BREEDING GOALS FOR NATIONALLY AND INTERNATIONALLY OPERATING PIG BREEDING ORGANISATIONS.

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SUMMARY

The definition of breeding objectives within any breeding organisation implies the choice of a set of goals reflecting as closely as possible present and future production conditions. Considering the appreciable genetic gains achieved in lean tissue feed conversion, the decline in pork quality and the lack of improvement in reproductive traits, greater attention should now be paid to lean growth, meat quality and reproductive ability. Economic weights given to each goal are usually based on profit equations, derived in a production perspective, but profit of the breeding organisation itself is also to consider. Economic weights incorporating competitive position of each organisation may be derived. Such policies however tend to compromise long-term response. Developing alternative stocks to meet a variety of production systems is a strategy usually applied by private breeding companies. In selecting dam lines, selection for extreme objectives, in terms of relative emphasis of reproduction and production traits, is shown to cover satisfactorily a wide range of economic and genetic situations. Important goals for the future may also be guessed from present technological developments in pig production and breeding. A valuable though rather long-term target would be to improve traits conditioning selection efficiency or application of new technologies such as embryo transfer.

INTRODUCTION

The definition of breeding objectives has always been a major preoccupation in pig breeding. Starting from the early goal of preservation of breed type by traditional breed societies, the evolution has been towards an increased attention paid to economic considerations. This has come along with a diversification of breeding structures all over the world, and in many countries a growing part taken by private breeding organisations in the supply of improved stock. It can also be foreseen that international exchanges of breeding stock will become common practice and that worldwide perspectives will increasingly tend to be considered by breeding organisations. In view of those changes and of the need to satisfy both home and international markets, breeding organisations will have to adapt their breeding goals. It is the purpose of this paper to examine the conditions under which breeding goals will have to be defined in the future and the consequences as to the choice of traits to be considered for improvement, their relative emphasis, and also the way to maintain flexibility of the whole genetic system in view of diverse breeding and production conditions.

TRAITS TO CHOOSE AS BREEDING GOALS

When defining breeding objectives, a distinction should be made between choosing the breeds to be included in a programme and within-breed selection. The traits to consider in the choice of breeds will be determined by the role of each breed in the genetic system, either dam line, sire line or multipurpose line. Specific breed characteristics, usually fixed, will have to be chosen in view of particular market requirements, as would be the case for coat or skin colour for instance. Colour in some
cases is a rather absolute requirement imposed by traditional rural environments, as it has been experienced in repopulating Haiti (Delatte et al., 1989). In general, two important principles apply in the choice of traits: first, all economically important traits should be considered (Gjedrem, 1972) and, second, the choice should be based on purely economic grounds (James, 1982). For various practical reasons, however, the number of traits actually considered by breeding organisations, at least explicitly, is somewhat reduced. Smith (1983) suggests that traits with low value of $ah^2$ (i.e. economic value of one phenotypic standard deviation unit x heritability) can be ignored, in apparent violation of the above two principles, provided trends in those "minor" traits be periodically estimated. This may also apply to "major" traits. Some of them may have experienced fast genetic improvement to the point of reaching nearly optimal levels. Others may have remained unchanged or shown deleterious changes. Emphasis on the latter would then appear to be justified.

In the last decades, a major part of the selection pressure in pigs has been directed towards improvement of production traits. Sellier and Rothschild (1990) mention annual responses achieved for growth and body composition traits of the order of 0.5 % of the mean, and even higher figures for a compound trait such as efficiency of conversion of food to lean meat, for which responses well above 2 % of the mean per year have been reported in some countries.

One consequence of that by and large successful selection is a concern often expressed about a tendency to a decline in voluntary food intake (Riley, 1989). Two types of arguments can be given in favour of increased appetite. First, appetite by itself is an important trait at several stages of the production cycle, outside the growing-fattening period, such as for early weaned piglets and for young lactating sows. A second argument is a concern about long-term implications for selection, as a low appetite may compromise further economic improvement through selection. One may envisage that efficiency will no more be increased through a reduction of fatness (a lower limit being reached for this trait) but rather by a reduction of maintenance requirements through faster lean growth (Fowler et al., 1976; Webb, 1989).

The decline in voluntary food intake experienced in several pig populations and in some selection experiments (see review by Webb, 1989) may be considered as an automatic consequence of the economic approach applied generally in defining selection indices, as first suggested by Fowler et al. (1976). As daily food intake (DFI) = average daily gain (ADG) x food conversion ratio (FCR), DFI is expected to decline when $(d_{ADG}/ADG) < - (d_{FCR}/FCR)$, i.e. when, in relative terms, the response in gain is inferior to the response in feed conversion. This is in fact to be expected from the relative weights respectively given to ADG and FCR. For instance, the ratio, in terms of genetic standard deviation, is in favour of FCR by a factor exceeding 2 on average in the European survey of Lindé et al. (1980). Another reason is that FCR is more closely correlated to lean content than growth rate. The figures given by Sellier and Rothschild (1990) for the ranges of realised annual responses, i.e. 3 to 6 g for ADG and -0.02 to -0.04 for FCR, also tend to satisfy the inequality given above. The trend in appetite also depends on whether the trait itself is exposed to selection or not. Fowler et al. (1976) predicted that selection for lean tissue food conversion under ad libitum feeding would reduce DFI, whereas under restricted feeding this would not occur. Such a prediction has been confirmed in a selection experiment emphasising efficiency and leanness under ad libitum and scale feeding (Mc Phee, 1981, 1985). Thus selection objectives should be defined according to the selection regime applied. As testing under ad libitum feeding is to be recommended in view of future commercial conditions, a greater emphasis on growth rate is advisable in order to maintain or improve appetite: see Kanis (1988) and Krieter and Kalm (1989).
Another concern often expressed about side effects of selection relates to the quality of lean and fat tissues. These have to fit the requirements of both industrial processing and consumers demand. Among the properties implied, meat quality certainly occupies a prominent place, and especially a set of characteristics known as technological quality. Though genetic trends for such traits are generally less significant than for amounts of meat and fat in the carcass, they tend to indicate a gradual, though relatively slow, decline in several pig populations (e.g. Lundeheim and Eriksson, 1984; Christensen et al., 1986; Molénat et al., 1986). It is generally admitted now that pork technological quality is largely determined by the rate and extent of post mortem pH change (Bendall and Swatland, 1988; Monin, 1989). Muscle pH (taken as such or deviated from an optimal value) may thus be considered as a major goal in breeding for technological quality, as it is related to its three major components, i.e. colour, firmness and degree of exudation. However, whereas the relationship of pH with exudate is reasonably well understood, "much remains to be learnt about the causal relationships of pH with paleness or softness" (Bendall and Swatland, 1988). This would justify including other traits (such as colour, firmness, processing yield) in addition to pH among the breeding goals. Chemical composition of meat may also be important for future processing techniques. In some breeds, the existence of genes with marked effects on quality (such as the halothane gene) may imply considering variation within specified genotypes.

From the consumer's point of view, a more important aspect relates to eating (or sensory) qualities, of which the three main components are tenderness, juiciness and flavour. According to several authors (Barton-Gade and Bejerholm, 1985; Bout and Girard, 1988; Schwörer et al., 1989), the amount of intramuscular fat is an essential determinant of meat sensory qualities. There is a consensus of opinion among consumers that pork quality has declined in recent years as a consequence of the reduction of the amount of fat in carcasses. Though no within-breed genetic trend appears to have been reported in support of this opinion, breed comparisons show that intramuscular fat tends to be higher in breeds which have not been intensely selected for growth and lean content (Schwörer et al., 1989). However, among modern breeds, apart from a lower quality associated with halothane sensitivity, there is no clear association between carcass fatness and amount of intra-muscular fat (see review of Sellier, 1988). Age may also play an important role and this is particularly important for production systems implying high slaughter weights, as in the case of the mediterranean pig. Casabianca and Luciani (1989) show that a mediterranean breed such as the Corsican pig is able to accumulate intramuscular fat with increasing age at a much faster rate than the Large White breed, selected for a high lean content at an early age.

The quality of fat also deserves to be considered. However modification of fat quality appears to offer much less genetic prospects than meat quality, as properties such as firmness, cohesiveness, colour, are closely dependent on the amount of fat. They can also be more easily manipulated via the diet. In addition, fat sensory qualities are negatively correlated with nutritional quality as expressed by the ratio of polyunsaturated to saturated fatty acids (Wood and Enser, 1989).

Sow productivity is an essential objective for pig breeding, and it has, in the last 15-20 years, experienced quite dramatic increases in most countries. In France, the gain in annual sow productivity has been almost linear over the period 1970-1986, at a rate of about 0.3 piglet/year (Legault, 1988). Contrary to food conversion, this evolution is an example of increase in efficiency obtained through non-genetic means, as it is the result of changes in management practices, essentially a reduction of farrowing interval due to shorter lactation. Tess et al. (1983) evaluate the impact of a reduction of 35 days of the farrowing interval, taking due account of adverse effects on litter size and re-breeding interval, to be of the order of 3-4 % of biological as well as economic costs under USA Midwest conditions. Incidentally, the adverse effects on litter size and
rebreeding interval can be counterbalanced by improved nutrition and management conditions. This seems to have been the case in France, where litter size at weaning has increased and rebreeding interval decreased while lactation length was being decreased. However, weaning age has now reached a level below which any further decrease would have adverse effects on sow productivity. Further gains will then more and more depend on improvements in litter size, piglet viability and, to a lesser extent, on reduced age at puberty, as shown by economic evaluations of Tess et al. (1983) and Bidanel (1988).

Phenotypic trends in litter size do not generally show any improvement over very long periods of time: see Fredeen (1958), Skjervold (1979), Johansson (1981), Legault (1988). On the other hand, rather surprisingly, very few estimates of genetic trends have been published (Johansson, 1981). There is also good evidence that selection pressure on litter size has so far been quite negligible in most breeding programmes. One tends to think that this may be the main reason why no genetic progress has been made, and there is now some ground on which to predict future success in that direction. Breeding organisations will more and more consider litter size as an essential breeding goal.

A number of other traits, though usually not formally included in the selection process, are recognised as valuable goals in pig breeding. Among these, sow longevity may become important in the future, as it reflects a number of characteristics related to physical soundness (such as legs and udder quality), maternal behaviour, short rebreeding interval etc... An economic study of De Vries (1989a) shows that one more farrowing in a sow’s lifetime is equivalent to 0.26 extra piglet per litter. Some concern about the future evolution of sow longevity may be nurtured by the unfavourable incidence of fast lean growth on subsequent sow longevity, as found by Guébéz et al. (1985). In summary, the choices of future breeding goals by the various organisations will be dominated by an increased attention paid to (lean) growth, reproduction and product quality (table 1), as indicated by Webb and Bampton (1987). Probably also several traits considered to-day as secondary will receive more attention in the future.

Table 1 Breeding goals in pigs : past, present and future

<table>
<thead>
<tr>
<th>Year</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sow productivity</td>
<td>?</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>growth rate</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>food conversion</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Product value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean content</td>
<td>++</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>meat quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>technological</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>sensory</td>
<td>0</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>fat quality</td>
<td>0</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>Other traits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(soundness,longevity,..)</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>
DERIVATION OF ECONOMIC WEIGHTS

Once the breeding goals have been chosen, the question arises of giving to each of them its proper weight in the aggregate genotype. Among a large variety of different approaches, a common practice is to use profit equations of the form $P(\text{profit}) = R(\text{return}) - C(\text{costs})$. By deriving $P$ with respect to the traits considered, economic weights can be obtained for each of them. However, as pointed out by Moav (1973), these depend on the perspective taken in defining profit. An example given by Brascamp et al. (1985) can be applied to a pig production enterprise, if $R$ and $C$ are expressed as functions of 3 variables, sow productivity ($n$) in terms of pigs slaughtered /sow/year, weight of lean ($w$) and days of growth ($d$) per pig, and of 3 economic parameters, value of lean ($V$), cost of day ($C_1$) and of sow/year ($C_2$). Then $R = nwV$ and $C = ndC_1 + C_2$, if profit is expressed per sow. It can easily be shown that economic weights of $n$, $w$ and $d$ derived from that definition of $P$ are different from the values obtained if profit is defined per slaughter pig. This anomaly is removed, as shown by Brascamp et al. (1985), if profit is set to zero, which is equivalent to considering profit as a normal cost of production. Another way to remove the anomaly, proposed by Smith et al. (1986), is to impose two conditions. The first is that all costs should be considered as variable costs, i.e. attached to an individual animal, the sow in the above example, which satisfies this condition. The second condition is that the extra profit due to genetic change that can also be obtained otherwise by changing the size of the enterprise (or rescaling) should not be counted. Application of these two conditions also gives the same economic weights as those obtained by considering efficiency instead of profit, i.e. $R/C$ instead of $R-C$. Methods using bio-economic models (Tess et al., 1983; De Vries, 1989a) are based on efficiency of production and therefore should avoid the difficulties raised by profit equations. In practice, as pointed out by Smith et al. (1986), those difficulties may be of minor importance, as profit of pig enterprises is usually quite small compared to costs. Perhaps more importantly, the approach of Smith et al. (1986) has the advantage of stressing reduction of production costs, or increase of efficiency, rather than increase of output. Therefore it applies to situations where total output is limited. On the other hand, it can be argued that the point of view taken is that of countries which artificially maintain prices above world market levels, for instance by imposing production quotas, which leads to lowered economic values (McArthur, 1987). This could apply to sow productivity ($n$) in the above example and, in a worldwide perspective, the case could be made for applying unconstrained economic values.

The discussion on perspectives has been so far limited to production, as the ultimate goal considered was the producer’s profit. Profit of the breeding organisations should also be considered, because saleability of the breeding stock is in fact the primary objective of the breeder. When several breeding companies compete on a same market, differences in performances between companies play a major role in determining the market share of each of them. They tend to put more emphasis on traits for which they are behind their competitors and less on traits for which they are ahead, thus implicitly considering that higher performance in one trait does not compensate for a lower performance in another. This is often done rather empirically, though more rational procedures could be used. One alternative is offered by selection indices for desired gains (Brascamp, 1984). However this implies a precise knowledge of the relevant genetic parameters and any error on these may considerably reduce the efficiency of such indices (see Campo and Velasco, 1989).

An objective way of incorporating competitive position in the breeding goal has recently been proposed by De Vries (1989b), using a marketing approach. For each trait, an acceptance level is defined as the minimum level of the trait considered as acceptable by a potential buyer of the stock. Assuming a normal distribution of acceptance level over all customers, the performance level of a given stock determines a percentage ($p$) of the distribution which is below that level, which also is the percentage...
of customers satisfied. The economic weight of the trait with regard to the saleability of the stock is then expressed as the economic value of the trait for the producer multiplied by \((z/p)(\pi/2)^{0.5}\), which is a function of the acceptance level corresponding to \(p\) \((z\) being the ordinate of the standardised normal curve corresponding to \(p\)). It can be seen that this correction term, equal to one for an average acceptance level \((p = 0.5)\), tends to decrease as \(p\) increases. Consequently emphasis will increase on traits which are below average of the stocks available and decrease on traits above that average. The difficulties in applying such a type of approach have been discussed by De Vries (1989b). Even assuming that the additional information required is available, especially with regard to the buying behaviour of the customers, taking competitive position into account amounts to deviate economic weights from their optimum (assuming stable economic conditions) and it must reduce overall response. It can only be considered as a short-term strategy to correct for weaknesses of a particular breed or strain, and so it would need periodical revision.

Some standard of reference is required to ensure that short-term interests of breeding organisations do not compromise overall long-term response. There is a basic need of appropriate definition of a breeding objective for average production conditions of each country, as competition means applying correction factors to coefficients which reflect actual production conditions. On the other hand, competition between breeding organisations can only be adequately dealt with if their breeding stocks are properly evaluated against each other in an independent manner, as false estimates of differences would further compromise long-term response. This would justify that some effort be devoted to comparative trials on a national basis, and to monitoring genetic trends in order to make sure that producers and consumers interests are adequately served by the breeding system. International cooperation could also be recommended for setting a network of comparisons among the world's breeds and strains, as suggested by Sutherland et al. (1985).

The desirable objectivity in deriving economic weights cannot always be satisfied, as when the level of a trait has no incidence on price, which is the case for most meat quality characteristics for lack of proper on-line measurement systems. Rather arbitrary choices have then to be made, applying constraints such as a given desired gain or no genetic change if present level of the trait may be considered as satisfactory. The latter approach is taken for meat quality in several European countries :see Sellier (1988).

**ADAPTATION OF BREEDING GOALS TO CHANGING PRODUCTION CONDITIONS**

Adaptation of breeding goals to the economic environment is an obviously sound principle. Past experience shows that this has indeed occurred in several countries, with periodical re-evaluation of the economic weights applied to each trait. An example of such an evolution is given in table 2. Though at each step efforts are made to foresee the changes to be expected, the exercise is never entirely satisfactory and discrepancies between presently defined goals and future production conditions are unavoidable. In fact, the breeding goal defined at any given time can never be optimal with regard to later situations, because of the genetic lag implied by the dissemination of genetic improvement. However, this should be of little concern as long as the evolution of production conditions is slow and gradual, because using "false" economic weights has a limited impact on overall selection efficiency, in most cases (see Vandepitte and Hazel, 1977).
Table 2  Evolution of selection objectives in the French national breeding programme: weights are relative to food conversion ratio (-100)

<table>
<thead>
<tr>
<th>Trait</th>
<th>1970</th>
<th>1980</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily gain (g)</td>
<td>0.16</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Lean content (%)</td>
<td>6.7</td>
<td>5.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Meat quality (s.d)</td>
<td>-</td>
<td>11.1</td>
<td>8.9</td>
</tr>
</tbody>
</table>

The above reasoning applies to breeding plans intended for well defined and rather standardised production systems, as is the case with national "herd book" programmes. When a wider perspective is taken, either over space or over time, the question of diversifying the breeding goals arises. The need to develop a variety of breeding stocks in order to satisfy a wide range of production-marketing systems has been stressed by Smith (1986). Diversity in breeding goals may be considered at three different levels: (i) between lines within production systems (ii) between production systems within countries and (iii) between countries. Diversity between lines is the basis of the system of specialised sire and dam lines, nowadays extensively applied. Smith (1964) laid out the principles on which to base the definition of the breeding objective in each line according to its role in the crossbreeding system. The objectives considered in each line correspond to profit realised in the slaughter generation, including dam and progeny performance. As shown in table 3, with 3 breeds available and 6 crossbreeding systems combining them in various manners, 4 different breeding objectives would have to be defined and 7 different lines would be required.

Table 3  Breeding objectives (defined according to Smith, 1964) for reproduction (G1) and production (G2) traits in crossbreeding systems using 3 different breeds.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Crossbreeding system (dam x sire)</th>
<th>A x C</th>
<th>A x B</th>
<th>A x C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single cross</td>
<td>aG1+0.5G2</td>
<td>-</td>
<td>G2</td>
</tr>
<tr>
<td></td>
<td>Two-breed rotation</td>
<td>aG1+G2</td>
<td>aG1+G2</td>
<td>aG1+G2</td>
</tr>
<tr>
<td></td>
<td>Three-breed rotation</td>
<td>aG1+0.5G2</td>
<td>aG1+G2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Back-cross</td>
<td>aG1+0.5G2</td>
<td>aG1+0.5G2</td>
<td>G2</td>
</tr>
<tr>
<td></td>
<td>Three-way cross</td>
<td>aG1+0.5G2</td>
<td>aG1+G2</td>
<td>G2</td>
</tr>
<tr>
<td></td>
<td>Four-way cross</td>
<td>aG1+0.5G2</td>
<td>aG1+G2</td>
<td>G2</td>
</tr>
</tbody>
</table>

Number of lines (breeding objectives) per breed 2 3 2

a: economic weight of G1 relative to G2 (both expressed in phenotypic standard-deviation)

When different production-marketing systems are considered, or different countries, additional variation has to be taken into account. Taking again the above example of specialised lines, the relative emphasis on production and reproduction traits (the a-parameter, considered as fixed in table 3) may vary considerably. Tess et al. (1983) give examples of such variation, and they even show that increased lean growth may have adverse effects on economic efficiency because of increased feed costs, when payment is based on liveweight. Given that the number of lines which can be selected by a breeding organisation meets financial limitations, some kind of strategy is required in
order to maximise genetic gains over a range of production conditions at a reasonable cost. In table 4, two strategies are compared, for the case of specialised dam lines. Selection may be based either on an average situation leading to a single objective, or on two extreme situations with two objectives far apart, the best of the two lines being used in intermediate situations. The results in table 4 clearly show that selection for extreme objectives is able to cover rather satisfactorily a wide range of economic as well as genetic situations. However, the advantage of developing extreme lines over selection for an average situation only appears when the genetic correlation $r$ between production and reproduction traits is unfavourable. This is because an average strategy is rather efficient when gains for one goal can make up for gains in the other, which is only possible when the goals are not antagonistic. Present knowledge tends to indicate that likely values of $r$ are close to zero (Brien, 1986) and so no marked advantage for diverse objectives is to be expected. It can however be argued that selecting extreme lines offers guarantees against future changes of the genetic correlation or against any increase in the range of production conditions. Table 4 shows that the extreme strategy, in addition to being more efficient on average, minimises the loss in the worst situation. Beneficial effects on heterosis may also result from gene frequency divergence induced by such a selection, as implied in a similar breeding scheme considered by Bretschneider et al. (1989). Those arguments probably justify that most private breeding companies select a series of lines in order to fit a variety of customers and production-marketing systems, in spite of the higher costs involved. An example of such a strategy is also offered by the "hyperprolific" scheme proposed by Legault and Gruand (1976), which has attracted the attention of several breeding organisations. The respective percentages selected in the first-stage selection on dam prolificacy (about $1^{g}/o$) and in the second-stage selection on individual lean growth (about 5%) are indeed equivalent to applying a selection index for the most extreme situation of table 4 ($a=10$).

Table 4  Relative selection efficiency in specialised dam lines for 2 ranges of production conditions, using 2 selection strategies (100 : one line selected for each objective)

In each case, average efficiency (assuming a uniform distribution of the production conditions) and lowest efficiency (in brackets) are given.

<table>
<thead>
<tr>
<th>Range(1)</th>
<th>Stategy(2)</th>
<th>-0.4</th>
<th>-0.2</th>
<th>0</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>narrow</td>
<td>average</td>
<td>89 (0.78)</td>
<td>95 (0.88)</td>
<td>97 (0.93)</td>
<td>99 (0.96)</td>
</tr>
<tr>
<td></td>
<td>extreme</td>
<td>96 (0.85)</td>
<td>98 (0.92)</td>
<td>99 (0.97)</td>
<td>99 (0.98)</td>
</tr>
<tr>
<td>wide</td>
<td>average</td>
<td>86 (0.26)</td>
<td>92 (0.56)</td>
<td>96 (0.78)</td>
<td>98 (0.89)</td>
</tr>
<tr>
<td></td>
<td>extreme</td>
<td>96 (0.84)</td>
<td>96 (0.86)</td>
<td>98 (0.92)</td>
<td>99 (0.95)</td>
</tr>
</tbody>
</table>

(1) breeding objective $aG_1 + 0.5G_2$ (symbols defined in table 3)
- narrow range : $a = 0 1 2 3 4$
- wide range : $a = 0 1 2 .... 10$

(2) selection strategy
- average : one line selected with $a = 2$ (narrow) or $a = 5$ (wide)
- extreme : two lines selected on $a = 0$ or 4 (narrow)
- $a = 0$ or 10 (wide)

(3) $r$ : genetic correlation between production and reproduction traits (other genetic parameters given in Ollivier, 1983)
If one considers the existence of a number of available "extreme" breeds such as Piétrain for lean content, Duroc for intramuscular fat, Meishan for litter size, etc., the immediate gains from selection for different objectives is expected to be less than with an initial homogeneous set of breeds. However, this "natural" variation that we can exploit to-day may also be viewed as the result of past selection for diversity. It would be unwise not to maintain for the future some kind of similar strategy in our breeding methods.

IMPACT OF NEW TECHNOLOGY

Future technological developments in pig production and breeding should have important consequences for the definition of selection objectives. One major evolution in recent years has been the development of more accurate systems of carcass evaluation, which have led to an increased attention paid to lean content by the producer. The same evolution may be expected in coming years for other carcass and meat quality characteristics. More generally, new developments in electronics offer automatic animal identification (electronic tagging), rapid and cheap recording of body weight and food consumption, remote data capture and transmission, and more accurate measurement of physical and chemical body composition (Steane et al., 1987). This technology will thus improve accuracy, allow the recording of additional traits on larger numbers of pigs and draw attention to new selection goals.

Electronic feeding stations already allow recording of individual food intake for pigs penned in groups. Incorporation of a weighing platform would allow selection to change the shape of the growth curve. Selection pressure could also be placed on size and frequency of meals, or on some index of social rank. Objectives can therefore be defined more precisely with regard to the requirements for performance in the commercial environment.

Already realtime ultrasonic scanners are being developed with greatly improved resolution. These may allow direct selection for waterholding capacity, intramuscular fat or perhaps fat quality in the live pig, raising the emphasis given to product quality in the objective. Identification of individual joints through the processing plant offers the opportunity to select directly on commercial yield using data on slaughtered relatives. Distribution and quality of lean may become more important as optimum fat levels are reached, and variation in profitability becomes less associated with overall lean percentage.

Increased computing power has allowed the application of mixed models (eg BLUP) in pig selection. Mixed models allow more accurate selection for a trait such as litter size in a population large enough to avoid inbreeding. The cost-benefit ratio of selection for litter size therefore improves and raises its importance in the objective. Multi-trait mixed models can incorporate traits such as the lifetime productivity of relatives, and offer the opportunity to select for example for longevity or physical reliability.

Non-genetic means of manipulating physiological functions have also to be considered when defining breeding objectives for the future. Presently lean growth appears to offer the best prospect for such manipulations. It may be safe to envisage that efficient growth promoters can be used economically by pig producers. Then, at least in the medium term, selection pressure on lean growth might be relaxed. This would switch emphasis towards improving appetite, which appears to be adversely affected by high levels of growth hormone.

Direct manipulation of the genotype by gene transfer is expected to have a major impact on the livestock industry. At present, however, commercial introduction of genetically engineered lines remains a distant prospect, not likely to occur over the next decade, owing to "a number of formidable hurdles" which must be overcome (Wall et al.,
The first attempt at applying this technology to domestic animals has been the introduction of the human growth hormone gene (hGH) into the genome of pigs. From the limited experience available so far (recently reviewed by Pursel et al., 1989), the consequences as to growth and carcass composition seem to be rather similar to the effects obtained by using exogenous GH. With gene transfer also, appetite depression appears as a limiting factor preventing full expression of the response to high level of GH, which brings a further argument in favour of stressing appetite among present selection goals.

CONCLUSIONS

Evolution of improved pig populations in developed countries during the last decades has brought some performances closer to their biological or economic optimum, thus reducing their future importance in the overall breeding objective. This tendency will probably be enhanced by further increases in selection efficiency, exploitation of major genes, natural or genetically engineered, and also non-genetic manipulation of physiological functions. As a consequence, traits such as food intake capacity, product quality and reproductive ability are likely to receive more and more attention. On the other hand, breeding structures have also evolved and breeding organisations, either private or nationally supported, are facing strong competition to maintain or extend their market shares. Competition has direct effects on the relative emphasis given to various breeding goals. The tendency also is to diversify breeding goals in order to satisfy a wide spectrum of customers, representing different countries, with different levels of development and different production systems. This implies introducing quantitative as well as qualitative variation in the targets of selection, while requiring an adequate evaluation of the additional costs involved and of the benefits expected.

Looking further ahead, traits may be taken as targets of selection with the objective of improving selection efficiency, in addition to being themselves of importance for some given production conditions. Components of reproductive potential, such as age at puberty, male fertility, female prolificacy, have obvious potential impact on selection efficiency, through their effects on generation interval and selection intensity. Prolific and early breeding Chinese breeds offer the possibility of increasing selection efficiency for production traits by nearly 50% (Bidanel, 1988). This possibility may be exploited in European x Meishan synthetics, and their lag in production traits behind conventional European dam lines could, in theory, be quite rapidly reduced. Ovulation rate, in addition to being a basic component of prolificacy worth being selected for itself, could also be selected in order to create an environment more favourable to selection for uterine capacity. The model of unilateral hysterectomy-ovariectomy (UHO), proposed by Christenson et al. (1987), indicates that litter size would become independent of ovulation rate in a highly ovulating strain and could be more accurately selected for. In such a case, intense selection for ovulation rate over several generations might later allow a more efficient selection for litter size based on uterine potential. In turn, uterine potential would be a most valuable asset for applications of new technologies based on embryo transfer. For example, embryos selected exclusively on lean growth could be transferred into a recipient line of high uterine capacity. Such a system might offer very high biological efficiency, but its success would depend on selection for properties of the reproductive tract. Development of such specialised stocks is a valuable target to consider for future pig production. Returns however can only be expected in a very long term. Objectives of that type are probably beyond the scope of any single organisation and would require cooperative effort as well as some kind of external support.
REFERENCES
