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The effects of disease on productivity and profitability of livestock: How should it be assessed?

R. S. MORRIS
Veterinary Clinical Sciences Department
Massey University, Palmerston North

ABSTRACT

Among the factors influencing the productivity and profitability of livestock, animal diseases deserve special attention because they diminish the capacity of the animal to achieve its inherent potential level of production, for any given feeding and management regimen.

Evidence concerning the nature of the various effects of disease is reviewed, and a hierarchy of effects is defined. The major effects are on protein metabolism and secondarily on energy metabolism. Effects on feed intake are also common, but even diseases which severely ravage the wall of the gastrointestinal tract do not appear as a general rule to significantly reduce feed digestibility.

The primary effects of disease on nutrient metabolism flow through to various consequential effects on the productivity of the individual animal, and hence on herd replacement patterns and herd improvement. At least some diseases can continue to affect productivity even after the disease has been cured by treatment. Consequently, the adage that *prevention is better than cure* has a sound scientific basis. Analyses have shown exceptionally high economic returns from disease prevention, commonly 500 to 1500% return on invested funds. This is much higher than from curative methods in most cases.

As veterinary science evolves from a curative approach towards an economically grounded *health management* approach, veterinarians will make use of evaluation aids through which the economic and practical implications of alternative actions are compared, so that the action most advantageous to the livestock enterprise can be taken.

Keywords Animal disease; nutrients; productivity; economics; health management.

INTRODUCTION

The traditional distinction between *animal health* and *animal production* has become increasingly blurred in recent years, as the trends in livestock production systems have led advisers to progress from formerly looking at single technical issues to now consider multiple issues simultaneously in order to optimize the system. Greater and greater emphasis is being given to *fine-tuning* the management system by modifying various facets of the management strategy in response to monitoring data obtained from a farm. In the health area this trend has led to emphasis on subclinical diseases and their interaction with management, as the more spectacular and visible diseases have been brought under control.

In dealing with animal health issues in livestock enterprises, economic evaluation has become far more important as the effects of the diseases which remain to be controlled are far more subtle than was the case for *epidemic* problems — where the question of economics did not have to be raised because the answer was self-evident. Before it is possible to develop appropriate techniques for improving the economic efficiency of a livestock enterprise through health management methods, it is first necessary to define the ways in which a particular disease lowers productive efficiency.

There is now ample evidence from a wide variety of studies that disease control can yield very high economic returns, but that there are exceptions to this generalization. In order to measure the effects of disease and hence to conduct economic studies, it is first necessary to define the exact mechanisms by which a disease can influence productivity. This information is also relevant to animal scientists, who have in many cases failed to recognize the confounding influence of diseases in studies they undertake of management factors in livestock production.

MECHANISMS BY WHICH DISEASE MAY ALTER ANIMAL PRODUCTIVITY

Fig. 1 summarizes the various pathways through which disease can adversely affect the productivity of a livestock herd. In the case of infectious and parasitic diseases the underlying principle is that a disease agent is in constant competition with its host for access to nutrient supplies. The agent is successful if it can divert for its own use and reproduction, nutrients which the animal would otherwise have used for growth and production. The agent must therefore have some adverse effects on the host if it is to survive and multiply. Non-infectious diseases cannot be understood in the same

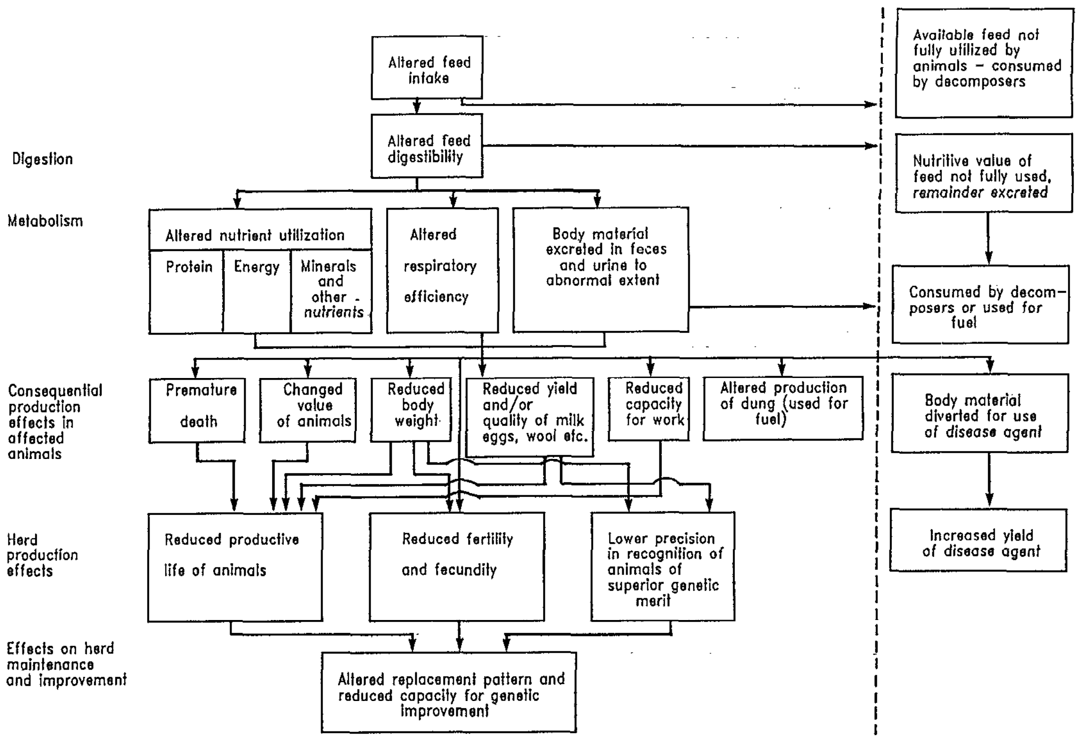

FIG. 1 The various ways in which disease may affect the productive value of animals in a herd or flock.

simple way, but do frequently represent a change in ecological balance, in which the flow of nutrients and toxins (copper deficiency, facial eczema, etc.) or of controlling signals (hypocalcaemia, ketosis, etc.) through the agricultural ecosystem is distorted by human or environmental interventions of some type. Some of the same principles therefore apply.

The purpose of Fig. 1 is to summarize all the possible direct and indirect mechanisms through which a disease can influence the productive efficiency of livestock. Not all diseases will have all of the effects, but an economic study should consider all possibilities and select for examination those which appear to be relevant. Each of the mechanisms will be discussed individually, and then consideration will be given to how they should be combined to evaluate the effect of disease on profitability.

Effects on Ingestion

Many diseases alter feed intake in affected animals. In almost all cases intake is reduced (Hawkins and Morris, 1978), but rarely it may be increased (Dargie, 1973). Diseases which cause pain during prehension (contagious ecthyma of sheep) or mechanical difficulty (actinobacillosis of the tongue in cattle) will reduce intake temporarily. Diseases which affect locomotor ability or reduce appetite due to a fever or similar discomfort will also lower intake. However many diseases appear to reduce intake in subtle ways which may not be recognized unless careful measurements are made. These effects have been documented most carefully for parasitic diseases (Roseby, 1973; Larbier *et al.*, 1974), although in some cases intake has been reduced only in more severe forms of the disease (Hawkins and Morris, 1978). Depression of feed intake can also occur in non-infectious diseases such as nutritional deficiencies (Scott *et al.*, 1980).

It is intriguing that feed intake should be commonly depressed by disease when other evidence shows clearly that feed requirements are increased by many of the same diseases, since productivity falls under the influence of the disease. From the limited studies which have been conducted to resolve this apparent paradox, it would appear that it results from disturbances in body homeostatic mechanisms of the host. Symons and Hennessy (1981) have found that cholecystikin levels rise as appetite falls in *Trichostrongylus colubriformis* infestations, and return to normal in line with appetite when the infestation is terminated. In the same disease, corticosteroid levels rise and thyroxine levels fall in response to the parasite, while insulin levels fall apparently in response to reduced intake rather than directly due to the parasite (Prichard *et al.*, 1974;

Hennessy and Prichard, 1981). The disease ageny may also in some cases produce a toxic substance which depresses intake directly (Seebeck *et al.* (1971). It is important to differentiate between diseases which merely depress feed intake and those which lower the efficiency of feed conversion — with or without any effect on feed intake. Seebeck *et al.* (1971) called the effect on intake the *anorectic effect* and that on feed conversion efficiency the *specific effect*. The specific effect is the more serious of the 2, since lower production is achieved from the same feed intake, and efficiency of the production process is adversely affected, whereas the anorectic effect reduces both intake and output without altering the efficiency of production. This is an important consideration in studies of animals which consume purchased feed, such as pigs. It is less important in grazing ruminants, for which feed production is closer to being a fixed cost.

Effects of Disease on Feed Digestibility

Disease agents do not normally seem to affect feed digestibility, even in the case of diseases which undoubtedly alter the morphology and physiological function of the gastrointestinal tract (Parkins *et al.*, 1973; Roseby, 1973; Reveron *et al.*, 1974). Barker (1974) found that abnormal mucosa was not necessarily linked to poor growth, and it seems that changes in the mucosal surface itself are not responsible for the change in feed conversion efficiency which results from parasitism and other diseases, but rather the physiological processes that occur after absorption. Similar findings have been obtained with parasites such as *Fasciola hepatica* which do not cause mucosal changes (Hawkins and Morris, 1978). One of the few reports of a reduction in feed digestibility for ruminants was for magnesium deficiency in dairy cows (Wilson, 1980). However the situation may be different in monogastric animals, since 2 studies of the effects of internal parasites in pigs both showed reductions in feed digestibility (Hale *et al.*, 1979; 1981).

It nevertheless seems likely that at least in ruminants adverse effects of disease on productivity which cannot be explained by reduction in feed intake can reasonably be attributed to lower feed conversion efficiency; although as Symons (1969) points out, digestibility trials are a crude method of assessing changes in digestive function. Nevertheless, they are expensive and demanding, and studies of the economic effects of disease become easier to conduct if changes in digestibility can be disregarded as a major factor in altering feed converison efficiency. It is also clear from the various studies in this general field that the nature and extent of pathological changes in the body cannot be used as any direct guide to the severity of effects of a disease on productivity.

Effects of Disease on Physiological Processes

Diseases can modify many different physiological processes, such as nutrient metabolism, respiration and excretion. Most of the available data relate to parasitic diseases, but the evidence from these studies suggests that the fundamental effect is on protein metabolism.

Steel (1974) and Symons and Steel (1978) have reviewed the metabolic consequences of gastrointestinal parasitism, with particular reference to sheep. They conclude that helminth disease causes a series of metabolic changes to occur in the animal, the primary impact of which is on protein metabolism. The effects, however, carry through to the metabolism of other nutrients. The result is to produce a syndrome analogous to undernutrition.

In gastrointestinal nematode infestations, plasma is lost into the digestive tract at the attachment sites of the parasites, and haemoglobin is also removed by blood-sucking parasites. Much of this protein is digested and reabsorbed lower in the tract, but the host uses energy and protein to replenish the mucosa and plasma proteins which have been depleted. This places demands on the liver and increases its nutrient utilization. There is increased excretion of nitrogen as urea in urine, demonstrating that recycling of the nutrients is not completely efficient in maintaining nitrogen balance, even though considerable energy costs are incurred by the host for increased protein synthesis.

Animals tend under these circumstances to run down their pool of plasma proteins because production in the liver cannot keep pace with the loss, even though the synthesis rate is unusually high. Adjustments are made to other nitrogen-using processes of lower priority, notably synthesis of wool protein and muscle protein. In sheep, sulphur-containing proteins are put in especially short supply by *Trichostrongylus colubriformis* infestation, demand cannot be met, and wool production shows an exceptionally large fall.

If feed intake is reduced either due to the parasite or to a low plane of nutrition, protein intake may fall below the level required to maintain an adequate serum protein pool. Bown *et al.* (1986) have shown that direct post-ruminal infusion of casein in sheep receiving daily doses of larvae of *Trichostrongylus colubriformis* increased nitrogen retention 5-fold, and supported the argument as outlined above that the primary defect is one of protein loss and an anabolic cost of tissue regeneration. Infusion of glucose in amounts isocaloric with the casein only doubled nitrogen retention, showing that energy supplementation was not as beneficial as protein replacement.

A contrasting example to *Trichostrongylus colubriformis* is the cattle tick *Boophilus microplus*, which sucks blood much like some internal parasites, but differs in that the animal cannot recover any of the nutrient content of the blood in this case. The effects of ticks on host metabolism have been studied by Seebeck *et al.* (1971), O'Kelly *et al.* (1971) and Springell *et al.* (1971). Haemoglobin and plasma albumin fell, whereas globulin rose. Thus the animal was able to synthesize increased supplies of globulins, but could not maintain levels of the other 2 blood constituents. This was attributed in part to a disturbance of protein metabolism, but the injection of a toxin by the tick was also hypothesized. To further emphasize the tenuous link between the pathology of a disease and its effects on productive processes, O'Kelly and Kennedy (1981) found that ticks adversely affected function in the gastro-intestinal tract and reduced organic matter digestibility. It is difficult to explain why this should be so when such effects are not common for parasites directly affecting the tract.

Although these are the 2 most fully studied diseases, evidence for other diseases in a variety of species confirms the central importance of the derangement of protein metabolism in the disease process.

There is also impairment of energy metabolism, but this appears to be largely secondary to the alterations in protein metabolism, and is a result primarily of the energy costs of tissue regeneration.

Mineral and micronutrient metabolic flows are also altered by parasitic diseases, which are the only ones to have been studied. There is reduced retention of ingested calcium and phosphorus in growing sheep infested with *Trichostrongylus colubriformis* or *Ostertagia circumcincta* (Symons and Steel, 1978). Consequently, bone growth and skeletal development are impaired; and this can reduce mature body size and capacity to accumulate muscle (Sykes *et al.*, 1977).Cobalt, copper and vitamin status of animals have all been reported to be affected by parasitism (Downey, 1965; 1966 a,b) as well.

Since lung disease can adversely affect productivity, another mechanism by which disease might impair physiological function is a reduction in respiratory function. It seems more likely, however, that it is the regenerative processes following lung disease which cause the production deficit.

MEASURABLE EFFECTS OF DISEASES ON LIVESTOCK PRODUCTIVITY

The functional derangements described above translate into measurable economic effects in a number of ways, summarized in Fig. 1.

Premature Death

This effect is the easiest of all the consequences of disease to measure, and therefore tends to be considerably over-emphasized in comparison with other effects. In economic studies, death losses should be measured as the difference between the potential market value of the animal and its value when dead (which may not be zero), less the costs which would have been incurred in obtaining the market value (such as extra feed and care to market age, marketing costs, etc.)

Changed Value of Animals and Products from Slaughtered Animals

Diseased animals may have lower market value either due to visible lesions or due to indirect changes in appearance or body conformation which make them less attractive to buyers. True market value of final products may be altered due to changes in the ratio of meat to fat or to bone (Springell *et al.*, 1971; Sykes *et al.*, 1980), or reduced protein content. The value of offals may also be reduced due to pathological changes caused by agents such as *Fasciola hepatica* or *Echinococcus granulosus*. Presence of lesions of a zoonotic disease may render the animal totally unfit for consumption.

Some diseases (such as caseous lymphadenitis in sheep) may render products less attractive to the consumer for aesthetic reasons, and hence may reduce meat consumption. Diseases which affect the skin, such as warble fly infestation or even sheep lice (Britt *et al.*, 1986), may reduce the market value of hides or their value to the user.

Reduced Liveweight Gain

There have been well in excess of 50 published studies on the effect of diseases on weight gain in animals, and in general they find that diseased animals gain weight more slowly than equivalent disease-free animals. Notable as an exception is lice infestation in cattle. It has been among the most intensively studied but the evidence shows that differences in weight gain between infested and free animals are modest or negligible, and certainly not enough to yield an economic benefit from treatment. Therefore caution is required in assuming an effect on weight gain of a disease without experimental data to support it.

Reduced Yield and Quality of Products From Live Animals

Yield of products such as milk, wool and eggs may also be reduced by disease, and there have been numerous papers showing the effect of various diseases on wool growth or milk yield. Quality of the products may also be reduced, as in the case of the changes in milk composition which result from bovine mastitis, and these may or may not be detectable by the consumer. In the first case price will fall and the livestock producer will suffer; in the second case the consumer will suffer the loss. For example, parasitic disease can reduce the market value of wool per kg, as well as the quantity produced (Morris *et al.*, 1977); but the structural characteristics of the wool may also be altered in ways which reduce its value to the manufacturer but cannot be detected in the normal marketing process (Johnstone *et al.*, 1976).

Reduced Capacity for Work

Worldwide, the single most important use of animals is as a source of traction. The second largest (after dung) productive energy output of animals in developing countries is for work, and products considered as of central importance in developed countries are seen as byproducts under those conditions (Odend'hal, 1972). There have been no published reports directly measuring the effects of diseases on capacity for work, but field evidence is that diseases can severely curtail rice paddy preparation and other tasks for which animals are essential, so this effect can be very important and should be considered in developing countries.

Altered Production of Dung for Fuel and Fertilizer

In Asia and Africa cattle dung is a vital source of cooking fuel, and in much of the developing world it is an important fertilizer. Diseases which cause high death rates in cattle will also indirectly influence human nutrition by reducing dung supplies.

Altered Feed Conversion Efficiency

As discussed earlier, it appears that disease primarily affects animal productivity by altering the metabolic processes for protein and other nutrients, thereby reducing the feed conversion efficiency of affected animals and producing a number of ramifications which reduce herd productivity. Feed intake may also be reduced, but this is not usually the primary effect.

Feed conversion efficiency is the ultimate measure of the influence of disease on the production process, but its measurement requires accurate measurement of feed intake, and that is only possible under controlled feeding conditions. In grazing systems, it is usually reasonable to take changes in productivity as an adequate indication of changes in feed conversion efficiency when comparing diseased and disease-free animals kept under identical conditions.

Intuitively, it seems likely that the rate of decline in productivity would increase as the disease becomes more severe, and body functions become more deranged. However the limited evidence available favours the alternative view, that the most dramatic changes occur at low or subclincial levels of disease, and that each additional parasite, for example, has less effect than the one before it (Hawkins and Morris, 1978). This emphasizes the importance of the health management approach in which the focus is on optimizing productive efficiency rather that the clinical approach in which a disease must be detectable to be considered important.

EFFECTS OF DISEASE ON HERD PRODUCTIVITY

The effects of disease flow through from consequences for individual animals to broader ramifications for herd replacement and improvement.

Reduced Productive Life of Animals

Apart from animals which die, all remaining herd members are culled when the manager considers them less potentially productive than the animal which would replace them. This issue has been investigated in detail by Renkema and his co-workers (Renkema and Stelwagen, 1979; Korver and Renkema, 1979; Dijkhuizen *et al.*, 1985 a,b). They showed that in general a substantial economic benefit could be achieved by taking action to extend the herd life of the average dairy cow, principally by reducing the amount of involuntary culling due to health-related causes. This is not limited to disposal specifically because of disease, but also includes culling for low yield or other causes, where the underlying cause is lowered productivity due to disease, but the manager is unaware of this fact.

Less Accurate Genetic Selection

If a disease alters any of the components of productivity which are the subject of genetic selection pressure in the herd (such as milk or wool yield), it will affect the efficiency with which animals of superior genetic merit are identified, especially if the probability of an animal being affected by the disease is unrelated to yield level. Provided susceptibility to the disease and yield level are not correlated, the presence of the disease will confound the genetic selection effort. For example, Johnstone *et al.* (1976) showed that internal parasitism can affect wool production by sheep in ways which distort selection by objective measurement of wool characterisitics. Since resistance to internal parasitism cannot be regarded as a heritable trait for practical purposes, genetic selection will be more efficient if effective parasite control is being carried out in the herd.

Effects on Capacity to Maintain and Improve Herd

If less progeny are born, less animals are available as herd replacements or for sale as market products. Thus not only will livestock sale income be reduced, but management flexibility for herd improvement will be curtailed.

It is self-evident that diseases of the reproductive tract in both males and females can substantially reduce the level of reproductive performance, and hence the number of progeny born in the herd.

Less obviously, diseases which adversely affect body metabolism (but do not directly affect the reproductive tract) can also affect the number of progeny born. The mechanisms have not been fully explored, but may well operate through an effect on live weight and condition, or through indirect means such as the induction of pyrexia at critical stages in the reproductive process. For example, both gastro-intestinal parasites (Murray *et al.*, 1971) and liver fluke (Hope Cawdery, 1976) have been shown to affect reproductive performance in ewes. In cattle, bovine leucosis (Schmied *et al.*, 1979; Parchinski, 1979) and ephemeral fever (Theodoris *et al.*, 1973) have been reported to affect reproduction.

If reproductive performance is too poor, it may even become impossible to maintain herd size through home-bred replacements, necessitating the purchase of breeding animals with all the additional risks which that entails.

EFFECT OF DISEASE CONTROL MEASURES ON PRODUCTIVITY OF ANIMALS

In evaluating the economic benefit of disease control, it is necessary to consider not only the difference in productivity between diseased and disease-free animals, but also the changes in productivity which follow elimination of a disease from an affected animal.

This has not been studied for very many diseases, but some examples exist. For instance, bovine mastitis appears to be a disease for which complete regeneration occurs in most animals over the dry period following elimination of an infection (Morris, 1973), although yield remains depressed for the rest of the lactation in which a cure is achieved. Conversely, when infestations with *Fasciola hepatica* are eliminated in growing animals, sheep do not regain their former productivity or feed conversion efficiency, even when the infestation had existed for as little as 8 weeks (Hawkins, 1984). In a study of a nematode parasite, wool growth and live weight gain responded quite differently to anthelmintic treatment (Coop *et al.*, 1984).

Therefore each disease type must at least in the first instance be considered separately, since the nature and extent of recovery following elimination of a disease is not predictable from general principles. The selection of an economically optimal control strategy will be strongly influenced by this consideration.

EFFECTS OF ANIMAL DISEASE ON HUMAN WELFARE

Effect on Human Nutrition

The major direct effect of animal disease on human wellbeing is through reducing the supply of high quality protein, such as diseases which reduce the supply of milk for young children. Animal products are also important sources of other nutrients, notably minerals and vitamins, and diseases can both reduce the total supply of animal products and modify the composition of animal products in ways which reduce their nutritional value.

Effect on Community Development

As well as the effects on human nutrition, animal diseases can affect other aspects of community welfare, especially in developing countries. As discussed earlier, the 2 most important services provided by animals in such circumstances are traction and dung production, and disease may reduce the supply of both of these. Animals are also important sources of products (wool, hair, hides, feathers, fur, etc.) used for clothing, decoration and for manufacture of utensils and other products.

A further effect of those animal diseases which are zoonotic is to cause disease in the human as well as the animal population, thus amplifying their impact.

Cultural Significance of Animals

In most communities animals serve functions far beyond the utilitarian roles which are the focus of this paper. While these are not strictly economic in nature, they are vital functions which should be included in any consideration of the significance of animal disease.

EFFECTS OF DISEASE ON ANIMAL WELFARE

In considerations of animal welfare issues, little is said about the importance of ensuring through disease control that animals are in a healthy state — yet this is a vitally important issue in protecting the welfare of managed animals. It deserves more prominent attention in discussions of animal welfare matters.

METHODS OF MEASURING THE ECONOMIC BENEFIT OF ANIMAL DISEASE CONTROL

This issue has been considered in detail in an earlier paper (Morris and Meek, 1980). The past practice of considering the *cost of disease* was unsound, and has given way to economically sound analyses which estimate the economic benefit of control measures. A large number of such studies has been published over recent years, and there are good published models for analyses of most major types of diseases.

The foregoing discussion has aimed to document the diverse ways in which disease can affect animals. In designing experimental studies concerned with the economic effects of disease, consideration should be given to each of these issues, so that the study includes all aspects which are relevant in the particular case.

Studies will have the greatest realism and practical relevance if they are conducted on farms. The simplest approach is to compare alternative control programmes within farms, provided that this is epidemiologically sound for the particular disease. Such studies are much easier to conduct than is usually recognized, and produce sound results at fairly low cost. Ideally, a number of farms should be included in such studies to obtain estimates of variation in outcome between farms. In some cases it may be necessary to conduct a comparison solely between farms because the farm is the smallest feasible experimental unit. This is quite practical but requires a large number of farms because of the extent of variation in uncontrolled factors between farms.

There are standard economic techniques which should be used to describe and summarize the outcome of economic studies. The most useful ones are partial farm budgeting, gross margins analysis and cost-benefit analysis. Each of these techniques, their application and limitations have been discussed by Morris and Meek (1980).

The focus of economic studies must be on estimating the benefit of action against a disease, rather than just on the economic impact of the presence of a disease. Although it is not possible to get all of the economic data which might be desired for every disease, experimental studies can now be supplemented and expanded using other analytical approaches, of which computer modelling is among the most useful. It is also necessary in cases where chance is an important element in the epidemiology of the disease to include in economic studies an evaluation of the riskiness of each of the alternative courses of action.There are standard economic procedures for doing this.

IMPLEMENTATION OF THESE PRINCIPLES

If the understanding of disease processes and their effects described above are to form the basis for veterinary services to livestock, then the focus of these services needs to be one of health managment rather than principally disease treatment. A rational approach to provision of health care requires that the productive and welfare significance rather than the pathological severity of the disease should be the measuring stick for livestock.

This in turn requires that carefully selected health and productivity indicators be monitored in the herd to provide the basic information required for action. The DairyMAN program described by McKay (1988) is an example of such a monitoring system. It can be used in combination with on-farm evaluation to decide on the health management strategy best suited to the particular livestock unit both for immediate needs and for strategic management. It can also be used to monitor the effect of actions taken in the light of earlier evaluations.

In this way health and production issues can be brought together for the benefit of the livestock producer — and equally of the consumer.

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