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REGULAR ARTICLE

Productivity in different cattle production systems in Kenya

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Abstract Cattle are kept as an important source of livelihood in many Kenyan farming households whilst also having cultural and social value. A review was undertaken to estimate productivity in the three main Kenyan cattle production systems: small-scale dairy and meat; small-scale dairy; and large-scale dairy and meat. Data on production parameters were collected through a systematic literature search of electronic databases for peer reviewed and grey literature. The parameters included were reproductive rates, mortality rates and yields. Prices for livestock and livestock products were estimated from markets. The data were used to estimate net output from cattle using the Livestock Productivity Efficiency Calculator (LPEC), a deterministic steady state model which measures productivity as net output per megajoule (MJ) of metabolisable energy (ME). The estimated net outputs per livestock unit year^{-1} were USD 146.6, USD 215.1 and USD 84.8 in the large-scale dairy and meat, small-scale dairy and meat and small-scale dairy systems, respectively. Milk production contributed significantly to net output in all systems and was 91.8 % of total output in small-scale dairy. Cattle sales had the highest contribution to net output in large-scale dairy and meat system (45.1 %). Sensitivity analysis indicated that output was most affected by milk yield, age and weight at maturity and parturition rate. The productivity differences between the production systems call for more detailed research on the constraints to the production systems such as diseases, and to describe the benefits that farmers and society would obtain from disease control and improved management.

Keywords Systematic review · Parameters · Constraints · Kenya

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Introduction

According to national statistics, Kenya has approximately 17 million head of cattle kept in different production systems broadly classified as small-scale dairy, small-scale dairy and meat, large-scale dairy and large-scale dairy and meat (KARI/ODA 1996). This classification is based on type of output from systems, species kept, climate and scale of production. About 13.5 million head of cattle kept are beef breeds while the remaining 3.5 million head are dairy breeds together with their crosses (MoLD 2007). These production systems have similar structure and function which allows for their description and analysis of development opportunities and constraints (Dixon et al. 2001). The herd sizes kept under these systems vary between two and four cows in small-scale dairy, three to ten cows in small-scale dairy and meat and 56–177 cows in large-scale dairy and meat (Muhuyi et al. 1999; Bebe et al. 2003; Alice and Ilatsia 2011).

Productivity is defined as a measure of efficiency of a production system and is represented by a quantitative term of output divided by input (Upton 1989). Forage has also been described as an important input in grazing cattle systems and the economic margin per unit of forage is an index of productivity that is useful in assessment of development opportunities and constraints (James and Carles 1996). A steady state model measuring productivity as net output megajoule of ME from forage is used for this purpose (PAN-Livestock Services Limited 1991). Input parameters to this model are production parameters measured in cattle raised under similar production system and management. These production parameters include reproduction rates, mortality rates and level of yields (Upton 1989).

Constraints to cattle production impact negatively on production parameters thus affecting the level of productivity of cattle systems and the farms they are part of. In Kenya, tick-borne diseases such as East Coast Fever, anaplasmosis and babesiosis affect the cattle production (Okuthe and Buyu 2006; Gachohi et al. 2011). They have an effect on mortality and reproductive rates, and some studies have described them as a major constraint to growth rate in calves (Gitau et al. 2001). Trypanosomosis is also prevalent especially in pastoral and lowland humid areas (Thumbi et al. 2010) and it causes stunted growth in calves, loss in milk yield, loss of working ability and mortality in affected cattle (Maichomo et al. 2009). Contagious bovine pleuropneumonia caused by *Mycoplasma mycoides* subspecies *mycoides* was reported to be highly prevalent in large-scale dairy and meat production system especially in pastoral areas. It is hypothesized that during outbreaks, it can cause high mortality in affected cattle, prolonged morbidity period, reduced fertility rate and loss in milk production from lactating cattle (Wanyoike 2009). The recent re-emergence of Rift-Valley Fever in northern Kenya and its subsequent spread to other parts of the country also poses a threat to cattle production (Rich and Wanyoike 2010); this is in addition to its zoonotic importance (Munyua et al. 2010). *Brucella abortus* and *Brucella melitensis* organisms have also recently been isolated in milk samples, aborted foetuses and vaginal discharges collected from cattle kept in small-scale dairy farms with a history of recurrent abortions (Muendo et al. 2012). This high incidence of diseases in cattle systems threatens food security situation in the country besides loss of lucrative international livestock market due to trade sanctions. They also result in lost opportunities to farmers who cannot keep high productive breeds in tsetse fly infested areas due to fear of their cattle acquiring trypanosomosis, in addition to direct and indirect public health costs of controlling zoonotic diseases.

Whilst it is believed that the main Kenyan cattle systems suffer from a myriad of constraints that limit productivity, the baseline level of productivity is unknown. Some authors have stated that the main production constraints are high incidence of diseases and unpredictable weather patterns characterised by drought (Wakabi 2006; Bett et al. 2009), while others have described inadequate feeding, lack of credit facilities and lack of proper breeding services as production constraints (Bebe et al. 2003; Alice and Ilatsia 2011). This report will explore how to establish a productivity baseline for Kenyan cattle systems and discuss how this could be used in planning and policy making.

Material and methods

Systematic literature review

A review of published studies and grey literature describing cattle productivity in Kenya was performed according to the procedure described by the Cochrane collaborators (Higgins and Green 2011). The literature search was conducted on major electronic databases including PubMed, Science direct, Cabi direct and Springer using specified search terms. The search terms were cattle production parameters (calving interval, days; growth rates, kg/day; parturition rate, year^{-1}; lactation milk yield, kg; offtake rates, year^{-1}; culling rates, year^{-1}; mortality rates, year^{-1} and morbidity rates year^{-1}). The inclusion criteria were studies that had longitudinal design and where results were published in English in a peer-reviewed journal and studies where original research articles or full text of reports were available. Studies describing productivity using secondary data and those that did not specify the type of production system were not included.

Estimating values of production parameters

Data on point estimates for production parameters and sample sizes used in studies were extracted and entered into a database for further analysis. The prices of output and costs of cattle production in different systems were obtained from Livestock Marketing and Information System database, Kenya National Bureau of Statistics report (KNBS 2009) and studies carried out under these production systems (van Schaik et al. 1996; Meme 1998; Mburu et al. 2007; Nyariki et al. 2009; Wanyoike 2009). A discount rate of 8 % was used to calculate future values of cost of cattle production and prices of outputs using the following formula; Future value=Present value $(1+r)^n$, where r is the discount rate and n the number of years into the future. The currency unit used is U.S. dollar (exchange rate: USD 1=80 KES). With descriptive statistical analysis the average values for each production parameter were determined. Most studies had reported reproduction and mortality rates as risk rates. These were converted into true rates for use in estimating net output using the formula: True rate=−ln(1−risk rate) (Martin et al. 1987).

Estimation of net output from cattle systems

The estimation of net output was performed using Livestock Productivity Efficiency Calculator (LPEC) (PAN-Livestock

Services Limited 1991). Briefly, LPEC is a steady-state herd model built on the algebraic relationship between production parameters, output and herd structure. The herd structure equation calculates the percentage of each age and sex category of animals in the herd at equilibrium, the feed intake equation calculates ME required by an animal in each category to achieve a certain level of performance and the output equation calculates the rate of each type of output from the herd. The herd structure, nutrient intake estimate and offtake are converted into an output per unit of ME intake to measure efficiency in a production system. The unit of forage resource used is the carrying capacity unit which is a measure of feed supply and is defined as a unit of forage resource producing 100 MJ of ME/day. One carrying capacity unit is equivalent to the feed supply providing 100 MJ of ME/day throughout the year. This is approximately the feed requirement for a dairy cow producing 4,000 kg of milk per lactation. The output is an accurate estimate of output per livestock unit year^{-1} (Upton 1993). Livestock unit is defined as the relative feed energy requirement per head of cattle per year, and an adult milking cow is treated as the standard and has a value of unity (Upton 1993). The estimated average values of parameters, prices of output and annual cost of cattle production per livestock unit in different systems were used to estimate the value of net output as described for LPEC.

Sensitivity analysis

Sensitivity analysis was done on effects of production parameters on net output from systems as recommended for LPEC (PAN-Livestock Services Limited 1991). It involved varying the level of production parameters by steps of ±10 % and noting the corresponding value of net output. The production parameters included in the sensitivity analysis were mortality rates, culling rates, parturition rates, milk yield and prices, cattle offtake rates and prices, weaning and maturity ages and weights.

Results

Findings from systematic review

In total, there were 42 studies describing various aspects of productivity in cattle systems in Kenya. Of these studies 28 were eligible for inclusion in the analysis. They were carried out between 1994 and 2012. The production systems considered in the analysis were small-scale dairy and meat, small-scale dairy and large-scale dairy and meat. The large-scale dairy production system was not included as no recent studies with measures of productivity were available. The mortality rates were high in all age categories of cattle in the systems reviewed (Table 1). The mortality rate in calves was 20 % in large-scale dairy and meat, 18.4 % in small-scale dairy and 24.8 % in small-scale dairy and meat production systems. Cattle maturity age was 4 years in all systems but, maturity weights for cows in small-scale dairy system was higher (300 kg) compared to small-scale dairy and meat system (212.7 kg) and large-scale dairy and meat systems (180.5 kg). The ratio of breeding females to males varied across systems. The small-scale dairy system had a ratio of 76:1, while large-scale dairy and meat system had a ratio of 10:1. The parturition rates were similar across the production systems. Cows kept in small-scale dairy production system had a higher lactation milk yield of 2,434 kg per cow while in large-scale dairy and meat production system the lactation milk yield was low at 305 kg per cow.

Cost of production in cattle systems

The main inputs to the systems included purchase of extra feed, grown fodder, breeding and veterinary services, vaccination costs, tick control and hired labour. The inputs for the large-scale dairy and meat system were cost of trypanocides, antibiotics and acaricide (Roderick et al. 2000; Wanyoike 2009). The annual cost of production per livestock unit under this system was estimated at USD 10.5. There were no estimates for cost of cattle production in small-scale dairy and meat system and estimates for large-scale dairy and meat system was used since both are under extensive management. For the small-scale dairy system the amount of concentrate fed to a milking cow was used to estimate the cost of purchased feeds fed to dairy cows. An estimate of 1 kg of concentrates was reported to be fed daily at milking time per cow (Meme 1998). Other inputs included breeding and veterinary services, disease control and hired labour. The annual cost of production per livestock unit under this system was estimated at USD 372.50.

Net output in cattle systems

Lactation milk yield contributed a higher percentage of the total output in all systems reviewed as compared to cattle offtake, with the highest proportion in small-scale dairy system (91.8 %) (Table 2). The value of annual net output per livestock unit varied across production systems. Net output as a percentage of total output was 15.7 % in small-scale dairy system, 98.9 % in large-scale dairy and meat system and 95.4 % in small-scale dairy and meat system (Table 3). The highest net output was in small-scale dairy and meat system with USD 215.1, while the lowest net output was in small-scale dairy system with USD 84.8.

Table 1 Average measure of production parameters in cattle systems

Cattle production parameters	Small-scale dairy	Small-scale dairy and meat	Large-scale dairy and meat	Data sources
Mortality rate breeding cows	10.8	3	9.0	a,b,d,k,p,o
Mortality rate female calves	18.4	24.8	20.0	a,b,d,k,o,p,q,x,z
Mortality rate heifers	6.4	5.0	8.4	a,d,k,r,o,p
Mortality rate mature bulls	20.5	3.0	9.0	a,d,k,o,p
Mortality rate male calves	23.1	24.8	20.0	a,b,d,k,q,p,x,z
Mortality rate bullocks	19.7	5.0	8.9	a,b,d,k,p
Culling rate cows	10.4	13.0	10.8	a,b,d,o,p
Culling rate bulls	66	20.0	41.5	a,b,d,k,o,p
Birth weight females (kg)	28.1	15.8	19.7	a,c,m,n,x
Birth weight males (kg)	28.3	15.8	19.9	a,c,m,n,x
Weaning weight female (kg)	51.8	65.5	64.0	a,c,g,m,x
Weaning weight males (kg)	51.8	65.5	64.0	a,c,g,m,x
Weaning age (years)	0.33	1.0	1.0	a,c,g,m,x
Maturity age females (years)	3.4	3.5	4.0	a,g,m
Maturity age males (years)	3.0	4.0	4.0	a,g,m
Maturity weight cows (kg)	300	212.7	180.5	a,h,g,m,$
Maturity weights bulls (kg)	450	216.2	180.5	a,h,g,m,$
Breeding female/male ratio	75.9	22.2	10.0	a,d,e,r,o,s
Calving rate	65.9	65	64.3	a,b,d,k,r,p
No. of offspring/calving	1.01	1.01	1.01	a
Milk yield per lactation (kg)	2434	600.0	305	c,i,e,k,u,o,t,y,&
Herd sizes	3.8	10	100	b,j,l,e,k,v,o,p,w,f

[a] KARI/ODA (1996)
[b] Roderick et al. (1998)
[c] Roderick et al. (1999)
[d] Nyariki et al. (2005)
[e] Nyariki et al. (2009)
[f] Muhuyi et al. (1999)
[g] Maichomo et al. (2005)
[h] Mwangi et al. (1998)
[i] Ilatsia et al. (2007)
[j] Oba (2001)
[k] Wanyoike (2009)
[l] Maritim (2009)
[m] Wasike et al. (2006)
[n] Ilatsia et al. (2012)
[o] Meme (1998)
[p] Bebe et al. (2003)
[q] Gitau et al. (1999)
[x] Latif et al. (1995)
[z] Muraguri et al. (2005)
[$] Machila et al. (2008)
[r] Omore et al. (1996)
[s] Okuthe and Buyu (2006)
[u] van Schaik et al. (1996)
[t] Omore et al. (1999)
[y] Muraguri et al. (2004)
[&] Bebe et al. (2008)
[v] Gitau et al. (1994)
[w] Alice and Ilatsia (2011)

Table 2 Value for each type of output per livestock unit per year in cattle systems (USD)

Types of output (USD)	Small-scale dairy and meat	Small-scale dairy	Large-scale dairy and meat
Culled breeding females	27.7	18	25.8
Mature surplus females	6.3	15.9	8.6
Barren females	1.1	1.1	1.1
Culled breeding males	2.3	0.95	18.9
Mature surplus males	25.6	1.7	16.6
Milk yield (kg)	162.8	419.9	86.2
Total output	225.7	457.3	157.1

Large-scale dairy and meat system had a net output of USD 146.6. The highest contribution of cattle offtake to total output was in large-scale dairy and meat system (45.1 %) and was lowest in the small-scale dairy system (8.2 %). The estimated number of animals per livestock unit was 3.8, 2.3 and 4.3 for small-scale dairy and meat, small-scale dairy and large-scale dairy and meat systems, respectively. The value of parturition rates, ages and weights at maturity, lactation yield and milk offtake considerably affected the value of net output in systems on sensitivity analysis. However, net output was only marginally affected by changes in mortality and culling rates.

Discussion

Most publications reviewed for the present study were designed to estimate epidemiological parameters such as prevalence and incidence rates of infectious and vector-borne diseases in farms within different cattle production systems. There were also studies that described objectives of breeding programs for different cattle breeds kept under these systems. These studies documented measures of productivity and their levels. Most of these measures were affected to a varying degree by the presence of diseases and other production constraints. Estimates of some production parameters were based on a few studies because not many longitudinal studies had reported them under the cattle systems analysed. There were generally fewer studies carried out in the small-scale dairy and meat system while no recent study was found for the large-scale dairy production system. The review has shown that the level of productivity differs considerably between the cattle systems. The production parameters that considerably affected productivity in the cattle systems reviewed were growth rate (ages and weights at maturity), parturition rate and level of outputs. Mortality and culling rates did not considerably affect productivity in the systems analysed. However, cattle mortality resulting from diseases and starvation due to drought in pastoral areas has been reported to affect cattle production (Wakabi 2006; Bett et al. 2009). This is demonstrated by the high mortality rate in all age categories of cattle under these systems. The high mortality rate in calves negatively impact on herd growth potential and this ultimately leads to inability of raising replacement stock. Indeed, it had been reported that replacement stock cannot be raised from herds in both small-scale dairy and large-scale dairy and meat production systems (Bebe et al. 2003; Wanyoike 2009). The review has further highlighted the presence of fewer breeding males to females kept in the small-scale dairy system. This is mainly due to adoption of improved breeding techniques including artificial insemination in the highland ecological zones where majority of the small-scale dairy farms are located (Alice and Ilatsia 2011). However, natural breeding is still the preferred method under a large-scale dairy and meat system where in a typical herd the number of breeding males is approximately 10 % that of breeding females. The small-scale dairy production system had higher level of total output but due to intensification of management and associated high cost of inputs including costs of feeds, breeding and veterinary services, the value of net output was relatively low. However, studies have shown that in order to improve the level of productivity under this system, intervention measures should focus on holistic management of feeding and breeding practices (Bebe et al. 2008; Alice and Ilatsia 2011). It is also noted that any intervention that focuses on any one of these measures in isolation will result in low level of production from cattle that only supports subsistence (Bebe et al. 2008). Previous studies designed to describe the economic performance of farms under smallholder systems reported that most farms had negative gross margins resulting from high cost of inputs and low levels of production (Meme 1998; Mburu et al. 2007). In addition,

Table 3 Value of net output per livestock unit per year in cattle systems (USD)

Level of output (USD)	Small-scale dairy	Small scale-dairy and meat	Large scale-dairy and meat
Total output	457.3	225.7	157.1
Cost of production	372.5	10.5	10.5
Net output	84.8	215.2	146.6

USD, United State dollar; KES, Kenya shillings (USD 1=80 KES) breed selection practices in these farms also affect the level of production. The exotic dairy breeds commonly kept have been shown to have lower overall milk production, longevity, fertility and disease tolerance compared to improved indigenous cows (King et al. 2006). Another study reported that 25 % of dairy heifers born of exotic dairy breeds are culled before reaching first calving age in farms while 34 % are culled before 4 years of age (Menjo et al. 2009). Although the culling rate did not considerably affect the level of productivity in the cattle systems analysed, the reduction of this involuntary culling of breeding and lactating females should be considered as a key production goal if the smallholder dairy enterprises are to be managed sustainably. This is because of the high cost of rearing or purchase of replacement stock. These exotic breeds also suffer from excessive heat stress due to the tropical climate (King et al. 2006). This has an impact on their milk production potential and reproductive performance which eventually affects the availability of replacement stock in farms. Additionally, clinical and subclinical mastitis have been reported in these farms especially those under zero-grazing management (Omore et al. 1999). Although the level of inputs in both large-scale dairy and meat and small-scale dairy and meat production systems were low, thus resulting in higher values of net outputs, the presence of infectious and vector-borne diseases poses a threat to improvement in level of production under these systems. East Coast Fever, anaplasmosis, babesiosis, trypanosomosis and contagious bovine pleuropneumonia are examples of cattle diseases that have been reported to be endemic under these production systems (Muraguri et al. 2005; Bett et al. 2010). Moreover, zoonoses such as Rift Valley Fever and brucellosis are increasingly reported in farms located in these systems (Munyua et al. 2010; Muendo et al. 2012). These diseases have a significant economic, trade, public health and food security importance to households and the national economy. They affect livestock production and national economy through their effect on level of production, product pricing, reduction and elimination of market opportunities resulting from international trade barns, food security in addition to their direct and indirect cost of control and prevention. Their impact on cattle production is due to increased mortality rate, reduced level of production, reduced fertility rates and reduced growth rates. Indeed, sensitivity analysis on effects of production parameters on net output revealed that milk yield, maturity age and weight and parturition rates considerably affected the level of productivity in the systems analysed. Therefore diseases that affect these measures of production have got a direct impact on net output in cattle systems where milk and cattle sales are the main production goals.

Conclusion and recommendation

The value of total output in the small-scale dairy system was high but due to the high cost of production the overall net output was low. However, as a result of low cost of production per livestock unit year^{-1} in the other two production systems, the net outputs were higher than in small-scale dairy system. Given the evidence from literature sources the high incidence of diseases in different cattle systems negatively impact on the level of production to a different degree. It is recommended that impact of each cattle disease on production parameters and level of production within these systems be investigated and costs of their control and prevention be estimated. This will allow for targeted disease control interventions in order to optimise productivity from these systems.

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Conflicts of interest The authors declare that they have no conflict of interest.

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