The economics of optimal health and productivity in smallholder livestock systems in developing countries

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Summary
Livestock kept or produced in smallholder farming systems are an important component of the agricultural economy in the developing world. The role of livestock on smallholder farms varies widely, providing draught power for crop production or as a production activity for subsistence needs or market sale under systems ranging from extensive pastoralist to intensive, peri-urban feeder and dairy systems. A set of unique conditions and features characterise smallholder systems, and these need to be appreciated when assessing the strategies that have evolved for managing animal health in smallholder systems, and evaluating opportunities for improving disease control strategies.

To provide a framework for discussing animal health issues and analytical methodologies, a typology of smallholder livestock and crop/livestock systems is developed. The typology considers livestock systems both in terms of the degree of intensification, as measured by market orientation and intensity of factor use, and in terms of importance within the household economy, as measured by contribution to household income. A number of characteristics are identified that distinguish smallholder systems from the commercialised systems of developed countries, including the multiple functions livestock serve, the integrated nature of livestock activities, multiple objectives of producers and lower capacity to bear risk at the household level, as well as poor infrastructure, markets, and access to information at the community level.

Three representative smallholder livestock systems from Africa are described in detail, highlighting the relevant characteristics and the implications for analysing disease control strategies. Smallholder dairy systems in Kenya demonstrate the role of individual producer decision-making for animal health management in intensive, market-oriented systems, placing emphasis on farm-level risk and production management aspects of disease control. In extensive pastoralist systems where epidemic diseases are still important and infrastructure is poor, disease control primarily involves managing communal natural resources, requiring a different analytical approach. Finally, in crop farming systems using draught cattle, the livestock activity is an integrated component of crop production and this must be reflected in the approach used to evaluate draught animal health management. Continued development of analytical approaches and decision-support tools for disease control strategies adapted to the special characteristics of these systems will be needed as smallholder systems continue to intensify in areas with good market access, and those in marginal areas face increasing pressures to optimally manage the natural resource base.

Keywords
Africa - Animal health - Developing countries - Economics - Kenya - Productivity - Smallholders.
Introduction

In many developing countries, livestock and mixed crop/livestock production systems are of crucial importance to both household and national economies. For example in Laos, 50% of the gross domestic product (GDP) was attributed to agriculture and 22% to livestock production (47). Overall, livestock production is considered to account for approximately 20% of agricultural output in Asia, 25% in Africa and 40% in Latin America (86). For Asia, where mixed crop/livestock smallholdings predominate, the estimate rises to 30% when manure and draught contributions are included (86). In these continents, usually 60%-80% of the population consists of farmers. This is in sharp contrast to developed countries. For example, in the United States of America, less than 3% of the population are farmers and only 2% of the GDP is attributable to agriculture (5).

Smallholder farming systems in developing countries are varied, depending on ecological, demographic and socio-economic influences. In this paper, smallholdings will be considered to be livestock or mixed crop/livestock production systems whose inputs are primarily derived from the household and whose outputs are meant to contribute to household needs. In many cases, this implies only meeting basic subsistence needs, but in some market-oriented smallholder systems, farmers are able to earn sufficient income to pay for other non-subsistence needs such as education and building livestock and other capital assets. In areas of high population density, particularly close to growing urban markets, a rapidly accelerating trend of both increased intensification and more pronounced market-orientation has been reported among smallholders, particularly dairy farmers (89). While traditional smallholder farmers have not had a strong demand for animal health and production services, both increasing demands and improved opportunities for delivering animal health and production services to farmers will arise in these rapidly intensifying, market-oriented systems.

To consider the economics of animal diseases and disease control in smallholder livestock systems, the unique conditions of these systems need to be well understood. These conditions are both biological and socio-economic. Because of the small size and complex household goals of smallholder systems, animal health and disease control programmes designed for livestock systems in developed countries are not directly transferable; the standard health, productivity and economic indicators used to assess herd health and productivity in larger-scale livestock holdings often need to be modified. In this paper, the key characteristics and dynamics of smallholder systems are reviewed and the influence of these factors on methods for conducting economic analysis of animal diseases and disease control in the developing world context are discussed.

Smallholder livestock production systems in the developing world

As stated above, a relatively broad definition of smallholding has been selected, emphasising the role of household inputs and income as the classification criteria. This differs from common definitions of smallholder livestock units that are often defined as having less than a certain number of livestock (e.g. ≤ 10 TLU [tropical livestock unit, the equivalent of an animal of 250 kg live weight]) or a certain land size (≤ 5 ha). This approach to defining smallholdings has been adopted for two main reasons. Firstly, livestock numbers and land size of smallholdings are dependent on agro-ecological potential, demographic and other socio-economic factors. Thus, if uniform livestock number and land size criteria were applied, units that would be classed as a smallholding in a semi-arid area of Africa would be a largeholding in a densely-populated area of South-East Asia. Secondly, a focus on household inputs and income provides a common, farmer-centred, economic indicator for understanding the decisions made in the diverse circumstances faced by farmers. This approach means that both the common and unique features can be highlighted, across the full range of pastoral, mixed crop/livestock, and landless livestock production systems. The authors believe that this is very important; both to learn lessons from, and make predictions about, specific smallholder systems found within the spectrum of market-orientation and intensification levels currently practised.

This comparative perspective, calls for a general typology of smallholder livestock systems that takes into account the gradients from extensive pastoral to landless, from subsistence to market-oriented, from livestock-dominated to crop-dominated and from mixed to specialised systems, using only a few, generic classification criteria. With respect to
household income and livestock production practices, key characteristics would include the following:

a) type of inputs used (e.g. forages, concentrates, preventive medicines and supplements, cattle breeds and services [breeding, health])

b) source of inputs (purchased or gathered)

c) density of livestock units (land area per livestock unit)

d) market-orientation (percentage of livestock products or services sold)

e) relative contribution of livestock to agricultural and household income.

Many of these household characteristics are correlated with each other and are strongly influenced by factors such as markets, disease risk and livestock policies operating at regional, national and agro-ecological levels.

A number of potentially useful typologies, from different intervention perspectives, could be used (e.g. feeds [7]). From the perspective of the theme of this book 'The economics of animal disease control', disease risk and ability to provide and sustain disease control inputs need to be considered. Some important variables influencing disease risk are management practices, livestock density, livestock movement patterns, and level of production. With respect to providing disease control services, the potentially important variables are disease risk, livestock density, market-orientation and degree of specialisation in livestock. Given the focus here, on the economics of animal disease in smallholder systems and the correlation between many of the important household characteristics that influence this subject, a typology is proposed with two broad classification axes that encompass what the authors consider to be the most important factors.

**Axis 1: degree of intensification of the livestock activity**

The first axis relates only to the livestock sub-sector of the household, regardless of the importance of this aspect within the household economy, and characterises the relative intensity of the livestock production activity. Numerous measures of intensification have been proposed which are often highly correlated. The authors consider the following particularly relevant:

a) use of purchased inputs (indicator: percentage of inputs used for livestock activities that are purchased)

b) land area per head of livestock used for the livestock activity or maintenance of livestock

c) market orientation for production (indicator: percentage of livestock production and services sold).

**Axis 2: importance of livestock activities within the household economy**

The main indicator is the percentage of total household income generated by livestock activities. Household income includes both cash and non-cash income (e.g. milk consumed on-farm). As noted above, in integrated crop/livestock systems, an estimation of income indirectly derived from livestock activities, such as the additional crop production generated by use of manure and draught power, is also important.

The principal, generic smallholder systems can then be related in terms of these two axes, generating the classification shown in Figure 1.

As an example, this typology has been used to classify some important African smallholder livestock production systems (Fig. 2).

A number of important economic characteristics of smallholder systems vary along the gradients of these two axes of intensification, and together with them, characteristics related to disease risk and animal health strategies. For example, epidemic diseases are of much greater importance in extensive systems, and production diseases only found in very intensive systems. With respect to the supply and demand of animal health and production services, as a general rule, the greater the degree of intensification, the greater the demand for specialised services and the lower the transaction costs. Another key attribute of households in intensive systems is the greater need for decision-making tools. Tools are required to optimise the allocation of resources to different livestock and crop enterprises on the farm and to manage risk. While households in intensive systems may have less absolute risk than those in extensive systems (particularly in extreme environments), these households have a greater ability to manage risk. Thus, in intensive systems, decision tools for risk management will be more relevant. This is particularly important for households in intensive systems that are highly dependent on livestock. The other important feature of the livestock dependency axis is that farmers dependent on livestock have and can develop more specialised animal health and production management skills. These general economic features will be further expanded in the individual smallholder system scenarios presented later.

**Special considerations in smallholder systems in developing countries**

To set the stage for the discussion of the economics of optimal health and productivity in certain smallholder livestock systems, it is useful to highlight the unique features of
smallholder systems that influence animal health and production, and that differ from commercialised livestock production systems in developed countries. Highlighting these differences is important in guiding decisions concerning which economic decision-making techniques might be usefully applied in smallholder systems. The generic characteristics of smallholder systems that might limit the usefulness of techniques presented elsewhere in this issue will be identified below. This should also help to motivate subsequent discussion on the needs for economic decision-making techniques in smallholder systems, whether newly developed or adapted from other settings.

### Household level

Fundamental differences exist in structure, objectives and function between smallholder farms and large-scale commercial farms. Some important differences with respect to the economics of animal health and production programmes are listed below.

- **Small size**, which is reflected in lack of market power for both inputs and outputs and relatively high transaction costs.
- **Low proportion of monetised transactions related to costs and returns**, making allocation of values difficult in economic analyses.
- **Lower capacity to bear risk.** Smallholder households are generally much closer to the survival threshold, and given that livestock often represent relatively large-value assets, loss of animals has particularly important implications for household welfare.
- **Different economic objectives of producers.** Smallholder farmers are often not solely interested in simple profit maximisation, as can be safely assumed in economic decision-making tools for large-scale commercial producers. As noted in c), above, in many situations smallholders will be equally as anxious to minimise risk.
- **Multiple functions of livestock.** On smallholder farms, livestock provide multiple primary products (meat, milk, and hides). In addition, livestock provide inputs for cropping and other farm activities (draught, manure and transport). Livestock also often serve two crucial banking functions: as a tool to build assets and as a source of regular cash and emergency funds during the year.
- **Livestock serve as a non-separable component of an integrated farming system.** In integrated crop/livestock systems, livestock do not represent a classic, isolated input-output enterprise activity. Instead, livestock activities are seen to have many interactions, joint inputs and joint outputs associated with other farm activities (for example,
improvements in soil fertility and crop yields due to increased efficiency of nitrogen and phosphorus cycling through ruminant livestock).

g) Low or no economies of scale. In most smallholder systems the opportunity costs of labour are very low. With low opportunity cost of labour, there are few opportunities to achieve economies of scale, which in livestock technology are mainly associated with substituting capital for labour (milking machines, mechanised feeding, etc.). Thus, smallholders can often compete very well with large-scale animal production in such settings, resulting in the observed small proportion of successful large-scale production in many developing countries.

External factors

In addition to inherent differences at the household level, because of the characteristics of small size and location in developing countries, smallholder farms are much more reliant on, and susceptible to, the external environment. The following external factors have important implications for animal health and production.

a) Inefficient livestock input and output markets. Market access is a crucial feature determining demand and prices for livestock products and costs and supply of inputs. In many countries, concentrated effective demand to support strong markets for inputs and livestock products is lacking, especially in poor rural areas. In other settings, the occurrence of epidemic diseases restricts access to export markets.

b) Poor infrastructure and public services. The lack of infrastructure and public services is an indirect constraint limiting input and output markets. This is also a direct animal disease constraint in many developing countries where state Veterinary Services can no longer supply the essential public goods of controlling epidemic and endemic diseases (especially those with externalities, such as vector-borne diseases).

c) Poor flow of information. Smallholder farmers make animal health management decisions based on very limited information. Constraints include limited opportunities to learn by direct observation of successes on other farms, poor extension and information systems and lack of training or practice in decision-making. Improved information flow can
be a powerful tool to support animal health decisions on smallholder farms.

d) Potential benefits of community action. Because of the small scale of production and lack of external infrastructure, smallholders are often more reliant on support from other community members for activities such as vector control, and input supply (e.g. water or communal grazing). While community action is often necessary, problems in mobilising community support may be encountered, particularly when opportunities exist for individual livestock owners to benefit from the disease control activities of others. This is termed 'free-riding' and examples include benefiting from herd immunity due to vaccination programmes or reduced vector or parasite populations due to treatments by neighbours.

e) A range of dependence on communal resources. Smallholder systems vary greatly in this regard, from pastoral herders at one extreme to small private dairy farmers at the other. Most, however, do depend to some extent on communal resources for animal feed. Even small dairy farmers may cut and carry grass from roadsides. In many cases, therefore, the behaviour and decisions of the farmer are associated with 'externalities' which concern others in the community.

Case studies of economic impacts of animal diseases and disease control in different smallholder systems

This section develops three examples from the range of smallholder systems across the typology spectrum developed above. These include:

a) the smallholder mixed dairy system in highland Kenya
b) the pastoralist system in arid and semi-arid Africa
c) the draught oxen/cotton system in West Africa.

For each case study, the unique considerations of the system will be explored, the major disease constraints will be outlined, methods found successful in constraint diagnosis in the system will be described, and strategies proposed or used to control disease and improve animal health and production will be highlighted. These would include both farm and extra-farm diagnostic techniques and issues.

The smallholder dairy farming system in Kenya

Description of the farming system

The smallholder dairy systems of the Kenya highlands are an example of intensive small-scale production systems in which crops and livestock are very closely integrated and where market factors have been crucial to development. Characteristic of tropical regions with good market access, the development of smallholder dairy systems in the Kenya highlands is marked by three elements: declining farm size, upgrading into dairy breeds and an increasing reliance on purchased feeds, both concentrates and forage (9). With high population growth and consequent reduction in land-holding sizes, farmers have developed a dairy enterprise which is closely integrated into a multi-objective farming system, also relying on cash crops (coffee, tea, and closer to the urban centres, market vegetables and fruit), maize and beans, and supported by off-farm income from towns. Central to the success of this intensive highland system has been a high demand for dairy products, particularly liquid milk.

Within this system, farms can be divided by level of intensification, based on land-holding size and use of grazing, and fall into two main zones. A marked increase in more intensive dairy production has occurred in the last ten years (1). The most intensive dairy producing areas are found within 150 km of the capital, Nairobi, at altitudes over 1,500 m. Two harvests of field crops per year are usually possible under the bimodal rainfall pattern. Farms are frequently 1-2 ha in size with one to two dairy cows (generally high percentage Holstein-Friesian or Ayrshire crossed with local Zebu) with about the same number of female calves and heifers. Feeding is mainly 'cut-and-carry' of planted Napier grass (*Pennisetum purpureum*) and crop residues, especially from maize and bananas, as well as weeds ('cut-and-carry' refers to the practice in smallholder dairy farms of feeding stall-confined cows by daily harvesting of grasses or other feedstuffs from the nearby vicinity and by carrying these grasses to the stall). Fodder from roadsides and other common land sources forms an important contribution to the basal diet. Purchases of Napier grass, maize stover and roadside grass are common, and a complex market has developed to supply these. On some farms, grazing/tethering along roadsides is occasionally carried out, but very few farms devote land to pasture. In most cases, cattle rarely leave the homestead dairy enclosures. In addition, 2-3 kg of concentrate feed is given to milking cows each day, in the form of either compounded dairy meal, maize bran, cotton seed cake, or others. On average, total daily milk output is some 10 kg per farm, of which a quarter is for home consumption and the remainder sold (76). In more land-extensive areas of the highlands, further from urban areas, smallholder dairy production relies on grazing to a greater extent. Farms range from 1.5 to 5 ha in size, rotated between natural or planted pasture and maize, sorghum and potatoes, depending on altitude. Dairy animals thus rely mainly on grazing, although fodder maize or sorghum is commonly grown to provide for the dry season and concentrates are often fed to milking cows. The breeds are the same as those in the more intensive areas, although often with higher local Zebu content. Milk production per acre per year is less than 500 kg on these farms, compared to over 1,000 kg on intensive farms (75).
Particularly in the intensive areas, cattle manure and/or manure mixed with urine are used to fertilise food and cash crops, market vegetables, and on planted fodder. In some cases, manure is sold to other farmers, and manure is also imported by truck from drier pastoral areas and marketed to farmers. The general nutrient deficits in soils under the intensive bimodal cropping result in a high value for manure, due to demand for both nitrogen and organic matter. As a result, the market value for manure is relatively high, and the value of manure produced is equivalent to some 28% of the value of the annual milk production on small farms (41). This is indicative of the importance of manure for the farming system as a whole, and the importance of manure as a livestock product.

Marketing of milk is the crucial element of this system. Until the late 1980s, milk sales were mainly through local dairy cooperative societies, which then sold the milk to a large parastatal monopoly processor. However, significant amounts of milk were also sold directly by farmers to consumers or informally through raw milk vendors. Since economic reforms and liberalisation in the early 1990s, marketing channels have diversified (see Figure 3 for an example of evolving channels in an intensive dairy area bordering Nairobi), with a larger proportion of direct sales or informal sales (56). These sales are considered 'informal', as they are generally of raw milk and are not sanctioned by the authorities. These more direct sales of milk provide higher sales prices to farmers and lower purchase prices to consumers, but create increasing concerns about milk safety. Regardless of market outlet, smallholder farms are highly market-oriented, with milk sales as the primary production objective.

The liberalisation of the early 1990s also affected the provision of livestock services. Public support for artificial insemination (AI) and clinical veterinary services declined, with the private sector left to assume responsibility. Some cooperatives and private veterinarians have begun providing these services. However, the use of AI has declined and some farmers report difficulty in obtaining veterinary services. In the intensive areas, AI is used by some 40% of farmers, but the proportion falls to 10% in the more extensive zones (75).

Income increases with intensification. Estimates from 1998 showed that intensive dairying offered the highest returns to labour per farm (returns to labour are profits after all variable and fixed costs have been deducted, with the exception of family labour costs), on average the equivalent of nearly US$1,000 per year (1). However, this does not recognise differences in the opportunity cost of family labour compared to the extensive production areas, where opportunity costs for labour are considerably lower. When the same returns to labour are calculated per litre of milk, the results are reversed. On average, intensive farms earn lower returns to labour per litre of milk than less intensified farms (about US$0.21 versus US$0.40, respectively). These results suggest that if real milk

![Fig. 3](image-url)

**Fig. 3**
Sale and consumption of milk from dairy farms in Kiambu District, Kenya
prices decrease over time, low intensity systems will remain competitive, while high intensity dairy production may not. These results also underline the importance to intensive farms of relatively high volumes of production, in order to cover higher fixed costs.

**Disease challenge and other risks**

Because of minimal movement of animals, directly transmissible infectious diseases, such as brucellosis, are uncommon (37). Endemic diseases, particularly, pneumonia and diarrhoea of calves are much more common, with calf mortality exceeding 20% on average (19). Since calves are in direct competition with humans for milk, growth rates are low (0.2 kg-0.25 kg per day) and significant morbidity and mortality are associated with premature weaning (18). Calf mortality, combined with long calving intervals associated with poor breeding decisions (54), limits the number of heifers available for selection to join the dairy herd.

East Coast fever (ECF) caused by *Theileria parva*, transmitted by the tick *Rhipicephalus appendiculatus*, has been an important problem in highland areas because of the high climatic suitability for the tick (59). Infections with other tick-borne pathogens, particularly *Babesia bigemina* and *Anaplasma marginale*, are relatively common but morbidity and mortality are uncommon (33). Until the late 1980s, the Government provided tick control in the form of weekly acaricide dipping. The risk of ECF varies according to agro-ecological zone and grazing system (20). In intensive areas where all cows are stall-fed (zero-grazing), ECF challenge is characterised by low intensity and infrequent challenge resulting in low risk of mortality. On grazing farms in more extensive areas, challenge is more frequent and of higher intensity. Significant mortality can result under such conditions if tick control (usually by band-spraying) and other risk management strategies are not applied (53). Treatment for clinical ECF is available, but requires rapid diagnosis and is expensive. Thus, although risk is low in intensive areas, case-fatality rates can be high. This can be an important worry for risk-averse smallholder farmers owning only one or two expensive cattle. An infection and treatment immunisation method, costing approximately US$18-US$20, has been developed but is not widely available due to requirements for a liquid nitrogen cold chain and careful veterinary follow-up for adverse reactors (49). Recombinant vaccines are under research but are not yet available.

Given the intensive and sometimes unhygienic conditions on dairy farms, the potential for the occurrence of mastitis and lameness is high. Infections with mastitis-causing organisms and high somatic cell counts are common. However, impacts of mammary infections on the relatively low levels of milk produced on most farms are inconsequential (55). Likewise for lameness: a high proportion of cows have abnormal hoof conformation or lesions but do not exhibit clinical lameness (21, 22). It has been suggested that the incidence and impact of both mastitis and lameness (and perhaps other diseases associated with intensive dairy farming in developed countries) will increase as milk production levels increase over time (55). This is also likely to be the case for nutritional disorders, especially as farmers have to manage a more complex set of feed inputs, often varying seasonally (75) to support better reproductive performance and increased milk production.

Risk to farmer income and welfare also occurs through the high degree of market exposure of the dairy enterprise, both in inputs and outputs. Research in the intensive dairy system has shown that extension recommendations towards higher use of concentrate feed and animal health inputs may not raise farmer welfare (38). Although incomes are raised by these interventions through higher milk yields and reduced mortality, the variability of income is also raised. This is due to climatic variability in fodder production, and fluctuations in milk prices. Increased expenditure on inputs increases the exposure of the farm to these risks, and stochastic dominance analysis indicates that under these circumstances, risk-averse farmers would suffer a greater loss in welfare than if the system remained at lower levels of input use, production and average income.

**Assessing the economics of optimal dairy health and production**

**Issues arising from specifics of the system**

The description of the smallholder dairy systems and the risks farmers in these systems face raises several issues which must be addressed in any analysis of the impact of diseases on cattle in these systems. These issues are as follows:

* a) the high complementarities/interactions between livestock, crops and rest of the farm
* b) a high degree of market orientation for both inputs and outputs
* c) manure as an important product
* d) risks due to variability in markets and production
* e) the essentially private nature of the smallholder dairy enterprise.

The first issue affects the way in which the impact of livestock disease and its control is valued for smallholder dairy animals. Whereas in commercialised systems, livestock are analysed in isolation, the physical complementarities in smallholder systems require an examination of the contribution of livestock to other farm crops and activities, as well as the dependence of livestock on these activities (Fig. 4). The lost value of the various livestock outputs, including manure, must be captured in the overall losses due to disease. Unlike in the crop/livestock systems of West Africa (described later), animal draught power is not an output, so the main livestock products are milk, culled and sold animals and manure. Methods for assessing the value of manure are discussed below. Livestock may also add value to some crops and planted fodder used by livestock as feed. Maize is both a food
and fodder crop, with maize stover fed to dairy animals, as are maize threshing and leaf strippings. The value of planted fodder, either Napier grass, or maize and sorghum planted as fodder, naturally depends entirely on the contribution of this fodder to livestock output. Generally, the returns to both crop residues and planted fodder are considered as a part of the revenues from livestock marketed outputs, so that a loss in milk and animal sales revenue is partially a loss in returns to crops and planted fodder. When evaluating disease losses, quantification of the share represented by the value of crops fed is of little use since the overall loss to the farm remains the same. What is important, however, is valuing cost savings in terms of the residual market value of those crop and fodder products otherwise not used when livestock are lost. In the smallholder dairy areas of Kenya, maize stover and planted fodder are readily marketed, and the market value can be easily measured. In an analysis of losses due to animal disease, those losses should then be reduced by the market value of crop residues and fodder that are made available to the market by the lower on-farm demand for fodder.

Aside from the physical crop/livestock interactions, economic complementarities between dairy and other farm/household activities may be important. Off-farm income, as well as seasonal income from cash crops, may be important sources of working capital to pay for feeds and other purchased inputs and the role of this income needs to be considered in any analysis of a dairy enterprise.

The major risk elements mentioned above, climatic and market variability, may accelerate the decline in the marginal value product of purchased inputs as the level of use increases. The importance of risk here can be understood by comparison with other smallholder systems. In pastoral systems, the actual risks faced, of severe hunger due to loss of all livestock from drought, are substantially higher. However, pastoralists have few livelihood choices available beyond livestock keeping, and the risks are simply an unavoidable part of the cost of the system. In the highland dairy system, on the other hand, many choices are available to farmers through various cash crops, food crops or even employment off-farm. Risk management can greatly influence farmer choice of enterprise, the level of enterprise, and the mix of enterprises. For example, the complementary income flows from dairy and coffee (daily versus seasonally) may lead farmers to combine these two activities to maximise cash flow and savings objectives. Thus, although risks, and the costs of these risks, may be lower in the highland system, the effects on decision-making by the farmer are greater.
The high degree of market orientation, combined with the private nature of land and cattle ownership, and the relatively low use of communal or public land, makes the smallholder dairy enterprise an essentially private one. Decision-making rests solely within the household, in this case, shared by husband and wife due to the strong traditional role of women in milk production. Costs and revenues are almost all privately captured, with few externalities through use of common property, in contrast to pastoral systems where much of the costs of grazing are borne by the community. The private nature of the enterprise has several effects as follows:

a) Economic analysis can largely follow a standard enterprise analysis (although accounting for household objectives) with externalities playing a small role, if any.

b) Demand for inputs and services are enterprise-driven. This means that many farmers are willing to pay for livestock services, so that animal disease control measures may be privatised to a much greater extent. From an analytical point of view, this also means that expressed demand of farmers fairly values those inputs and services. Farmers may prefer technologies which they can manage individually. One example of this has been the switch from communal acaricide dips to spraying by farmers themselves. This technology allows farmers individual control of resource allocation for tick control, providing a control level suitable for each dairy enterprise.

Approaches to analysing farm/household economic losses due to disease

Two basic approaches can be used to assess the losses due to animal disease at the smallholder farm level, as follows:

a) Partial budget or cost-benefit analysis (CBA)

b) Mathematical modelling, either of the optimisation or simulation type. Extrapolating farm-level results to the regional level requires an adjustment of the results based on numbers of animals and probabilities of loss, in addition to other assumptions regarding changes in prices, etc.

Rushton et al. describe the essence of CBA in an accompanying paper in this issue (67). The reader can find additional comprehensive presentations of the methodology elsewhere (15, 23, 63, 64). This technique can quite easily be applied to the market-oriented smallholder dairy setting in most cases. This type of analysis requires that unit values of all resource flows, inputs and outputs in the farm/household system be first estimated and then entered into the analysis. In the highly market-oriented system, this may be relatively straightforward, even for unconventional products, since manure, crop residues and fodder values can often be observed in the market place. However, the researcher must judge whether these market values reflect adequately the value of those resource contributions to inter-farm flows.

More difficult to value may be the opportunity cost of family labour, which often represents a substantial portion of production costs in intensive dairy systems. Some indication of the value can be obtained from the observed rural daily wage rate, conditioned by the expectation of employment and the reservation wage (a reservation wage rate is that below which a person would rather not work at all, and reflects the value of leisure). Conversely, if the opportunity cost of land is known, the labour opportunity cost can be estimated through the returns to the main agricultural commodities in the region. The opportunity cost of labour is generally lower than the market rural wage rate. Similarly, an indication of the opportunity cost of land can be obtained by rural land rental rates.

More sophisticated analysis of the impacts of losses due to diseases often requires the use of a mathematical model. Simulation models can be thought of as more detailed benefit-cost models in that models simply tabulate outcomes based on pre-estimated physical or economic relationships, and based on initial farm and market parameters. However, by adding estimates of the probability distributions of key variables (related to production and markets), risk assessment can also be incorporated. Van Schaik et al. use a Monte Carlo simulation model which allows experimentation with the key production and economic factors affecting economic performance on smallholder dairy farms in Kenya (87). The same model applied to strategies for controlling ECF in smallholder dairy systems along the coast of Kenya, using the stochastic dominance-ranking criterion to assess risk, is found in Nyangito et al. (52).

Because disease control decisions affect resource allocation, methods and tools for optimising resource use will be of increasing utility in this system. Optimisation models (usually linear programming [LP] models; also discussed in the accompanying paper by Rushton et al. (67)) are set up much like simulation models, and describe the interactions and resource availability on a farm. However, the models then solve for the optimal level and direction of resource allocation based on some assumed farm objectives (usually some form of best net returns, conditioned by risk considerations, household food security, etc.). The particular value of such models in this sort of analysis is twofold. Firstly, the links and interrelationships between livestock and other farm activities are captured explicitly. Secondly, within this integrated context, the models are able to determine internally consistent imputed 'shadow' values for intermediate outputs and inputs such as manure, crop residues and planted fodder. In a situation where these values are not easily obtained from market observations, an LP model could be considered. Griffith and Zepeda describe one such model applied to a smallholder dairy (26). Several techniques are also available for incorporating risk assessment into LP models, depending on the perception of the researcher in regard to which factors (e.g. disease risk, price variability) create the most important risk and what the primary farm objectives are. The assumption that farmers seek to ensure a target minimum farm income, for example, may lead one to employ the target MOTAD (minimum of total absolute derivations) model.
Descriptions of different approaches to risk modelling can be found in Hazell and Norton (28) and Boisvert and McCarl (4). Again, if uncertainty exists regarding key parameters, sensitivity analysis should be used to assess changes in these values.

The smallholder dairy system in the highlands of Kenya has intensified rapidly in recent years and this trend is expected to accelerate. Markets for milk and farm inputs have changed even more rapidly. The epidemiology of animal diseases will also evolve, with an increasing importance of production-associated diseases, requiring husbandry and nutrition solutions, rather than therapy or vaccination. Because of these rapid changes and also the increasing competition between farms to improve the efficiency of dairy production, a real need (and an opportunity) exists to enhance farmer decision-making in resource allocation, financial management and risk management. Decision-making tools can be adapted from dairy health and production management programmes that have evolved over the past thirty years in the developed world.

**Pastoralist extensive systems in semi-arid areas of Africa**

**Unique considerations of the system**

Pastoralism is the dominant livestock production system in areas of the developing world with uncertain rainfall or other natural constraints to crop production. It is an important production system in human welfare terms, supporting approximately 12% of the population of the world (31), but is relatively insignificant in marketed livestock production, accounting for less than 10% of all marketed meat and milk (7). However, this limited market orientation greatly underestimated the importance of livestock in pastoralist systems. Livestock are crucial and are often the principal activity supporting livelihoods in harsh environments unsuited to any other form of agriculture. In these societies, livestock are the centrepiece of daily and ceremonial life and are the principle currency for social and commercial transactions.

In Africa, a number of traditional pastoralist societies have been under pressure to change, due to increased competition for land and other factors. Over time, with the expansion of settled crop/livestock farming, pastoralists have been pushed into more and more marginal areas. In some areas, traditional land use arrangements have been modified and new organisations, such as group ranches in Kenya, Mali and Botswana, have developed. Such areas also often have increased access to input and output markets. The emergence of new structures such as these is at a comparatively early stage. Other pastoralist societies have, to a large extent, been able to retain traditional land use, herding and other practices.

The primary characteristic of pastoralist systems is the movement of people and animals to exploit available food and water. Distances travelled are usually a function of the harshness of the environment. In Africa, these systems are found almost exclusively in and semi-arid areas. This mobility of human and livestock populations has a number of practical livestock production, animal disease and economic implications. Due to movement and large distances to markets, high transaction costs are involved in the delivery of animal health goods and services and also in marketing of livestock products (as evidenced by the low amounts of marketed meat and milk described above). High transaction costs contribute to the low sale value of individual animals in pastoralist areas. Transaction costs also dominate the planning and assessment of animal health service delivery in pastoralist systems, greatly influencing the approaches and methods used to assess delivery strategies.

**Disease constraints**

An important consequence of the large, mobile, and mixing livestock populations of pastoralists is to enhance the probability of transmission of epidemic diseases. In Africa, rinderpest has been the most important of these (see, for example, the historical summary by Schwabe [71]), but the classical form of rinderpest has now been restricted to the southern Sudan by the activities of the Pan African Rinderpest Campaign (PARC) coordinated by the Organisation of African Unity. In recent years, contagious bovine pleuropneumonia has become a more serious threat in a number of countries, where it causes significant morbidity, mortality and production loss (93). In small ruminants, contagious caprine pleuropneumonia is important in many countries. Foot and mouth disease (FMD) is also widespread in many pastoralist areas. Occurrence of FMD in pastoralist areas usually exhibits peaks at approximately three-year intervals, when a sufficient population of susceptible animals has formed to support transmission. The loss of production due to FMD infection is not particularly significant in pastoralist herds. However, the occurrence of the FMD, along with that of other epidemic diseases, restricts possible export of livestock and livestock products. Export restrictions due to diseases in pastoralist areas may impact on neighbouring non-pastoralist areas in the same or neighbouring countries.

In addition to epidemic diseases, which are the main focus of interest to national and international veterinary authorities, a number of endemic zoonotic diseases are also of significance. Zoonoses are both common and important in most pastoralist areas because of the close associations between humans and animals. Of particular importance is brucellosis, due to *Brucella abortus* and *Brucella melitensis*. In many pastoralist areas, the high prevalence of brucellosis in cattle and small ruminants is mirrored by a high prevalence in humans (17, 50). The disease in humans can be extremely debilitating. Other zoonoses of importance to pastoralists include tuberculosis, echinococcosis and anthrax, among others (71).

Endemic diseases, particularly bacterial and viral pneumonia and diarrhoea and parasitism in young stock are important...
(indeed, these diseases are important for all the smallholder production systems discussed in this paper). Morbidity and mortality rates are consistently high in young animals and can also be high in adults under adverse conditions. Reproductive performance, growth rates and milk production are low on average and also fluctuate markedly depending on environmental conditions (3, 91, 92). Inadequate animal nutrition is an important determinant and interacting factor for both poor health and productivity. Nutrition is based exclusively on access to, and exploitation of, natural pastures and browse.

Analysis of the impact of animal diseases and disease control

In the pastoralist sector, economic assessment tools have focused on decisions to invest in control programmes, particularly vaccination campaigns, for epidemic diseases. Initial analyses, based on simply estimating all direct and certain indirect losses from a disease and implying that all the losses are recoverable through disease control, have been discredited (45). In Africa, ex post CBAs of rinderpest vaccination, for both the JP15 programme in the 1970s (13) and the PARC programme since the 1980s (81), have been conducted. Specific eradication campaigns are much more amenable to assessment by classic CBAs than the delivery of services that must be sustained over a much longer period. A number of methodological considerations are important to consider in conducting CBAs (15), particularly since estimates of livestock numbers and different direct and indirect losses may be difficult to obtain and of variable quality. Clearly, the assumption of how quickly eradication occurs is crucial to ex ante assessments. A number of strategies can help in decision-making, including sensitivity analysis across the range of important variables and integration with mathematical models of disease transmission under different scenarios.

For large-scale vaccination programmes that cover nations and regions, costs and benefits to different individual sectors need to be estimated. In some circumstances, specific sectors benefit much more from the control or eradication of epidemic diseases, particularly when trade restrictions are involved. This can have direct implications for the pastoralist sector, e.g. a recent example being a national ban on Somali livestock exports to the Middle East in 1998, subsequent to reports of Rift Valley fever outbreaks in Somalia and northern Kenya. More common is the situation in which it is economically justified for the government to subsidise pastoralists to help control or eradicate diseases that otherwise would limit trade by commercial livestock sectors. This permits part of the benefits from expanded exports captured by the commercial sector to be effectively transferred to pastoralists whose control measures allow the commercial trade opportunities. Such subsidies are used in southern Africa (88) for the above reason as well as for social equity reasons. Another example is found in the regional analysis of FMD in South-East Asia (60).

A key constraint to sustained delivery of animal health and production services to pastoralists is the extremely high transaction costs. Thus, analyses of potential delivery pathways and assessments of which parties benefit from, and which parties are willing to pay for control and clinical services are of crucial importance to determine the long-term viability and sustainability of these services. In these analyses, the type of animal health good or service should be distinguished as public, private or public with externalities (85). Such classifications are not always simple. For example, in the rinderpest eradication campaign in Africa, some programme elements, particularly the establishment of quarantine areas, clearly represent pure public goods whereas vaccination is a private good with certain public good externalities (the individual herder benefits from the protection of his/her animal and other herders benefit from decreased disease transmission due to enhanced population immunity). The degree to which pastoralists are willing to pay for vaccination will depend on perceptions of the associated risk and benefits. Samburu pastoralists in Kenya, for example, have been willing to pay for rinderpest vaccination, because individuals perceive both important risks and losses. However, the same individuals have been unwilling to pay for vaccination for FMD since losses incurred by FMD are considered to be inconsequential (29).

Pastoralists are keen to receive other veterinary services beyond vaccination for epidemic diseases. These could be divided into strictly private goods (e.g. clinical services), private goods with moral hazards (e.g. drugs for which protection from sub-standard or fraudulent products is important), private goods with externalities (e.g. pour-on insecticide treatments), and public goods (e.g. quality control of drugs and control of zoonotic diseases). Economic issues related to the delivery of veterinary services in Africa have raised interest in recent years (8, 35, 42, 85), particularly with the downsizing of state Veterinary Services and the increasing reliance on private services. Economic approaches such as the New Institutional Economics (43) and structure-conduct-performance analysis (69) can be applied to assess the suitability and performance of potential delivery pathways for different types of animal health and production services. Economic analysis usually indicates that veterinarians are too expensive and immobile to provide routine clinical and advisory services to pastoralists. Strategies for providing these services are discussed below.

The specific issues related to the economic assessment of zoonotic diseases deserve special mention because of the importance of zoonotic disease in pastoralist systems.

Techniques of public health economics and poverty alleviation are most relevant in this context, with the assumption that the importance of human health precludes the use of standard CBAs, shifting the focus, therefore, to analyses of cost-effectiveness. This may be true in wealthy countries, but the huge scale of public health problems in most African countries with pastoralist areas, and the scarce
resources available to tackle these, mean that prioritisation of public health problems is needed first. One useful technique is the standardisation of human health impact using disability adjusted life years (DALYS) (51). For brucellosis, it would be useful to incorporate the additional animal health and productivity effects to prioritisation estimates, possibly justifying control programmes in animals.

Standard techniques to assess economic decision-making on farm 'enterprises', such as gross margins or partial budgets (11), have little utility for pastoralists now or in the near future. Economic values of inputs and outputs in these systems are difficult to estimate and not of particular interest in most pastoral settings.

Animal health and production service strategies

As mentioned, a key necessity for providing veterinary services to pastoralists is to reduce transaction costs. Constraints and options for the delivery of different animal health and production services are presented in Table I. A number of schemes have been proposed (see for example, Majok [46]). Trained paraveterinarians or 'barefoot vets' (25, 27, 71) have been used, with some success. In livestock-based societies, many people have specialist knowledge and skills in obstetrics, surgery and other procedures (25). The advances of modern veterinary research such as vaccines and drugs can be combined with well-documented traditional veterinary expertise in most pastoralist cultures (72), either by training traditional healers or by developing partnerships between them and trained paraveterinarians (71).

Delivery of multiple services could also reduce transaction costs for delivery of services to pastoralists. One option proposed by Schwabe is to mix community and veterinary health services (71). This is a particular option in pastoralist areas where veterinary services are often more readily available and in greater demand than medical services. Another option for reducing transaction costs is to schedule service provision to coincide with market days or other community events.

While paraveterinarians are likely to be, and to remain, the main cadre of animal health service providers for pastoralists, some graduate veterinary expertise will probably be required. The trend is for this to be provided by private veterinary practitioners (8). Again, special incentives and innovative arrangements will be required. In Kenya, private veterinary practice has flourished in areas of high human and livestock densities close to major cities over the last ten years, but almost no private veterinarians are based in the more remote pastoral areas (90). This may be overcome by allowing the development of quasi-private or public-private practitioners with either public vets allowed to conduct some

<table>
<thead>
<tr>
<th>Animal health good/service</th>
<th>Class of economic good</th>
<th>Beneficiary (who can or should pay)</th>
<th>Delivery constraints</th>
<th>Options to improve delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical service curative drugs</td>
<td>Private</td>
<td>Herder</td>
<td>High transaction costs, Public education, Trained personnel, Poor markets</td>
<td>Trained paraveterinarians, Community education and participation</td>
</tr>
<tr>
<td>Parasite/vector control</td>
<td>Private with externalities</td>
<td>Herder</td>
<td>High transaction costs, Public education, Trained personnel, Poor markets</td>
<td>Trained paraveterinarians, Community education and participation, Adaptive research</td>
</tr>
<tr>
<td>Vaccination (compulsory or voluntary)</td>
<td>Private with externalities</td>
<td>Herder, Government, Other beneficiaries</td>
<td>High transaction costs, Public education, Trained personnel, Poor markets</td>
<td>Community education and participation, Subsidies from beneficiaries</td>
</tr>
<tr>
<td>Quality control drugs/vaccines</td>
<td>Public</td>
<td>Herder, Government</td>
<td>Trained personnel, Infrastructure, Public awareness of benefits</td>
<td>Community education and participation</td>
</tr>
<tr>
<td>Surveillance/movement control</td>
<td>Public</td>
<td>Government, Identified beneficiaries</td>
<td>Understanding of collective benefits</td>
<td>Community education and participation</td>
</tr>
<tr>
<td>Public health</td>
<td>Public</td>
<td>Government, Community, NGOs</td>
<td>Public education, Infrastructure, Trained personnel, Public education</td>
<td>Community education and participation, Adaptive research</td>
</tr>
<tr>
<td>Adaptive research</td>
<td>Public</td>
<td>Government, Community, NGOs</td>
<td>Trained personnel, Public education</td>
<td>Community participation</td>
</tr>
<tr>
<td>Policy</td>
<td>Public</td>
<td>Community, Government</td>
<td>Weak public institutions, Low political importance of pastoralism</td>
<td>Political activism, Community education and participation</td>
</tr>
</tbody>
</table>

NGO: non-governmental organisation
private practice, as has been the case in India (68), or to guarantee private veterinarians a basic level of public sector service contracts, a practice common in many developed countries.

Nutrition is a major constraint in pastoralist systems and is a major contributing factor in the occurrence of endemic diseases. Seasonal shortages of natural pastures is a perennial problem but has been exacerbated in many cases by partial or complete loss of grazing areas, particularly more favourable ones, to sedentary farmers. The need for information to guide policy decisions in this area is extremely important. While large-scale nutritional supplements to natural pastures are not feasible, targeted interventions can be useful. A good example is provided by Stem who reported on the assessment of vitamin A supplementation among the Tuareg in Niger (78).

For any animal health and productivity strategy, the importance of community participation and education cannot be overemphasised (29, 78). Techniques need to be adapted for local circumstances (78). Pastoralist societies are quite heterogeneous in regard to traditions and exposure to, and acceptance of, outside influences. In some areas, pastoralist societies have retained a strong structure of traditional grazing management and animal health services. Ethnoveterinary approaches have shown considerable benefits in fostering community participation and improving understanding of how interventions can be adapted to local contexts (44).

Important issues for the future
Pastoral systems are unique and require different approaches to animal health and productivity improvement. A number of policy issues are of crucial importance. These include land rights, optimal land use, enhancement of market-oriented trade, alleviation of poverty and prioritisation of investments. Better information and community participation and consensus will be the key ingredients in the process of developing optimal strategies for animal health and productivity in pastoral systems. Economic assessments can play an important role. At the micro-economic level, an ethnoveterinary approach to help better understand poverty issues and the impact of different interventions at household level is necessary. Interventions intended to benefit all households need to make a special effort to reach poorer groups (78). A particular advantage of the ethnoveterinary approach is that communities are involved in the research process so that results will have greater relevance and thus are more likely to be adopted and have impact. Methods being developed in environmental impact assessment can contribute to the many important questions about natural resource management relative to pastoralist livestock production and environmental sustainability as traditional pastoral strategies come under increasing pressure. An important task for researchers in this process is to develop better transdisciplinary approaches (involving, for example, biology, range and veterinary science, economics or sociology) to support decision-making by pastoralists and policy makers (10). Pastoralists have adapted to harsh environments by understanding and adapting to the system. Such a broad perspective needs to be kept at the centre of strategies to improve animal health and productivity in pastoral systems.

Mixed farming system with draught oxen in West Africa
The farming system
Over the past three decades, the use of livestock for animal traction for crop production has expanded significantly across the sub-humid zones of West Africa. As a result, new farming systems have evolved that integrate draught livestock – particularly cattle – into sedentary, crop-based smallholder farms.

The areas where this has occurred lie mainly in the transition zone between the Sahara and the humid forests along the coast of West Africa. This transition zone, which from The Gambia and Senegal stretches east through northern Nigeria, consists of the semi-arid Sahelo-Sudanian and semi-humid Sudano-Guinean zones with flat plains or rolling hills of partially wooded savanna (24). Although the zone has generally good agricultural potential, development had long been constrained by health problems, especially onchocerciasis for humans and trypanosomosis for livestock. While onchocerciasis has been nearly eradicated from the region, trypanosomosis transmitted by the tsetse fly remains endemic throughout much of the zone.

The threat of trypanosomosis has been an important factor in shaping farming systems in the region. Cattle herding has generally been concentrated in pastoralist systems in the drier areas where fewer tsetse flies are found; the cattle are only moved southward to look for water and grazing during the dry season, or when being taken to markets on the coast. Farming systems in the semi-arid and sub-humid zones to the south are predominantly crop-based, with livestock playing a minor role, mainly as a savings mechanism. If cattle are kept, they are generally kept off the farm in transhumant, communal herds managed by pastoralist peoples (70, 83).

To improve rural incomes in this zone, policy makers have long promoted the development of cash crop production: groundnuts and cotton in Senegal and The Gambia, and rice and cotton elsewhere. However, small farm sizes and low availability of labour limited the area that could be devoted to such crops and the capacity to intensify production, creating supply constraints for the agro-industrial sector that depended on this output. In response, the parastatals responsible for developing cash crop production promoted mechanisation technologies based on draught cattle (77). Uptake was initially slow since most people had little or no tradition of keeping cattle on-farm, and losses were often high (65, 77). In the 1970s and 1980s, however, cotton production in particular expanded rapidly in many areas, and
accompanying this was a rapid expansion in the use of draught power. In Côte d'Ivoire, for example, the number of draught oxen in the country increased from 200 in 1965 to 6,500 in 1975, and reached 39,100 by 1985 (32). By the mid-1980s, 25% of all crop farms in the cotton zone of Boundiali in northern Côte d'Ivoire possessed draught oxen (70). It is interesting to note that Itty partially attributes the adoption of animal traction during this period to the droughts of the 1970s since the dryer weather apparently reduced the threat of trypanosomosis (32).

The use of draught power is now well established throughout the zone. Teams of draught animals are often kept by larger farmers, who use the animals mainly for land preparation, as well as for transport. These farms usually practise rotational cropping on areas of two to ten hectares, devoting a significant portion of land to the cash crop (cotton, groundnuts) and the rest to food crops (rice, maize, millet) or fallow. Keeping draught animals also provides additional benefits in terms of manure to fertilise crops, although this practice is certainly not yet generalised in West Africa. Smaller farms often hire animal traction services for land preparation if they do not keep their own. Cattle traction is also found on irrigated rice schemes such as the 45,000 ha Office du Niger scheme in Mali (36).

**Disease constraints**

The most important health constraint faced by farmers keeping draught animals in West Africa remains trypanosomosis (77). The impact of the disease on draught animals is portrayed in Figure 5. Swallow makes a very useful distinction between the impact of trypanosomosis incidence versus trypanosomosis risk (79). The main effects associated with incidence are often related to morbidity. A diseased animal will be less available for fieldwork, will provide less power if worked, and cows will produce less milk and have longer calving intervals and lower reproduction rates. A sick animal will also consume less, so weight gain will be reduced and manure output will also decline. In some cases, the animal may die. Initial mortality rates for draught animals of up to 10%-25% have been recorded in several areas across West Africa (77), and even 40% in Mali (65). Bangura, for example, reported 20% mortality for draught oxen in an oxen traction project in Sierra Leone in 1985, in this case mostly

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**Fig. 5**

The impact of trypanosomosis risk and incidence on draught cattle-based farming systems

Adapted from Swallow (79)
attributed to Stomoxys flies (2). For farmers in West Africa who do not have a tradition of livestock keeping, it is the loss of draught power, especially during the period of critical crop operations, together with mortality that represent the most important losses (40). Based on a large farm survey in Ethiopia, Swallow estimates draught oxen in high trypanosomosis risk areas to be 33% less efficient than those in low risk areas (79). Shaw estimated trypanosomosis to be responsible for five lost workdays of the annual total of forty draught power workdays in The Gambia for an infected animal, and with an incidence of 20%, this translates to an average two workdays lost for all draught cattle (73). Lost workdays, in turn, translate into reduced crop production, either through reduced area that can be cultivated, or through lower yields due to late timing of operations (62). Mortality over the longer term also leads to lower weight gain, which can affect the efficiency and final resale value of draught animals (66). Nutrient cycling by using manure for crop production is still fairly limited, and milk is generally not important in farm household diets (except for settled pastoralists). Since farmers keep only a few heads of cattle for traction, reproductive efficiency and the impact of this on herd dynamics are less of a concern.

Beyond the direct effects of incidence on productivity, trypanosomosis has dramatic risk impacts. Firstly, the disease is associated with lost potential since it continues to discourage adoption of animal traction in areas where trypanosomosis challenge remains high, especially in the southern portions of the sub-humid zone of West Africa. In Côte d'Ivoire, for example, the proportion of cotton farms with draught animals declines on a north to south gradient (32). Secondly, trypanosomosis risk is a major factor influencing the choice of breed (77). Farmers prefer to keep smaller, less powerful N'Dama or Baoulé cattle in areas of high risk, to the south, because these indigenous breeds are known to be trypanotolerant. Travelling north, trypanosomosis risk decreases, and farmers rapidly switch to more powerful crossbreeds and the larger Zebu for animal traction (14). Choice of breed, therefore, represents another form of lost potential. Thirdly, the risk and incidence of trypanosomosis require other control measures, either to control the parasite using trypanocides prophylactically or curatively, or to control the vector through the use of pour-on treatments or tsetse traps. Control measures increase the cost to the farmer of maintaining draught animals, and so also contribute to economic losses.

Analysing the impact of diseases and their control

Given the situation described above, methods typically used for assessing the impact of disease on production livestock are often not fully appropriate for draught animals. As explained in the accompanying paper in this issue, by Rushton et al (67), economic analyses of disease and disease control usually consider livestock keeping as a production activity that uses capital (land, equipment) and consumes inputs to produce outputs (milk, meat, more livestock) for sale or on-farm consumption. This type of production activity can be represented as an enterprise budget, and thus is amenable to gross margin analysis and CBA techniques as described above for smallholder dairy systems. However, keeping draught animals is not the same type of production activity (58). The animals are viewed instead as farm equipment or capital. What they produce - draught power - is an intermediate output that serves as an input for crop production activities. Many of the inputs used in maintaining the animals, as well as the output - the draught power produced - are frequently not subject to market transactions, and so should be valued in terms of their contribution to the principal activity: crop production. The value of draught power, as well as that of manure, if used, is therefore determined by the profitability of the crop production activity. Since draught animals are used on a number of different crops on a given farm, the valuation problem becomes even more complicated.

Two approaches are used to address this situation. Firstly, if a market for traction services and manure exists, then the current market price can be used to value the opportunity cost, and the standard analytical techniques then applied. The appropriate market price to apply may not be obvious; ittyy, for example, notes that in The Gambia, farmers pay a fee to animal owners to have the animals tethered in the field to depasture manure, rather than pay for the manure itself (32). Market prices for these types of unconventional products must be reviewed carefully; for example, local prices for traction services may be adjusted to account for reciprocal obligations (e.g. exchange labour, whereby a farmer works on the farm of a neighbour one day, and the neighbour comes to work on his farm the next). In addition, animal traction used on-farm would probably be more valuable since it would be reserved for the most timely use, and hired off-farm at other periods. To date, most analyses of trypanosomosis control for this farming system have resorted to this simplified approach of using some type of proxy market price for traction services and manure lost to disease, preferring to ignore the potential implications for the farm profitability of crop production.

To better capture the role of draught animals as an integrated component of the farming system, an alternative approach is to model the complete system, as described above for LP models in the case of smallholder dairy systems. An appropriately constructed LP model can provide, for example, the value in a draught animal farming system of a day lost of animal traction or a quantity lost of manure due to disease. In the case of animal traction, consideration of multiple time periods (which are easily developed in LP models) becomes useful to estimate how shadow prices of draught power vary over the year as a function of seasonal fluctuations in the opportunity cost of labour (77). This type of analysis could provide, for example, an economic justification for strategic chemoprophylactic control of trypanosomosis as recommended by Connor (6).
To capture the dimension of draught animals as farm equipment, consideration of investment analysis techniques in extended, multiple-year time horizons is also useful. Panin, for example, describes a classic CBA for the acquisition of a pair of draught oxen on a farm in northern Ghana (57). Benefits from animal traction are expressed in terms of increased crop yields over a ten-year period. One advantage of this approach is that it permits capturing costs and returns associated with the final resale of a draught animal, which is likely to be the single largest source of profitability (77). The analysis by Panin does not incorporate any risk or costs associated with animal morbidity, although it does include the cost of insuring against mortality. It also fails to capture the other non-market costs and benefits associated with animal traction noted above. This shortcoming could be resolved by integrating single-period LP models, and thereby serves as a framework for analysing the longer-term impact of animal traction noted above. This shortcoming could be resolved by integrating single-period LP models, and thereby serves as a framework for analysing the longer-term impact of diseases and their control. In the case of trypanosomosis, this type of framework would be useful for quantifying the impact of the disease on reduced weight gain over the service life of draught animals, and the implication for the final resale value. Itty uses a ten-year herd model when conducting social CBA to compare the returns to the use of trypanocides and the introduction of trypanotolerant cattle across six sites in Africa, but due to lack of data on returns to animal traction and manure, does not consider the case of draught cattle (32).

The quality of the models described above depends on the quality of the data used to construct the model. The data required, or technical coefficients, can often be derived partly from available literature, but as Starkey points out, technical data for animal traction are often from on-station trials, and so will probably require additional data collection on-farm (77). Preliminary diagnostic surveys using farming systems research (FSR) techniques are useful to distinguish the role played by draught animals in the farm household and their interactions with crop production (74). Data then need to be collected on all aspects of the economic activities and resource use of the farm, and so require fairly detailed, longitudinal farm household surveys. Also, specific data would need to be generated regarding the relationship between management practices, disease, and the productivity of draught animals. As Thorne notes, such information is largely lacking at present, and so limits the accuracy of this type of modelling (84). Rowlands et al. stress the difficulties involved in quantifying such parameters, even using longitudinal studies (66).

Two other issues related to analysing the impact of trypanosomosis merit mention. The first relates to the choice of breed by the farmer for draught animals. We expect farmers to consider several criteria when deciding which breed to use. The most obvious would relate to the productivity of the animal in its different functions, particularly traction power. Moreover, since a draught animal represents the equivalent of a long-term investment in farm equipment, the farmer would be likely to also give priority to insuring against the loss of his/her capital. In terms of animal health, the farmer in West Africa may therefore give preference to the smaller trypanotolerant indigenous breeds over the larger trypanosusceptible ones. Several innovative approaches have been used recently to explore these issues. Jabbar et al. report a matrix-rating technique in which farmers in Nigeria scored criteria for different cattle breeds using beans on a game board (33). The criteria included milk yield, disease resistance, size of animal, ease of handling, market value, marketability, ability to graze diverse species of grasses, need to move long distances for grazing, and overall desirability. The scores for the criteria were then compared to farmer breeding practices using regression analysis. One of the results confirmed that farmers who give preference to disease resistance are indeed more likely to keep trypanotolerant cattle. Tano et al. conducted a similar study in Burkina Faso and found that mixed crop/livestock farmers in that country preferred more powerful Zebras to the smaller trypanotolerant breeds, whereas subsistence farmers preferred the lower risk associated with trypanotolerant breeds (83).

A similar approach that has been borrowed from the consumer marketing literature is referred to as conjoint analysis. Farmers are asked to rank different combinations of attributes in cattle. By using a carefully planned experimental design, the ranking of the combinations permits the analyst to quantify the relative contribution of each individual attribute in the selection decision. Tano et al. have applied this approach in southern Burkina Faso and found that all livestock keepers give high preference to disease resistance (82). Traits related to beef and milk production were consistently related below other factors such as fitness for traction and disease resistance. Of the different types of livestock keepers, mixed crop/livestock farmers in particular gave the highest preference to fitness for traction.

The second issue relates to vector control options that require collective action, such as tsetse traps and screens. Similar to natural resource management under pastoralist systems (discussed earlier), these strategies require a coordinated effort off the farm, which is increasingly the responsibility of the local community to manage. Unlike other control strategies (chemotherapy, breed choice, pour-on insecticide treatments) that are basically private goods, the use of traps is essentially a public good. The analysis of such strategies therefore requires an assessment of the willingness of individuals to actively contribute to the management of vector control rather than to act as 'free riders'. Polou et al. (61) describe the use of contingent analysis, based on earlier work by Swallow and Mulatu (80) and Echessah et al. (12) in East Africa, to evaluate the willingness of livestock keepers in northern Côte d'Ivoire to contribute money or labour, or both, to tsetse control using traps. The results indicate that type of production system (sedentary versus transhumance), region, and breed kept, significantly influence the expressed willingness to contribute. Cotton growing, which could be considered a proxy for the use of cattle for traction, is not a significant determinant. Elsewhere, Mullins et al. assessed the willingness of both
tourist industries as well as nearby farmers to participate in
tsetse control near a natural preserve in Botswana (48). Some
of the farmers were willing to provide days of animal traction
as a contribution.

As the above examples demonstrate, several aspects of
keeping draught animals on mixed crop/livestock farms in
West Africa render unsuitable many of the standard
approaches for evaluating the economic impact of
trypanosomosis and other livestock diseases. To appreciate
farmer decision-making in this context, a more
comprehensive view of livestock is often necessary, livestock
should be seen as an integrated, inseparable component of the
whole-farm production system. Researchers will need to
continue experimenting with new, innovative approaches to
more accurately capture the multiple effects of animal disease
and its control.

Current lessons and future
trends

Animal health strategies: a systems perspective

The case studies presented have illustrated the utility of
considering strategies for improving animal health and
production in a systems context. In the typology framework
presented, a number of characteristics useful in distinguishing
different livestock production systems were summarised into
two main axes. The most important of these is the degree of
intensification. Intensified systems evolve in response to good
marketing opportunities and infrastructure. Under these circumstances,
livestock activities are naturally more market- and profit-
oriented and the focus is on optimising productivity on the
individual farm. In this context, disease is simply one of many
variables to manage. Usually, farmers have access to, and can
choose from, a number of animal health and production
options, thus management skills are required to choose
between the options. The focus on animal health economics is
to support decision-making at the farm level. Recalling that
endemic and production, rather than epidemic, diseases are
most important in intensive systems, the animal health goods
and services and their delivery are almost exclusively private
goods.

This is in sharp contrast to more extensive systems, where
epidemic diseases are of greater importance and farmers rely
on communal natural resources. Infrastructure and markets
are undeveloped and animal health and production strategies
are adaptive rather than managerial. Although animal health
risks are higher in most extensive systems, the ability to
manage risk at the farmer level is much more limited. The
focus on animal health economics in these systems shifts to
natural resource management and disease control at the
community level and greater emphasis is placed on the public
good aspects of animal health goods and services and their
delivery.

The second axis, dependence of the household economy on
livestock, is less useful in characterising differences in
approaches to animal health and production management
across systems. The only key distinction relates to the greater
specialisation in livestock management and the greater
awareness and demand for animal health and production
information. This awareness and demand can be used to
advantage in animal health programmes at community level
in pastoralist systems.

Main future trends

Intensification will remain the key future determinant of
livestock development within smallholder systems in the
developing world. Livestock development will follow two
main paths, one for market-oriented systems and the other for
subsistence-oriented systems.

On average, the demand for livestock products in the
developing world is predicted to outpace population growth.
Already, in smallholder farming areas with good market
access, farmers have responded in innovative ways to increase
livestock production and cash income. The smallholder dairy
system in the highlands of Kenya is one example. The authors
expect this trend to accelerate in areas with good market
access, since many of the necessary components, such as more
efficient input and output markets and private-sector service
provision are present or developing. Poor provision of
necessary public service may be a weakness in some
countries. The scale of livestock enterprises in intensifying
systems will vary, based on a number of factors. The authors
expect smallholder systems to dominate in areas where labour
inputs are relatively cheaper than capital, and larger-scale
systems where capital is less expensive. Smallholdings are
expected to maintain a more diversified portfolio of farm
activities while large holdings will be increasingly specialised.
For intensifying smallholder systems, livestock or livestock
products will provide both non-marketed intermediate
outputs and marketed final products. In some systems, such
as the draught/cotton system described for West Africa,
traction is the main livestock output, and livestock will
remain the principal source of draft for smallholders. In
highly integrated crop/livestock systems, intermediate
livestock outputs will be less obvious but crucial, for example,
the importance of manure in the market-oriented smallholder
dairy system (28% of the estimated value of livestock
products).

For less market-oriented systems, different trends and
economic influences will be important. In these systems,
usually found in more marginal and arid areas, farmers and
herders rely almost entirely on natural resources (pastures and
shrubs) for survival. Adaptations to improve the management
of these natural resources will be the key future challenge, a
particularly difficult challenge in pastoral areas where the
grazing range of herders is increasingly constrained by
sedentary farmers. The role of community action in this
process will be crucial, as will policy and other public inputs.
Targeted policies for poverty alleviation will be an important social issue, and improvements in natural resource management in subsistence areas will be an important strategy for poverty alleviation (30).

**Priority issues and approaches**

In the intensifying market-oriented smallholder systems, priority issues in animal health and production will be improved farm-level decision-making, both for farm and financial management. The management of financial risk will become a key skill for market-oriented smallholders. The emphasis in animal health will shift from infectious diseases to production diseases.

Many of the economic decision-making approaches required will be adaptations of available methods. Farm management decision-making techniques and financial management techniques used on dairy and swine farms in developed countries will be applicable with some minor adaptation (11). A new researchable aspect will be to understand more fully the joint production and economic effects of the complex of inputs and outputs of highly integrated crop/livestock smallholdings. Simulation models and other systems analysis techniques will be useful at a research level. Decision-support tools based on LP (34), portfolio theory (16) and other decision-analysis techniques would be helpful in the hands of advisors to smallholder farmers.

In these intensified and commercialised smallholder settings, farmers will need to make many more decisions and will be under greater financial risk. An example of these new kinds of decision-making pressures is in the control of tick-borne diseases. In the past, smallholders in Kenya were mandated to dip cows at communal, government-subsidised plunge dips every week. Now farmers are responsible for all decision-making regarding tick-borne disease control, but with a greater number of control options. Farmers need to choose from a combination of acaricide products and modes of application, an infection and treatment vaccination method, drugs, and grazing management strategies. Choosing the optimal combination of these methods and deciding on the supplier and method of supply is a complicated task, requiring a good understanding of the actual disease risk in addition to the level of risk the farmer is willing to accept. This is not a trivial decision for farmers whose one or two cows may be worth approximately US$1,000 each.

While animal health and production decision-making in intensifying systems can largely rely on adapting available techniques, in subsistence settings, new methods and strategies will be required. Clearly, tools for natural resource management decision-making under constraints are required that consider social, environmental and economic components. These techniques need to incorporate community as well as individual decision-making. Policy decisions - such as assessments of poverty, causes of poverty and targeted solutions - will be crucial. On account of high transaction costs and the relatively greater importance of public, relative to private, provision of services in the subsistence system, ex ante assessments should be undertaken regarding the potential adoption and impacts of animal health and production services (39). To improve the effectiveness, feasibility and sustainability of delivery systems, competing delivery pathways need to be assessed using techniques such as the New Institutional Economics (43) and structure-conduct-performance (69).

**Conclusion**

Smallholder crop/livestock and livestock systems are crucial with respect to contributions to human welfare on a global basis. Large numbers of poor people currently depend, and will continue to depend on these systems for survival. Substantial changes and accelerating intensification of smallholder systems with good market access are being observed, and accompanying this trend, great opportunities for increasing incomes and welfare. For non-market-oriented systems, the challenge will be to ensure sustainability and adaptation in the face of increasing pressures that compromise traditional community and producer resource management strategies. Animal health economics can play an important role in both these situations, to support better farm level decision-making in more intensive systems and to improve understanding of the community and natural resource issues required for more effective animal health and production strategies in more extensive systems.

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Aspects économiques de l’optimisation de l’état sanitaire et de la productivité des systèmes d’élevage à petite échelle dans les pays en développement

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Résumé
Les animaux qui sont gardés ou se multiplient dans des systèmes d’élevage à petite échelle constituent une part importante de l’économie agricole des pays en développement. Leur rôle varie considérablement selon les cas : soit ils servent d’animaux de trait pour l’agriculture, soit ils sont destinés à la consommation domestique ou à la vente dans le cadre de systèmes allant du pastoralisme à des élevages laitiers et d’engraissement intensifs situés en périphérie des villes. Les petites exploitations se distinguent par des conditions et caractéristiques qui leur sont propres, ce dont il faut tenir compte lors de l’évaluation de la gestion de la santé animale dans ce type d’élevages ainsi que lors de l’évaluation des moyens qui peuvent permettre à ces élevages d’améliorer leurs stratégies de prophylaxie. Pour fournir un cadre de discussion sur les questions de santé animale et les méthodes analytiques, les auteurs ont élaboré une typologie des petits systèmes d’élevage et de culture/élevage. Ils classent ainsi les différents systèmes selon leur degré d’intensification, mesuré par leur accès aux marchés et par l’intensité d’utilisation des facteurs de production, mais aussi selon leur importance au sein de l’économie familiale, évaluée d’après leur contribution au revenu du foyer. Les auteurs définissent un certain nombre de caractéristiques qui distinguent ces systèmes de petites exploitations de celui des élevages industriels propres aux pays développés. Cette classification prend notamment en compte la polyvalence des animaux, l’intégration des activités d’élevage, les objectifs multiples des éleveurs et la capacité réduite du foyer à supporter les risques, sans oublier la faiblesse des infrastructures, des marchés et de l’accès à l’information au plan local.

Les auteurs décrivent ensuite en détail trois petits systèmes d’élevage africains représentatifs, faisant ressortir les principales caractéristiques et les conséquences pour l’analyse des stratégies de prophylaxie. Les petits élevages laitiers du Kenya illustrent l’importance du rôle de l’éleveur dans la prise de décision en matière de gestion de la santé animale. Ce type de systèmes intensifs favorise les mécanismes du marché et l’attention y est concentrée sur les risques au niveau de l’élevage et sur les aspects de la prophylaxie qui peuvent être contrôlés par la gestion de la production. Dans les systèmes pastoraux, qui sont encore victimes d’épidémies majeures et où l’infrastructure est faible, la prophylaxie repose principalement sur la gestion au plan local des ressources naturelles, ce qui implique une approche analytique différente. Enfin, dans les systèmes céréaliers, où les animaux sont utilisés aux travaux des champs, l’élevage fait partie intégrante du système de production agricole, ce dont doit tenir compte la méthode de gestion de la santé de ces animaux de trait. Il convient d’élaborer de manière soutenue des méthodes analytiques et des outils d’aide à la décision appliqués aux stratégies de prophylaxie les mieux adaptées aux caractéristiques particulières de ces systèmes, car ceux-ci ne cessant de se développer dans les régions bénéficiant de bons débouchés ; dans les zones moins bien desservies, ces systèmes doivent s’efforcer d’optimiser rapidement la gestion de leurs ressources naturelles.

Mots-clés
Optimización económica de la sanidad y la productividad en minifundios ganaderos de países en desarrollo

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Resumen
El ganado mantenido o criado en sistemas minifundistas es una pieza fundamental de la economía agraria de los países en desarrollo. En esas pequeñas explotaciones el ganado cubre necesidades muy variables, desde la provisión de animales de tiro para la labranza o la producción de subsistencia hasta su venta en el mercado, con sistemas productivos que van del pastoreo extensivo a las granjas periurbanas intensivas de engorde o producción lechera. Los sistemas minifundistas se caracterizan por una serie de rasgos y condiciones singulares, que conviene tener en cuenta a la hora de estudiar las técnicas de gestión zoosanitaria que han ido progresivamente implementando o de valorar el margen existente para mejorar sus métodos de control sanitario.

A fin de disponer de un sistema de referencia para abordar cuestiones de sanidad animal y elaborar métodos para su análisis, los autores construyen una tipología de los sistemas minifundistas pecuarios y agropecuarios. Esa tipología clasifica las explotaciones ganaderas en función de su nivel de intensificación (indicado por la vocación comercial y la intensidad del uso de los factores de producción) y de su importancia dentro de la economía doméstica (que se mide por la contribución a la renta familiar). Los autores apuntan un conjunto de características que distinguen al sistema minifundista de los sistemas industriales propios de los países desarrollados: la atribución de funciones diversas al ganado, el carácter integral de las actividades pecuarias, los objetivos múltiples de los ganaderos y la menor capacidad de la unidad familiar para asumir riesgos, junto a la escasez de infraestructuras, mercados e información a escala de la comunidad.

Después describen en detalle tres ejemplos representativos de los minifundios ganaderos africanos, destacando los rasgos que les son propios y la manera en que inciden en el análisis de sus estrategias de control sanitario. Los sistemas minifundistas de producción lechera de Kenia dejan patente la influencia que tienen las decisiones de cada ganadero sobre la gestión zoosanitaria de este tipo de sistemas intensivos con acceso a mercado, decisiones que se concentran en los riesgos en la propia explotación y a determinados aspectos de control sanitario ligados a la gestión de la producción. En sistemas pastorales extensivos, con elevada incidencia de epidemias y notable escasez de infraestructuras, el control sanitario está ligado básicamente a la gestión de recursos naturales de propiedad comunitaria, aspecto éste que impone un tratamiento analítico distinto. En sistemas agrícolas donde se utilizan animales de tiro, por último, la actividad del ganado es un elemento más de los que integran la producción agraria, hecho que debe incorporarse al método utilizado para evaluar la gestión sanitaria de esos animales. En un momento en que los sistemas minifundistas de zonas con buena salida comercial intensifican sus actividades, y los de zonas más aisladas sufren crecientes presiones para optimizar su gestión de los recursos naturales, se hace necesaria la creación permanente de técnicas analíticas y herramientas de ayuda a la decisión en materia de control sanitario adaptadas a las especiales características de tales sistemas productivos.

Palabras clave
África - Economía - Kenia - Minifundios - Países en desarrollo - Productividad - Sanidad animal.
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