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Bovine brucellosis in Sub-Saharan Africa:
Estimation of sero-prevalence and impact on meat and milk offtake potential

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Preface

This is the eigth of a series of 'Livestock Policy Discussion Papers'. The purpose of the series is to provide up-to-date reviews of topics relating to the livestock sector and its development in various regions of the world. A strong emphasis is placed on the compilation of quantitative information, methodological aspects and on the development of policy recommendations for the topic at hand.

The livestock sector plays a vital role in the economies of many developing countries. It provides food, or more specifically animal protein in human diets, income, employment and possibly foreign exchange. For low income producers, livestock also serve as a store of wealth, provide draught power and organic fertilizer for crop production and a means of transport. Consumption of livestock and livestock products in the developing countries, though starting from a low base, is growing rapidly.

In this study, published literature on the sero-prevalence of brucellosis in cattle in sub-Saharan Africa was subjected to statistical analysis. Few presumed predictor variables, such as production system or region proved to significantly influence sero-prevalence, which was estimated to be 16.2% with a 95% confidence interval ranging from 10.2% to 25.7%. A deterministic herd model was used to estimate additional milk and meat offtake potential that would result from the elimination of brucellosis from the cattle population. The highest potential benefits of brucellosis control were estimated to accrue to the smallholder dairy systems in the East African highlands.

It is hoped that the paper stimulates discussion and any feedback would gratefully be received by the authors and the Livestock Information and Policy Branch of the Animal Production and Health Division of FAO.

Disclaimer

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Keywords

Sub-Saharan Africa; agro-ecological zones; cattle production systems; additional milk and meat offtake; brucellosis; sero-prevalence; meta-analysis

Summary

Data on the serological evidence of brucella infection in cattle populations in sub-Saharan Africa retrieved from published literature was subjected to meta-analysis using binary multiple logistic regression. Production system, region, serological test applied and tested cattle (sub-) population were included as fixed effects in the model. Production system and region were not identified as significant determinants of brucellosis sero-prevalence. Using Rose Bengal type diagnostic tests as the reference test group, average sero-prevalence in the cattle population as a whole was estimated to be 16.2% with a 95% confidence interval ranging from 10.2% to 25.7%. The estimated average sero-prevalence of brucella infection in the cow sub-population was estimated to be 2.48 times higher than the overall average sero-prevalence.

The Livestock Development Planning System model (LDSP2) was used to estimate current and additional milk and meat offtake potential resulting from the elimination of brucellosis in various traditional cattle production systems of SSA and in the smallholder dairy system prevalent in the East African highlands. Additional milk and meat offtake potential was estimated for three levels of sero-prevalence in cows (31.4%, 40.2% and 51.6%), based on publications on the impact of brucella infection on cow fertility and on the mortality risk of calves from infected dams. In order to allow valid comparison between scenarios, herd growth in the brucella-free scenarios was kept identical to that predicted under current conditions and productivity increases were entirely realized as additional offtake.

In the traditional production systems, relative additional milk and meat offtake potential was estimated to lie in the range of 5% to 11% and 12% to 35% respectively for the different scenarios analysed, while for the smallholder dairy system corresponding values were 4% to 7% and 10% to 21%. The highest absolute additional milk offtake potential, however, was obtained in the relatively more intensive smallholder dairy system, where additional offtake potential was estimated at 25.4 to 41.6 kg/cattle/year while in traditional production systems additional milk offtake potential was estimated to lie between 1.3 and 3.7 kg/cattle/year. Estimates of absolute additional meat offtake potential were much less variable and fell in the range between 1.2 and 3.8 kg/cattle/year for all systems investigated, again with the highest values predicted for the smallholder dairy system. Additional income potential for livestock keepers, based on a wide spread of milk and meat prices and assuming that prices for meat and milk remain unchanged after elimination of brucellosis, was estimated to lie in the range of US$2.6 to US$12.9 per cattle and year in the smallholder dairy system and in the range of US$0.70 to US$4.5 per cattle and year in the traditional production systems.

Given that traditional cattle production systems in SSA are low input low output systems, even substantial relative improvements in productivity result in low increments of total production and are thus unlikely to constitute a sufficiently large incentive for livestock keepers to invest in brucellosis control, despite the average benefits outweighing the costs. As the costs of brucellosis control in the traditional production systems are likely to be the same or higher than in the smallholder dairy system while the direct benefits are estimated to be highest in the latter, the smallholder dairy system was identified as the production system for which a more detailed analysis of the costs and benefits of brucellosis control should be carried out.

Human health benefits were not considered in this study and the reduction in human suffering from brucellosis following the reduction or elimination of bovine brucellosis might be a stronger justification for its control in traditional production systems than the associated productivity gains.

Estimates of total additional milk offtake potential for East Africa are very sensitive to assumptions about the proportion of cattle in the highlands kept in the smallholder dairy system.

For any assumed brucellosis sero-prevalence, estimates for East Africa varied by around 50 thousand tons, i.e. 10% to 15%. Overall additional milk offtake potential for East Africa was calculated to lie between 334 and 615 thousand tons/year. Estimates of additional meat offtake potential for East Africa were much less sensitive to assumptions about the prevalence of smallholder dairy cattle (less than 1% difference) and were calculated to lie between 163 and 271 thousand tons/year. For sub-Saharan Africa as a whole, additional milk and meat offtake potential resulting from the elimination of brucellosis was estimated to lie between 481 and 859 thousand tons and between 287 and 478 thousand tons respectively.

Despite many of the limitations in the available data on the prevalence and impact of brucellosis in SSA, this study could show, that the concept of cattle production system is useful for the exploratory analysis of the production impact of endemic diseases within a region. Similar analysis for other diseases might form a basis for decision-makers to identify those diseases, for which detailed studies on the costs and benefits of alternative control strategies should be conducted. Such studies should (a) quantify the distribution of the benefits of the reduced risk of infection within society; and (b) on a regional level, based on economic and epidemiological grounds as well as the regionally available financial and human resources, compare control strategies that can be applied to achieve a defined goal.

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Introduction

Sub-Saharan Africa (SSA) has the world's fastest growing human population coupled with the lowest average annual per capita consumption of livestock products (FAOSTAT, 2002). Growth in livestock production in SSA has barely kept pace with the growth in demand for food of animal origin and annual per capita consumption of meat and milk are estimated to remain low at 9.6 kg and 28.3 kg respectively (FAO, 2002) if current trends of production growth and population increase persist.

More important still, livestock rearing is the principal economic activity supporting livelihoods in the desert, arid grasslands and savannahs, which cover about 14 million km^2, i.e. more than 50%, of the SSA land surface (Chema, 1984). In these areas, the harsh environmental conditions are unsuitable for any other form of agriculture and for the people living in these environments, around one third of the human population of SSA, livestock is the principal currency for social and commercial transactions (McDermott et al., 1999).

In order to increase the availability of livestock products in the SSA, its livestock population has to expand and/or livestock productivity has to be improved. An increase of the ruminant livestock population in SSA, which in 2001 was in the order of 210 million cattle and 368 million small ruminants (FAOSTAT, 2002), would require an increase of feed resources, e.g. in the form of grazing land. However, grazing land is already now under increasing pressure in SSA (Tacher et al., 2000). Sanitary, genetic and nutritional constraints are the three main limitations to increased livestock productivity (Kabagambe et al., 1988). In Kenya, for example, mainly diseases, but also the lack and/or poor artificial insemination services, lack of feeds and problems of provision and delivery of livestock services were found to be the major constraints to cattle production (Emongor et al., 2000).

Within SSA, many of the known infectious diseases occur commonly and are poorly controlled, both in livestock and in human populations. Despite their social and economic importance, public funds raised for the control of infectious diseases, such as brucellosis for example, progressively decreased over the last 20 years (McDermott & Arimi, 2002). Brucellosis is widely spread within African countries (e.g. Chukwu, 1985; Akakpo & Bornarel, 1987; Abbas, 2002) and was considered by the World Health Organisation as being 'responsible for more sickness, misery, and economic loss than any other zoonosis' (Alausa, 1979).

Brucellosis affects domestic and wild animals as well as humans (Charters, 1980). Its public health significance consists, according to Alausa (1979) of two main factors: Firstly the direct or indirect transmission of the disease from infected animals to man, resulting in illness and loss of manpower, and secondly, the serious reduction of much needed animal proteins in human nutrition. This study will focus on the reduction of much needed animal proteins attributable to bovine brucellosis in SSA.

Objective of the study

The objectives of this study were threefold:

- to obtain estimates of the prevalence of bovine brucellosis in cattle in the different production systems in SSA by systematically reviewing published literature on bovine brucellosis in SSA,

- to test a methodological framework for the crude but rapid estimation of production losses attributable to selected diseases as a first step towards more detailed cost-benefit analysis of disease control interventions, and

- to estimate the potential additional beef and milk offtake that might result from the elimination of bovine brucellosis from the various cattle production systems in SSA, using the above framework.

Outline of the paper

The paper is organised in five sections as follows:

- Section 2 – presents a review of bovine brucellosis and production systems in SSA. This section further provides a review of previous studies that estimated the impact of bovine brucellosis in SSA.

- Section 3 – describes the methodology applied to (a) estimate the prevalence of bovine brucellosis, and to (b) estimate the additional beef and milk offtake potential after elimination of brucellosis from SSA cattle populations.

- Section 4 – summarizes the results of the analysis of the retrieved literature on bovine brucellosis in SSA. Further, this section presents the estimated additional beef and milk offtake that might result from the elimination of brucellosis from SSA cattle populations.

- Section 5 – discusses for each of the objectives the applied methodology, the assumptions made and the results obtained. A more general discussion follows. This section ends by presenting the main conclusions.

General background

Bovine brucellosis

Brucellosis is named after Sir David Bruce, who in 1886 isolated the causative agent from a soldier in Malta where the disease caused considerable morbidity and mortality among British military personnel. During the 19th century, brucellosis was thus known as Malta or Mediterranean fever (Charters, 1980). Brucellosis infection is caused by species of the bacterial genus Brucella (Morgan & MacKinnon, 1979; Halling & Young, 1994). There are six different species of Brucella, whereby *Brucella abortus* is the predominant species infecting cattle (Morgan & MacKinnon, 1979). Apart from cattle, goats, sheep, pigs, buffaloes, camels, reindeer and, less frequently, other mammals are affected by brucellosis (Charters, 1980).

Brucellosis is a zoonosis that exists worldwide and is more or less endemic within most countries of Africa (Chukwu, 1985; Anonymous, 1986; Akakpo & Bornarel, 1987; Abbas, 2002). Humans are infected either by direct contact with infected animals or by ingesting contaminated products, mainly unpasteurised dairy products (Charters, 1980; Halling & Young, 1994).

Effects of brucella infection in cattle

Brucella infection in pregnant cows can cause abortion or premature calving. Furthermore, brucella infection can lead to temporary sterility (Ray, 1979), death from acute metritis and decreased milk production (Nuru & Schnurrenberg, 1975). In Africa, infection of cattle with brucella spp. has been reported to result in the formation of hygromas (Pilo-Moron et al., 1979; Domenech et al., 1980b; Akakpo et Bornarel, 1987), but these do not appear to be a consistent feature of infection (Ray, 1979; Charters, 1980; Bloch & Diallo, 1991; Sylla et al., 1982). Akakpo & Bornarel (1987) highlighted that infection does not necessarily lead to clinical signs.

Transmission of bovine brucellosis

Large quantities of the bacteria are excreted with the foetus, the placenta and the uterine fluid, mainly at the time of calving. After abortion or parturition, the organism continues to be excreted mainly via the milk of infected cows (Charters, 1980; DFRA, 2002). According to DFRA (2002), infected breeding bulls can transmit the infection to cows at the time of service via the semen. Apart from direct contact between animals, other sources of infection within and between herds are contaminated water and feed supplies (Morgan & MacKinnon, 1979).

Diagnosis of brucellosis

The diagnosis of brucellosis is confirmed by isolation and identification of the causative organism. However this approach is time-consuming, and the specific tests needed to characterise the bacteria are complicated. In order to be able to screen a large number of animals, the diagnostic tests should be 'inexpensive, easy to perform, rapid, highly sensitive and fairly specific'. Several serological tests have been designed to meet these requirements (Bricker, 2002).

Nielsen (2002) recently produced a comprehensive review of the serological tests for brucellosis that are in common use. Therefore, within this section the most commonly used serological tests are only briefly summarised. Tests that are comparable (similar specificity and sensitivity as well as similar other characteristics) are grouped together. These tests are:

a) Acidified antigen agglutination tests such as the rose-bengal/card test (RBT) and the buffered antigen plate agglutination test. These serological tests are simple to perform, inexpensive and suitable for screening individual animals (Domenech et al., 1980a;

Nielsen, 2002). However, false negative reactions occur. Within the rest of this paper, these tests are referred to as the RBT-tests.

b) Standard agglutination tests (SAT) such as the standard tube agglutination test and the sero-agglutination test of Wright constitute another group of tests that are comparable with each other. In the rest of this paper they are referred as the SAT-tests. According to Nielsen (2002), SAT tests are susceptible to producing false positive reactions.

c) The Complement fixation test (CFT) is another, separate test. The CFT is recommended by the OIE as the test prescribed for international trade (Nielsen, 2002). CFT is often used as a second test for confirmation of RBT-positive sera.

d) Indirect enzyme immunoassays (ELISA) are the fourth serological test group that is often used to determine the prevalence of brucellosis in surveys. Recently developed ELISA tests are, according to Tounkara et al. (1994) highly sensitive, simple to use but expensive. Tounkara et al. (1994) highlighted that the indirect ELISA is more sensitive than RBT tests and have a sensitivity of 100% and a specificity of 84.5%.

e) Milk ring test (MRT) is an adaptation of the agglutination test. This test is used to show if antibodies are present in the milk.

Impact of brucellosis on cattle production

In infected cattle populations brucellosis might lead to a lower calving rate due to temporary infertility and/or abortion, resulting in a decreased milk production cows, increased replacement costs as well as lowered sale value of infected cows (Nuru & Schnurrenberg, 1975). General economic losses, however, go far beyond the financial losses suffered by cattle producers alone. Not only cattle but also other species might be affected by brucellosis, including humans. Chukwu (1987) summarised the economic losses of brucellosis to be:

1) Losses due to abortion in the affected animal population;

2) Diminished milk production, Brucella mastitis and contamination of milk;

3) Cull and condemnation of infected animals due to breeding failure;

4) Endangering animal export trade of a nation;

5) Human brucellosis causing reduced work capacity through sickness of the affected people;

6) Government costs on research and eradication schemes;

7) Losses of financial investments.

Most studies that focussed on brucellosis in African cattle highlight the fact that the control of brucellosis is of economic importance. However, only very few studies were found to have carried out a crude economic analysis to evaluate the impact of bovine brucellosis in traditional cattle systems in SSA, or to evaluate the possible costs of controlling the disease. Esuruoso (1979), for example, conducted a preliminary evaluation of the possible costs and benefits to cattle farmers from controlling brucellosis in Nigeria (1979). The assumptions of this study were based on earlier sero-epidemiological surveys and other investigations done by the same author[1]. However, all those studies were conducted in non-traditional, intensively managed cattle production systems, such as large dairy herds and ranches. Furthermore, those herds were mostly known or at least suspected to be infected with brucellosis (Esuruoso & Van Blake,

[1] Esuruoso & Hill (1971); Esuruoso & Van Blake (1972); and Esuruoso (1974a and 1974b)

1972; Esuruoso, 1974a). For some of the government-owned dairy herds so-called ‘abortion storms’ had been observed (Esuroso & Van Blake, 1972).

Rickin (1988) conducted an economic study of brucellosis control in Nigeria. In his study he used a cost-benefit approach to measure the economic efficiency of a control program and an eradication program for bovine brucellosis. Within this study, the costs of the control program were estimated as well as the additional losses that would result from no intervention. The net present value (NPV), benefit-cost ratio (B/C) and the internal rate of return (IRR) were calculated as measures of economic efficiency. The obtained results were favorable for the control program. However, Rickin (1988) gave no description about the assumptions underlying his cost-benefit calculations.

A few studies investigated and compared the production performance of infected and non-infected cattle herds, or the performance of infected (sero-positive) and non-infected (sero-negative) cows. These studies were mainly done within traditionally kept cattle in SSA. Camus (1980), for example, compared the production performance of brucellosis-infected herds with brucellosis-free herds in the Ivory Coast. Domenech et al. (1982b; 1987) compared the production performance of brucellosis-infected herds with brucellosis-free herds within traditional managed herds in Chad. Finally, McDermott et al. (1987a, b), compared the production performances of sero-negative cows with those of sero-positive cows in the Kongor Rural Council in Sudan.

Camus (1980) compared the production performance of infected herds with non-infected herds, whereby the average sero-prevalence of infection in infected herds was about 35% of the adult female population. The infected herds had a slightly higher incidence of abortions compared with non-infected herds, a slightly higher proportion of calves born dead, a higher calf mortality the first year of life (11.7% and 7.8% respectively) and a lower fertility rate (38% and 41% respectively). According to the cited study the reduced production performance attributed to brucellosis in infected herds resulted in a 10% loss of the annual revenue of cattle farmers.

Domenech et al. (1982a) estimated the calf mortality risk of offspring from sero-negative cows (using the RBT) to be 12.5% as opposed 17% for offspring from sero-positive cows. Based on the observation that in infected herds 30.4% of the cows would be serologically positive, the calculated calf mortality risk in an infected herd was 14% (Domenech et al., 1982b; 1987). They further found that the fertility rate for RBT-negative cows was 63.3% while it was 54.4% for RBT-positive cows, resulting in an overall fertility rate of 60.5% within a brucella-infected herd. According to Domenech et al. (1980b), the formation of lesions in the locomotory system due to brucellosis might cause pain to the affected animals, resulting in a reduction of their ability to move. Within their economic evaluation, Domenech et al. (1982b) took this into consideration by assuming a 7% lower meat price for slaughtered cows from infected herds. However, for males they did not consider any production losses based on the argument that Domenech et al. (1980b) had found hygromas in 9.5% of all sero-positive cows, whereas only 1 out of 1,000 sero-positive male animals had shown lesions. In their earlier study, Domenech et al. (1980b) also reported, that from 1,000 sero-positive cows about 12.7% had shown at least one typical sign of brucellosis during the last 5 years. 5.4% of the sero-positive cows had aborted at least once and 3.3% had shown a temporary sterility.

In a later study, Domenech (1987) estimated a 6% reduction of the net revenue per animal per year due to brucellosis, assuming a within-herd infection rate of 20%. According to Domenech (1987) the main losses resulted from decreased meat production. This study was based on earlier published studies, mainly Domenech et al. (1980b, 1982a, and 1982b).

In Sudan, McDermott et al. (1987 b) estimated that sero-positive cows produced on average 10% less calves than sero-negative cows. Other findings were that RBT-positive cows had a higher abortion rate, 34.9%, compared to 15.7% in RBT-negative cows. Furthermore, RBT-positive cows had hygromas twice as often as RBT-negative cows (22.1 % versus 10.6 %.)

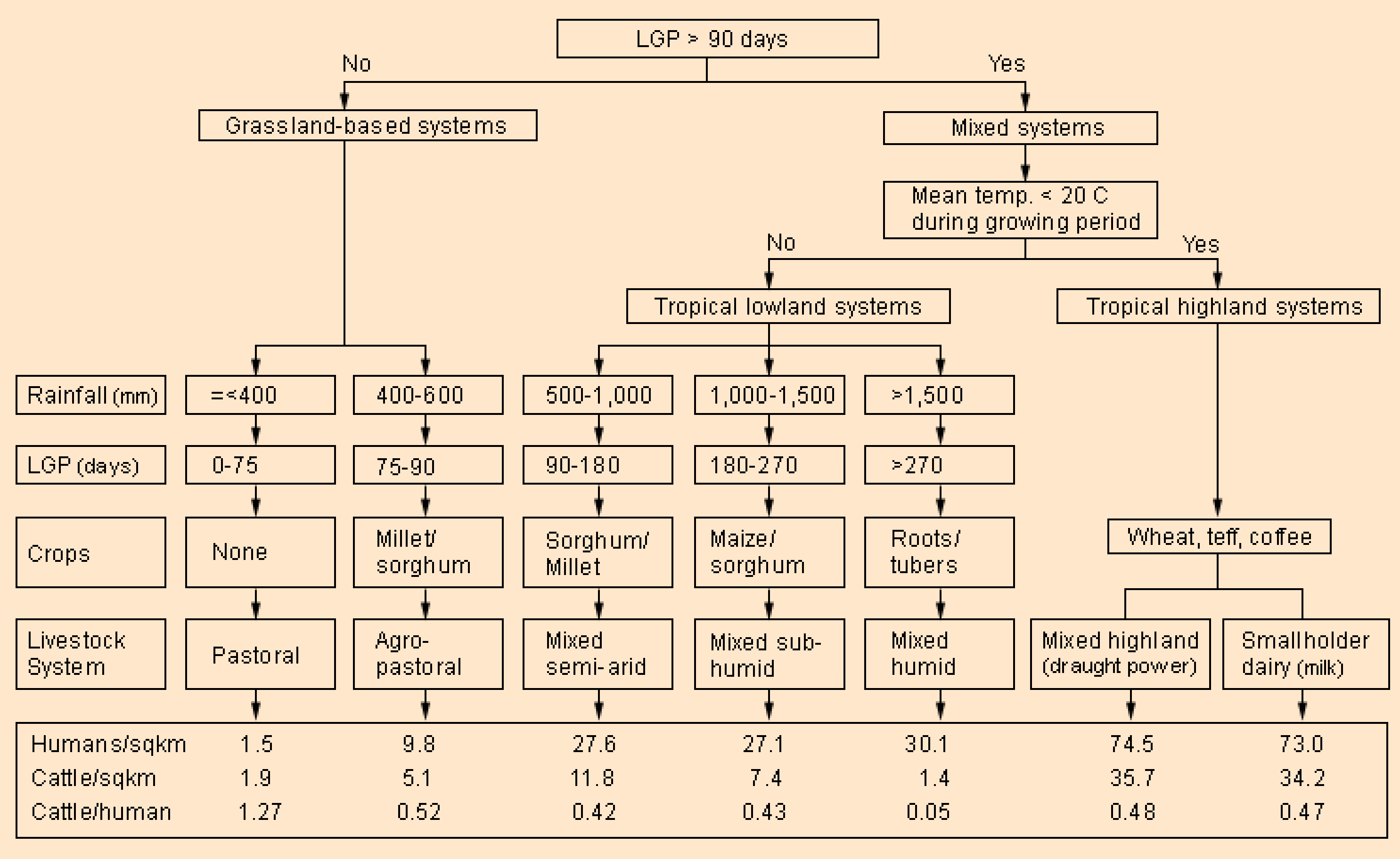
Cattle production systems in SSA

Density of animal populations, herd size and management, as well as environmental factors are thought to be important determinants of the infection dynamics within and between herds (Domenech et al., 1980b; Akakpo & Bornarel, 1987; Omer et al., 2000b). A hypothesis of this study was that the prevalence of brucellosis would be different between cattle production systems n SSA.

Cattle production systems can be defined using a variety of criteria. For this study the cattle production systems as defined for SSA by Otte and Chilonda (2002), based on Seré and Steinfeld (1996) were used. In SSA most cattle (more than 90%) are still kept in traditional production systems, with each of the traditional cattle production systems being closely linked to specific agro-ecological zones (AEZ) within which they constitute the predominant livestock system. Descriptors of these cattle production systems are the length of growing period (LGP), rainfall, crops planted and mean temperature (see Figure 2.1 for more details). Traditional cattle production systems in the lowlands can be classified as: pastoral; agro-pastoral and mixed systems (semi-arid, sub-humid and humid). In the Ethiopian highlands the predominant form is the mixed highland system, while in the Kenyan, the Tanzanian and the Ugandan highlands most cattle are kept in smallholder dairy systems. However, the smallholder dairy system is less well developed in the Uganda and Tanzania highlands than in the Kenyan highlands (Otte and Chilonda, 2002). Figure 2.2 shows the geographical distribution of the main livestock systems in SSA.

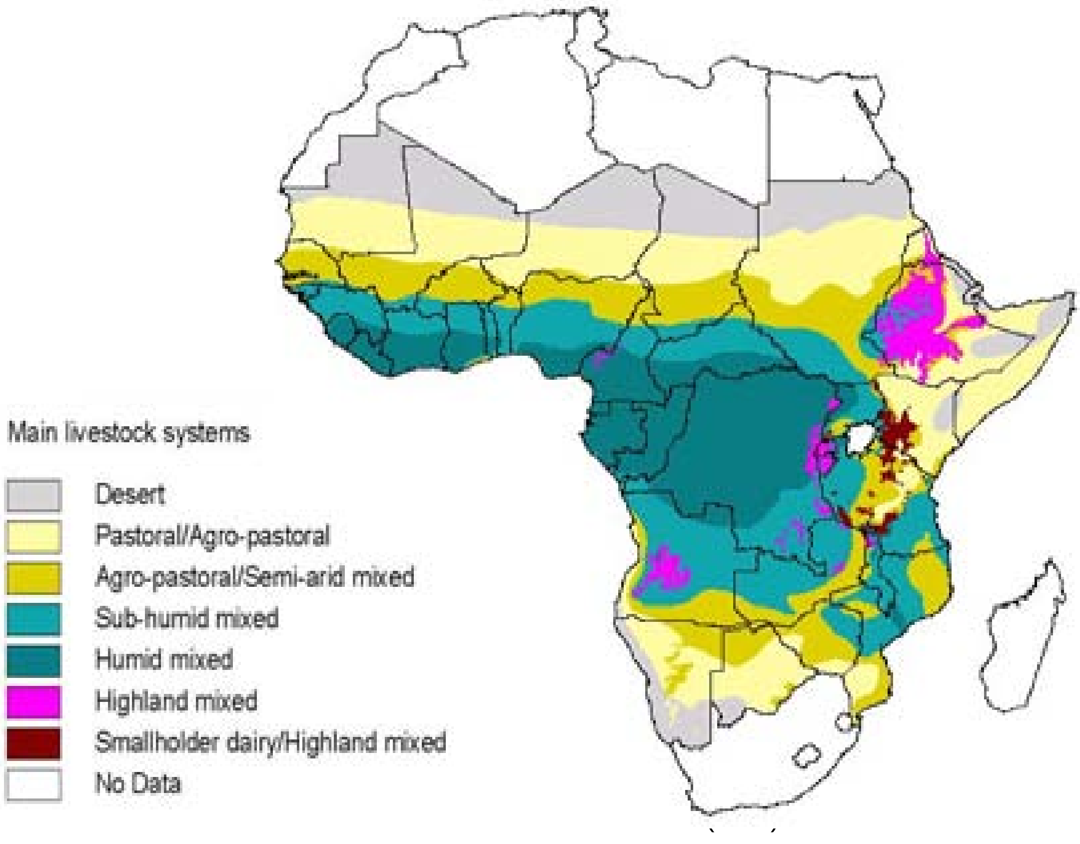
Ranching and commercial dairy systems are classified as non-traditional production systems. Ranching systems consist of labour-extensive enterprises that are specialised in one or more livestock species. Ranches and commercial dairy systems generally have improved herd, pasture and water management.

Figure 1 Classification of traditional ruminant production systems in sub-Saharan Africa



Source: Otte & Chilonda (2002)

Figure 2.2 Estimated geographical distribution of the main livestock systems in SSA.



Methodology

Estimation of sero-prevalence of bovine brucellosis in SSA

Data sources

For the literature review, published studies on the prevalence and incidence of brucellosis in cattle populations in SSA, from 1970 onwards, were retrieved by using Medline, Agris, Agricola and CAB. Furthermore, the lists of references in the retrieved articles, especially of review articles focusing on brucellosis in African cattle populations, were used to identify additional studies. Unfortunately not all identified studies could be obtained. Grey literature, if known and available was also included in the literature review.

Dataset for meta-analysis

A dataset containing the following information for all population sub-groups included in each of the retrieved studies was created in EXCEL: country, production system (following Otte and Chilonda, 2002), study type[2], number and type of animals sampled, test(s) applied, test results, year of study and author. The list and summary of all retrieved studies (86) is presented in Annex 1. Study types, selection of animals, test protocols etc were very variable between studies. In order to reduce the potential sources of variation between study results, studies included in the final data set, on which a meta-analysis was applied were restricted to:

- Sero-epidemiological field surveys,
- carried out on traditionally managed cattle kept either in pastoral and agro-pastoral systems; mixed lowland systems; mixed highlands; or in smallholder dairy systems were included, and
- carried out on non-vaccinated cattle populations or cattle populations with a known poor vaccination coverage,
- with a known number of sampled and positively tested animals.

These restrictions resulted in a data set of 217 records from 44[3] different references. (See Annex 1)

Meta-analysis of brucellosis sero-prevalence

A binary, multiple logistic regression analysis (STATA 7.0, Statistics Data Analysis, version 7.0) was used to estimate the brucellosis sero-prevalence for the different cattle production systems. A backward elimination process was used to identify the main determinants of brucellosis sero-prevalence, the initial model containing the following variables: production system, sampled animal group, serological test used, and region.

The variable 'sampled animal population group' was introduced to reflect the fact that a significant increase in sero-positivity of the sampled animals was found with increasing age (Domenech et al., 1980a; Akakpo & Bornarel, 1987; Turkson & Boadu, 1992; Maiga et al., 1995; Ocholi et al., 1996; Kubuafor et al., 2000), whereas, no difference was found in field surveys between males and females of the same age category (Akakpo & Bornarel, 1987; Turkson & Boadu, 1992; Ocholi et al., 1996; Kubuafor et al., 2000). The variable 'sampled animal population group' was recorded for each record as follows:

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[2] Cross-sectional survey, slaughterhouse study, etc

[3] Sometimes results of the same sero-survey of bovine brucellosis were presented in different papers, only one reference relating to a particular survey was included in the analysis.

- entire cattle population, calves, youngstock and adults, sampled (including studies limited to entire female population[4]);
- only the adult cattle population, males and females, sampled;
- only adult females, i.e. cows, sampled; or
- sampled cattle group not defined.

Differences in the sensitivity and specificity of the serological tests used are one important factor that might have contributed to the variation in the obtained sero-prevalence of brucella infection. In order to account for the possible effect of the different tests on the obtained brucellosis sero-prevalence, 'test' was included as a variable in the model. This variable indicated for each record the applied test group. The serological test groups distinguished were:

- ELISA;
- RBT plus an additional test for confirmation (mostly CFT);
- SAT plus an additional test for confirmation;
- CFT;
- RBT;
- SAT; and
- serological diagnostic test not specified.

The RBT-tested animals were used as reference group as the RBT was the most frequently used serological test and because the estimates of the impact of brucella infection on production were based on studies using RBT type tests.

Estimation of additional production potential under different scenarios

Production modeling with LDPS2

Production performances of the different cattle production systems under different scenarios were estimated using the Livestock Development Planning System version 2 (LDPS2). LDPS2 is a multi-period, deterministic quantitative livestock model, developed by Lalonde & Sukigara (1997). Similar to the study conducted by Otte & Chilonda (2002) the herd growth routine of LDPS2 was applied to model the production performances of brucellosis-infected and brucellosis-free cattle populations in the various traditional cattle production systems and the smallholder dairy system of SSA. The herd growth routine 'traces the expansion of a herd from a given base year over time and simultaneously estimates offtake (meat, milk, hides and skins), herd composition and feed requirements.

Baseline production parameters and herd composition for cattle production systems under study were mainly taken from the systematic literature review of Otte & Chilonda (2002), except where otherwise stated. According to Upton (1989) comparisons between scenarios are only valid if they are made under standard conditions. In order to have standard conditions for a comparison of different scenarios, herd size, the number of cows and herd growth rate within each cattle production system were maintained for all modeled scenarios by increasing offtake parameters. LDPS2 was run for 10 years, but only the base year was used to compare the baseline scenario with alternative scenarios.

[4] There were less than 10 records where only females of all age categories were tested. These were therefore considered together with the records where the whole cattle population was sampled.

Assumptions on the impact of brucellosis on cattle performance

This study only considered impacts of brucella infection on cattle performance for which some quantitative estimates were available. For example, as described previously, some studies mentioned that brucellosis infection might result in weight loss or in a reduction of the meat quality. However, as none of the retrieved studies provided quantitative estimates of this 'weight loss' or the possible 'reduction in beef quality' these potential effects of brucellosis were not considered. Neither was it possible to find any estimate on the reduction of milk production attributable to brucella infection in SSA, nor was any information on the possible reduction of work days of draught animals available. Therefore, only the impact of brucellosis on overall herd fertility as well as its impact on overall calf mortality from birth to one year were taken into account.

Camus (1980) and Domenech et al. (1982b) both obtained a difference in the fertility rate of RBT-negative cows and RBT-positive cows of about 9%. Based on the above studies it was assumed that RBT-positive cows would have a 10% lower fertility rate than RBT-negative cows. To estimate the overall herd fertility rate (FR_i) in a brucellosis-free scenario, the following formula was applied:

$$\mathbf{FR_i = (a_i*x) + (b_i*y)}$$

Where: FR_i is the overall herd fertility rate for scenario i;

a_i is the percentage of sero-negative cows for scenario i, whereby $a_i = (1 – b_i)$;

b_i is the percentage of sero-positive cows for scenario i, whereby $b_i = (1 – a_i)$;

i = 0 (baseline scenario) or 1 (brucellosis free scenario);

x is the fertility rate of sero-negative cows;

y is the fertility rate of sero-positive cows; whereby it was assumed that y = (x – 10)

Furthermore, both Camus (1980) and Domenech et al. (1982b) found a higher mortality risk for calves from RBT-positive cows compared to calves from RBT-negative cows. The differences in mortality risk observed in the two studies however varied considerably. Domenech et al. (1982b, 1987) estimated a difference in the calf mortality risk of 5% between the two groups, whereas Camus (1980) estimated a difference in mortality risk of about 12%. To take both studies into consideration, two alternative scenarios were modeled. For alternative 1 it was assumed that difference in the calf mortality risk between offspring from sero-positive and sero-negative cows would be 5%, whereas for alternative 2 it was assumed that the difference in calf mortality risk would 10%. To estimate the overall herd calf mortality risk (CMR_i) in a brucellosis-free scenario, the following formula was applied:

$$\mathbf{CMR_i = (a_i*z) - (b_i*v)}$$

Where: CMR_i is the overall herd calf mortality risk for scenario i;

a_i is the percentage of sero-negative cows for scenario i, whereby $a_i = (1 – b_i)$;

b_i is the percentage of sero-positive cows for scenario i, whereby $b_i = (1 – a_i)$;

i = 0 (baseline scenario) or 1 (brucellosis free scenario);

z is the mortality risk of calves from sero-negative cows;

v is the mortality risk of calves from sero-positive cows; whereby it was assumed for Alternative 1 that v = z + 5 and for Alternative 2 that v = z + 10.

Brucellosis prevalences in baseline scenarios

In the baseline scenarios brucellosis was assumed to be endemic and the production parameters, as shown in Annex 2, were used to estimate the milk and meat offtake for the different cattle production systems under study.

In order to take into account the uncertainty surrounding the estimated most likely brucellosis sero-prevalence, three levels of prevalence were assumed in the baseline scenarios against which to compare the alternative scenario of brucellosis freedom. The binary logistic regression model used to obtain an estimate of the sero-prevalence of brucellosis in SSA cattle, provides a point estimator with a lower and an upper 95% confidence limit. The three baseline scenarios were intended to encompass different possible brucellosis prevalence levels in SSA cows, which were:

- equal to the predicted brucellosis sero-prevalence, or,
- equal to the lower confidence limit (best case scenario), or,
- equal to the upper confidence limit (worst case scenario).

These sero-prevalence estimates were then used to calculate three adjusted fertility rates and calf mortality risks using the above formulae assuming total elimination of brucella infection, i.e. reduction of sero-prevalence to 0, for each of the production systems modelled. All remaining production parameters, except for years in the breeding herd for cows, years in the replacement herd for heifers, and in some cases years to slaughter for other stock[5], were left unaltered.

Estimation of additional milk and meat offtake potential of SSA cattle

For each cattle production system under study, the calculated milk and meat offtake in the baseline scenario was compared with the calculated milk and meat offtake for the different alternative scenarios. Given the base year, the difference obtained between the base scenario and the different alternative scenarios, holding herd size and the number of cows constant, was taken to represent the additional milk and meat offtake potential.

Based on bovine density maps (Wint et al., 1999) and livestock systems distribution maps (Otte & Chilonda, 2002), the cattle population in each cattle production systems within each region (East, West, Centre and Southern SSA) were estimated for 1994 (see Annex 3). Assuming that the cattle distribution in 1999 was roughly the same as in 1994, the cattle population in the different cattle production systems within the four regions was calculated for 1999 (FAOSTAT, 2000). Using the earlier calculated additional milk and meat offtake/cattle/year for the various cattle production systems, the total additional milk and meat offtake potential/year for the whole SSA region and the four sub-regions was calculated.

The smallholder dairy system is the most intensified of the cattle production system included in the study. This production system is mainly found in the Kenyan highlands, but also to a lesser extent in the Tanzanian and the Uganda highlands. It is, however, more prevalent in the Kenyan highlands than in the highlands of Uganda and Tanzania (Otte & Chilonda, 2002). Furthermore, not all cattle in the Kenyan, Ugandan and Tanzanian highlands are kept in smallholder dairy systems, some being kept in mixed highland systems. To take this uncertainty into consideration, two different calculations were made based on extreme assumptions about the percentage of cattle kept in smallholder dairy systems versus mixed highland systems in Kenya, Tanzania and Uganda. The first calculation was based on the assumption that 70% of

[5] For the traditional cattle production systems it was mainly 'years that cows were kept in the breeding herd', which were adjusted downwards (mostly by more than 2 years), whereas 'years in the replacement herd' for heifers, and, if appropriate, 'years to slaughter' for other stock was only slightly adjusted, whereby even in the most extreme case iadjustment was by less then 1 year.

the cattle in the Kenyan, Ugandan and Tanzanian highlands would be kept in the smallholder dairy system and the remaining 30% of the cattle in the mixed highland system while the second calculation was based on the assumption that that 90% of the cattle in the Kenyan, Ugandan and Tanzanian highlands would be kept in the smallholder dairy system and only 10% of the cattle would be kept in the mixed highland system. The real situation, however, is expected to fall somewhere in between.

The geographical distribution of estimated additional milk and meat offtake potential/year/km^2 were estimated with the help of ArcView and by using bovine density maps (Wint et al., 1999), livestock systems distribution maps (Otte & Chilonda, 2002) and the estimated additional milk offtake potential/cattle/year, respectively the additional meat offtake potential/cattle/year.

Financial benefits of additional meat and milk production

Under the assumption that prices for meat and milk would stay constant and no additional costs were be incurred, the 'additional potential income for farmers' that might result from a brucellosis-free status was calculated by multiplying the additional milk and meat offtake with the corresponding producer prices. This is obviously a very simplified financial assessment, but the obtained figures might be useful for a preliminary evaluation of whether or not any intervention to control brucellosis might prove to be cost-effective.

Based on price series from FAO (2002) the Uganda on-farm beef and milk prices for 2000 were obtained. They were 0.92US$/kg beef and 0.14US$/kg milk. However, producer prices vary considerably within SSA and therefore the additional income was calculated for each scenario by using a base producer price (Uganda prices of 2000), a low producer price (50% of the base) and a high producer price (150% of the base). The total additional potential income for SSA and the four sub-regions, under the assumption of the elimination of brucellosis, was estimated as described previously. The geographical distribution of the 'additional potential income for farmers' in US$ per km^2 was estimated using ArcView and the available bovine density maps (Wint et al., 1999) and livestock systems distribution maps (Otte & Chilonda, 2002).

Results

Estimated sero-prevalence of bovine brucellosis in SSA

The retrieved literature on the prevalence of bovine brucellosis in SSA countries is summarised in Annex 1. For each retrieved study, the country; the cattle production system(s); the number of animals sampled; the overall prevalence of brucellosis, as well as the lowest and highest brucellosis prevalence in different sub-groups, if given; the test(s) applied, and the source reference(s) are listed. Furthermore, Annex 1 shows if the study was included in the final data set used for estimating the sero-prevalence of brucellosis in SSA cattle.

The age and sex group of cattle sampled as well as the applied serological test were both found to be significant in the binary logistic regression model, and were therefore included in the final model for the estimation of the sero-prevalence of brucellosis in the entire cattle population, as well as for the estimation of the sero-prevalence of brucellosis in the cow population of SSA. The results of the model are summarised in Table 4.1. Although, the hypothesis was that the cattle production system might be an important factor to explain variation in brucellosis sero-prevalence, none of the cattle production systems included in the study was found to have a sero-prevalence significantly different from that in other systems.

The estimated most likely brucellosis sero-prevalence, using a test from the RBT-group, was 16.2% for the cattle population as a whole and 40.2% for the cow population. Although, it was expected that in a cow population a higher brucellosis prevalence would be obtained, a predicted brucellosis prevalence in cows, which was about 2.48 times higher than within the whole cattle population might be rather on the upper side.

Table 4.1 Estimated brucellosis sero-prevalence in the cattle population as a whole and in the cow population of SSA, using the RBT-group as a diagnostic test.

Brucellosis Sero-Prevalence	Cattle Population (%)	Cow Population (%)
Most likely value	16.2	40.2
Lower 95% confidence limit	10.2	31.4
Upper 95% confidence limit	25.7	51.6

Estimated additional milk and meat offtake potential from brucellosis-free cattle

Estimated changes in fertility rate and calf mortality risk

The fertility rate and the calf mortality risk for the alternative scenario of brucellosis freedom were calculated using the formulae described previously and the estimated most likely brucellosis sero-prevalence for cows, as presented in table 4.1, and its 95% confidence limits. The new, estimated fertility rates and two alternatives for the change in calf mortality risks for the different production systems are presented in Table 4.2. All other production parameters are summarised in Annex 2.

Table 4.2 Estimated fertility rates and calf mortality risks for six cattle production systems for the baseline and the alternative scenarios

Scenario	Cattle Production System: Pastoral	Mixed semi-arid	Mixed sub humid	Mixed humid	Mixed highland	Smallholder dairy
	Fertility rate (%)					
Baseline[1]	58.0	58.0	61.0	59.9	43.6	73.7
Scenario I & II						
lower c.l.	61.1	61.1	64.1	63.0	46.7	76.9
most likely	62.0	62.0	65.0	63.9	47.6	77.7
upper c.l.	63.2	63.2	66.2	65.1	48.8	78.9
	Calf mortality risk (%)					
Baseline[1]	23.5	21.0	21.9	17.0	21.7	9.8/9.5[2]
Scenario I						
lower c.l.	21.9	19.4	20.3	15.4	20.1	8.2/7.9[2]
most likely	21.5	19.0	19.9	15.0	19.7	7.7/7.5[2]
upper c.l.	20.9	18.4	19.3	14.4	19.1	7.2/6.9[2]
Scenario II						
lower c.l.	20.4	17.9	18.8	13.9	18.6	6.6/6.4[2]
most likely	19.5	17.0	17.9	13.0	17.7	5.7/5.5[2]
upper c.i.	18.3	15.8	16.7	11.8	16.5	4.6/4.3[2]

[1] Source: Otte & Chilonda (2002)
[2] Female calf mortality rate (%) / Male calf mortality rate (%).

Estimated additional milk and meat offtake potential

The current and the estimated additional milk offtake/cattle/year (in kg and in relative values) that might be obtained from a brucellosis-free SSA cattle population are presented in Table 4.3 for the six cattle production systems modelled, while Table 4.4 shows the current and estimated additional meat offtake potential/cattle/year (in kg and in relative values) that might be obtained by a brucellosis-free status for the six cattle production systems. Although both tables are self-explanatory, the fact that the slightly more intensively managed smallholder dairy system would benefit considerably more from a brucellosis-free situation than any of the traditionally managed cattle production systems under study should be highlighted. For the smallholder dairy system, the calculated additional milk offtake (kg/cattle/year) was more than 10 times higher than the calculated additional milk offtake (kg/cattle/year) for any of the other cattle production systems under study. The additional meat offtake (kg/cattle/year), however, was found to be similar throughout all cattle production systems under study. The mixed highland system was predicted to obtain the lowest additional meat offtake (kg/cattle/year) while the smallholder dairy system would obtain the highest additional meat offtake (kg/cattle/year).

As in the LDPS2 model milk offtake potential is strongly driven by cattle fertility, the estimated additional milk offtake potential/cattle/year was comparable for both alternative scenarios of high and low brucella-specific calf mortality. The estimated additional meat offtake potential/cattle/year was slightly higher for alternative scenario 2 (high brucella-specific calf mortality) than for alternative scenario 1. For simplicity, however, only results of alternative scenario 1 are presented in the rest of this section. Results estimated for alternative scenario 2 are presented in the Appendices.

Table 4.3 LDPS2 estimates of current and additional milk offtake potential/cattle/year by eliminating brucellosis in different cattle production systems of SSA

Production system	Current Offtake[1]	Absolute Additional Milk Offtake[1] (Scenario I)[3]			Relative Additional Milk Offtake[2] (Scenario I)		
		Lower c.l.	Most likely	Upper c.l.	Lower c.l.	Most likely	Upper c.l.
Smallholder dairy	599.7	25.4	32.2	41.6	104	105	107
Mixed highland	24.8	1.6	2.1	2.7	107	108	111
Pastoral	41.4	2.2	2.8	3.7	105	107	109
Mixed semi-arid	40.4	2.2	2.8	3.6	105	107	109
Mixed sub-humid	26.4	1.3	1.7	2.2	105	107	108
Mixed humid[4]	25.5	1.3	1.7	2.2	105	107	109

[1] kg/cattle/year, [2] base = 100
[3] The estimated additional milk offtake potential/cattle head/year in alternative scenario 1 was more or less similar to those obtained in alternative scenario II. Therefore only alternative scenario 1was presented here.
[4] In mixed humid cattle production system heavier cattle breeds are used in East and Southern Africa than in West and Central Africa. The milk offtake/cattle, however is similar in both breed types (Otte & Chilonda, 2002).

Table 4.4 LDPS2 estimates of current and additional meat offtake potential per animal by eliminating brucellosis in different production systems of SSA

Production System	Current Offtake[1]	Absolute Additional Meat Offtake (kg/cattle/year)			Relative Additional Meat Offtake (base = 100)		
		Lower c.l.	Most likely	Upper c.l.	Lower c.l.	Most likely	Upper c.l.
Scenario I							
Smallholder dairy	18.3	1.8	2.3	3.0	110	113	116
Mixed highland	6.8	1.2	1.5	1.9	117	122	128
Pastoral	11.8	1.6	2.0	2.7	114	117	122
Mixed semi-arid	10.9	1.6	2.1	2.6	115	119	124
Mixed sub-humid	12.1	1.5	2.0	2.6	1113	117	121
Mixed humid (East)[1]	13.2	1.6	2.1	2.7	112	116	121
Mixed humid (West)[1]	11.5	1.4	1.8	2.4	112	116	121
Scenario II							
Smallholder dairy	18.3	2.3	3.0	3.8	113	116	121
Mixed highland	6.8	1.4	1.8	2.3	121	127	135
Pastoral	11.8	2.0	2.6	3.4	117	122	129
Mixed semi-arid	10.9	2.0	2.6	3.4	119	124	131
Mixed sub-humid	12.1	2.0	2.6	3.3	116	121	127
Mixed humid (East)	13.2	2.0	2.6	3.4	116	120	126
Mixed humid (West)[1]	11.5	1.8	2.3	3.0	115	120	126

[1] kg/cattle/year

Table 4.5 shows the current and, for alternative scenario 1, the additional milk and meat offtake in kg/cattle/year for SSA as a whole and for the sub-regions of West, Central, East and Southern Africa respectively, while Table 4.6 summarises the current and additional milk and meat offtake potential in kg/year which would accrue to SSA as a whole and to the four sub regions. The current and additional milk and meat offtake in kg/capita/year, based on the SSA human population of 1999 (FAOSTAT, 2002), are shown in Table 4.7.

In the case of East African highlands, it was assumed that all the cattle in Ethiopia are kept in mixed highland systems, while for the highlands of Kenya, Tanzania and Uganda, it was assumed that 70% are kept in smallholder dairy systems with the remainder in mixed highland systems. The latter may be an underestimation for Kenya and an overestimation for Tanzania and Uganda, which have less developed smallholder dairy systems.

Table 4.5 LDPS2 estimates of current and additional milk and meat offtake potential (kg) per animal and year by elimination of brucellosis for West, Central East and Southern Africa and SSA as a (Scenario I, low brucella-specific calf mortality) [2]

Region	Milk offtake (kg/cattle/year)				Meat offtake (kg/cattle/year)			
	Current	Additional offtake			Current	Additional offtake		
		Lower c.l.	Most likely	Upper c.l.		Lower c.l.	Most likely	Upper c.l.
Central Africa	28.0	1.4	1.9	2.4	11.5	1.5	1.9	2.5
East Africa[1]	60.7	3.0	3.8	5.0	10.4	1.5	1.9	2.4
West Africa	35.5	1.9	2.4	3.1	11.4	1.6	2.0	2.6
Southern Africa	35.7	1.9	2.4	3.2	11.4	1.6	2.0	2.6
SSA[1]	49.8	2.5	3.2	4.2	10.8	1.5	1.9	2.5

[1] It was assumed that 70% of the cattle in the Kenyan, Ugandan and Tanzanian highlands are kept in smallholder dairy systems and 30% in mixed highland systems.
[2] Full details of the obtained results for alternative scenarios I and II are shown in Annex4.

East Africa would obtain the highest increase in milk offtake potential per animal from the elimination brucellosis, which is not surprising given the relatively wide distribution of smallholder dairy, while the increase in meat offtake potential is fairly similar across regions.

Table 4.6 Current and estimated total additional milk and meat offtake potential (in thousand tons/year) by elimination of brucellosis for West, Central East and Southern Africa and SSA as a whole (Scenario I, low brucella-specific calf mortality) [2]

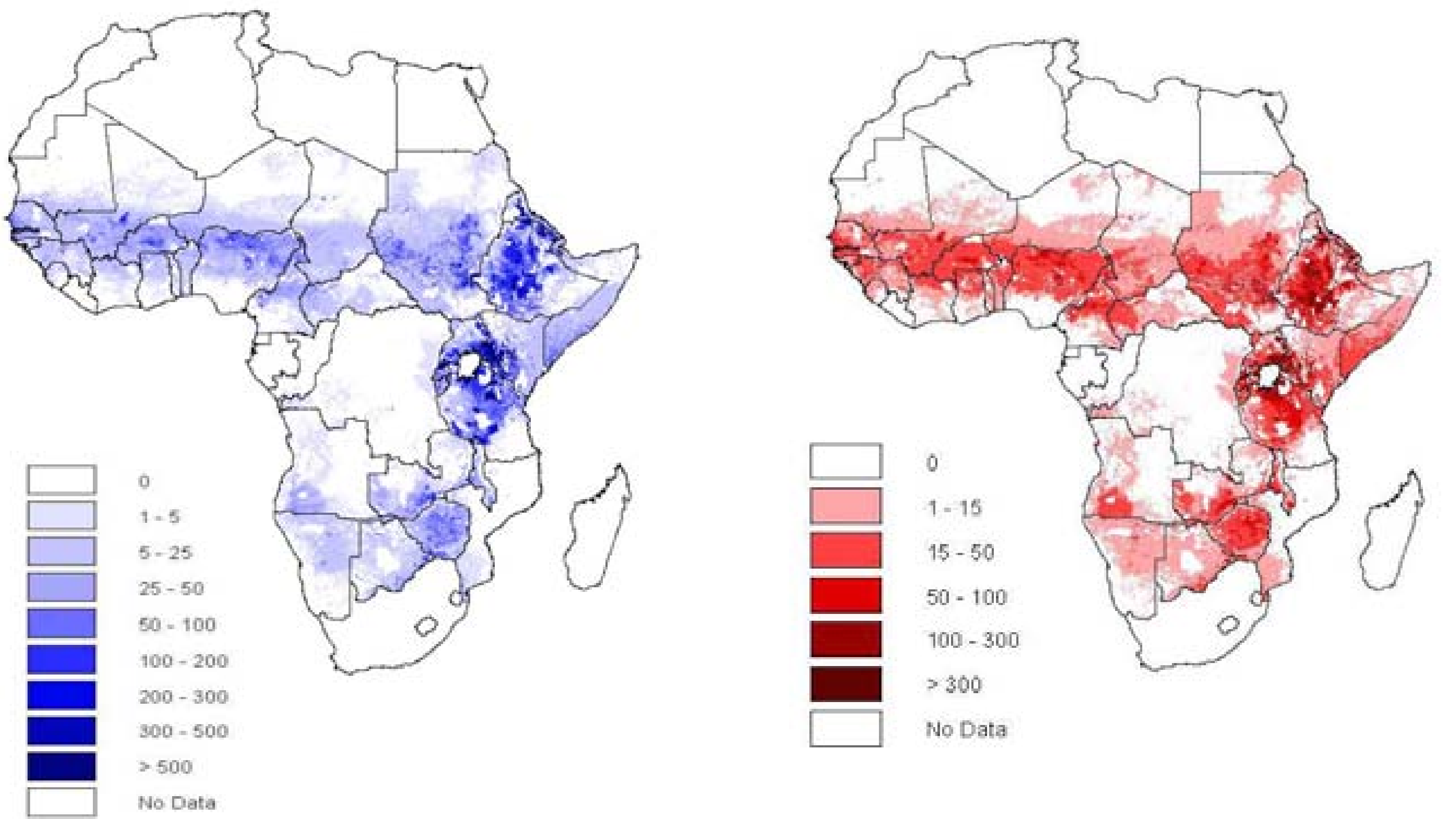
Region	Milk offtake (thousand tons/year)				Meat offtake (thousand tons/year)			
	Current	Additional			Current	Additional		
		Lower c.l.	Most likely	Upper c.l.		Lower c.l.	Most likely	Upper c.l.
Central Africa	276	14	19	24	113	14	19	24
East Africa[1]	6,763	334	427	554	1,154	163	209	269
West Africa	1,794	94	122	158	577	79	103	132
Southern Africa	700	37	48	62	222	31	40	51
SSA[1]	9,532	481	616	798	2,067	287	371	476

[1] Same notes as for Table 4.5.
[2] Full details of the obtained results for alternative scenarios I and II are shown in Annex4.

Table 4.6 shows that East Africa as a region would obtain the largest total amount of additional milk and meat offtake potential from the elimination of brucellosis from its cattle population. This is not surprising as around 60% of all SSA cattle are kept in this region and as, the highlands of Kenya, Uganda and Tanzania, where the predominant cattle production system is the smallholder dairy system, also falls also within this region. Although, the cattle populations in the highlands of Kenya, Uganda and Tanzania represent only about 4% of the total SSA cattle population, the elimination of brucellosis, assuming that 90% (rather than 70%) of the cattle in this region are kept in smallholder dairy systems, is estimated to result in an additional 40 to 50 thousand tons of milk. Despite the relative low proportion of all cattle in SSA kept in smallholder dairy systems, it is estimated that 29% (assuming 70% of the cattle in tropical highlands of Kenya, Uganda and Tanzania are kept in smallholder dairy systems) to 35% (assuming 90% of the cattle in tropical highlands of Kenya, Uganda and Tanzania are kept in smallholder dairy systems) of the total additional milk offtake potential in SSA resulting from the elimination of brucellosis would accrue to the smallholder dairy systems.

For the estimation of the geographical distribution of additional milk and meat offtake potential (kg/km^2) in SSA (Figures 4.1 and 4.2 respectively), it was assumed, for the sake of simplicity, that all cattle in the Kenyan, Tanzanian and Ugandan highlands are kept in smallholder dairy systems whereas all cattle in the Ethiopian highlands are assumed to be kept in mixed highland cattle production systems. Except for the smallholder dairy system all cattle production systems considered had very similar additional milk and meat offtake potential resulting from the elimination of brucellosis. Therefore, the additional milk and meat offtake potential per area (kg per km^2) is strongly related to the cattle density, apart from the Kenyan, Tanzanian and Ugandan highlands, where the smallholder dairy system is the predominant cattle production system.

Figure 4.1 Estimated additional milk and meat offtake potential (kg) per km² resulting from the elimination of brucellosis in Sub-Saharan Africa, (most likely prevalence, low brucella-specific calf mortality)



Additional milk offtake (kg) per km²

Additional meat offtake (kg) per km²

Estimated additional income potential for farmers

This estimation of additional income potential for farmers from the elimination of brucellosis has to be regarded as very preliminary, whereby the main assumption was that the milk and the meat prices used remained unchanged, despite an increase in milk and meat supply. Furthermore, no costs for brucellosis elimination were considered, whereby the estimate of additional income potential may be regarded as an indication of the level of investment in brucellosis control which might be acceptable to farmers. The additional income potential for farmers resulting from the elimination of brucellosis was obtained by multiplying the additional annual milk and meat offtake, as given in Tables 4.3 and 4.4, with the corresponding producer prices. As producer prices vary considerably throughout SSA (as well as seasonally), three different price levels per kg milk and meat were assumed. The so-obtained estimates of additional income potential for farmers on a per cattle basis are presented in Table 4.7 for the six production systems under investigation for Scenario I (low brucella-specific calf mortality) and three different assumed brucellosis prevalence levels. The results for Scenario II are shown in Annex 5.

Table 4.7 Current and estimated additional income potential (US$/cattle/year) by elimination of brucellosis for six cattle production systems in SSA (low brucella specific calf mortality, three assumed brucellosis prevalence levels and three producer prices)

Production System	Current income (US$/cattle/year)			Additional Income Potential (US$/cattle/year)								
Prevalence				Lower c.l.			Most likely value			Higher c.l.		
Price	low[1]	base[2]	high[3]	low	base	high	low	base	high	low	base	high
Smallholder dairy	50.4	100.8	151.2	2.6	3.3	4.3	5.2	6.6	8.6	7.8	9.9	12.9
Mixed highland	4.9	9.7	14.6	0.7	0.8	1.1	1.3	1.7	2.1	2.0	2.5	3.2
Pastoral	8.3	16.7	25.0	0.9	1.1	1.5	1.8	2.2	3.0	2.7	3.3	4.5
Mixed semi-arid	7.8	15.6	23.5	0.9	1.2	1.4	1.8	2.3	2.9	2.7	3.5	4.3
Mixed sub-humid	7.4	14.8	22.2	0.8	1.0	1.4	1.6	2.1	2.7	2.3	3.1	4.1
Mixed humid (East)	7.9	15.7	23.6	0.8	1.1	1.4	1.7	2.2	2.8	2.5	3.3	4.2
Mixed humid (West)	7.1	14.2	21.2	0.7	0.9	1.3	1.5	1.9	2.5	2.2	2.8	3.8

[1] low: 0.07US$/kg milk and 0.46US$/kg meat, base: 0.14US$/kg milk and 0.92US$/kg meat; high: 0.21US$/kg milk and 1.38 US$/kg meat.

As might be expected from the earlier results, under the assumptions made, smallholder dairy farmers would obtain the largest additional income potential per cattle per year, ranging from a minimum estimate of 2.6 US$/cattle/year to a maximum estimate of 12.9 US$/cattle/year. In all other systems considered, additional income potential was very similar ranging from 0.7 to 4.5 US$/cattle/year, suggesting that only very low-cost interventions are likely to be acceptable to farmers.

The estimated total additional income potential (in Million US$/year) resulting from the elimination of brucellosis for the four sub-regions as well as for SSA as a whole are shown in Table 4.8, using the most likely estimate of brucellosis prevalence and the low brucella-specific calf mortality scenario (Scenario I). Results for the calculated alternative scenarios are given in Annex 5. The estimated geographical distribution of additional income potential in US$ per km^2 for Scenario I, using the most likely estimate of brucellosis prevalence and the base price, are shown in Figure 4.3. Similar as for the estimated additional milk and meat offtake potential, the additional income potential per area (US$ per km^2) is strongly related to the cattle density, apart from the Kenyan, Tanzanian and Ugandan highlands, where the smallholder dairy system is the predominant cattle production system.

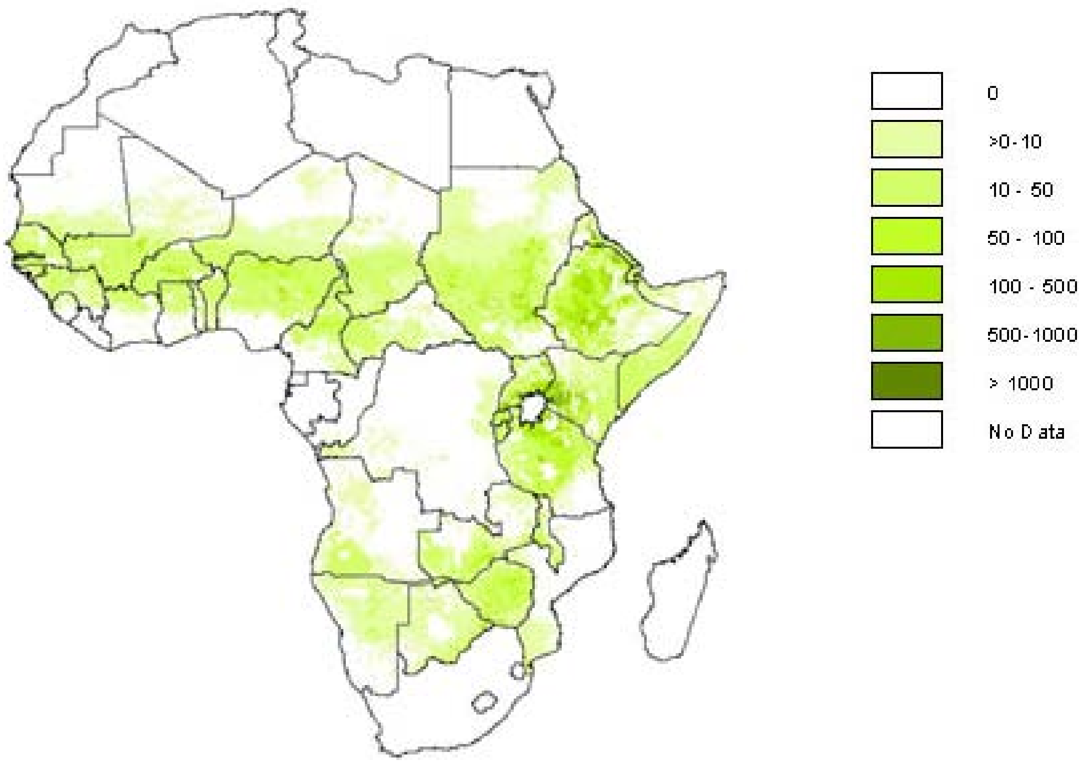
Table 4.8 Value of current meat and milk offtake and value of estimated total additional milk and meat offtake potential (million US$/year) by elimination of brucellosis in the four sub-regions of SSA and in SSA as a whole using the most likely brucellosis prevalence level and assuming three different producer prices[2]

Region	Value of Current Meat and Milk Offtake (Million US$/year)			Value of Additional Offtake Potential (Million US$/year)		
Assumed prices[3]	low	base	high	low	base	high
Central Africa	71	143	214	10	20	30
East Africa[1]	1,004	2,008	3,013	126	252	378
West Africa	391	782	1,174	56	112	168
Southern Africa	151	302	454	22	43	65
SSA[1]	1,618	3,236	4,854	214	427	641

[1] The cattle production system distribution in the highlands of Kenya, Uganda and Tanzania was assumed to be 70% smallholder dairy and 30% mixed highland system

[2] low: 0.07US$/kg milk and 0.46US$/kg meat, base: 0.14US$/kg milk and 0.92US$/kg meat; high: 0.21US$/kg milk and 1.38 US$/kg meat.

Figure 4.3 Estimated additional income potential (US$/km^2) from meat and milk by elimination of brucellosis in Sub-Saharan Africa, using the base price and the most likely estimate of brucellosis prevalence.



Discussion

Estimation of sero-prevalence of bovine brucellosis in SSA

Data set for meta-analysis

Mainly studies published in scientific journals were used in the meta-analysis because access to grey literature was limited. As stated by Wolf (1986), meta-analysis done only on published studies might be biased in favour of 'significant' findings, because non-significant findings are rarely published. However, it is questionable to what extent published findings on brucellosis sero-prevalence might be considered as being 'significant' as opposed to non-published findings. Thus, by not including grey literature, this study might be criticised for not using all available sources, however it seems unlikely that the results are subject to a selection bias in favour of 'significant' findings.

As more than 95% of all retrieved studies on the prevalence of bovine brucellosis in SSA were based on serology, it was decided to include only serology-based studies in the data set. Furthermore, a large number of studies had to be excluded as the surveyed cattle were kept either on multiplication and/or research centres, or on intensively managed farms and ranches. However, as already explained previously, only a small proportion of cattle in SSA are kept in those cattle production systems and these studies were therefore not included in the dataset used for the estimation of brucellosis sero-prevalence. Furthermore, surveys carried out on animals or farms, selected because they were known to have health problems suspected to be related to brucellosis infection, were also excluded from the dataset, because inclusion of such studies is likely to have biased the overall results.

Unfortunately, not all retrieved studies on the sero-prevalence of bovine brucellosis in traditionally managed cattle in SSA provided information on the vaccination status of the sampled animals. However, those studies that provided this information clearly indicated that the sampled animals were either not vaccinated or that vaccination coverage was extremely poor (e.g., Msanga et al., 1986; Ahmadu et al., 1999). The poor vaccination coverage within the traditional cattle production systems was said to be due to 'uncoordinated attempts of controlling this disease' as well as the lack of support from livestock owners (Msanga et al. (1986)). Other authors made similar remarks. In a recently published review on the distribution of brucellosis in SSA McDermott & Arimi (2002) highlighted that programmes to control infectious diseases such as brucellosis in SSA had, despite their economic and social importance, greatly declined over the past 20 years. Further, they noted that 'outside of southern Africa, vaccination is rarely conducted and if done, it has been on an ad hoc basis, rather than as part of a co-ordinated national program'. Therefore, and to include as many studies as possible in the analysis, it was assumed that, if not indicated otherwise[6], the sampled cattle population in traditional cattle production system was not or only very poorly vaccinated.

After all the above restrictions had been imposed on the original dataset, a total of 246 records were left for analysis. Of those records, 87% were based on field surveys, while the remaining studies were conducted in slaughterhouses (5.7%), in a single village or on very few farms (4.5%) or in other circumscribed places, for example a veterinary clinic, (1.2%). For 1.6% of the records the place/area of survey was not defined. Although slaughterhouse surveys are useful to obtain a qualitative indication of the presence of a disease in a population, they are likely to yield quantitative results that are not representative for the true field situation. Staak & Protz (1973) for example, obtained different sex-specific prevalences in their field survey (6.4% in

[6] Angba et al. (1987) was the only known survey that was applied in a traditional managed cattle population in which apparently in two of the three regions under study a large-scale vaccination campaign was applied. Further this was also the only known study where in following years the regions were consequently surveyed to observe the development of the brucellosis infection within a region. To avoid multiple reports only one record per region was included in the dataset, whereby the recorded observation referred to an unvaccinated cattle population.

males and 7.5% in females) and in their abattoir survey (5.4% in males and 19.6% in females). Another example of a discrepancy between field and abattoir sero-prevalence is provided by Hellmann et al. (1984), who obtained an infection rate of 11.6% for female Dinka animals above the age of 4 years in a field survey, whereas in an abattoir survey this group had an infection rate of 21.2%. They explained the difference by the custom of cattle owners to sell female cattle only for slaughter if they 'seem to be of no further use'. Not only slaughterhouse surveys might be biased, but also surveys done for example in veterinary clinics. It was therefore decided to apply the meta-analysis only to sero-epidemiological field surveys, which restricted the original 246 records to 217 records.

Predicted brucellosis sero- prevalence

The estimated most likely brucellosis sero-prevalence in the whole cattle population, assuming the RBT is used as serological test, was 16.2%. The actual brucellosis sero-prevalence reported in studies that had used a test from the RBT-group varied considerably. Relatively low sero-prevalences (less than 10 %) for the total cattle population were reported for example for Benin (4.3 %) by Akakpo et al. (1984), for Ethiopia (4.2 %) by Bekele et al. (1989) and for Ghana (6.6 %) by Kubufaor et al. (2000). Sero-prevalences between 10% and 20% were reported for example for Mali (19.7 %) by Maiga et al. (1985), for Uganda (19.6 %) by Newton et al. (1974) and for Senegal (14.4 %) by Doutre et al. (1977). Even higher brucellosis sero-prevalences (>20%) were reported for Rwanda (25.7 %) by Kabagambe et al. (1988) and for Togo (22.5 %) by Akakpo et al. (1981). In relation to these reported values, 16.2% seemed to be a reasonable point estimator for the most likely overall brucellosis sero-prevalence within traditionally managed SSA cattle populations.

Different authors found a significant increase in sero-positivity with increasing age of the sampled cattle (brucellosis being a chronic infection this is an expected finding). Therefore, it was expected that the brucellosis sero-prevalence within the sub-population of cows would be higher than the sero-prevalence within the cattle population as a whole. The estimated most likely sero-prevalence for the sub-population of cows was 2.48 times higher than the estimate for the cattle population as a whole. This factor of nearly 2.5 may appear to be on the high side, at least when compared with the findings of Domenech et al. (1980a), who obtained a factor of 1.5. Only few records with cows only as the sampled animal population group were included in the data set and the confidence interval for the estimated brucellosis sero-prevalence in cows is therefore wider than the corresponding estimate for the cattle population as a whole. The ratios of the upper and lower 95% confidence limit of the estimate for the cow-subpopulation and that of the cattle population as a whole are 2.00 and 3.01, both of which are higher than the value reported by Domenech et al (1980a). The ratio of the sero-prevalences will largely be determined by the composition to the 'entire' sampled population (ratio of cows to other types of stock, e.g. young males included in the sample or not) and the average age of the cow population. Therefore, the ratio is likely to be strongly influenced by the sampling protocol and not too much weight should be given to a single study. Given the long average time cows spend in the breeding herd in traditional SSA production systems (around 10 years), a sero-prevalence of 40% in cows does not appear unlikely (it might however be an overestimation for the smallholder dairy system, where both the average age of cows and the contact between animals is lower than in the traditional system)

As expected the applied serological test was a significant determinant for the predicted sero-prevalence. Differences in the sensitivity and specificity of the different serological tests used are important factors that contribute to the variation in brucellosis sero-prevalence obtained by different authors. Another factor that might have contributed to the variation in sero-prevalence between studies, which was not considered in this analysis, was the use of different cut-off points by different authors for the same diagnostic test. Choice of the RBT-test group as the reference tests for the prediction of the brucellosis sero-prevalence will have led to an overestimation of the true prevalence of brucella infection as false positive reactions are likely to be more common than false negative reactions. However, as the assumptions on the impact of brucellosis infection on animal production were based on studies, that had used the RBT-test, the use of RBT-positivity as measure of brucellosis prevalence was consistent with the second aim of the study, namely the estimation of production losses attributable to the infection.

Contrary to our hypotheses, sero-prevalence of brucellosis was not significantly different between the various cattle production systems considered in this study. Although, 'a livestock production system represents a group of farms with a similar structure, whereby individual farms are likely to share similar production functions', different management practices within the 'same' livestock production system cannot be fully considered in such a definition. For example, in pastoral/agro-pastoral systems in Chad and Cameroon, Domenech et al. (1980b) found a brucellosis sero-prevalence in the cow population ranging from 15% to 40%, while in cattle of one particular tribe they only found a brucellosis sero-prevalence of 8.5%. They explained the unusually low sero-prevalence by the different way of herd management practiced by this tribe[7]. Other authors have also highlighted the importance of herd management. For example, Kadohira et al. (1996) studied the risk of infection of different diseases at multiple levels in three contrasting districts of Kenya. They found that the most important source of variation for brucellosis prevalence was between-farm, a finding, which, however, they could not explain by the information available to them. Thus, variation in cattle management within crudely defined production systems, as was the case for this study, appears to be more important than the factors used for differentiating between systems, which were mainly environmental variables.

No significant difference in brucellosis sero-prevalence was found between the four regions of SSA. However, according to McDermott & Arimi (2002), bovine brucellosis has in recent years been actively controlled in Southern Africa. Movement controls, stamping out or vaccination with *B. abortus* strain 19 have been carried out in this part of SSA. Studies done in South Africa were excluded from the beginning from the analysis as cattle production systems in this country are known to be in general more intensified than in the rest of SSA. In the end, only three studies on the sero-prevalence of brucellosis in southern African countries were included in the data set, which seriously limits the power to detect significant between-region variation. Vaccination campaigns conducted in Southern Africa may have reduced the brucellosis prevalence and therefore, this study may have overestimated the sero-prevalence and consequently the impact of brucellosis in Southern SSA.

Estimated additional milk and meat offtake potential from brucellosis-free cattle

Assumptions made on the impact of brucellosis on animal production

This study only attempted to estimate the additional milk and meat offtake potential that might result from the elimination of brucellosis from traditionally managed cattle and from cattle in the smallholder dairy system in SSA, while the impact of disease elimination on other productive functions was ignored. However, hygromas or other lesions in the locomotory system attributable to brucella infection, might have an impact on the ability of infected cattle to move (Domenech et al., 1982b). A reduced ability to move might reduce the feed intake, resulting in lower livestock weight and/or lower daily growth. In the case of draught animals, a reduced ability to move might decrease the number of days that they are used for draught purposes. These possible effects were not considered in the estimation of the additional production potential resulting from the elimination of brucellosis because no study was found that had evaluated the possible impact of brucellosis on the live-weight and/or the draught power. Furthermore, the potential reduction in milk production attributable to brucella infection of the dam and the reduction in milk production resulting from brucellosis-specific calf mortality which, in most cattle breeds kept in traditional production systems, leads to premature cessation of lactation have also not been considered. Therefore, for any given brucellosis sero-prevalence, the current study is likely to underestimate the direct impact of brucellosis on cattle production.

[7] According to Domenech et al. (1980b), in the rainy season this tribe kept its cattle in small herds while during the dry season all the animals were grouped together on their move to grazing land, with the exception of pregnant animals, which remaind in the village. All the other tribes, however, mixed up all animals, pregnant or not.

Comparison of scenarios

By holding the development of herd size and the number of cows in the alternative scenarios equal to that of the baseline scenario, the increased productivity attributable to the elimination of brucellosis was directed entirely into 'additional offtake/consumption' rather than into 'additional investment' into herd (asset) growth. Although this procedure might have resulted in an artificial situation as increased herd growth might be the preferred option for a variety of livestock keepers, it is the method of choice for such comparisons (Upton, 1989) as it eliminates the need for the valuation of changing herd inventories (they remain virtually the same in the various scenarios) and as offtake on a per animal basis remains constant, thereby eliminating the need for defining a time horizon for the comparison (and consequently the need to introduce a discount factor). Furthermore, by holding the herd size and the number of cows in the alternative scenarios equal to the baseline scenario, similar feed requirements for all scenarios, baseline and alternatives, were obtained and thus production costs could be assumed to remain very similar. The increased fertility rate and the decreased calf mortality risk assumed for the alternative scenarios, did, however, lead to slightly different herd compositions. In the case of the smallholder dairy system the required feed was increased slightly by a factor 1.01 to 1.02. for the alternative scenarios, which, however, still appears to lie in a range that does not invalidate the comparisons.

The comparison of the productivity under different scenarios does not provide any information about the costs of moving from one scenario to another, it just gives an indication of whether or not the issue might warrant further investigation.

Estimated additional milk and meat offtake potential

This study estimated the additional milk and meat offtake potential that might result from the elimination of brucellosis in traditional cattle production systems of SSA. These systems are low input and low output systems (Chilonda and van Huylenbroek, 2001) as indicated by the low amounts of milk (25 to 40 litres) and meat (7 to 14 kg) offtake per animal per year. Consequently, the elimination of brucellosis from such production systems is expected to yield only small amounts of potential additional milk and meat offtake per animal. In such traditionally managed cattle production systems, brucellosis is usually endemic and, according to Ferney & Chantal (1976), 'abortion storms', as found in intensively managed herds in temperate zones, are not common. Nevertheless, the estimated relative losses in meat offtake potential ranged from 12% to 28% and 15% to 35% for the low and high brucella-specific calf mortality scenarios respectively. Given that, in value terms, meat is the main output from the traditional cattle production systems, the overall relative reduction in offtake potential attributable to brucellosis is quite sizeable.

Once intensification occurs, as for example in research and multiplication farms in SSA, clinical signs due to brucella infection are similar to those observed in temperate zones (Ferney & Chantal, 1976; Akakpo et Bornarel, 1987), and absolute production losses attributable to the infection increase. The smallholder dairy system, which is the most intensified production system of those included in this study, despite obtaining the lowest relative increase in milk and meat production potential for any given brucellosis sero-prevalence, obtained the highest absolute increase in milk and meat production potential, in the case of milk, more than ten times the predicted increase in any other system. Thus, the cost-benefit ratio of disease control is likely to improve with intensification as the costs of control per animal are likely to remain very similar (or even decrease with intensification due to improved infrastructure) while the production gains increase.

Aggregation of the estimated additional offtake potential per animal and system to estimate the total additional offtake potential within regions of SSA and SSA as a whole may appear problematic given the large uncertainty surrounding the assumed number of animals within each production system and region in SSA. In fact, the estimate of additional milk offtake potential is very sensitive to the assumptions made about the prevalence of the smallholder dairy system in the East African highlands. For example, in 1999, around 18% of all SSA cattle were in kept in the Ethiopian highlands. Assuming that of these cattle 5% rather than none, as done in this study, are kept in smallholder dairy systems, would have resulted in an estimated additional 40 to 66 thousand tons of milk offtake potential per year, over and above the estimated 475 tons (results not shown). This difference is of the same order of magnitude as the difference in estimated additional milk offtake potential obtained for the two scenarios calculated for the highlands of Kenya, Tanzania and Uganda (10% versus 30% of cattle kept in the smallholder dairy system). Thus, the overall estimate of additional milk offtake potential for East Africa has wide bounds of uncertainty of around ± 10% for any assumed brucellosis sero-prevalence. In the case of the estimated additional meat offtake potential for East Africa, however, the obtained results are much less sensitive to the above assumptions as meat offtake per animal is not very different between the small scale dairy system and the other systems considered. The same holds true for the additional milk and meat offtake potential estimated for the other three regions of SSA, as the smallholder dairy system hardly contributes to milk production and as differences in productivity between other systems are minor.

Preliminary financial evaluation

Preliminary estimation of the possible additional income potential for livestock keepers was based on the simplifying assumptions that producer prices would be the same in all scenarios (baseline scenario as well as alternative scenarios) despite increased milk and meat supply, and that no (or only very minor) additional costs would be incurred. However, according to economic theory a larger supply of meat, respectively of milk, will result in a decrease of the respective producer prices. Given the currently low per capita milk and meat production in SSA (29.3 and 9.5 kg/capita/year) and the rapid population growth, it is unlikely that the additional production would lead to major price decreases. Nevertheless, to some extent prices would be affected and not all of the benefits from increased production would go to the livestock keepers. However, given the preliminary nature of the analysis, the potential price effects were not considered and no attempt was made to estimate producer and consumer surpluses.

The estimated relative increase in income potential was in the order of 6% for the smallholder dairy system while is was around 15% for the other systems considered. For the smallholder dairy system, two thirds of the 'losses' resulted from decreased milk offtake potential while for the other systems included in the study around four fifth of the 'losses' were attributable to decreased meat offtake potential. These estimates for the non-dairy systems are considerably higher than those of Camus (1980) and Domenech et al. (1982a and 1987), who estimated a 10% and 6% reduction of net revenue per animal and year respectively. However, Camus (1980) and Domenech et al. (1982a 1987), both assumed a brucellosis prevalence of about 30% within cows, whereas the estimated most likely value of brucellosis prevalence within cows in this study was 40.2 %. As already discussed earlier the estimated brucellosis prevalence within cows might have been overestimated. As a consequence also the estimated relative increase in income potential might have been on the upper end.

Given that no additional costs were considered within this preliminary financial evaluation, the estimated additional income potential (in US$/cattle/year) might be interpreted as the upper limit of possible control costs/cattle/year (e.g. vaccine and vaccination costs) livestock keepers might be expected or willing to bear. Tambi et al. (1999) reported an average cost of 0.42 ECU[8]/animal for the large-scale vaccination campaign against rinderpest in various African countries. If this average vaccination cost/animal is assumed to be achievable for a large-scale vaccination campaign against brucellosis, then such a campaign would probably more than cover its costs, even under the low milk and meat price and low sero-prevalence scenario. Although a well managed large-scale vaccination campaign against brucellosis would lead to a marked reduction of brucellosis prevalence within the SSA cattle population, it would not lead to the elimination of brucellosis, i.e. not all the estimated benefit would be obtained. On the other hand, the incidence of brucellosis can be significantly reduced by vaccination of female cattle only, once in their lifetime, i.e. a large proportion of the minimum estimated benefits of 0.7 to 0.8

[8] 1 ECU is approximately 1 US $.

US$/animal/year would accrue from annual vaccination of newborn females, which constitute around 10% of a standard herd. Overall, it therefore appears that, despite the simplifying assumptions, the average additional income potential from a significant reduction of the incidence of brucellosis is likely to be enough to recoup vaccination costs and that livestock keepers would not be worse off if they vaccinated than if they did nothing.

However, it has to be borne in mind that traditionally managed cattle herds are low input and low output systems, in which the additional milk respectively meat offtake potential/herd/year resulting from the elimination of brucellosis would hardly be noticed by the cattle holder. Apart from the low average benefit, the incidence of brucellosis will vary between herds, meaning that some cattle holders are likely to benefit more than average from vaccination while others are likely to make a loss. Therefore, to assume that the average cattle holder might be willing to pay the vaccination costs, even if in theory it is probably profitable, is too optimistic. Thus, large scale vaccination campaigns on full cost recovery basis are likely to meet considerable opposition by cattle keepers, while vaccination on a voluntary basis is likely to increase costs per vaccination and in many areas, will probably only lead to low vaccination coverage. One possible way out of this impasse might be to combine vaccination against brucellosis with the vaccination against a disease that causes high visible losses in cattle, such as contagious bovine pleuropneumonia, anthrax or haemorrhagic septiceamia.

The average additional income from increased milk offtake potential obtained in smallholder dairy systems (1.8 US$/cattle/year under the low price low prevalence scenario, which is equivalent to 4.7/US$/cow/year) will by far outweigh the cost of vaccination of females once in their lifetime (average of 7.5 years in the breeding herd) under the assumed range of sero-prevalence. In addition to the increase in milk offtake potential, supplying brucellosis-free milk to consumers must be considered as a positive side effect, even if it does not constitute a priority for the farmers within those countries. Furthermore, small-scale dairy systems are reliant on an infrastructure that permits the marketing of milk, which conversely would facilitate the delivery of vaccination(s).

Issues for consideration in future studies

Cattle are not the only species affected by *B.abortus*. Therefore, similar studies might be necessary for other prevailing livestock species at-risk in SSA to evaluate the whole impact of *B.abortus* infection on animal production in SSA. Brucellosis sero-prevalences in camels, reported by Abbas & Agab (2002), for example, varied from 1.9% up to 20% (these authors however also considered non-SSA countries (e.g. Egypt) in their literature review. According to Abbas & Agab (2002), the infection in camels is caused by biotypes of *B. abortus* and *B. melitensis*. Reported brucellosis prevalence in small ruminants (sheep and goats) in SSA varied from 2.4 % to 22.7 % (McDermott & Arimi, 2002), mainly due to *B.melitensis* however. Further, according to Alausa (1979) 'the geographical distribution of human brucellosis is closely related to the endemicity of animal infection, the methods of animal husbandry, human food habits, the standard of hygiene, and other socio-economic activities'. Therefore, not only the impact of brucellosis infection in the livestock has to be considered but also the impact of brucellosis infection on humans.

By reducing the incidence of bovine brucellosis in SSA, livestock keepers could produce more and therefore might supply the markets with more livestock products. Whether this increase in supply of livestock products would also result in a higher return for the producers, would strongly depend on the market reaction in form of changing producer prices. Consequently, not only the economic welfare of cattle producers might change, but also that of the other stakeholders involved in meat and milk production, marketing and consumption. For example, consumers might benefit from a larger supply of milk and meat and probably also from lower milk and meat prices. However, if by being "brucellosis-free" producers could sell their products to new export markets with higher prices, which are currently closed to them due to sanitary reasons, then consumers might lose some or all of their potential benefits (higher supply and/or lower prices).

Of perhaps greater economic importance than the production effect, is the improvement in public health resulting from the reduction or elimination of bovine brucellosis. Fewer human infections with brucellosis result in decreased curative expenditure and reduced loss of working capacity, while an increased supply of animal protein to the human population in SSA would provide nutritional benefits. However, the latter impact would be difficult to evaluate, if at all possible. Furthermore, ethical and animal welfare considerations might favour the control of brucellosis as it would reduce suffering in both humans and animals.

Thus, a more detailed economic evaluation of the control and or elimination of bovine brucellosis should be carried out as a follow-up to identify the actual distribution of costs and benefits of various types of intervention. In such a study the change in productivity of all affected livestock species should be considered. Such an expanded economic evaluation might be conducted for each region or for selected countries. When looking at a national, respectively regional level, three modelling approaches are of interest: (a) general equilibrium models, (b) partial equilibrium models or (c) input-output matrixes. For example, Ebel et al. (1992), Miller et al. (1996) and Andersson et al. (1997) used partial equilibrium based welfare analysis to evaluate the social benefits of disease eradication programmes. Garner & Lack (1995) and Garner et al. (2001) used the concept of input-output matrixes to analyse the indirect losses of epidemic and endemic diseases on a national economy as a whole. Whereas, Crooks et al. (1994) analysed the macro-economic implications of improved animal health using multi-sector models. All the above studies focused on diseases that did not have any impact on human health. Valuation of the improvement of the human health status resulting from the control of a livestock disease might become the most challenging part of such studies. Roth & Zinsstag (2001) for example used the concept of DALYs (disability adjusted life year)[9] in their cost-effectiveness studies to analyse the cost per DALY averted from various strategies for brucellosis control in Mongolia.

Information about the improvement in livestock production potential, and information on the distribution of the benefits and dis-benefits of disease control programmes, would be valuable support to decision-makers. However, this information would still be insufficient. Based on epidemiological, social, and general economic grounds, but also given the nationally or regionally available financial and human resources, an analysis of possible control strategies should be conducted. The actual national or regional brucellosis prevalence, as well as the long-term goal and the financial and human resources available will determine what to do first and when to implement which measure. If the goal were to eradicate the disease from the national or regional herd, a mandatory vaccination phase followed by a stamping-out phase might be the appropriate control strategy. However, if the goal were merely to control the disease, other strategies could be pursued. The simplest approach might be voluntary or selective vaccination to decrease disease incidence. Another approach might be education. By educating farmers for example to improve their herd management in the sense of higher bio-security measures (e.g. less contacts with other herds). Such measures, if properly applied, might result in the long-term in a lower brucellosis prevalence within and between herds. Apart from brucellosis, such measures might also reduce the disease spread of other infectious diseases. Apart from controlling the disease only in livestock, education of livestock keepers, slaughterhouse workers and consumers, and the pasteurisation of the milk would help to reduce the risk of brucellosis infection within the human population. Again, measures such as the pasteurisation of milk for example, would not only decrease the risk of brucellosis infection in humans, but tackle also other zoonoses, such as those caused by *Mycobacterium bovis* Campylobacter and Listeria spp, that are transmitted via unpasteurised milk to humans.

Final conclusion

The available literature on the prevalence of brucellosis in SSA, published over the last 30 years was inadequate to derive a reasonably detailed picture of the distribution of bovine brucellosis by production system and region. Of the 86 retrieved references, 44 could not be

[9] DALY is one of the measurement methods applied in human health economics to combine mortality and morbidity data in humans into a single unit (Anonymous, 1999).

used in a formal meta-analysis because of a lack of representativity or inadequate information on the study protocol. Information on the impact of brucella infection on cattle productivity was limited to three studies.

Despite the severe data limitations, it can be concluded that the elimination of brucellosis from traditional cattle production systems would lead to substantial (>10%) and fairly uniform relative improvements in productivity, mainly through additional meat offtake potential, even under the lowest assumed sero-prevalence. This does not include potential benefits obtained from the elimination of *B.abortus* infection from other susceptible species (e.g. camels).

Given traditional cattle production systems in SSA are low input low output systems, even substantial relative improvements in productivity are quite low in absolute terms and unlikely to constitute a sufficient incentive for livestock keepers to invest in brucellosis control, although on average benefits are likely to outweigh costs. Combination of vaccination against brucellosis with vaccination against acute diseases that have a strong visible impact, e.g. anthrax or blackleg, might improve livestock keepers' willingness to 'co-invest' in brucellosis control.

Human health benefits were not considered in this study and the reduction in human suffering from brucellosis following the reduction or elimination of bovine brucellosis might be a stronger justification for its control in traditional production systems than the associated productivity gains. This possibility should be assessed by studies similar to that carried out by Roth & Zinsstag (2001) in Mongolia.

Smallholder dairy farmers in the highlands of East Africa were identified as the producer group most likely to reap the highest absolute benefits from brucellosis control, mainly through increased milk offtake potential stemming from improved fertility. This estimate was however not based on studies on the sero-prevalence in smallholder dairy systems, which might be substantially different from the overall average value used, as in these systems contact between adult cattle is reduced through the relatively widespread practice of zero-grazing. Thus, a more detailed analysis of the impact of brucellosis in smallholder dairy systems appears warranted, particularly as in this system the public health impact is highest whilst the infrastructure required for brucellosis control needs the least investment.

Finally, it might be highlighted that this study could show, despite all its limitations, that the concept of cattle production system is useful for preliminary analysis of the production impact of endemic diseases within a region. Similar analysis for other diseases might form a basis for decision-makers to identify those diseases, for which detailed studies on the costs and benefits of alternative control strategies should be conducted. Such studies should (a) quantify the distribution of the benefits of the reduced risk of infection within society; and (b) on a regional level, based on economic and epidemiological grounds as well as the regionally available financial and human resources, compare control strategies that can be applied to achieve a defined goal.

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Annexes

Annex 1 Summary of retrieved literature on brucellosis prevalence in cattle populations of Sub-Saharan Africa.

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
West Africa							
Benin	mixed lowland	920	RBT	4.3 (2.0 – 6.6)	Akakpo et al., 1984; Akakpo, 1987; Akakpo & Bornarel, 1987.		Y
			CFT	8.3 (5.0 – 12.1)			
			RBT or CFT	10.4 (6.6 – 12.4)			
Burkina Faso	pastoral; mixed lowland; ranch (dairy & beef)	1,270	RBT	7.4	Akakpo, 1987; Akakpo & Bornarel, 1987; Bornarel et al., 1987b.		Y
			CFT	9.7			
			RBT or CFT	12.3 (0 – 55.2)			
	pastoral; mixed lowland	1,335	MRT	11.5 (6.0 – 21.5)	Gidel et al., 1974	Different animals sampled 4)	Y
			SAT or CFT	8.1 (2.3 – 10.9)			
	peri-urban 5)	1,107	6)	8.0	Coulibaly & Yameogo, 2000	Ad hoc collection from various sources	N
Chad	pastoral; mixed lowland;	6,679	RBT	31.9 (15.4 – 39.5)	Domenech et al., 1982a; partly in Domenech et al., 1980b;	Only adult females	Y
Ghana	mixed lowland	323	RBT	9.3 (5.1 – 26.0)	Turkson & Boadu, 1992.	Mainly mixed lowland	Y
	5)		none	1.7	Otupiri et al., 2000.	Based on surveillance by butchers	N
	mixed lowland	183	RBT	6.6 (0.0 – 20.0)	Kubuafor et al., 2000		Y
Guinea	mixed lowland	1,861	RBT	6.9 (0.0 – 27.0)	Sylla et al., 1982.	Further analysis using SAT and CFT	Y
	mixed lowland	2,748	RBT or CFT	6.5 (0.6 – 7.6)	Diallo, 1994		Y
Ivory Coast	mixed lowland	1,327	MRT	42.9 (23.0 – 51.0)	Gidel et al., 1974	Different animals sampled 4)	Y
		749	SAT or CFT	15.5 (2.6 – 25.8)			
	mixed lowland	6)	SAT, RBT	11.3 (9.5 – 14.0)	Angba et al., 1987	7)	Y
	mixed lowland	13,343	SAT & RBT	10.1 (1.0 – 39.3)	Pilo-Moron et al., 1979	And eventually CFT to confirm	Y

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
	mixed lowland	6)	MRT		Camus, 1980	41.5% of the herds positive tested	N
		364	SAT			Cows that had aborted or had hygromas	N
		1,214	RBT	28.3 (9.1-37.7)		Adult females only surveyed	Y
Mali	mixed lowland	867	RBT, CFT	19.7 (5.3 – 35.9)	Maiga et al., 1995		Y
	5)	8,276	5)	11.4	Kané et al. (unpublished data)	Cited by Tounkara et al. (1994)	N
	pastoral; mixed lowland	1,000	ELISA	22 (6.5 – 25.4)	Tounkara et al., 1994	53% of all herds were infected, ranging from 10 to 87% by region	Y
Niger	pastoral	245	MRT	21.2	Gidel et al., 1974	Different animals sampled 4)	Y
		42	SAT or CFT	2.4			
	pastoral	826	RBT	18.3	Akakpo et al., 1986; Akakpo, 1987; Akakpo & Bornarel, 1987		N
			CFT	27.6			
			RBT or CFT	30.9 (5.9 – 51.7)			
	pastoral	2,794	RBT	1.4 (0 – 2.3)	Bloch & Diallo, 1991.		Y
Nigeria	mixed lowland	400	RBT	6.3	Ishola et al., 1997	Sera collected in abattoir	N
			SAT	5.0			
	pastoral	762	ELISA	6.6 (1.7 – 26.8)	Ocholi et al., 1996		Y
			SAT	3.0			
			RBT	2.1			
	pastoral	200	RBT	15.0	Adesiyun & Oni, 1990	Sera collected in abattoir	N
			SAT	1.5			
	2 ranches	1,989	RBT & SAT	2.9 (2.2 – 4.8)	Agunloye et al., 1988	Based on the 1981 survey.	N
	research station	48	RBT, SAT, Rivanol test	68.8	Falade et al., 1981		N
	breeding centre	71	RBT, SAT	38.0	Bale & Kumi-Diaka, 1981		N
	farms (dairy & beef)	282	SAT	46.5 (1.5 – 79.7)	Esuruoso & Ayanwale, 1980	Only on one farm with vaccinated cattle	N
	Only positive farms 5)	54	6)	24.0	Pullan, N.B., 1980	Milk herd samples and serology only within the infected herd	N

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
	various systems 5)	1,650	RBT	47.4	Alausa, 1979	Investigation due to a shortage in meat; Brucellosis infection suspected.	N
	5)	198	6)	7.1 (2.8 – 11)	Nuru & Schnurrenberger, 1975	Mainly livestock multiplication centres	N
	pastoral; mixed lowland	1,186	SAT	14.8 (0.0 - 17.6)	Esuruoso, 1974a	Sera collected in abattoir	N
	farms	376	SAT CFT & HIT8)	9.6 (0.0 – 33.3)		Only selected farms surveyed (on some farms cattle were vaccinated)	N
	range cattle	452	SAT	29.1 (0.0 – 50.0)	Esuruoso, 1974b	range cattle (not vaccinated)	N
	farms	741	SAT CFT & HIT8)	8.8 (0.0 – 26.0)	Esuruoso & van Blake, 1972	Only selected farms surveyed (on some farms cattle were vaccinated)	N
	pastoral;	5,000	SAT	4.4 (3.7 – 8.1)	Banerjee & Bhatty, 1970.	Also survey on research farms	Y
Senegal	5)	5)	6)	5.74	Konté et al., 1997		N
	mixed lowland	388	RBT	14.4	Doutre et al., 1977	Survey in one village	N
			SAT	13.3			
			CFT	13.3			
	pastoral	621	SAT or CFT or RC	8.7	Chantal & Thomas, 1976	Sera collected in abattoir	N
	5)	1,379	RBT or CFT	10.3	Akakpo & Bornarel, 1987	Partly sera collected in abattoir.	N
Sierra Leone	mixed lowland	110	RBT, MRT, Reazurum test	26.4	Hassan, 1979		N
Togo	Mixed lowland	1,112	6)	41.2 (35.5 – 51.9)	Domingo, 2000		Y
	Mixed lowland & research farm	1,056	RBT	22.5	Akakpo et al., 1981. Akakpo, 1987; Akakpo & Bornarel, 1987		Y
			CFT	28.7			
			RBT or SAT or CFT	40.9 (19.5 – 55.0)			
Central Africa							
Came-roon	pastoral & mixed lowland	962	RBT	6.7	Akakpo, 1987; Akakpo & Bornarel, 1987; Bornarel et al., 1987a		Y
			CFT	10.5			
			RBT or CFT	12.5 (4.8 –22.2)			

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
	pastoral & mixed lowland & ranch	7,665	RBT	30.8 (8.5 – 43.9)	Domenech et al., 1982a; partly in Domenech et al., 1980b;	Only adult females	Y
Central African Republic	mixed lowland	6)	6)	25	Fio-Ngaindiro, 1987	Only females	N
Congo	ranch	30	6)	16.7	Nygo & Kiafouka, 1989	1 ranch	N
	ranch	674	CFT	25.5 (9.3 – 42.0)	Bula et al., 1987	7 ranches	N
East Africa							
Burundi	mixed highland	957	RBT & SAT	4.5 (0.0 – 13.0)	Merker & Schlichting, 1984	Preliminary survey (1978)	Y
		127	RBT & SAT	12.8 (8.2 – 22.8)		Survey in one region (1979)	
		528	MRT	14.4		Only milking cows in one region (1981)	
			SAT	18.3			
			RBT	25.4			
Eritrea	pastoral; mixed highland; smallholder dairy	2,427	RBT & CFT	5.6 (0.0 – 8.5)	Omer et al., 2000 a&b	Only adult animals sampled	Y
Ethiopia	mixed highland	685	SAT	0.4	Domenech & Lefevre, 1974		Y
	pastoral; mixed highland	1,609	RBT	4.2 (4.1 – 4.3)	Bekele et al., 1989		Y
Kenya	pastoral; smallholder dairy	1,146	ELISA	10.2 (0 – 27)	Kadohira et al., 1996		Y
	5)	835	CFT	12.1 (7.3 – 24.5)	Ndarathi & Waghela, 1991	3 randomly selected Maasai ranches	N
			SAT	9.7 (7.0 – 12.5)			
			RBT	16.9			
	smallholder dairy	200	SAT	7.5 9)	Gössler et al., 1973	Veterinary clinic survey	N
			CFT	5 9)			
			SAT or CFT	10.5 9)			
	pastoral; smallholder dairy	10,361	RBT	9.9 (0.0 – 23.5)	Kagumba & Nandokha, 1978		Y
			RBT & SAT	3.6 (0.0 – 5.8)			
			RBT & CFT	8.7 (0.0 –25.5)			

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
	pastoral	220	RBT	7.7	Kagunya & Waiyaki, 1978		Y
			SAT	4.6			
			CFT	3.2			
	pastoral; mixed lowland; smallholder dairy	1,125	SAT	20.8 (4.0 – 40.0)	Thimm, in preparation	Cited by Thimm (1971)	Y
	pastoral; smallholder dairy	4,960	/	6.6 (0.9 – 11.1)	Oomen and Wegener (1974)	Cited by Waghela (1977)	Y
	pastoral; mixed lowland; smallholder dairy	8,468	CFT	3.2 (0.8 – 17.6)	Waghela, 1977		Y
	pastoral; ranch	10,459	/	5.5 (2.8 – 7.0)	Waghela, 1976; Waghela, 1977		Y
Rwanda	mixed highland	/	RBT	27.8	Akakpo, 1987; Akakpo & Bornarel, 1987		Y
			CFT	27.7			
			RBT or CFT	34.9 (8.1 – 42.5)			
	mixed highland	1,385	RBT	25.7 (0.0 –86.1)	Kabagambe et al., 1988		Y
			SAT	5.2 (0.0 – 18.7)			
Somalia	pastoral; feedlots	660	SAT	15.4 (10.7 -24.4)	Andreani et al., 1982	based on slaughtered animals and animals kept in feedlots	N
	pastoral; ranch	5,056	SAT	9.5 (4.8 – 16.0)	Werney et al., 1979		Y
		579	MRT	12.2 (10.3 –15.0)			
	pastoral; ranch	3,086	SAT	9.0 (1.7 – 12.2)	Hussein et al., 1978	farm, village and abattoir	Y
Sudan	pastoral	113	RBT	13.3	Agab, 1997	Veterinary clinic survey	N
	pastoral	762	RBT & CFT	20.2	McDermott et al., 1987a & b		Y
	pastoral	5,982	SAT & CFT	9.2 (6.5 – 22.5)	Hellmann et al., 1984		Y
	5)	2,064	MRT	38.0	Ibrahim & Habiballa, 1975		N
	5)	1,522	MRT	57.4	Ibrahim, 1975	Cited by Chukwu (1985)	N
	5)	76	MRT	38.16	Ibrahim, 1973		N
Tanzania	mixed lowland	23,017	RBT	5.9 (1.0 – 17.5)	Kagumba & Nandokha, 1978.		Y
			RBT & SAT	5.0 (1.0 – 11.6)			

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
			RBT & CFT	5.2 (1.0 – 10.3)			
	mixed lowland; smallholder dairy	2,289	SAT	14.0(12.3 – 14.1)	Weinhäupl et al., 2000		Y
	mixed lowland; dairy farms & ranches	13,087	SAT	10.8 (0.2 – 17.5)	Jiwa et al., 1996	The prevalence rate for traditional herds was 4.3%, for dairy 6.3% and for ranch 15.8%	Y
	pastoral; dairy; multiplication and research farms	17,758	SAT	10.6 (0.0 – 31.4)	Msanga et al., 1986		Y
	pastoral	923	SAT	1.6 (0.5 – 3.8)	Ecimovic & Mahlau, 1973		Y
	pastoral; mixed lowland	5,836	SAT	6.3 (1.9 – 11.5)	Staak & Protz, 1973	1 ½ year or older cattle	Y
Uganda	smallholder dairy	274	MRT	herd level	Oloffs et al., 1998	10% of the herds tested positive, but only 25% of the cows were lactating.	N
		756	RBT & CFT	3.0			Y
	dairy	1,606	/	18.1 (1.0 – 23.3)	Ndyabahinduka & Chiu, 1984		N
	pastoral; mixed lowland	1,739	RBT	5.0 (0.0 – 23.1)	Kagumba & Nandokha, 1978.		Y
			RBT & SAT	4.0 (0.0 – 23.1)			
			RBT & CFT	4.6 (0.0 – 23.1)			
	pastoral; mixed lowland	2,005	RBT	19.6 (14.4 -22.2)	Newton et al., 1974		Y
			RBT & SAT	9.6 (7.7 – 11.3)			
			RBT & CFT	15.6 (12.4 –18.7)			
	1 farm	/	SAT	33.0	Plagemann, 1974	Farm with clinical signs	N
	pastoral; mixed lowland	2,985	SAT	11.3 (6.7 – 41.0)	Thimm, in preparation	Cited by Thimm (1971)	Y
Southern Africa							
Botswana	5)	6)	RBT	18	Anonymous, 1974	Cited by Chukwu (1985)	N
Malawi	mixed lowland	2,017	RBT & SAT	0.3	Bedard et al., 1993		Y
	mixed lowland	5,021	RBT	0.25	Klastrup & Halliwell, 1977		Y
			RBT & SAT	0.01			
Zambia	mixed lowland	291	RBT	17.2 (14.7 – 18.4)	Ahmadu et al., 1999	Sera collected in 3 abattoirs	N
			SAT	16.2 (13.3 – 17.3)			

Country	Cattle production system[1)]	Nr of animals sampled	Test applied[2)]	Overall prevalence (%) (average prevalence within sub-groups in %)	References	Note	Study used[3)]
	mixed lowland	214	SAT	28.5 (10 – 39)	Ghioretti, 1991	5 traditionally managed herds	N
			RBT	37.4			
			CFT	22			
	mixed lowland	6)	6)	15 - 25	Akafekwa, 1980		N
	mixed lowland	705	RBT, SAT	27.9 (8.7 – 39.4)	Sovjak, 1977	Only female cattle	Y
	5)	705	SAT	27.9	D'Cruz, 1976	Cited by Chukwu (1985)	N
		432	SAT	11.1			
		788	SAT	9.5			
	5)	1,879	RBT, SAT, CFT	11.3	Gallagher, 1973		N

1) Pastoral (pastoral and agro-pastoral systems); mixed lowland (semi-arid, sub-humid and humid mixed cattle production systems); mixed highland (mixed highland systems) and smallholder dairy systems were the cattle production systems of interest in this study. Each of those cattle production system is predominant in at least one of the AEZ's in SSA. However, within SSA also other cattle production systems can be found, for example dairy and beef ranches or farms, as well as multiplication and research centres. Those studies are reported as well, although they were not considered for the meta-analysis. Furthermore, for a few studies the cattle production system could not be defined either because of too less information, or because an overall prevalence was reported for cattle from various cattle production systems.

2) The most frequently applied tests were: the milk ring test (MRT); serological tests of the RBT-group (acidified antigen agglutination tests such as the rose-bengal/card test and the buffered antigen plate agglutination test); serological tests of the SAT-group (standard agglutination tests such as the standard tube agglutination test and the sero-agglutination test of Wright); the serological complement fixation test (CFT) and the ELISA-test (enzyme linked immunoassay). Other tests, which were less frequent applied were: RC: 'réaction antiglobuline de Coombs'; HIT: heat inactivation test; Riv: Rivanal test and the Reazurum test. If more than one test was applied, the obtained results might have been based on the fact that either at least one of the multiple test was positive (or), or that all the used tests reacted positive (&). For those cases were more tests were used but it was not possible to distinguish between or or &, the different tests were named and separated by a comma.

3) This column indicates if the study was included (Y) or not included (N) in the final data set on which the meta-analysis was applied. Some studies were only partly included in the data set.

4) MRT was applied only on milking cows. Due to the low percentage of milking cows within some of the analysed cattle population blood samples were taken as well, mainly from young animals.

5) The information available is insufficient to distinguish clearly a specific cattle production systems under study.

6) No information was given in the retrieved study.

7) Angba et al. (1987) gave the average for the whole country, as well as for the South, Centre and the North of the country as found in 1978. Furthermore, Angba et al. (1987) reports the prevalence for those three regions over the years, starting from 1976 for the North and the South, respectively from 1979 for the Centre, until 1984. A vaccination campaign was started in 1978 in the North and in 1983 in the Centre. Only one reported prevalence per region was included in the data set, which was for the North 10.3% (1976), for the South 9.6% (1976) and for the Centre 14.9% (1980). All prevalence recorded were from an unvaccinated cattle population (see also footnotes 2 and 3).

8) Two SAT-tests (tube and plate) were used. CFT and HIT were eventually used to confirm, if the two SAT test gave different results.

9) Prevalence based on *Brucella abortus* only, a few animals reacted positively to *Brucella melitensis*

Annex 2 Production parameter values for cattle production systems in SSA

A. Non-traditional smallholder dairy system

Parameter	Value
Fertility rate	0.74
Prolificacy rate	1.01
Breeder males per breeder female	0.02
Milk yield per lactation (tons)	2.20
Fraction of females milked	1.00
Cow mortality rate	0.05
Bull mortality rate	0.04
Female replacement mortality rate	0.09
Male replacement mortality rate	0.22
Female young mortality rate	0.098
Male young mortality rate	0.095
Other stock mortality rate	0.10
Years in breeding herd, cows	7.50
Years in breeding herd, bulls	2.86
Years in replacement herd, females	3.00
Years in replacement herd, males	2.00
Years from young to slaughter, other stock	0.67
Years as young	1.00
Carcass weight of female breeders (tons)	0.14
Carcass weight of male breeders (tons)	0.21
Carcass weight of other stock (tons)	0.08
Males in the system? [2]	1.00
Are young males slaughtered at birth? [2]	0.00
Fraction of fallen animal eaten	0.75
Proportion of female breeders with usable skin	0.70
Proportion of male breeders with usable skin	0.70
Proportion of other stock with usable skin	0.70
Weight of skin for female breeders (tons)	0.01
Weight of skin for male breeders (tons)	0.01
Weight of skin for other stock (tons)	0.01
Average live weight, breeder female (tons)	0.30
Average live weight, breeder male (tons)	0.45
Average live weight, replacement female (tons)	0.25
Average live weight, replacement male (tons)	0.30
Average live weight, other stock (tons)	0.17
Average live weight, young female (tons)	0.11
Average live weight, young male (tons)	0.10
Milk fat content(g/kg)	38.00

[1] Source: Otte & Chilonda (2002)
[2] Yes = 1 and No = 0.

B. Traditional cattle production systems

Parameter	Pastoral, arid/semi-arid	Mixed, semi-arid	Mixed, sub-humid	Mixed [3], humid	Mixed [4], humid	Mixed, highland
Fertility rate	0.58	0.58	0.61	0.60	0.60	0.44
Prolificacy rate	1.00	1.00	1.00	1.00	1.00	1.00
Breeder males per breeder female	0.11	0.17	0.07	0.07	0.07	0.41
Female breeder mortality rate	0.09	0.07	0.05	0.03	0.03	0.04
Male breeder mortality rate	0.08	0.07	0.05	0.03	0.03	0.04
Female replacement mortality rate	0.06	0.08	0.05	0.07	0.07	0.09
Male replacement mortality rate	0.08	0.08	0.10	0.07	0.07	0.10
Young mortality rate	0.24	0.21	0.22	0.17	0.17	0.22
Other stock mortality rate	0.08	0.07	0.05	0.03	0.03	0.04
Years in breeding herd, cows	11.50	11.50	10.0	9.00	9.00	11.50
Years in replacement herds	3.00	3.00	3.00	3.00	3.00	3.40
Years as young	1.00	1.00	1.00	1.00	1.00	1.00
Years from young to slaughter, other stock	3.00	4.00	4.00	4.00	4.00	9.50
Carcass weight of female breeders (tons)	0.12	0.12	0.12	0.12	0.10	0.10
Carcass weight of male breeders (tons)	0.15	0.15	0.15	0.15	0.13	0.13
Carcass weight of other stock (tons)	0.15	0.15	0.15	0.15	0.13	0.13
Fraction of females milked	0.77	0.79	0.60	0.50	0.50	0.60
Milk yield per lactation (tons)	0.25	0.25	0.21	0.25	0.25	0.29
Fraction of calves that are fertile	1.00	1.00	1.00	1.00	1.00	1.00
Retention ratio for young females	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of fallen animals eaten	0.75	0.75	0.75	0.75	0.75	0.75
Are young males slaughtered at birth?[2]	0.00	0.00	0.00	0.00	0.00	0.00
Prop. of female breeders with usable skin	0.70	0.70	0.70	0.70	0.70	0.70
Prop. of male breeders with usable skin	0.70	0.70	0.70	0.70	0.70	0.70
Proportion of other stock with usable skin	0.70	0.70	0.70	0.70	0.70	0.70
Weight of skin for female breeders (tons)	0.01	0.01	0.01	0.01	0.01	0.01
Weight of skin for male breeders (tons)	0.01	0.01	0.01	0.01	0.01	0.01
Weight of skin for other stock (tons)	0.01	0.01	0.01	0.01	0.01	0.01
Average live weight, breeder female (tons)	0.25	0.25	0.24	0.24	0.20	0.20
Average live weight, breeder male (tons)	0.32	0.32	0.32	0.32	0.25	0.27
Av. live weight, replacement female (tons)	0.19	0.19	0.19	0.19	0.19	0.15
Av. live weight, replacement male (tons)	0.16	0.19	0.20	0.20	0.20	0.19
Average live weight, other stock(tons)	0.32	0.31	0.31	0.31	0.25	0.27
Average live weight, young female (tons)	0.12	0.11	0.11	0.11	0.11	0.10
Average live weight, young male (tons)	0.12	0.11	0.11	0.11	0.11	0.10
Milk fat content (g/kg)	41.00	41.00	41.00	41.00	41.00	41.00
Are there draught specific oxen?[2]	0.00	1.00	1.00	1.00	1.00	1.00
Are male breeders used for draught?[2]	0.00	1.00	1.00	1.00	1.00	1.00
Are female breeders used for draught?[2]	0.00	1.00	1.00	1.00	1.00	1.00
Are male replacements used for draught?[2]	0.00	0.00	0.00	0.00	0.00	0.00
Number of days worked, draught specific animals	0.00	12.50	25.0	25.0	25.0	37.50
Number of days worked, breeders	0.00	1.00	1.00	1.00	1.00	1.23
Number of days worked, replacements	0.00	0.00	0.00	0.00	0.00	0.71
Average productivity /animal/day, draught specific oxen	0.00	1.00	1.00	1.00	1.00	1.00
Average productivity/animal/day, breeders	0.00	1.00	1.00	1.00	1.00	1.00
Average productivity/animal/day, replacements	0.00	1.00	1.00	1.00	1.00	1.00

[2] Yes = 1and No = 0.
[3] Mixed humid cattle production system in East & South Africa.
[4] Mixed humid cattle production system in West & Central Africa.

Annex 3 Land area and cattle population by cattle production system in SSA

Region and AEZ/Cattle production system	Area[1] ('000 Km²)	Cattle Distribution[1] (%)	Cattle Population ('000 head)	
			1994[1]	1999[2]
Central Africa [3]				
Desert	0.0	0.0	0.0	0.0
Pastoral/Agro-pastoral	30.0	6.3	496.4	619.6
Agro-pastoral/Semi-arid mixed	77.4	8.3	656.4	819.3
Sub-humid mixed	847.9	36.0	2,841.2	3,546.1
Humid mixed	3,039.2	44.8	3,542.5	4,421.4
Highland mixed	94.6	4.6	364.3	454.7
Sub-total	**4,089.1**	**100.0**	**7,900.8**	**9,861.0**
East Africa 4				
Desert	1,013.9	5.6	5,576.6	6,192.1
Pastoral/Agro-pastoral	2,217.5	18.3	18,405.0	20,436.3
Agro-pastoral/Semi-arid mixed	1,106.5	21.9	22,019.5	24,449.7
Sub-humid mixed	988.3	15.5	15,516.2	17,228.7
Humid mixed	100.3	1.2	1,192.9	1,324.6
Ethiopian highlands	538.1	30.5	30,565.8	33,939.3
Kenya, Uganda and Tanzania highlands	202.9	7.0	7,061.1	7,840.4
Sub-total	**6,167.5**	**100.0**	**100,337.1**	**111,411.0**
West Africa				
Desert	1,893.0	0.5	173.6	257.5
Pastoral/Agro-pastoral	2,090.2	15.0	5,091.6	7,552.8
Agro-pastoral/Semi-arid mixed	1,450.7	49.8	16,959.1	25,156.8
Sub-humid mixed	1,164.7	32.0	10,894.0	16,160.0
Humid mixed	704.1	2.6	891.4	1,322.3
Highland mixed	27.6	0.1	32.1	47.6
Sub-total	**7,330.3**	**100.0**	**34,041.8**	**50,497.0**
Southern Africa				
Desert	356.0	2.7	494.8	527.3
Pastoral/Agro-pastoral	915.4	18.7	3,441.9	3,668.2
Agro-pastoral/Semi-arid mixed	1,391.0	45.0	8,270.2	8,814.0
Sub-humid mixed	1,717.3	30.1	5,525.1	5,888.4
Humid mixed	133.8	0.7	131.2	139.8
Highland mixed	179.9	2.8	505.9	539.2
Sub-total	**4,693.4**	**100.0**	**18,369.1**	**19,577**
SSA (Total)	**22,280.3**		**160,648.8**	**191,346.0**

1) Cattle population estimated for 1994 by using a geographical information system. Source: GIS calculations from Wint et al., (1999). See Otte & Chilonda (2002).
2) Cattle population in 1999 estimated by using the cattle stock statistics given by FAOSTAT for 1999 (FAOSTAT 2000), assuming the same cattle distribution as for 1994. See Otte & Chilonda (2002).
3) Cameroon, Central African Republic; Democratic Republic of Congo; Republic of Congo and Gabon are considered as the Central African region in SSA.
4) Burundi; Djibouti; Eritrea; Ethiopia; Kenya; Rwanda; Somalia; Sudan; United Republic of Tanzania and Uganda are considered as the East African region of SSA.
5) The highlands excluding Kenya, Tanzania and Uganda. In the Ethiopian highlands the prevailing cattle production systems is mixed highlands, whereas mainly in Kenya, but also in Tanzania and Uganda the prevailing cattle production systems is smallholder dairy (Chilonda, 2002 personal communication).
6) Benin; Burkina Faso; Chad; Ivory Coast; Gambia; Ghana; Guinea; Guinea-Bissau; Liberia; Mali; Mauritania; Niger; Nigeria; Senegal; Sierra Leone and Togo are considered as the West African region in SSA.
7) Angola; Botswana; Lesotho; Malawi; Mozambique; Namibia; Swaziland; Zambia and Zimbabwe are considered as the Southern African region of SSA.

Annex 4 Estimated additional milk and meat offtake potential

Annex Table 4.1 Estimated total additional milk offtake potential (in Thousand tons/year) by elimination of brucellosis for the various cattle production systems within sub-regions of SSA.

Region	Alternative Scenario I [1] (Thousand tons/year)			Alternative Scenario II [1] (Thousand tons/year)		
Brucellosis prevalence	lower c.l.	most likely	upper c.l.	lower c.l.	most likely	upper c.l.
Central Africa						
Desert	0.0	0.0	0.0	0.0	0.0	0.0
Arid	1.4	1.7	2.3	1.4	1.8	2.3
Semi-arid	1.8	2.3	2.9	1.8	2.3	2.9
Subhumid	4.6	6.0	7.8	4.6	6.0	7.8
Humid	5.7	7.5	9.7	5.7	7.5	9.7
Highland	0.7	1.0	1.2	0.7	1.0	1.2
Sub-total	**14.3**	**18.5**	**24.0**	**14.3**	**18.6**	**24.0**
East Africa						
Desert	13.6	17.3	22.9	13.6	18.0	22.9
Arid	45.0	57.2	75.6	45.0	59.3	75.6
Semi-arid	53.8	68.5	88.0	53.8	68.5	88.0
Sub-humid	22.4	29.3	37.9	22.4	29.3	37.9
Humid	1.7	2.3	2.9	1.7	2.3	2.9
Highland [2]	54.3	71.3	91.6	54.3	71.3	91.6
Highland [3]	143.2	181.7	234.7	142.1	183.3	233.0
Sub-total	**334.0**	**427.5**	**553.7**	**332.9**	**431.8**	**552.0**
West Africa						
Desert	0.6	0.7	1.0	0.6	0.7	1.0
Arid	16.6	21.1	27.9	16.6	21.9	27.9
Semi-arid	55.3	70.4	90.6	55.3	70.4	90.6
Sub-humid	21.0	27.5	35.6	21.0	27.5	35.6
Humid	1.7	2.2	2.9	1.7	2.2	2.9
Highland	0.1	0.1	0.1	0.1	0.1	0.1
Sub-total	**95.3**	**122.1**	**158.1**	**95.3**	**122.9**	**158.1**
Southern Africa						
Desert	1.2	1.5	2.0	1.2	1.5	2.0
Arid	8.1	10.3	13.6	8.1	10.6	13.6
Semi-arid	19.4	24.7	31.7	19.4	24.7	31.7
Sub-humid	7.7	10.0	13.0	7.7	10.0	13.0
Humid	0.2	0.2	0.3	0.2	0.2	0.3
Highland	0.9	1.1	1.5	0.9	1.1	1.5
Sub-total	**37.5**	**47.8**	**62.1**	**37.5**	**48.2**	**62.0**
SSA	**480.9**	**616.0**	**797.7**	**479.8**	**621.5**	**796.0**

[1] Only very slight differences between alternative scenario I and II. The fertility rate was the same in both scenarios, resulting in the same number of cows calving.
[2] Excluding the highlands of Kenya, Uganda and Tanzania.
[3] The cattle distribution in the Kenyan,Ugandan and Tanzanian highlands was assumed to be 30% in the mixed highland system and 70% in the smallholder dairy system.

<u>Annex Table 4.2</u> Estimated total additional meat offtake potential (in Thousand tons/year) by elimination of brucellosis for the various cattle production systems within sub-regions of SSA.

Region	Alternative Scenario I (Thousand tons/year)			Alternative Scenario II (Thousand tons/year)		
Brucellosis prevalence	**lower c.l.**	**most likely**	**upper c.l.**	**lower c.l.**	**most likely**	**upper c.l.**
Central Africa						
Desert	0.0	0.0	0.0	0.0	0.0	0.0
Arid	1.0	1.2	1.7	1.2	1.6	2.1
Semi-arid	1.3	1.7	2.1	1.6	2.1	2.8
Sub-humid	5.3	7.1	9.2	7.1	9.2	11.7
Humid	6.2	8.0	10.6	8.0	10.2	13.3
Highland	0.5	0.7	0.9	0.6	0.8	1.0
Sub-total	**14.4**	**18.7**	**24.5**	**18.6**	**23.9**	**30.9**
East Africa						
Desert	9.9	12.4	16.7	12.4	16.1	21.1
Arid	32.7	40.9	55.2	40.9	53.1	69.5
Semi-arid	39.1	51.3	63.6	48.9	63.6	83.1
Sub-humid	25.8	34.5	44.8	34.5	44.8	56.9
Humid	2.1	2.8	3.6	2.6	3.4	4.5
Highland [1]	40.7	50.9	64.5	47.5	61.1	78.1
Highland [2]	12.7	16.2	20.9	15.9	20.7	26.3
Sub-total	**163.1**	**208.9**	**269.3**	**202.7**	**262.8**	**339.3**
West Africa						
Desert	0.4	0.5	0.7	0.5	0.7	0.9
Arid	12.1	15.1	20.4	15.1	19.6	25.7
Semi-arid	40.3	52.8	65.4	50.3	65.4	85.5
Sub-humid	24.2	32.3	42.0	32.3	42.0	53.3
Humid	1.9	2.4	3.2	1.9	2.4	3.2
Highland	0.1	0.1	0.1	0.1	0.1	0.1
Sub-total	**78.9**	**103.2**	**131.8**	**100.2**	**130.2**	**168.7**
Southern Africa						
Desert	0.8	1.1	1.4	1.1	1.4	1.8
Arid	5.9	7.3	9.9	7.3	9.5	12.5
Semi-arid	14.1	18.5	22.9	17.6	22.9	30.0
Sub-humid	8.8	11.8	15.3	11.8	15.3	19.4
Humid	0.2	0.3	0.4	0.3	0.4	0.5
Highland	0.6	0.8	1.0	0.8	1.0	1.2
Sub-total	**30.5**	**39.8**	**51.0**	**38.8**	**50.5**	**65.4**
SSA	**286.9**	**370.6**	**476.5**	**360.3**	**467.4**	**604.3**

[1] Excluding the highlands of Kenya, Uganda and Tanzania.
[2] The cattle distribution in the Kenyan,Ugandan and Tanzanian highlands was assumed to be 30% in the mixed highland system and 70% in the smallholder dairy system.

<u>Annex Table 4.3</u> Estimated additional milk and meat offtake potential per animal (in kg/cattle/year) by elimination of brucellosis for the four regions of SSA and SSA as a whole for alternative Scenario II

Region	Additional milk offtake (kg/cattle/year)			Additional meat offtake (kg/cattle/year)		
Assumed brucellosis prevalence	lower c.l.	most likely	upper c.l.	lower c.l.	most likely	upper c.l
Central Africa	1.4	1.9	2.4	1.9	2.4	3.1
East Africa [1]	3.0	3.9	5.0	1.8	2.4	3.0
West Africa	1.9	2.4	3.1	2.0	2.6	3.3
Southern Africa	1.9	2.5	3.2	2.0	2.6	3.3
SSA [1]	2.5	3.2	4.2	1.9	2.4	3.2

[1] The cattle distribution in the Kenyan, Ugandan and Tanzanian highlands was assumed to be 30% in the mixed highland system and 70% in the smallholder dairy system.

Annex 5 Estimated additional income potential

Annex Table 5.1 **Estimated additional income potential (in US$/cattle/year) by elimination of brucellosis for the six cattle production systems under Scenario II**

	Additional income potential for farmers (US$/cattle/year)								
Brucellosis prevalence	**Lower c.l..**			**Most likely value**			**Upper c.l.**		
Price	**low**	**base**	**high**	**low**	**base**	**high**	**low**	**base**	**high**
Smallholder dairy	2.8	3.7	4.6	5.6	7.3	9.3	8.5	11.0	13.9
Mixed highland	0.8	1.0	1.2	1.5	2.0	2.5	2.3	2.9	3.7
Pastoral	1.1	1.4	1.8	2.1	2.8	3.6	3.2	4.2	5.5
Mixed semi-arid	1.1	1.4	1.8	2.1	2.8	3.6	3.2	4.2	5.4
Mixed sub-humid	1.0	1.3	1.7	2.0	2.6	3.3	3.0	3.9	5.0
Mixed humid (East)	1.0	1.3	1.7	2.0	2.6	3.4	3.0	3.9	5.2
Mixed humid (West)	0.9	1.2	1.5	1.8	2.4	3.1	2.8	3.5	4.6

Annex Table 5.2 **Estimated additional income potential per animal (in US$/cattle/year) by elimination of brucellosis for the four sub-regions of SSA and for SSA as a whole**

Region	Alternative Scenario I (US$/cattle/year)			Alternative Scenario II (US$/cattle/year)		
Assumed brucellosis prevalence	lower c.l.	most likely	upper c.l.	lower c.l.	most likely	upper c.l.
Base price						
Central Africa	1.5	2.0	2.6	1.9	2.5	3.2
East Africa [1]	1.8	2.3	2.9	2.1	2.7	3.5
West Africa	1.7	2.2	2.8	2.1	2.7	3.5
Southern Africa	1.7	2.2	2.8	2.1	2.7	3.5
SSA [1]	1.7	2.2	2.9	2.1	2.7	3.5
Low price						
Central Africa	0.8	1.0	1.3	1.0	1.2	1.6
East Africa [1]	0.9	1.1	1.5	1.0	1.4	1.7
West Africa	0.9	1.1	1.4	1.0	1.4	1.8
Southern Africa	0.9	1.1	1.4	1.0	1.4	1.8
SSA [1]	0.9	1.1	1.4	1.0	1.4	1.7
High price						
Central Africa	2.3	3.0	3.9	2.9	3.7	4.8
East Africa [1]	2.6	3.4	4.4	3.1	4.1	5.2
West Africa	2.6	3.3	4.3	3.1	4.1	5.3
Southern Africa	2.6	3.3	4.3	3.1	4.1	5.3
SSA [1]	2.6	3.3	4.3	3.1	4.1	5.2

[1] The cattle distribution in the Kenyan, Ugandan and Tanzanian highlands was assumed to be 30% in the mixed highland system and 70% in the smallholder dairy system.
[2] The cattle distribution in the Kenyan Ugandan and Tanzanian highlands was assumed to be 10% in themixed highland system and 90% in the smallholder dairy system.

<u>Annex Table 5.3</u> Estimated total additional income potential (in Million US$/year) by elimination of brucellosis the four sub-regions of SSA and for SSA as a whole

Region	Alternative I (million US$/year)			Alternative II (million US$/year)		
Assumed brucellosis prevalence	lower c.l.	most likely	upper c.l.	lower c.l.	most likely	upper c.l.
Base price						
Central Africa	15	20	26	19	25	32
East Africa [1]	197	252	325	233	302	389
West Africa	86	112	143	106	137	177
Southern Africa	33	43	56	41	53	69
SSA [1]	331	427	550	399	517	667
Low price						
Central Africa	8	10	13	10	12	16
East Africa [1]	98	126	163	117	151	195
West Africa	43	56	72	53	68	89
Southern Africa	17	22	28	20	27	34
SSA [1]	166	214	275	199	259	334
High price						
Central Africa	23	30	39	29	37	48
East Africa [1]	295	378	488	350	453	584
West Africa	129	168	215	158	205	266
Southern Africa	50	65	83	61	80	103
SSA [1]	497	641	825	598	776	1,001

[1] The cattle distribution in the Kenyan, Ugandan and Tanzanian highlands was assumed to be 30% in the mixed highland system and 70% in the smallholder dairy system.