Development of livestock production in the tropics: farm and farmers' perspectives

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Because of an increasing demand for animal-source foods, an increasing desire to reduce poverty and an increasing need to reduce the environmental impact of livestock production, tropical farming systems with livestock must increase their productivity. An important share of the global human and livestock populations are found within smallholder mixed-crop–livestock systems, which should, therefore, contribute significantly towards this increase in livestock production. The present paper argues that increased livestock production in smallholder mixed-crop–livestock systems faces many constraints at the level of the farm and the value chain. The present paper aims to describe and explain the impact of increased production from the farm and farmers' perspective, in order to understand the constraints for increased livestock production. A framework is presented that links farming systems to livestock value chains. It is concluded that farming systems that pass from subsistence to commercial livestock production will: (1) shift from rural to urban markets; (2) become part of a different value chain (with lower prices, higher demands for product quality and increased competition from peri-urban producers and imports); and (3) have to face changes in within-farm mechanisms and crop–livestock relationships. A model study showed that feed limitation, which is common in tropical farming systems with livestock, implies that maximum herd output is achieved with small herd sizes, leaving low-quality feeds unutilised. Maximal herd output is not achieved at maximal individual animal output. Having more animals than required for optimal production – which is often the case as a larger herd size supports non-production functions of livestock, such as manure production, draught, traction and capital storage – goes at the expense of animal-source food output. Improving low-quality feeds by treatment allows keeping more animals while maintaining the same level of production. Ruminant methane emission per kg of milk produced is mainly determined by the level of milk production per cow. Part of the methane emissions, however, should be attributed to the non-production functions of ruminants. It was concluded that understanding the farm and farmers' perceptions of increased production helps with the understanding of productivity increase constraints and adds information to that reported in the literature at the level of technology, markets and institutions.

Keywords: development constraints, value chains, feed availability, productivity, methane emissions

Implications

Increasing production in smallholder mixed-crop–livestock systems in order to respond to the increasing demand for animal-source food (and concomitantly contribute to poverty reduction, improved global food security and improved global environment) faces serious difficulties. In development and research activities aimed at livestock production in the tropics, the farm and the farmers' perspective should be taken into account.

Introduction

Livestock production in the tropics dominates the global scene when it comes to the number of animals, total output and number of beneficiaries – that is, producers and consumers (Table 1) – when compared with livestock production in the western world. Many contextual reasons make livestock production in the tropics different from that in the West. This was noticed when simple livestock technologies and organisational infrastructure, which were successful in high-production regions, proved unsuccessful when introduced in the tropics (Udo *et al.*, 2011; Amankwah, 2013; Sumberg and Lankoandé, 2013). Climate, resource availability, input and supply market

Table 1 *Human and livestock population (numbers in millions) in Sub-Saharan Africa and South Asia*

		Poor livestock keepers						
Region/sub-region	Population (number)[1]	Number[2]	% of total population	Cows[1]	Buffaloes[1]	Sheep and goats[1]	Pigs[1]	Poultry[1]
Sub-Saharan Africa								
Central Africa	123	30	24.4	22		33	6	97
Western Africa	297	133	44.8	59		209	13	470
East Africa	316	105	33.2	123		149	10	308
Southern Africa	57	23[3]	40.2	20		41	2	177
South Asia								
India	1208	546	45.2	206	109	222	10	753
Bangladesh	147	61	41.5	23	1	51	0	221
World total	6818	na	na	1453		2062	941	19 842
Sub-Saharan Africa and South Asia as percentage of world total	36.3	na	na	34.9		43.2	4.3	10.2

[1]FAO (2013).
[2]Living below $2 per day (Herrero *et al.* (2013).
[3]FAO (2013). Herrero *et al.* (2013) gave an estimate of 53 million poor livestock keepers in Southern Africa.

functioning, social and cultural factors – individually and in complex interactions – create specific local opportunities and constraints for livestock production (Poole *et al.*, 2013). The global importance, specificity and complex nature of livestock production in the tropics make the specialisation 'tropical livestock production' a relevant discipline within the Animal Sciences.

In recent times tropical livestock production has become more prominent in scientific and societal discourses for a number of reasons. First, in developing countries the consumers' demand for meat, milk and eggs has increased considerably and will continue to do so (Food and Agriculture Organization of the United Nations (FAO, 2009). Second, the contribution of livestock production in the tropics to global greenhouse gas emissions is high (FAO, 2006; de Vries and de Boer, 2009; Gerber *et al.*, 2011; Herrero *et al.*, 2011). Third, as many of the livestock keepers in the tropics are poor (Table 1) livestock improvement could lead to poverty alleviation (World Bank, 2007, 2009; Herrero *et al.*, 2013). See Supplementary Material S1 for background information about these drivers for change.

Scientific and policy literature in the field of tropical livestock production, explicitly or implicitly, presents an objective: to increase the intensity of livestock production in order to meet the increasing food demand; reduce the environmental impact of livestock production per unit animal product; and contribute to poverty alleviation (World Bank, 2007, 2009; McDermott *et al.*, 2010; Herrero *et al.*, 2013). Research and development, policy making and extension aiming to increase livestock production have been taking place since the middle of the twentieth century. However, sustained adoption of the intensification of livestock production has been relatively marginal, which led Sumberg (2002) to conclude: '[T]he... technologies have not been able to reliably and economically deliver benefits of interests to large numbers of African farmers'. Apparently, benefits perceived by others were insufficient in the farmers' perspective to intensify their production and commercialise their marketing, or, in other words, the aforementioned discourses are not clearly connected to the reality of livestock farmers. We may assume that the reality of smallholders is complex and what may be a benefit or cost in their complex reality is insufficiently understood by scientists, policy makers and development practitioners (Sumberg, 2002; Bernard and Spielman, 2009; Jayne *et al.*, 2010; Amankwah, 2013; Sumberg and Lankoandé, 2013). The present paper aims to highlight the possible and real discourses at the farmers' level – that is, to identify reasons why farmers in the tropics perceive intensification of livestock production on their farms not simply as a benefit but also as a pathway towards increased costs, such as dependency on inputs and reduced resilience. We do this by describing the generic effects of intensification on farm size, the roles and functions of livestock within farms and the risks associated with competition between value chains, and we illustrate this by means of a modelling study in which we show the potential effects of interventions on production, methane emissions and animal functions.

Tropical livestock production systems

In this section we will describe the global farming systems with livestock production (FAO, 2009).

Mixed-crop–livestock systems
Mixed-crop–livestock systems are small farming systems with crops and livestock. Smallholder mixed-crop–livestock systems have developed in regions with relatively good conditions for agriculture. Farm sizes can be small (often less than 1 ha due to division of land within families) because small plots still give sufficient yields to sustain the families living from it. This implies that the best lands are often in

smallholder regions where land has become a scarce resource. In less favourable regions, sizes of smallholder mixed-crop–livestock farms may be bigger, and land may be or seem less scarce. However, prospects for high production are also lower, because of these same unfavourable conditions. Smallholder mixed-crop–livestock systems often have an intensive land use, which is the cause for the strong interaction between crops and livestock (Tittonell *et al.*, 2010; Amankwah *et al.*, 2012). From the perspective of agro-ecology, the individual smallholder mixed-crop–livestock systems producing for the local markets can be regarded as elements of local ecosystems. In such local ecosystems, livestock contributes to cycling of nitrogen and phosphorus, contributes to crop production by its capital stock function and by supplying draught power and transport, and converts crop residues, household wastes and biomass of marginal lands to valuable food products (Udo *et al.*, 2011).

Herrero *et al.* (2010) estimated that with regard to animal-source food production in the tropics, 65% of beef, 75% of milk and 55% of lamb are produced in such mixed-crop–livestock systems. In Kenya, smallholder farmers in mixed-crop–livestock systems contribute about 60% to 70% of the national milk output (Bebe *et al.*, 2002; Omiti *et al.*, 2006; Omore *et al.*, 2009) and milk contributes 70% of the total livestock revenue (Behnke and Muthami, 2011; Onono *et al.*, 2012) and provides a livelihood to the majority of rural households.

Grazing systems
Grazing lands are found where conditions for crop production are unfavourable: where it is either too dry, too cold, too high or too steep for crop production. Pastoralist systems – that is systems in which ruminants and their herders follow the feed – are relatively efficient systems found in such areas (Ayantunde *et al.*, 2011). Following an increasing demand for crops, grazing lands are gradually being turned into crop land through irrigation and fertilisation. In addition, a trend towards increased settling of pastoralists is reported in West and East Africa (Sendalo, 2009; McCabe *et al.*, 2010).

Rangeland system is another form of grassland-based system, often characterised by an extensive form of beef production on big private properties reaching thousands of hectares. Productivity is low and intensification of rangeland production may occur through irrigation and fertilisation, but this may eventually result in turning the rangelands into crop lands (Kimani and Pickard, 1998; Ayantunde *et al.*, 2011).

Furthermore, smallholder mixed-crop–livestock systems may have a grazing component where grazing occurs on communal lands. Overgrazing is a big issue here (Hardin, 1968; Jones and Sandland, 1974; de Haan *et al.*, 1997; Kemp and Michalk, 2007) because of high and increasing stocking rates. An important aspect of communal grazing lands is the nutrient transfer from these soils to farm homesteads through grazing animals (Rufino, 2008). This is beneficial for crop production at the homestead, but detrimental for the soil fertility and productivity of the communal grazing lands in the long run.

Industrial systems
In and around urban areas, very intensive systems, referred to as industrial systems, are found with pig, poultry and dairy production. Such systems benefit from urban infrastructure, from nearby markets, from by-products of urban and peri-urban processing industries and from urban wastes as inputs. Direct land use of such systems is often limited because of high land prices in and around cities. Consequently, industrial systems are highly dependent on rural farming systems for inputs such as basal feeds and breeding stock. In addition, accumulation of nitrogen and phosphorus occurs in such systems and sustainable disposal is often a problem (Schiere and van der Hoek, 2001; Gerber *et al.*, 2005).

Scope for increased livestock production
Increased animal-source food production and the reduction of environmental impact and poverty are targets set for livestock production in the tropics.

Smallholder mixed-crop–livestock systems could largely contribute to these targets because of the following reasons: (1) there are many of them; (2) beneficiaries of these systems are poor (Table 1); (3) they already have an important contribution to food production; (4) they reside in high potential regions; and (5) they will remain the dominant farming system in the foreseeable future (Herrero *et al.*, 2010).

Industrial systems with pig and poultry production close to urban areas could contribute to these targets as they are systems with high resource use efficiency resulting in high food output for growing urban populations and low environmental impact per unit of production (FAO, 2006).

The grazing systems could contribute to these targets as they occupy considerable amounts of land and, therefore, a small improvement per hectare could easily result in high overall improvement. Constraints for improvement are severe, however. Pastoralist systems are found in the most unfavourable and marginal conditions and settlement of traditional pastoralist occurs for socio-cultural reasons (Sendalo, 2009; McCabe *et al.*, 2010; Ayantunde *et al.*, 2011).

The present paper will focus on mixed-crop–livestock systems as they are the largest contributors to livestock outputs and they constitute the majority of livestock-keeping households.

Interventions and scientific disciplines

To narrow the gaps between productivity achieved under temperate and tropical conditions Animal Sciences at first studied and introduced purely western technologies such as breeds, housing systems, veterinary services, and feeds and feeding management to the tropics. Introduction and development of veterinary services were relatively successful (Bosman *et al.*, 1996; Amankwah, 2013) and had a good cost–benefit ratio (e.g. Aklilu, 2007). However, many projects introducing other types of technologies failed in the short or long term (Poole *et al.*, 2013; Sumberg and Lankoandé, 2013). Mortality rates among imported full-bred animals were high (de Jong, 1996), and improved housing systems and improved

feeding practices were not widely adopted (Schiere, 1995; Bosman *et al.*, 1996; Mekoya *et al.*, 2008). In Kenya, close to 80% of cattle farmers in the highlands keep exotic breeds, mainly breeds with a larger body size, which are perceived as producing more milk (Bebe *et al.*, 2003a). So far, however, milk production per cow has remained relatively low and strategies to increase yields have not been adequately adopted (Bebe *et al.*, 2003b). For example, despite the fact that herd improvement through artificial insemination with superior semen and herd replacement by high-quality heifers could potentially improve the productivity of cows, these strategies are not widely practised (Bebe *et al.*, 2003a; Baltenweck *et al.*, 2004; Bebe, 2008).

It was realised that technologies had to be appropriate for tropical conditions, and research and development concentrated on appropriate technological development. Housing systems of local materials, (Bosman *et al.*, 1996) attention for traction (Gryseels, 1988), breeding with local cattle (Samdup *et al.*, 2010), local feeds (Mekoya *et al.*, 2008) and practices (Schiere, 1995; de Jong, 1996) and taking into account genotype–environment interactions (Frisch and Vercoe, 1978; Seré *et al.*, 2008) should increase adoption by getting technology closer to the context of farmers. However, such appropriate technologies alone or in packages are not believed to have high adoption rates if not accompanied by good markets and measures to overcome institutional barriers (Barrett, 2008; Gildemacher *et al.*, 2009; Hounkonnou *et al.*, 2012).

Therefore, economics and social science aspects were introduced into studies of tropical livestock production (e.g. Bosman *et al.*, 1996; Aklilu, 2007; Amankwah *et al.*, 2012; Sumberg and Lankoandé, 2013). Markets and value chains were studied as pull factors for production increase (e.g. Kilelu, 2013). Input supply, milk and meat markets, chain logistics and farmers' organisations were and are seen as important for development (e.g. the International Livestock Research Institute (ILRI), 2011; Kilelu, 2013). The Social sciences, studying institutions and stakeholders, claim that organisational structures and formal and informal rules associated with them stimulate or hamper developments (Gildemacher *et al.*, 2009; Hounkonnou *et al.*, 2012). Moreover, social aspects such as values and interests of stakeholders along the chain are regarded in the development process often through participative approaches (van Mierlo *et al.*, 2010).

This evolution in reasoning and in the actions taken in livestock (and other) development reflects the fact that tropical livestock production systems are complex and that they operate in complex environments. The literature on livestock production in the tropics by the authors mentioned in the previous sections reveals that most of them see the complex nature of tropical livestock systems and that they recommend interdisciplinary approaches to meet the objectives of development. However, the literature also reveals that the theoretical frameworks used within tropical livestock production research are the theoretical frameworks of the disciplines: that is, feeds, housing, breeding and health for animal sciences; markets and monetary flows for economics;

and structures and values for social sciences. The conclusions and solutions offered to overcome constraints are kept within the framework of each individual discipline. Some authors seek a more integrated approach: Poole *et al.* (2013) discussed the importance of local and individual context when it comes to commercialisation of smallholder agriculture; Pica-Ciamarra and Otte (2011) reported variation between regions with regard to the development of demand for animal-source food; Sumberg and Lankoandé (2013) demonstrated that just the supply of improved animals in an in-kind heifer scheme will not be the panacea for poverty; and Udo *et al.* (2011) concluded 'Without development policies that deliberately consider the opportunities and threats faced by mixed-crop – livestock farming households, many of these households are likely to be excluded from the increased market opportunities'.

In the next sections of the present paper we will present two approaches that allow for an integrated view on farming system development from the farm and farmers' perspective. The first one looks at the value chain–livestock farming system interaction and the second one is a more technical model linking feed quality and availability to maximal and actual production of a total herd.

Livestock value chains and dynamics

Development of a farming system does not happen in isolation. Farms are part of a value chain (here, broadly defined as the total chain of goods from input supply to a farm, through farm production, to market supply to the consumer via processing, marketing and retailing). We present here the so-called Livestock Value Chain Analytical Framework (LIVCAF). LIVCAF distinguishes four major livestock value chains, each associated with different production systems, roles and functions of animals within the production system, and constraints for development (see Table 2).

Dynamics

The LIVCAF framework in Table 2 is used to illustrate the implications of the transition from smallholder subsistence farms to (more) specialised and commercial livestock farms. The emphasis will be on the transition from the rural–rural value chain to the rural–urban value chain. The peri-urban–urban value chain and the import chain may compete with the rural–urban chain and affect smallholder transition to this chain. Transitions from the rural–rural value chain to peri-urban or export value chains are possible: a rural farm could become a peri-urban farm when cities expand and/or better roads make the city 'closer'; an export chain could develop, making local farmers producers for foreign urban markets. Production developments in such situations most likely follow the economic theory as most farms involved will already be commercial farms and will not be discussed in the present paper.

The rural–rural value chain is dominated by smallholder mixed-crop–livestock systems. The majority of world farmers operate in such systems and almost three billion people

Table 2 *Livestock value chains, associated livestock farming systems and constraints*

Chain (producer–consumer)	Dominant livestock production system	Level of inputs	Major limitations for development
Rural–rural	Mixed-crop–livestock systems often subsistence	Low	• Labour • Low priority given to livestock production
Rural–urban	Specialised systems[1]	Medium	• Land • Chain cooperation, infrastructure, logistics, knowledge
Urban–urban	(Peri-)urban intensive production	High	• Capital • Feed supply, water use, waste disposal
External–urban	High-input systems abroad		• Dependency on world market

[1]Pastoralism can be considered a system that can fluctuate between a subsistence system in lean years and a specialised, market-oriented system with high outputs in flush years.

depend on such systems for their food supply (Herrero *et al.*, 2010). Production is carried out in rural areas for the family. Local markets are the major outlet for surpluses and, more importantly, for selling livestock in times of emergency (Omiti *et al.*, 2009; Amankwah *et al.*, 2012). Such livestock outputs may reach urban markets but supply is irregular and of secondary importance for urban consumers. As stated before, livestock in mixed-crop–livestock systems supports crop production directly by delivering manure, traction and draught power. Indirect support from livestock for crop production is by serving as a capital store to be sold to buy seeds and fertilisers (Doumbia *et al.*, 2012) or for emergencies (Udo *et al.*, 2011; Amankwah *et al.*, 2012).

From the scientists' and development agents' perspectives such smallholder farms should achieve increased agricultural and livestock production. Technologies to increase production are available; the increasing demand for food creates good markets and we understand how farmers could overcome institutional constraints for innovation. However, it could be too easy to assume that the benefits of increased production and marketing will exceed increased monetary and non-monetary costs at the farm level.

First, production increase at a farm implies that the farm has to make a very drastic change with regard to the market they produce for. If more is produced than what the family can consume, farms will become market-oriented for part of their production, and if more than a few farms in a village increase their production local markets will become saturated. For perishable products such as milk and meat this market saturation often means a price reduction (Sharma *et al.*, 2003) and farms will have to aim at markets with a high demand, which are often in growing urban regions. Such urban market-oriented farms become part of the second value chain in Table 2: the rural–urban value chain. Farms in this value chain are more specialised than the ones in the rural–rural value chain, are market-oriented and they may follow the generic pattern as described by Whittaker (2000) for dairy development in New Zealand. At the moment, land availability limits the establishment of new farms (and this is the case in many tropical regions); a part of the existing farms expand at the expense of others (hence, farm enlargement and reduction in the number of farms) with a

concomitant increase in the production per animal and per hectare. As a consequence, tropical farms with livestock production for urban markets are, compared with non-market-oriented farms, often bigger and obtain higher per-animal productivity through higher use of inputs, including external labour, land and capital (Tittonell *et al.*, 2010; Jayne *et al.*, 2010; Doumbia *et al.*, 2012; Amankwah, 2013). Inevitably, such farms are more specialised.

Second, the transition of livestock production from the informal rural–rural value chain to the rural–urban value chain implies that transport, processing and retail become important steps between a farmer and consumers. However, all stakeholders in these steps will want to take their share of the economic benefit, which may cause farm-gate prices in the rural-urban value chain to be lower than at local markets despite the higher consumer prices (Sharma *et al.*, 2003; Omore *et al.*, 2009). Moreover, product quality demands in the rural–urban value chain are higher than in the rural–rural value chain because of processing requirements, the longer time span between production and consumption, and consumer preferences.

A third reason that limits the possibilities for smallholders to enter the rural–urban chain with increased livestock production is competition. Within farms, crop commercialisation competes with livestock commercialisation. Many smallholder crop–livestock producers already have a market-oriented crop, such as dry-season vegetables (Amankwah *et al.*, 2012), coffee (Oosting *et al.*, 2011) and rice (Doumbia *et al.*, 2012). Livestock supports the production of these crops by supply of manure, transport and draught, and by acting as a capital store. Commercialisation of livestock production will at least partly affect these crop-supporting functions of livestock by demanding its share of available land, labour and credits.

A second competition for livestock is at the urban markets. As Table 2 illustrates, the peri-urban–urban chain produces predominantly for the urban markets. Peri-urban production may have comparative advantage over rural production because of economics of scale, better infrastructure for inputs and outputs, and better connection with urban markets. Imports also compete with rural products at urban markets; imports of chicken legs and wings, cheap because they are the least preferred parts in the region of origin (the EU), are

considered a major obstacle for poultry production development in Senegal, Ghana and the Ivory Coast (Dieye *et al.*, 2007) even for production by peri-urban farms (Mahama *et al.*, 2013).

It should be stated that chains may also benefit from each other: The Indian National Dairy Development Board used gains made on reconstituted milk from imports of cheap milk powder to support local milk production by smallholders (Candler and Kumar, 1998), and feed required by peri-urban livestock farming systems may open a new market horizon for rural smallholders.

From the previous section it can be concluded that livestock production increase is a big step for smallholders as it implies internal changes within the farm, and production for new markets in new value chains with different price settings and different quality demands. It can be questioned whether such big steps are easily made, especially because they affect the way in which farms have to deal with perturbations (external and internal disturbances of the system – e.g. drought, floods, diseases, competition, wars, etc.). The smallholder mixed-crop–livestock farms in the rural–rural value chain are resilient when judged on their ability to retain the functionality of providing livelihood to families in times of perturbations because of the following reasons: (1) the diversity of farm activities and magnitude of the livestock herd or flock; (2) the low dependency on inputs; (3) the low dependency of farm activities on inputs derived from other farm activities (referred to as interdependency); and (4) the low dependency on markets (Dahl and Hjort, 1976; Kitano, 2004; Ten Napel *et al.*, 2011). Farms in the rural–urban value chain became specialised and consequently less diverse, and acquired more dependency within the farm (e.g. where feed crops are grown for livestock, if one of the two activities fails, both fail) and within value chains, with regard to availability, prices and quality requirements. Such specialised farms may be robust in times of perturbations, but they have to take institutional or technological measures to prevent perturbations to affect the system – for example, irrigation to prevent droughts; housing systems to protect livestock against climate, diseases and predators; creation of external feed supply chains to assure feed supply; and disease prevention measures. If such measures fail, such farms should be well insured to avoid a total collapse of the system (Ten Napel *et al.*, 2011).

The transition process is not a gradual process (Sharma *et al.*, 2003; Udo *et al.*, 2011). A subsistence smallholder farm could keep a relatively small number of animals (up to 20 to 30 chickens) without investments. A larger number of animals requires investments in housing, feed and veterinary inputs and many more animals should be kept to cover the investment costs (Aklilu, 2007). Hence, the transition of rural–rural to the rural–urban value chain can be considered a system jump.

Tittonell *et al.* (2010) described three pathways for the dynamics of smallholder crop–livestock farmers: (1) market orientation (2) increasing dependency on off-farm income or (3) marginalisation. These pathways were characterised by Dorward *et al.* (2009) as stepping up, stepping out and

hanging in, respectively. Resource endowment, which could be the cause or effect of a stronger market orientation, was better for market-oriented farmers. Doumbia *et al.* (2012) illustrated such a pattern for Mali. Rice farmers with better resource endowment – for example, a cattle herd that provided manure, cash and traction animals – had a relatively good position in rice production, whereas those lacking livestock had to rely on working off-farm with a marginalised income from crop production.

The question is whether the process of increased market orientation could occur to all farmers in a community concomitantly. As the theory of Dorward *et al.* (2009) and results of Tittonell *et al.* (2010) and Doumbia *et al.* (2012) show, it is likely that a fraction of farmers will step up and that a portion will remain where they are – that is, hang in or (at least partly) step out. Developments in non-tropical regions, where the number of farms reduced drastically (Whittaker, 2000), suggest that production increase is associated with diminishing farm number and farm enlargement as a result of the need for economics of scale. Hence, developing farmers will be a pull factor on the labour and land of marginalised farmers. As a consequence, in the long term a considerable part of the smallholders in a village will not be part of the development: a part of them will have to become labourers in their community or migrate to urban areas to find employment (Jayne *et al.*, 2010; Tittonell *et al.*, 2010; Udo *et al.*, 2011).

Farm-level perspective

In the next section an approach is presented that studies the whole herd rather than individual animals and contributes to understanding the farmers' perspective with regard to animal breeding, feed improvement and the valuation of non-production functions of animals.

If availability of high-quality feeds is limiting livestock production, such high-quality feeds are imported. This is especially true in the west. In most tropical regions, however, export of high-quality feeds is more likely than imports; for the vast majority of production systems in developing countries it can be stated that livestock production follows feed availability. Feeding according to the animals' requirements is not common practice (Schiere, 1995).

This was modelled for dairy production in a small (virtual) region with a total annual availability of 1000 tonnes of feed dry matter (DM) on the basis of information from studies by Zemmelink *et al.* (2003) and Abegaz *et al.* (2007). This availability of feeds determines livestock production. Dairy is presented here as a representative example for ruminant production; modelling for beef, sheep or goat production revealed similar conclusions.

The assumption is that the total feed base consists of 10 equal quantities of 100 tonnes of DM, referred to as class 1 for the best feeds up to class 10 for the worst feeds (see Table 3).

At a low stocking rate (defined as the number of dairy cows relative to the total feed base), cows can select or be

Table 3 *Regional availability and quality of feed*

Feed class	Availability (tonnes dry matter/year)	Examples[1]	Organic matter digestibility (g/kg)	CP (g/kg)
1	100	Cereals, concentrates	850	200
2	100	Improved fodder trees, fodder crops	720	170
3	100	Local fodder crops, improved grass species, polishings of wheat and rice	620	160
4	100	Medium-quality grass	550	140
5	100	Good-quality coarse stovers, low-quality grass	500	100
6	100	Medium-quality coarse stovers, good-quality slender straws	450	70
7	100	Low-quality coarse stovers, medium-quality slender straws, tree leaves	400	50
8	100	Low-quality slender straws	350	45
9	100	Standing straw	300	40
10	100	Twigs, barks	250	30

[1]Adapted from Zemmelink *et al.* (2003) and Abegaz *et al.* (2007).

given the best-quality feeds. With an increasing number of cows, more feed classes need to be included in the diet and the (mixed) diet's quality will decrease with decreasing individual animal production (Figure 1a), an increasing herd size maintained on the feed base (Figure 1b) and a curvilinear relationship with total herd production (which equals herd size times production per animal; Figure 1c). Intake and dairy production were modelled for cows of 400 kg on the basis of studies by Ketelaars and Tolkamp (1992) and Zemmelink *et al.* (2003).

Figure 1c shows maximal herd output when up to class 4 feeds are being utilised. Inclusion of more feeds in the diet (and feeding more animals) reduced the total herd output. In the present modelling study we estimated maximal herd output to be 1419 kg milk/day when up to class 4 feeds were used and fed to a herd of 167 cows.

The first implication of Figures 1a to 1c is that maximal herd output in a situation of fixed feed availability is not achieved at the highest production per individual animal. This implies that genotype–ration-quality interactions may be of importance. Selection of breeds and genotypes within breeds with highest performance on high-quality diets might perform worse than other genotypes at the feed quality for maximal total herd output.

A second implication is that meeting non-production functions of animals goes at the expense of total herd output. Using a similar modelling approach, Zemmelink *et al.* (2003) and Abegaz *et al.* (2007) observed for regions in Indonesia and Ethiopia, respectively, herds with many more animals than the herd size for maximum production. If we, in the present example, assume that up to class 7 feeds are fed in order to maintain more animals to meet non-production functions such as manure production, traction and transport and capital store (all of which are favoured by a high number of animals) then 347 animals can be maintained with a total output of 875 kg of milk/day. Hence, 514 kg of milk is sacrificed to support 180 additional animals, and benefits of non-production functions are equivalent to at least the value of 514 kg of milk/day. The estimate of the value of non-production functions could be higher if monetary values

are given to the non-production functions of livestock, as suggested by Moll (2005).

A third implication is the effect of feed improvement. Feed improvement can be achieved by treatment of low-quality feeds or by introduction of better feeds (Gerber *et al.*, 2011; Hristov *et al.*, 2013). In the present example we elaborate the effect of treatment with low-quality feeds. Sarnklong *et al.* (2010) reviewed options for treatment with rice straw. The rice straw in their paper is representative of low-quality grass and crop residue, say for feeds in classes 5 up to 8 in Table 3. Chemical treatments (e.g. urea, ammonia or NaOH) and biological treatments (by growing fungi on the straw or by administering fungal enzymes to the straw) all aim to improve straw digestibility by loosening the cell wall structure and making the hemicellulose and cellulose fractions more readily available for rumen digestion. Urea treatment is the most propagated treatment in developing countries. The low-quality feed is mixed with an equal weight of a 0.5% to 3% urea solution and stored under airtight conditions for at least a week. Ammonia will be formed from the urea and the alkaline conditions will affect cell wall confirmation and improve intake and digestibility. An additional benefit is the provision of nitrogen through the treatment.

The effect of treatment is negatively related to the quality of the feed – that is, absolute and relative treatment effects were higher for lower than for higher quality feeds and effects are negligible above an organic matter digestibility (OMD) of 550 g/kg (based on Oosting, 1993). For the modelling study it was assumed that ammonia, urea, NaOH and biological treatments yielded similar effects on OMD.

These principles were applied to the feed classes of Table 3 – that is, only feed classes 5 and higher were treated and treatment effect was higher for the lowest (class 10) feeds (OMD going from 250 to 400 g/kg) than for the class 5 feeds (OMD from 500 to 530 g/kg). The effects are presented as solid lines in Figures 1 and 2. Treatment improved milk production of individual animals and the optimum feed inclusion for total herd production changed from class 4 to class 5 at almost the same output level. The major effect was that more animals could be kept without a reduction in milk
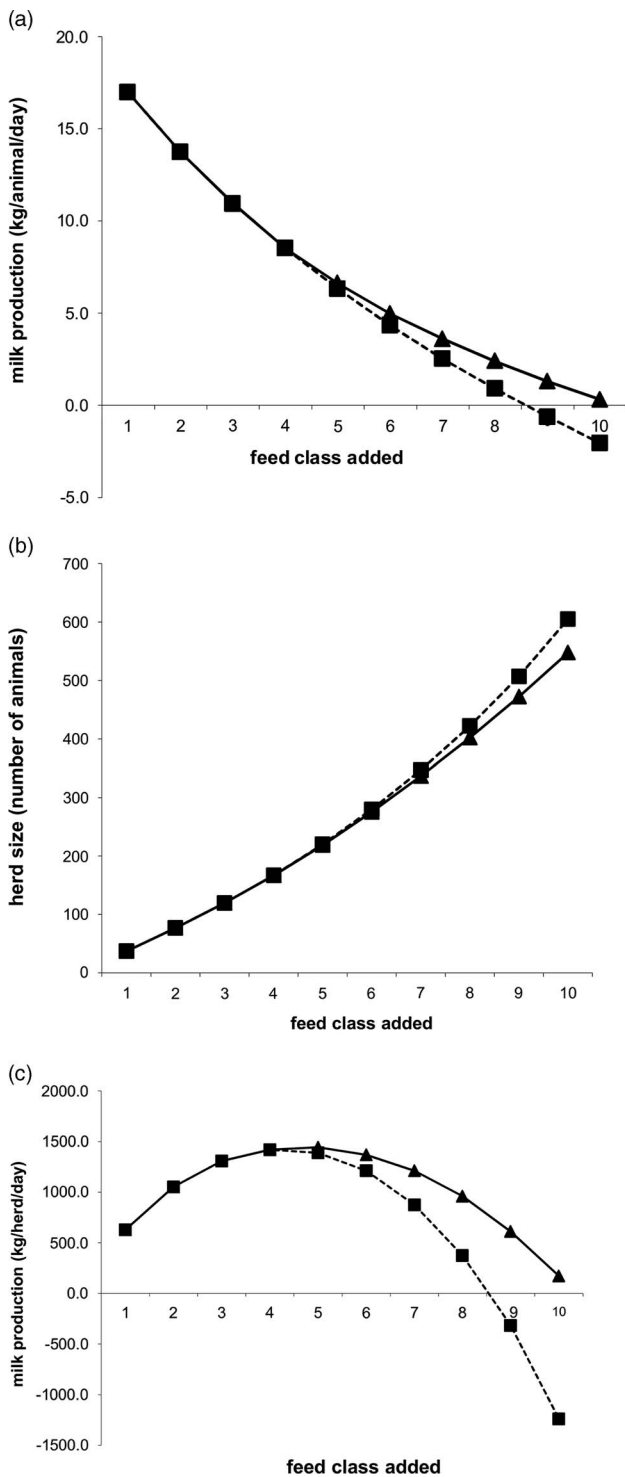
(a)

(b)

(c)

Figure 1 Effect of inclusion of feeds of different quality in the diet (class 1 is the best, class 10 is the worst) on individual daily milk production (a), herd size (b) and total herd daily milk production (c) for untreated (dotted line, squares) and treated (e.g. by urea or ammonia) feeds in class 5 up to 10 (straight line, triangles).

(a)

(b)

Figure 2 Methane emissions for the total herd (a) and per kg of milk produced (b) for untreated (dotted line, squares) and treated (e.g. by urea or ammonia) low-quality feeds (straight line, triangles).

output. In our example, even some of the class 9 feeds could be fed after treatment, maintaining a total herd output of 875 l, by almost 450 animals.

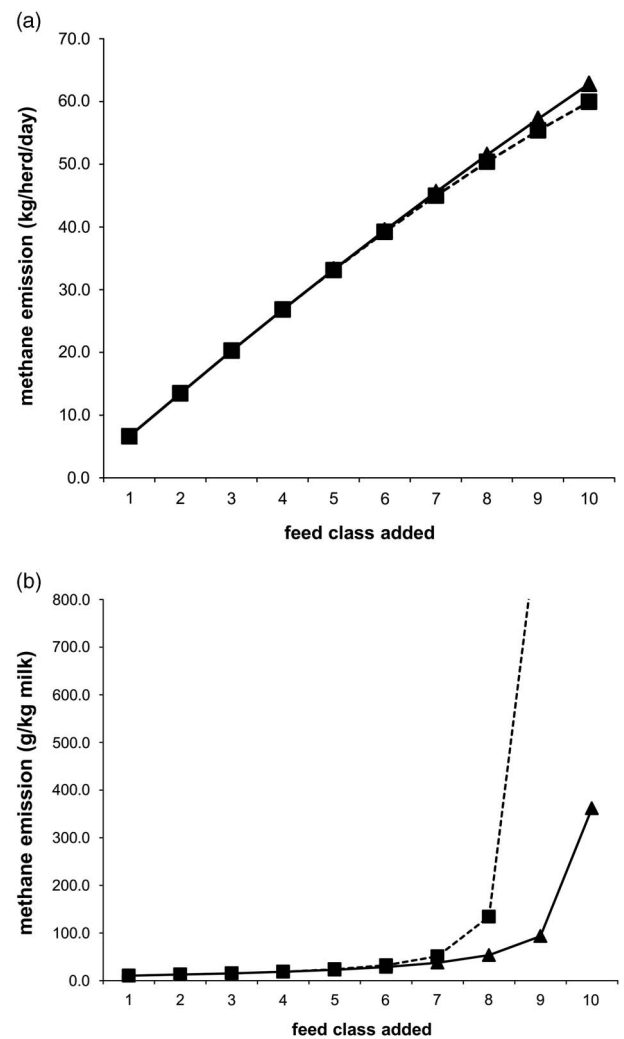Economics, labour needs and practical feasibility (e.g. fungal treatment is promising on laboratory scale, but process control is difficult in piles of material because of fermentation heat) have made adoption of treatments poor (Schiere, 1995). Roy and Rangnekar (2006) described one successful case of urea treatment in India, where treatment helps farmers overcome storage problems in humid conditions.

A fourth implication is the study of methane emissions. Enteric methane emissions were estimated on the basis of the models of Commonwealth Agricultural Bureaux (ARC) (1980) and Oosting *et al.* (1993) assuming a linear decrease in methane energy produced as a fraction of digestible energy intake (DEI) with increasing quality of the diet (i.e. methane varying from 120 J/kJ DEI for the poorest feed (class 10) to 75 J/kJ DEI for the best feed (class 1)). Increasing inclusion of lower quality feeds resulted in an almost linear increase in methane emissions from the herd (Figure 2a) and in an exponential increase in methane emissions per kg of milk (Figure 2b). Treatment (the solid lines in Figures 1 and 2) had only marginal direct effects on methane emissions. However, the indirect effect through milk production increase is obvious (see Figure 2b).

For the diet with the highest herd production (up to class 4 included), methane emissions were 18.9 g/kg of milk, and with the inclusion of feeds up to class 7 in order to feed a multi-functional herd the emissions were estimated to be 51.4 g/kg of milk. In the latter case, a part of the emissions should be attributed to the non-production functions of livestock. Earlier, we concluded that the economic benefit of the non-production functions was at least equivalent to 514 kg of milk/day. Thus, a fraction (equal to *production sacrificed/total potential production* = 514/1419) of 0.36 should be attributed to the non-production functions. The outcome is that 32.8 g CH_4/kg of milk is the methane emission attributable to the milk production. These estimates are much lower than those by Gerber *et al.* (2011), but still higher than estimates for the Netherlands of 12 to 13 g CH_4 emissions/kg of milk (De Haas *et al.*, 2011). Nevertheless, Figure 2b shows that reduction in stocking rates will reduce methane emissions per kg of milk produced. This mitigation option is highly recommended as it is also beneficial for livestock output (Figure 1c) and it lowers the impact of livestock production on nature, water and other agricultural land use.

Decreasing herd size will occur only if the benefits outweigh the costs of losing non-production functions. Hence, artificial fertilisation, short- and long-term financial institutions and mechanisation should become available reliably and at low cost (Udo *et al.*, 2011). Regulatory measures (taxes and quota) could reduce the benefits of keeping many animals.

If the non-production livestock functions could partly be replaced by technology and institutions (the aforementioned artificial fertilisation, short- and long-term financial institutions and mechanisation), then whole farm production increase could go along with strengthened agro-ecological values: less livestock would imply less pressure on lands with increased food security and income. Nevertheless, there will be the need to find balances between intensification of crop and livestock production on the one hand and the agro-ecological health of farming systems on the other. Trade-offs between intensification and agro-ecological values should be analysed and understood. Hence, it is a challenge for tropical livestock production research to find ways to deal with issues such as undesired loss of biodiversity – for example, when local breeds are replaced by high-producing exotic ones; social changes when farm intensification leads to fewer farms; and threatened resilience of farming systems when technologies and institutions fail in times of crisis.

Conclusion

The present review presented two approaches for analysis of the farm perspective of production improvement. Both show that the presumed generic drivers for livestock development – increasing demand for animal-source products and desire of smallholders to escape from poverty – meet important barriers at the farm and value chain level. The LIVCAF framework sheds light on constraints for commercialisation, such as the inevitable change of the subsistence-oriented farming system, with its mechanisms of resilience, into a

more specialised, land-requiring urban market-oriented farming system, which has to deal with lower prices, more competition and higher-quality demands. Moreover, there is only limited scope for a gradual shift from subsistence to commercial. Benefits of such transition will first meet mountains of monetary and non-monetary costs, which may explain, at least partly, the resistance to adoption.

The modelling study showed that limited feed availability affects breeding objectives and feed improvement. The model gives a tool for quantifying the contribution of non-monetary functions to a farmer or a farming community. Farmers sacrifice production in order to maintain other functions of cattle. Zemmelink *et al.* (2003), Abegaz *et al.* (2007), Budisatria *et al.,* (2007) and Udo *et al.* (2011) all argue that farmers optimise on the basis of maximal output of all functions combined and not on milk or meat production alone.

Both approaches presented in this paper focus on the farming system as a whole. The outcomes complement those of constraint studies on the level of inputs, markets and institutions.

References

Abegaz A, van Keulen H and Oosting SJ 2007. Feed resources, livestock production and soil carbon dynamics in Teghane, Northern Highlands of Ethiopia. Agricultural Systems 94, 391–404.

Aklilu HA 2007. Village poultry in Ethiopia. PhD, Wageningen University, Wageningen, the Netherlands.

Amankwah K 2013. Enhancing food security in northern Ghana through smallholder small ruminant production. PhD, Wageningen University, Wageningen, the Netherlands.

Amankwah K, Klerkx L, Oosting SJ, Sakyi-Dawson O, van der Zijpp AJ and Millar D 2012. Diagnosing constraints to market participation of small ruminant producers in northern Ghana: an innovation systems analysis. NJAS Wageningen Journal of Life Sciences 60–63, 37–49.

Ayantunde A, de Leeuw J, Turner MD, Said M 2011. Challenges of assessing the sustainability of (agro)-pastoral systems. Livestock Science 139, 30–43.

Baltenweck I, Ouma R, Anunda F, Mwai O and Romney D 2004. Artificial or natural insemination: the demand for breeding services by smallholders. Proceedings of 9th KARI Biennial Scientific Conference and Research week. 8 to 12 November, Nairobi, Kenya, pp. 1 – 11.

Barrett CB 2008. Smallholder market participation: concepts and evidence from eastern and southern Africa. Food Policy 33, 299–317.

Bebe BO 2008. Dairy heifer rearing under increasing intensification of smallholder dairy systems in the Kenya highlands. Livestock Research for Rural Development 20. article no. 23.

Bebe BO, Udo HMJ and Thorpe W 2002. Development of smallholder dairy systems in the Kenya highlands. Outlook on Agriculture 31, 113–120.

Bebe BO, Udo HMJ, Rowlands GJ and Thorpe W 2003a. Smallholder dairy systems in the Kenya highlands: breed preferences and breeding practices. Livestock Production Science 82, 117–127.

Bebe BO, Udo HMJ, Rowlands GJ and Thorpe W 2003b. Smallholder dairy systems in the Kenya highlands: cattle population dynamics under increasing intensification. Livestock Production Science 82, 211–221.

Behnke R and Muthami D 2011. The contribution of livestock to the Kenyan economy. IGAD LPI working paper No. 03-11. Odessa Centre, Great Wolford, UK. Retrieved August 19, 2013, from http://www.igad-lpi.org/publication/docs/IGADLPI_WP03_11.pdf

Bernard T and Spielman DJ 2009. Reaching the rural poor through rural producer organizations? A study of agricultural marketing cooperatives in Ethiopia. Food Policy 34, 60–69.

Bosman HG, Ayeni AO and Koper-Limbourg HAG 1996. Farmers' response to a package of innovations in goat production in south-west Nigeria. Tropical Science 36, 92–100.

Budisatria IGS, Udo HMJ, CHAM Eilers and van der Zijpp AJ 2007. Dynamics of small ruminant production: a case study of central Java, Indonesia. Outlook on Agriculture 36, 145–152.

Candler W and Kumar N 1998. India: the dairy revolution. The impact of dairy development in India and the World Bank's contribution. The World Bank, Washington, DC, USA.

Commonwealth Agricultural Bureaux (ARC) 1980. The nutrient requirements of ruminant livestock. Commonwealth Agricultural Bureaux, Slough, UK.

Dahl G and Hjort A 1976. Having herds. Pastoral herd growth and household economy. Department of Social Anthropology, University of Stockholm, Sweden.

De Haan C, Steinfeld S and Blackburn H 1997. Livestock & the environment. Finding a balance. Food and Agriculture Organisation, Rome, Italy.

De Haas Y, Calus M, Mulder H, de Haan M, Bannink A, Dijkstra J, Windig J and Veerkamp R 2011. Gensignalen voor voerefficiëntie en methaanemissie. Rapport 450. Wageningen UR Livestock Research, Lelystad, the Netherlands.

De Jong R 1996. Dairy stock development and milk production with smallholders. PhD, Wageningen University, Wageningen, the Netherlands.

De Vries M and de Boer IJM 2009. Comparing environmental impacts of livestock products: a review of life cycle assessments. Livestock Science 128, 1–11.

Dieye PN, Duteutre G, Cuzon J-R and Dia D 2007. Livestock, liberalization and trade negotiations in West Africa. Outlook on Agriculture 36, 93–99.

Dorward A, Anderson S, Nava Y, Pattison J, Paz R, Rushton J and Sanchez Vera E 2009. Hanging in, stepping up and stepping out: livelihood aspirations and strategies of the poor. Development in Practice 19, 240–247.

Doumbia D, van Paassen A, Oosting SJ and van der Zijpp AJ 2012. Livestock in the rice-based economy of Office du Niger: the development potential for increased crop-livestock integration through multi-actor processes. NJAS Wageningen Journal of Life Sciences 60–63, 101–115.

Food and Agriculture Organization (FAO) 2006. Livestock's long shadow. Environmental issues and options. Food and Agriculture Organization, Rome, Italy.

FAO 2009. The state of food and agriculture – livestock in the balance. Food and Agriculture Organization, Rome, Italy.

FAO 2013. FAOSTAT. Food and Agriculture Organization, Rome, Italy. Retrieved June to September 2013, from http://faostat3.fao.org/faostat-gateway/go/to/home/E

Frisch JE and Vercoe JE 1978. Utilizing breed differences in growth of cattle in the tropics. World Animal Review 25, 8–12.

Gerber P, Chilondra P, Franceschini G and Menzi H 2005. Geographical determinants and environmental implications of livestock production intensification in Asia. Bioresource Technology 96, 263–276.

Gerber P, Vellinga T, Opio C and Steinfeld H 2011. Productivity gains and greenhouse gas emissions intensity in dairy systems. Livestock Science 139, 100–109.

Gildemacher PR, Kaguongo W, Ortiz O, Tesfaye A, Woldegiorgis G, Wagoire WW, Kakuhenzire R, Kinyae PM, Nyongesa M and Struik PC 2009. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Research 52, 173–205.

Gryseels G 1988. Role of livestock on mixed smallholder farms in the Ethiopian highlands. A case study from the Baso and Worena Wereda near Debre Berhan. PhD, Wageningen University, Wageningen, the Netherlands.

Hardin G 1968. The tragedy of the commons. Science 162, 1243–1248.

Herrero M, Grace D, Njuki J, Johnson N, Enahoro D, Silvestri S and Rufino MC 2013. The roles of livestock in developing countries. Animal 7, 3–18.

Herrero M, Gerber P, Vellinga T, Garnett T, Leip A, Opio C, Westhoek HJ, Thornton PK, Olesen J, Hutchings N, Montgomery H, Soussana J-F, Steinfeld H and McAllister TA 2011. Livestock and greenhouse gas emissions: the importance of getting the numbers right. Animal Feed Science and Technology 166–167, 779–782.

Herrero M, Thornton PK, Notenbaert AM, Wood S, Msangi S, Freeman HA, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Parthasarathy Rao P, Macmillan S, Gerard B, McDermott J, Seré C and Rosegrant M 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science 327, 822–825.

Hounkonnou D, Kossou D, Kuyper TW, Leeuwis C, Nederlof ES, Röling N, Sakyi-Dawson O, Traoré M and van Huis A 2012. An innovation systems approach to institutional change: smallholder development in West Africa. Agricultural Systems 108, 74–83.

Hristov AN, Oh J, Lee C, Meinen R, Montes F, Ott T, Firkins J, Rotz A, Dell C, Adesogan A, Yang W, Tricarico J, Kebreab E, Waghorn G, Dijkstra J and Oosting SJ 2013. Mitigation of greenhouse gas emissions in livestock production – a review of technical options for non-CO$_2$ emissions. In FAO animal production and health paper No. 177. FAO, Rome, Italy.

Jayne TS, Mather D and Mghenyi E 2010. Principal challenges confronting smallholder agriculture in Sub-Saharan Africa. World Development 10, 1384–1398.

Jones RJ and Sandland RL 1974. The relation between animal gain and stocking rate − derivation of the relation from the results of grazing trials. The Journal of Agricultural Science 83, 335–342.

Kemp DR and Michalk DL 2007. Towards sustainable grassland and livestock management. Journal of Agricultural Science 145, 543–564.

Ketelaars JJMH and Tolkamp BJ 1992. Towards a new theory of feed intake regulation in ruminants. 1. Causes of differences in voluntary intake: critique of current views. Livestock Production Science 30, 269–296.

Kilelu CW 2013. Unravelling the role of intervention intermediaries in smallholder agricultural development: case studies from Kenya. PhD, Wageningen University, Wageningen, the Netherlands.

Kimani K and Pickard J 1998. Recent trends and implications of group ranch subdivision and fragmentation in Kajiado district, Kenya. Geographical Journal 164, 202–213.

Kitano H 2004. Biological robustness. Nature Review Genetics 5, 826–837.

Mahama EA, Andah EK, Amegashie DPK and Mensah-Bonsu A 2013. Break even analysis of broiler production in the Accra-Tema and Kumashi areas. Proceedings 1st International Interdisciplinary Conference, 24 to 26 April, Azores, Portugal. Retrieved September 27, 2013, from http://eujournal.org/index.php/esj/article/view/1492

McCabe JT, Leslie PW and DeLuca L 2010. Adopting cultivation to remain pastoralists: the diversification of Maasai livelihoods in Northern Tanzania. Human Ecology 38, 321–334.

McDermott JJ, Staal SJ, Freeman HA, Herrero M and van der Steeg JA 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livestock Science 130, 95–109.

Mekoya A, Oosting SJ, Fernandez-Rivera S and van der Zijpp AJ 2008. Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. Agroforestry Systems 73, 141–153.

Moll H 2005. Costs and benefits of livestock systems and the role of market and non-market relationships. Agricultural Economics 32, 181–193.

Omiti JM, Otieno DJ, Nyanamba TO and McCullough E 2009. Factors influencing the intensity of market participation by smallholder farmers: a case study of rural and peri-urban areas of Kenya. Afjare 3, 57–82.

Omiti JM, Wanyoike F, Staal S, Delgado C and Njoroge L 2006. Will small-scale dairy producers in Kenya disappear due to economics of scale in production? Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, 12 to 18 August, Gold Coast, Australia, Retrieved October 1, 2013, http://ageconsearch.umn.edu/bitstream/25674/1/cp060516.pdf

Omore A, Kurwijila L and Grace D 2009. Improving livelihoods in East Africa through livestock research and extension: reflections on changes from the 1950s to the early twenty first century. Tropical Animal Health and Production 41, 1051–1059.

Onono JO, Wieland B and Rushton J 2012. Productivity in different cattle production systems in Kenya. Tropical Animal Health and Production 45, 1–8.

Oosting SJ 1993. Wheat straw as ruminant feed. Effect of supplementation and ammonia treatment on voluntary intake and nutrient availability. PhD, Wageningen University, Wageningen, the Netherlands.

Oosting SJ, Boekholt HA, Los MHM and Leffering CP 1993. Intake and utilization of energy from ammonia treated and untreated wheat straw by steers and wether sheep fed a basal ration of grass pellets and hay. Animal Production 57, 227–236.

Oosting SJ, Mekoya A, Fernandez-Rivera S and van der Zijpp AJ 2011. *Sesbania sesban* as a fodder tree in Ethiopian livestock farming systems: feeding practices and farmers' perceptions of feeding effects on sheep performance. Livestock Science 139, 135–142.

Pica-Ciamarra U and Otte J 2011. The 'livestock revolution': rhetoric and reality. Outlook on Agriculture 40, 7–19.

Poole ND, Chitundu M and Msoni R 2013. Commercialisation: a meta-approach for agricultural development among smallholder farmers in Africa? Food Policy 41, 155–165.

Roy S and Rangnekar DV 2006. Farmer adoption of urea treatment of cereal straws for feeding of dairy animals: a success in Mithala milkshed, India. Livestock Research for Rural Development 18. article no. 8.

Rufino MC 2008. Quantifying the contribution of crop-livestock integration to African farming. PhD, Wageningen University, Wageningen, the Netherlands.

Samdup T, Udo HMJ, CAHM Eilers, Ibrahim MNM and van der Zijpp AJ 2010. Crossbreeding and intensification of smallholder crop–cattle farming systems in Bhutan. Livestock Science 132, 126–134.

Sarnklong C, Cone JW, Pellikaan W and Hendriks W 2010. Utilization of rice straw and different treatments to improve its feed value for ruminants: a review. Asian-Australasian Journal of Animal Sciences 23, 680–692.

Schiere JB 1995. Cattle, straw and system control: a study of straw feeding systems. PhD, Wageningen University, Wageningen, the Netherlands.

Schiere JB and van der Hoek R 2001. Livestock keeping in urban areas. A review of traditional technologies based on literature and field experience. FAO animal production and health paper No. 151. FAO, Rome, Italy.

Sendalo ED 2009. Understanding socio-economic dynamic of Maasai pastoralists under changing ecological and policy environment in Tanzania. Thesis, Animal Production Systems Group, Wageningen University, the Netherlands.

Seré C, van der Zijpp AJ, Persley G and Rege E 2008. Dynamics of livestock production systems, drivers of change and prospects for animal genetic resources. Animal Genetic Resources Information 42, 3–24.

Sharma VP, Staal S, Delgado C and Singh RV 2003. Policy, technical, and environmental determinants and implications of the scaling-up of milk production in India. Annex III. Research Report of IFPRI-FAO. International Food Policy Research Institute, Washington DC.

Sumberg J 2002. The logic of fodder legumes in Africa. Food Policy 27, 285–300.

Sumberg J and Lankoandé GD 2013. Heifer-in-trust, social protection and graduation: conceptual issues and research questions. Development Policy Review 31, 255–271.

Ten Napel J, van der Veen AA, Oosting SJ and Groot Koerkamp PWG 2011. A conceptual approach to design livestock production systems for robustness to enhance sustainability. Livestock Science 139, 150–160.

Tittonell P, Muriuki A, Shepherd KD, Mugendi D, Kaizzi KC, Okeyo J, Verchot L, Coe R and Vanlauwe B 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – a typology of smallholder farms. Agricultural Systems 103, 83–97.

The International Livestock Research Institute (ILRI) 2011. More meat, milk and fish by and for the poor. Retrieved October 8, 2013, from http://cgspace.cgiar.org/bitstream/handle/10568/3248/CRP37Proposal.pdf?sequence=6

Udo HMJ, Aklilu HA, Phong LT, Bosma RH, Budisatria IGS, Patil BR, Samdup T and Bebe BO 2011. Impact of intensification of different types of livestock production in smallholder crop-livestock systems. Livestock Science 139, 22–30.

Van Mierlo B, Regeer B, van Amstel M, Arkesteijn M, Beekman V, Bunders J, de Cock Buning T, Elzen B, Hoes A-C and Leewis C 2010. Reflexive monitoring in action. A guide for monitoring system innovation projects. Communication and innovation studies Wageningen University. Athena Institute Free University, Amsterdam, the Netherlands.

Whittaker WG 2000. One hundred years of herd improvement and farm management systems in New Zealand 1900-2000. Livestock Improvement Corporation, Hamilton, New Zealand.

World Bank 2007. World development report 2008: agriculture for development World Bank, Washington, DC. Retrieved August 18, 2013, from http://siteresources.worldbank.org/INTWDRS/Resources/477365-1327599046334/8394679-1327606607122/WDR_00_book.pdf

World Bank 2009. Awakening Africa's sleeping giant: prospects for commercial agriculture in the Guinea savannah zone and beyond World Bank, Washington, DC. Retrieved August 18, 2013, from http://siteresources.worldbank.org/INTARD/Resources/sleeping_giant.pdf

Zemmelink G, Ifar S and Oosting SJ 2003. Optimum utilization of feed resources: model studies and farmers' practices in two villages in East Java, Indonesia. Agricultural Systems 76, 77–94.