector with error terms;
X n x f incidence matrix indicating for each observation the fixed effects by which it is influenced;
Z n x s incidence matrix indicating for each observation the random effects by which it is influenced.

Expectations and variances on the observations and random effects are:

$E(\mathbf{y}) = \mathbf{Xb}$ $\quad$ $Var(\mathbf{y}) = \mathbf{V} = Var(\mathbf{Zg} + \mathbf{e}) = \mathbf{ZGZ}' + \mathbf{R}$ $\quad$ $Cov(\mathbf{y},\mathbf{g}) = \mathbf{ZG}$
$E(\mathbf{g}) = \mathbf{0}$ $\quad$ $Var(\mathbf{g}) = \mathbf{G}$
$E(\mathbf{e}) = \mathbf{0}$ $\quad$ $Var(\mathbf{e}) = \mathbf{R}$

From solving such a mixed model 'best estimates' (accurate and unbiased) for fixed effects (Best Linear Unbiased Estimates; BLUE) and for breeding values (Best Linear Unbiased Prediction; BLUP) are obtained simultaneously. Henderson showed that solving the model can be performed using the so called 'Mixed Model Equations' (MME)

$$\begin{vmatrix} \mathbf{X'R^{-1}X} & \mathbf{X'R^{-1}Z} \\ \mathbf{Z'R^{-1}X} & \mathbf{Z'R^{-1}Z + G^{-1}} \end{vmatrix} \times \begin{vmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{g}} \end{vmatrix} = \begin{vmatrix} \mathbf{X'R^{-1}y} \\ \mathbf{Z'R^{-1}y} \end{vmatrix}$$

where,
X is sized n x f, so **X**' is f x n (*number of rows* x *number of columns*);
R and $\mathbf{R}^{-1}$ are n x n. **Z** is n x s; **Z**' is s x n.
The total size of the left hand side matrix equals f+s rows and f+s columns and this matches with the size of the vector containing estimates for **b** and predictions for **g** and with the size of the right hand side of the equation.

The left hand side of the MME can be quite large, especially when going to animal models and multiple trait models.
Breeding values **g** can be predicted from

$$(\mathbf{Z'R}^{-1}\mathbf{X})\hat{\mathbf{b}} + (\mathbf{Z'R}^{-1}\mathbf{Z} + \mathbf{G}^{-1})\hat{\mathbf{g}} = \mathbf{Z'R}^{-1}\mathbf{y}$$

which is equivalent to

$$\hat{\mathbf{g}} = (\mathbf{Z'R}^{-1}\mathbf{Z} + \mathbf{G}^{-1})^{-}(\mathbf{Z'R}^{-1}\mathbf{y} - \mathbf{Z'R}^{-1}\mathbf{X}\hat{b}) = (\mathbf{Z'R}^{-1}\mathbf{Z} + \mathbf{G}^{-1})^{-}\mathbf{ZR}^{-1}(\mathbf{y} - \mathbf{X}\hat{b})$$

Now remember the selection index theory (Annex I), where the predicted breeding values were identified as I_y = ***b**y***'***x**y*** where **x** was a vector of observations and **b** was a vector with index co-efficients calculated as ***P***$^{-1}$***G*** (italics and underlining is used to clearly differentiate between symbols used in selection index theory and mixed model methodology). Reformulating the selection index derivations in terms of mixed model methodology:

- ***x*** in the selection index relates to **y** in the mixed model; in Annex I it was denoted that ***x*** should be corrected for a 'comparable average'; in fact the mixed model methodology accomplishes this by correction for estimated fixed effects;
  x = **y -Xb**
- ***P*** is the co-variance matrix of the observations and is therefore equal to Var(**y**) = **V** =**ZGZ**'+**R**
- ***G*** is the co-variance matrix between observations and breeding goal traits and is therefore equal to Cov(**y**,**g**) = **ZG**

As a result for the selection index

$$\hat{\mathbf{g}} = \mathbf{GZ}'(\mathbf{ZGZ}'+\mathbf{R}^{-1})^{-}(\mathbf{y} - \mathbf{X}b)$$

Henderson proved that the solutions for the breeding values g are equal for both selection index theory and mixed model methodology, apart from the fact that selection index theory assumes that comparable averages (or **Xb**) are known without error, while mixed model methodology estimates these comparable averages from the data. The full proof is not given here, but similarity is shown for a simple example. Assume we have an average of n observations on the animal, then

$$\mathrm{var}(\bar{y}) = \mathrm{var}(g) + \mathrm{var}(e)/n = \sigma_A^2 + \sigma_e^2/n$$
$$\mathrm{cov}(\bar{y}, g) = \mathrm{var}(g) = \sigma_A^2$$

The estimate of g from both the mixed model methodology and selection index theory then becomes:

$$\hat{\mathbf{g}} = n \Big/ \left(n + \sigma_e^2/\sigma_A^2\right) (\mathbf{y} - \mathbf{X}\hat{\mathbf{b}})$$

See for basic theory and advanced applications of mixed model methodology Henderson (1994, book).

Annex III. Calculation of GeneFlow

The basic principle of a breeding structure is that genetically superior animals are used to breed the progeny. The genetic response is the increased genetic value of the progeny because of using genetically superior parents. GeneFlow calculates genetic response and specifies its dynamics by modelling in detail **the flow of (superior) genes** through the population.

GeneFlow can be thought of in terms of the question: what proportions of genes do parents of different groups contribute to the genome of a certain group of progeny? To structure this analysis, first the population is divided into groups according to age classes of (breeding and production) animals within each sex. The choice of the length of age classes depends on the species concerned and the production system of interest. For example, in pig production age classes of half a year are convenient; in dairy cattle usually one year is used, while in broilers weekly periods relate better to the production system in use. Secondly, because the interest is in following the flow of genes in time, time is also divided into periods with the same length as age classes.

Now, let $m_t(i)$ be the proportion of genes of interest in age class i at time t. There are two processes that give a transfer of genes in time from one class to another class: reproduction and ageing.

Two matrices can describe the processes of reproduction and ageing, R for reproduction and Q for ageing. The total transfer of genes by reproduction and ageing is given by matrix P = R + Q.

An example

A population with the following specifications is considered:

1) *Males are kept for two age classes (i=1,2) and progeny is born to males in age class two only. These males are two years old at birth of progeny.*
2) *Females are kept for three age classes (i=3,4,5); culling takes place after age class three only. Females produce progeny when they are in the second and third age class. Female replacements are taken equally from two and three year old dams; male replacements are taken for 75 percent and 25 percent from two and three year old dams, respectively.*

Putting these words to mathematical equations, males in age class one at time t ($m_t(1)$) obtain half of their genes from males in age class two (i=2) at time t-1, 3/8 from females in age class two (i=4) and 1/8 from females in age class three (i=5):

$m_t(1) = ½\ m_{t-1}(2) + 3/8\ m_{t-1}(4) + 1/8\ m_{t-1}(5)$.

Likewise,

$m_t(3) = ½\ m_{t-1}(2) + ¼\ m_{t-1}(4) + ¼\ m_{t-1}(5)$.

Genes get into class two, four and five by ageing

$m_t(2) = m_{t-1}(1)$

$m_t(4) = m_{t-1}(3)$

$m_t(5) = m_{t-1}(4)$.

In the example

$$\mathbf{R} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \quad \mathbf{Q} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix} \quad \mathbf{P} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix}$$

R-elements denote proportions of genes in age classes obtained from an age class one time period earlier. **Q** contains only zero's and one's. The sum of elements per row of **P** should always be one.

For specific purposes, one might be interested in the dissemination of genes using one single initial selection path. For example, what is the future contribution by sows that are selected as boar mothers when compared to those by sows that are selected as sow mothers? To answer this question, one should study the gene flow as transmitted to the first generation of offspring through one single path, while transmission to following generations is by all paths. To do this, a matrix $\mathbf{R}_l$ is defined, containing zeros except for the one row describing the transmission of genes through path l. If an $\mathbf{R}_l$ is defined for all paths (including those which do not really represent a path of gene transmission), then

$$\mathbf{P} = \sum_l \mathbf{R}_l + \mathbf{Q}$$

(Note, that all $\mathbf{R}_l$s should be equally sized.) In matrix algebra, the transmission of genes can be described as two processes

$$\mathbf{n}_{l,t} = \mathbf{Q}^t \mathbf{n}_{l,O}$$

$$\mathbf{m}_t = \mathbf{P}\mathbf{m}_{t-1} + \mathbf{R}_l \mathbf{n}_{l,t-1}$$

The vector $\mathbf{n}_{l,0}$ will generally contain zeros but a one in the class for which the fate of genes has to be followed. The first process describes ageing and allows genes to arrive in those classes of $\mathbf{n}_{l,t}$ which contribute to reproduction. When there, the second term of the second process describes how these genes are transmitted by reproduction to the whole population, to $\mathbf{m}_{l,t}$. Vector $\mathbf{m}_{l,t}$ contains zeros initially ($\mathbf{m}_{l,0} = \mathbf{0}$), but as soon as genes have arrived in $\mathbf{m}_{l,t}$, further transmission to following generations is described by $\mathbf{P}\mathbf{m}_{l,t-1}$. After genes considered reach the oldest age class, $\mathbf{n}_{l,t}$ gets $\mathbf{0}$ (the initial genes die). At this stage, the second process simplifies to

$$\mathbf{m}_{l,t} = \mathbf{P}\mathbf{m}_{l,t-1}$$

The example – we will follow an initial set of genes present in young males that will be used as sires of sires.

Define $\mathbf{R}_{SS}$, $\mathbf{n}_{SS,0}$, $\mathbf{m}_{SS,0}$

$$\mathbf{R}_{SS} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \qquad \mathbf{m}_{SS,0} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} \qquad n_{SS,0} = \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

Step 1.

$$\mathbf{m}_{SS,1} = \mathbf{P}\mathbf{m}_{SS,0} + \mathbf{R}_{SS}\mathbf{n}_{SS,0} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

Initial genes are still in age class one and as only age class two males are used for reproduction, no transmission to next generation yet.

Step 2.

$$\mathbf{n}_{SS,1} = \mathbf{Q}\ \mathbf{n}_{SS,O} = \begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The initial genes of males (age class one time zero) are ageing and transmitted to age class two times one.

Step 3.

$$\mathbf{m}_{SS,2} = \mathbf{Pm}_{SS,1} + \mathbf{R}_{SS}\mathbf{n}_{SS,1} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} + \begin{vmatrix} 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \times \begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} \frac{1}{2} \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The initial set of genes has now got its first crop of sons in the population.

Step 4.

$$\mathbf{n}_{SS,2} = \mathbf{Q}\ \mathbf{n}_{SS,1} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The initial genes ‘died’ after having aged beyond the oldest age class.

Step 5.

$$\mathbf{m}_{SS,3} = \mathbf{Pm}_{SS,2} + \mathbf{R}_{SS}\mathbf{n}_{SS,2} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} \frac{1}{2} \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} + \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} 0 \\ \frac{1}{2} \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The first crop of sons has aged one year. As the second part of the equation is no longer important (n is always zero) we will proceed with the simplified equation.

Step 6.

$$\mathbf{m}_{SS,4} = \mathbf{P}\mathbf{m}_{SS,3} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} 0 \\ \frac{1}{2} \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} \frac{1}{4} \\ 0 \\ \frac{1}{4} \\ 0 \\ 0 \end{vmatrix}$$

The first crop of sons has got progeny themselves, both male and female progeny.

When this process of steps is continued, the following table is obtained; m-vectors are now presented as rows

$M_{SS,t}$	Age class				
	Male		Female		
	1	2	3	4	5
0	0	0	0	0	0
1	0	0	0	0	0
2	0.5	0	0	0	0
3	0	0.5	0	0	0
4	0.25	0	0.25	0	0
5	0	0.25	0	0.25	0
6	0.219	0	0.188	0	0.25
7	0.031	0.219	0.063	0.188	0
10	0.156	0.062	0.145	0.078	0.156
15	0.100	0.132	0.104	0.127	0.099
20	0.119	0.108	0.118	0.110	0.120
25	0.113	0.117	0.113	0.116	0.112

So far, the theory gives us derivation of $m_{l,t}$: the response to selection in different age classes in year t as a result of gene transmission and one cycle of selection. Following the dissemination of genes through age classes and time is not the final purpose of GeneFlow. The interest is in computing the contribution of a basic set of genes to future expression of traits. To obtain the total response in terms of expression of genetic superiority in improved performance in different age classes in different years, one needs to account for:

1. which age classes express genetic superiority together with their frequencies (at any time); this is specified in the incidence vector **h**;
2. discounting of future revenue to a base year (t=0); this is accomplished by regressing revenue in year t by a factor

$$\delta^t = \left[\frac{1}{1+q}\right]^t$$

where q is the interest rate in real terms.

Summarising, the cumulative discounted expression up to time horizon t_h from one cycle of selection for a single trait in a breeding structure equals

$$c_{l,t_h} = \sum_{i=0}^{t_h} h' m_{l,t} \delta^i$$

Two more advanced subjects of GeneFlow are (1) in the use of additional 'dummy' rows for the direct calculation of expressions by certain groups of animals and (2) in the use of multiple stages in the production column.

An example

Two types of traits are considered: (female) reproduction and production traits. Females in the 2nd and 3rd age class express reproduction traits, both age classes contributing equally. One-year-old slaughter progeny expresses production traits, like growth rate. As (breeding) males are replaced unequally from dams of both age classes (more from 2nd year old), somewhat more slaughter animals will have a 3rd year old dam. For simplicity, this aspect is ignored and a 50 percent contribution by each female age class is assumed.

Reproduction traits are expressed by age classes already included in **P** and contributions in year t are given directly by individuals in these age classes one and two of year t-1. Production traits are not expressed by breeding animals but by slaughter animals not yet considered in **P**. Therefore, contributions in year t are indirectly taken as contributions of parents of slaughter animals in year t-1: 50 percent males aged class two, 25 percent females aged class two and 25 percent females aged class three. P becomes

$$\begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} & 0 & 0 \end{vmatrix}$$

Note, that the last two columns of **P** are zero, because these dummy classes are not supposed to describe gene transfer. This expanded **P** matrix can be used in the sequential steps of calculating cumulative discounted expressions.

Note that contributions to expression of production traits are equal to proportions of genes in age-class females (i=3). Contributions to expression of reproduction traits are averaged proportions of genes in classes four and five. This means that inclusion of additional classes for producing and reproducing animals is not necessary; the incidence vector h can also do the job. However, when including additional classes the matrix algebra directly gives more information and the incidence vector **h** is simplified.

A closer look at the structure of **P** in the example shows resemblance to the selection paths defined earlier, SS, SD, DS and DD, and elaboration to paths for gene transfer to reproducing and producing animals.

$$\mathbf{P} = \begin{vmatrix} \mathbf{P}_{SS} & \mathbf{P}_{DS} & \mathbf{0} & \mathbf{0} \\ \mathbf{P}_{SD} & \mathbf{P}_{DD} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{P}_{DR} & \mathbf{0} & \mathbf{0} \\ \mathbf{P}_{SP} & \mathbf{P}_{DP} & \mathbf{0} & \mathbf{0} \end{vmatrix} = \begin{vmatrix} \mathbf{P}_{11} & \mathbf{0} \\ \mathbf{P}_{R1} & \mathbf{0} \\ \mathbf{P}_{P1} & \mathbf{0} \end{vmatrix}$$

(**0**s are matrices containing only 0-elements.)

P can be divided in sub-matrices describing gene transfer by different selection paths ($\mathbf{P}_{SS}$, $\mathbf{P}_{SD}$, $\mathbf{P}_{DS}$, $\mathbf{P}_{DD}$) and transition of genes to expression of female reproduction traits ($\mathbf{P}_{DR}$) and production traits ($\mathbf{P}_{SP}$, $\mathbf{P}_{DP}$). $\mathbf{P}_{11}$ is a matrix representing the flow of genes within the breeding population (or nucleus), while $\mathbf{P}_{R1}$ and $\mathbf{P}_{P1}$ describe the flow of genes from the breeding population to reproduction and production traits. This latter notation illustrates the possibilities of applying GeneFlow in levelled breeding structures as commonly applied in poultry and pig breeding, but also increasingly in cattle and sheep breeding.

Literature examples

Dairy cattle: Groen, A.F., 1990. Influences of production circumstances on the economic revenue of cattle breeding programmes. Animal Production, 51: 469-480.

Broilers: Jiang, X., A.F. Groen and E.W. Brascamp, 1998. Discounted expressions of traits in broiler breeding programs. Poultry Science, 78: 307-316.

Beef cattle: Wilton, J.W. and Ö.E. Danell, 1981. Relative rates of discounted expressions of traits in beef crossbreeding programs. Acta Agriculturae Scandinavica, 31: 207-216.

Hirooka, H. and A.F. Groen, 1999. Effects of production circumstances on expected responses for growth and carcass traits to selection of bull in Japan. Journal of Animal Science: in press.

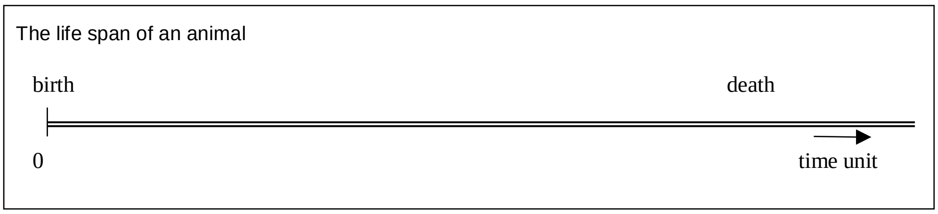
Swine: Danell, Ö.E., K. Rönningen, H. Ström, K. Andersson and P.-E. Sundgren, 1976. An extension of the discounted gene flow method with example in pig breeding. Acta Agriculturae Scandinavica, 26: 203-210.

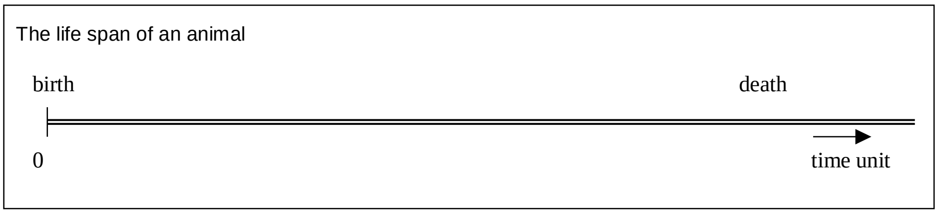
Annex IV. Characterisation of the Animal Production System and Development Objective

Annex IVa. A list of activities in the whole production system

Activity	Specification
Crop production	Production of grass and vegetables, only animal fertiliser used
......	......

Annex IVb. Herd composition





(multiple copies)

Average herd composition

Animal category		Age period (in ......)	Number in the herd	Specification
Reproducing female				
Total				
Reproducing male				
Total				
Slaughter female				
Total				
Slaughter male				
Total				

Annex IVc. A list of outputs of the animal activities

Animal activity	Output	To activity	In case of surplus to activity	In case of shortage from activity	Use for	Price differentiation[i]

[i]Is there any payment for quality of the product ? If yes, how much?

Annex IVd. A list of animal characteristics

Animal activity	Input	From activity	In case of shortage input	In case of surplus input	Owner	Price differentiation[i]

[i]Is there any payment for quality of the product ? If yes, how much?

Annex IVe. A list of animal characteristics

Animal activity, Species	Animal characteristic	Specification

Annex IVf. A flowchart

Set up the flowchart by first giving each activity a box. Then start adding arrows according to inputs and outputs.

Arrow	From activity	To activity	Commodity transferred	Specification of quality	Others ..
..	*animals cow*	*crop grass*	*dung*	*dried*	
A					
B					
C					
D					
E					
..					

Annex V. Reference lists of breeding goal traits

(to be completed for several species by experts)

A list of breeding goal traits in ………..

Sub-breeding goal					
Other index traits for the prediction of breeding values					

A list of breeding goal traits

Sub-breeding goal					
Other index traits for the prediction of breeding values					

A list of breeding goal traits

Sub-breeding goal					
Other index traits for the prediction of breeding values					

A list of breeding goal traits

Sub-breeding goal					
Other index traits for the prediction of breeding values					

Annex VI. Perspectives in deriving goal values

After Groen, A.F., T. Steine, J.J. Colleau, J. Pedersen, J. Pribyl and N. Reinsch, 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-Working Group. Livestock Production Science, 49: 1-21. (see this paper for references).

Three different interests of selection can be distinguished:

1) to maximise profit (= revenues - costs);
2) to minimise costs per unit of product; and
3) to maximize revenues / costs.

The base of evaluation establishes the size of the system considered in deriving economic values, according to social and economic production circumstances. The three possibilities are:

a) a fixed number of animals within the system;
b) a fixed amount of input of a production-factor into the system; and
c) a fixed amount of output of a product out of the system.

For illustrative purposes, derivation of three perspectives is worked out in detail; concepts of other perspectives can be derived from the same equations. The micro-economic approach of an individual farm is chosen. Equation (7) gives revenues and costs of the farm (in CU=currency unit).

$$\text{Revenues farm} = Y\,p_y = n\,y\,p_y \qquad (\text{CU.year}^{-1})(1)$$
$$\text{Cost farm} = X_v\,p_v + C_{fa} + C_{ff} = n\,(x_v\,p_v + c_{fa}) + C_{ff} \qquad (\text{CU.year}^{-1})$$

where,

n : number of animals on the farm;
y : level of product output (kg.animal^{-1}.year^{-1}; Y = n y);
p_y : price per unit product (CU.kg^{-1});
x_v : level of input of production-factor v, variable per animal (kg.animal^{-1}.year^{-1}; $X_v = n\,x_v$);
p_v: price per unit production-factor v (CU.kg^{-1});
c_{fa} : costs of input of production-factor fa, fixed per animal (CU.animal^{-1}.year^{-1}; $C_{fa} = n\,c_{fa}$);
C_{ff} : costs of input of production-factor ff, fixed per farm (CU.year^{-1}).

Profit and cost price per unit product of the farm can be expressed as:

$$\text{Profit farm} = Y\,p_y - (X_v\,p_v + C_{fa} + C_{ff}) \qquad (\text{CU.year}^{-1})(2)$$
$$\text{Costs per unit product farm} = (X_v\,p_v + C_{fa} + C_{ff}) / Y \qquad (\text{CU.kg}^{-1})$$

The economic value of a goal trait represents the change in profit or costs per unit product as a result of one unit change in genetic merit of the trait considered. It is assumed, that change in genetic merit of an animal will change y and x_v by δy and δx_v per animal, respectively. Depending on the base of evaluation, changes in y and x_v give rise to changes in n, Y, X_v and / or C_{fa}. With a fixed number of animals, it is assumed that marginal products produced and marginal production-factors required per animal are sold and purchased on the market, respectively. With fixed output it is assumed, that the amount of product Y produced at the farm is fixed. This implies, that an increase in production per animal (δy) will not increase the selling of a product on the market, but will reduce the number of animals on the farm. The reduction in number of animals is

$$(n+\delta n)(y+\delta y) = n\, y \quad \longrightarrow \quad \delta n = n * [- \delta y / (y+\delta y)]. \tag{3}$$

Related to the micro-economic approach, assuming agricultural price-taker markets, the prices of products and production-factors are constant. Change in profit of the farm is calculated as 'profit after change in genetic merit' minus 'profit before change in genetic merit', as the interest is maximization of profit. Change in cost price is calculated as 'cost price before change in genetic merit' minus 'cost price after change in genetic merit', as the interest is minimisation of cost price. Economic values within the cost price interest will be positive when increase in genetic merit results in a decrease in cost price per unit product. Levels of genetic merit of aggregate genotype traits are tied up to individual animals. Therefore, in deriving economic values, changes in profit of the farm are divided by the number of animals n (present before change in genetic merit). Changes in cost price per unit product for the farm are multiplied by the original level of output y per animal.

The economic value (EV) within the profit interest is:

$$\text{EV } \textbf{`profit'} = 1 / n * \{ \delta(\text{revenues farm}) - \delta(\text{costs farm}) \}. \tag{4}$$

With a **fixed number of animals**, changes in revenues and costs of the farm originate directly from changes in revenues and costs per animal multiplied by number of animals. So, $\delta(\text{revenues}) = n\, \delta y\, p_y$ and $\delta(\text{costs}) = n\, \delta x_v\, p_v$. In other words, the economic value 'profit, fixed number' is equal to the margin between marginal revenues and marginal costs of production of δy units product per animal

$$\text{EV } \textbf{`profit, fixed number'} = \delta y\, py - \delta x_v\, p_v. \tag{5}$$

With a **fixed output**, change in revenues of the farm is zero. Change in profit of the farm originates only from a change in costs of production-factors v and fa: change in costs of v per animal ($\delta x_v\, p_v$) corrected for change in costs due to a change in number of animals

($\delta n * [(x_v+\delta x_v)p_v + c_{fa}]$; δn is given by eqn (3)). The value of δy units of product originates from a reduction in variable costs of the farm due to a decrease in number of animals.

$$\text{EV } \textbf{‘profit, fixed output’} = \delta y[(x_v+\delta x_v)p_v + c_{fa}] / [y+\delta y] - \delta x_v\, p_v \qquad (6)$$

The economic value within the cost price interest is given by eqn (7): the cost price before genetic improvement minus the cost price after genetic improvement, multiplied by original level of output y per animal.

$$\begin{aligned}\text{EV } \textbf{‘cost price’} &= y \{ (\text{costs farm}) / Y - (\text{costs farm} + \delta(\text{costs farm})) / (Y + \delta Y)\} \\ &= y / (Y+\delta Y) \{ \delta Y / Y * (\text{costs farm}) - \delta(\text{costs farm}) \} \qquad (7)\end{aligned}$$

With a **fixed number of animals**, δ (costs farm) is given by n * marginal costs per animal = $n\, \delta x_v\, p_v$. Change in production of the farm $\delta Y = n\, \delta y$. Substituting this in eqn (7) gives eqn (8). The economic value ‘cost price, fixed number’ is positive, when marginal costs of producing δy are smaller than average total costs of δy units product.

$$\begin{aligned}&\text{EV } \textbf{‘cost price, fixed number’} = \\ &= y / (n\, y + n\, \delta y) \{n\, \delta y / (n\, y)\, (n\, x_v p_v + C_{fa} + C_{ff}) - n\, \delta x_v p_v\} \\ &= \delta y\, [n\, x_v p_v + C_{fa} + C_{ff}] / [n\, y + n\, \delta y] - [y / (y+\delta y)]\delta x_v p_v \\ &= \delta y\, [n(x_v+\delta x_v)p_v + C_{fa} + C_{ff}] / [n\, y + n\, \delta y] - \delta x_v p_v \qquad (8)\end{aligned}$$

Concepts are derived for a situation with one product and one variable production-factor per animal. However, concepts can easily be extended to situations with more products and more variable production-factors. The costs of other production-factors with variable input are always to be considered on average variable or average total costs. When the inputs of other variable production-factors are influenced by the level of genetic merit, the marginal costs of production will contain more terms. Analogously, the revenues of other products are always to be considered on average revenues. When the output level of other products is influenced by the level of genetic merit, marginal revenues will contain more terms. When the output level of other products is not influenced, within the profit, interest average variable costs are extended. In the latter case, the revenues of other products are ‘negative costs’ components. For the cost price interest, the consideration of the revenues of other products to be negative costs is optional. For example, in dairy cattle production, the gross or net cost price of milk can be calculated. The net cost price considers all costs minus revenues of beef production per unit of milk. The theory given is based on a single base of evaluation.

The essence of improving the efficiency of a production system is: saving inputs of production-factors per unit of product and / or a change towards the use of cheaper production-factors. Saved production-factors can either be used in the system where they are saved from (and thus extend the product output of this system) or transferred to another system (via the market). Likewise, additionally required production-factors are either to be drawn from the market or from an alternative use in the system. Obtained differences in concepts of production theory originate directly from differences in the assumed use of saved production-factors. Example given, for the ‘profit, fixed number’ perspective, saved production-factors are sold on the market. In other words, differences in concepts between perspectives will only lead to differences in economic values when the values of (saved) production-factors differ between alternative uses. Assuming (1) markets of products and production-factors being purely competitive markets and (2) industry and all individual firms to be in equilibrium, market prices will equal average total costs of production. This is the approach considered by Brascamp *et al.* (1985) in proposing to set profit equal to zero. Economic values based on a fixed number of animals are equivalent when derived within profit and cost price interests. On the base of fixed output, economic values within a profit interest are equivalent to economic values within a cost price interest. These economic values will also be equivalent to economic value ‘fixed number, cost price’ when (3) all costs of the farm are considered to be variable per unit of product. This equality was pointed out by Smith *et al.* (1986), who proposed to express fixed costs per animal or per farm, like variable costs, per unit of output.

To conclude: assuming that all costs are variable and that also the costs of producing the variable production-factor on the farm equals the market price, all perspectives are equivalent. However, in agricultural industries, products and production-factors are commonly heterogeneous and not fully divisible. Heterogenity of products and production-factors lead to division of markets and cause the average costs of production to be different for individual farms. Given (equilibrium) market prices, some farms will have a lot of profit; others will be just efficient enough to continue production. As an important result, the equivalent of perspective may hold in certain conditions for the sector as a whole but will not be valid from an individual producer’s point of view. In defining breeding goals, the definition of efficiency function has to correspond to the individual livestock producer’s interest of selection; the producer’s primary reason for buying a certain stock at a certain price, will be based upon his assessment of how animals will contribute to the efficiency of his farm. These concepts form the theoretical base for a diversification of breeding goals among (groups of) farms, and the usefulness of customised indices for (individual) farms.