Global Food Security 17 (2018) 103–112

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Trade-offs in livestock development at farm level: Different actors with different objectives

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ARTICLE INFO

Keywords:
Trade-offs
Livestock systems
Sustainable intensification
Smallholders
Decision making

ABSTRACT

The livestock sector in Low and Middle Income Countries (LMICs) is evolving. In response to growing demand for livestock products, it is likely that smallholder production systems will experience varying forms of intensification. Associated decision making is made complex, not only with the intrinsic characteristics of livestock in LMICs (for instance as sources of income, assets, or social symbols), but also by diverse objectives of stakeholders and agricultural development paradigms. This paper discusses trade-offs that are likely to arise in the choice of livestock production systems; with a focus at household and farm level, economic gains, gender equity, environmental concerns, human nutrition and food safety are all considered. We begin by describing trajectories of livestock intensification in LMICs. Then potential trade-offs during such intensification are depicted; with examples concerning environmental, economic and social aspects. Recognising and understanding trade-offs is imperative; therefore we discuss decision making methods, the management of trade-offs and the balance between providing an average benefit for a population and the variation in benefit for individuals. Finally, a (partial) trade-off analysis is illustrated by use of a case study on household dairy cattle enterprises in Senegal. The discussion advocates for holistic approaches to agricultural development efforts, which include recognition of the multiple objectives and the associated trade-offs.

1. Introduction

Livestock production is important for improving the livelihoods and survival of human populations in Low and Middle Income Countries (LMICs) (FAO, 2009; Herrero et al., 2013a, 2014). It is estimated that up to one billion smallholders are supported by livestock globally, whilst the sector's market chains employ many millions more (Herrero et al., 2009; Thornton et al., 2002). The functions of livestock in LMICs are diverse and varying, these are summarised in Table 1.

The demand for livestock produce in LMICs is expected to continue to increase significantly (WHO, 2003; Alexandratos and Bruinsma, 2012). For instance, according to recent Food and Agriculture Organization (FAO) projections, with business-as-usual scenarios LMIC demand for meat will increase by 80% by 2030 and by more than 200% by 2050 (FAO, 2018). This growth is largely attributed to increasing populations, economic growth and urbanisation; and with such drivers concentrated in sub-Saharan Africa this is where the greatest demand increases are expected (Baldi and Gottardo, 2017; Hassen et al., 2016; UN, 2017). Smallholders are currently responsible for large proportions of LMIC livestock production (FAO, 2015; IFAD, 2015; The World Bank, 2007), and with suggested yield gaps there is potential for increased production (Van Ittersum et al., 2016; Mayberry et al., 2017). Therefore, with varying levels of intervention and intensification smallholders are likely to remain a significant contributor, alongside more industrialised systems, in meeting the aforementioned demand (Herrero et al., 2014; McDermott et al., 2010; The Montpellier Panel, 2013; Thornton, 2010; Staal et al., 2009).

Livestock production is complex. The sector provides human populations in LMICs with important services and resources (including nutrition, livelihood support and ecosystem services) (FAO, 2012, 2016). However, there is also a global recognition that livestock production plays a significant role in human induced negative environmental impacts (including greenhouse gas emissions, water depletion and pollution, land use change, and biodiversity impacts)

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https://doi.org/10.1016/j.gfs.2018.04.002
Received 7 November 2017; Received in revised form 31 March 2018; Accepted 1 April 2018
2211-9124/

Table 1
A summary of the recognised functions of livestock in low and middle income countries.

Livestock function	Further information
Source of food and nutrition	(Moll et al., 2007; Ndlovu, 2010; Gupta, 2016; Wu, 2016)
Source of income through the sale of products, services or livestock; and as savings and insurance assets (for risk management and credit access)	(Ejlertsen et al., 2013; Weiler et al., 2014; Thompson et al., 2009)
Provision of manure fertilizer and draught power, as well as a use for crop by-products, within mixed crop livestock systems	(Moll et al., 2007; Udo and Cornelissen, 1998)
Climate-change and seasonal resilience	(Wilson et al., 2005)
Social functions including symbols of prestige and status, dowry value, and for ceremonies	(Crane, 2010; Pica-Ciamarra et al., 2011; Ejlertsen et al., 2013; Moll et al., 2007)

(Steinfeld et al., 2006; Rivera-Ferre et al., 2016). With cumulatively large animal populations and low levels of productivity, it is likely that smallholders contribute significantly towards these impacts (Herrero et al., 2013b). An increase in demand for livestock products, met by business-as-usual production systems, is likely to increase global environmental impacts significantly (O'Mara, 2011). In acknowledgement, the concept of sustainable intensification (SI) (increasing agricultural yields without further environmental impact) has existed for some time (The Royal Society, 2009; Cook et al., 2015; Godfray and Garnett, 2014). In recent years the original focus of SI on environmentally sensitive production has been criticised for not recognising the true complexities of food production systems, including social and economic aspects (Loos et al., 2014; Cook et al., 2015). It is therefore suggested that the inclusion of environmental, economic and social indicators and perspectives would improve the success of SI efforts, these aspects are now being adapted (Smith et al., 2017; The Montpellier Panel, 2013; Campbell et al., 2014).

There is agreement that approaches to future agricultural development need to take a more holistic approach. But with a greater number of possible indicators or metrics to measure successful sustainable development, decisions concerning a 'most appropriate' course of action are complicated (Smith et al., 2017). Multiple objectives from stakeholders (varying from livestock keepers to policy makers and national governments) mean trade-offs in agricultural development decisions are likely to exist. This paper contributes towards the discussion by demonstrating the complexity and variation of likely trade-offs in the choice of household livestock production systems. We recognize that other aspects such as policy and market interventions are also important for SI, but these are beyond the scope of this paper. Farm level choices in household livestock production systems are then illustrated through a case study comparing household dairy enterprises in Senegal, where different levels of intensification (choice of livestock breed and management input) are evident.

2. Livestock and sustainable intensification

Livestock will play a key role in LMIC roadmaps to realise the SI of agriculture. The urban demand for livestock products is increasing rapidly, whilst livestock are also important for rural food security. In dry regions, where crops are impractical, livestock can be the only option (Thornton, 2010; Thornton and Gerber, 2010; Turner et al., 2014); whereas with higher-rainfalls mixed crop-livestock systems are dominant, and nutrient cycles and traction rely on livestock (Herrero et al., 2010; Traore et al., 2017; McDermott et al., 2010). Intensification of livestock production can occur through increased and improved feed availability, improved feeding practices and genetic gains (McDermott et al., 2010; Marshall, 2014). In turn the improved management of livestock can also have positive effects on crop production. Improved nutrient recycling of manure and more efficient use of animal traction can make crop focused interventions, like the application of inorganic fertilizer, use of improved seed, conservation agriculture and small-scale mechanization, more efficient (Rufino et al., 2006). In addition many smallholder systems rely on animal traction for both timely planting and good production; differences in access to this resource can be an important factor in explaining variation in crop yields between different farms (Traore et al., 2017).

The livestock SI elements of increased and improved feed availability, improved feeding practices and genetic gains are often interrelated and constraining factors need to be overcome. For example if indeed farmers have access to necessary artificial insemination, improved breeds generally require feed of higher quality and quantity (Klapwijk et al., 2014); which in many cases means the use of improved fodders and their specialised production (White et al., 2013). Whilst a focus on improving feed availability, through the production of dual purpose crop varieties, producing grain and biomass for animal feed (Blümmel et al., 2003), requires as a pre-requisite, animals that have the potential to substantially increase their production. Typically SI of livestock systems in LMIC is a step-wise process in which a production system cannot in one go switch from 'low-input low-output' to 'high-input high-output'. The livestock ladder (Udo et al., 2011) is one example of a theoretical representation of this.

3. Recognising trade-offs between opposing objectives

As in any other economic decision when resources are scarce, the 'most appropriate' action to take is likely to be decided upon using some form of trade-off analysis; where the 'most appropriate' option could be defined as meeting as many recognised objectives as possible through the action. Consideration of the costs and benefits at the multiple levels that have influence on smallholder livestock enterprises in LMICs, in a holistic approach, is likely to improve the success of any chosen interventions (Loos et al., 2014). As agricultural systems often have key objectives (e.g. food production) to some extent they can be designed with this in mind (Tittonell, 2013). However, as livestock systems are tightly linked to the environment, and in LMICs provide numerous other benefits to human populations (Table 1), a trade-off analysis can support a balanced decision to be made and controllable and uncontrollable factors to be recognised. The complexity of agricultural systems, and the need to consider social, economic and environmental aspects, mean the indicators for the 'most appropriate' actions under SI that could be included in a trade-off analysis are countless (Smith et al., 2017). In the following sections we describe some potential objective trade-offs, selected to cover environmental, economic and social aspects, which can arise for livestock development initiatives. As historically the first objective of SI, we start with minimising environmental impact, then discuss how other aspects relate.

3.1. Environmental impact

The environmental impacts of livestock production systems are well recognised; these include both negative greenhouse gas emissions, land degradation, biodiversity loss, and effluent pollution (FAO, 2012), and positive ecosystem services (FAO, 2016). Globally, the measures for ecological stability within intensification are common and considered robust (Smith et al., 2017). Inherently a priority for SI is an increase in production efficiency; with an assumption, largely based on both global and local scale modelling, that smallholder contribution to environmental impacts can be reduced through realising productivity improvements in their livestock systems (Smith et al., 2008; Gerber et al., 2013; Salmon et al., 2017; Smith and Olesen, 2010). This would be achieved by effectively packaged nutritional, genetic and health interventions, that would reduce the environmental burden per unit of produce (e.g. milk, meat or eggs) (Hristov et al., 2013); with the presumption that the same level of production can occur with less animals required (Gill et al., 2010). Subsequently, modelling studies have demonstrated that environmental burdens associated with units of livestock production is generally lower in industrial 'high-input high-output' systems, where animals have higher production yields, than in 'low-input low-output' systems (Herrero et al., 2008; Opio et al., 2013). This would suggest that a shift from 'low-input low-output' towards 'high-input high-output' production systems would go towards the original objective of SI, to reduce environmental impact of food production. However, as the following sections will demonstrate such a shift may not meet with other potential objectives.

3.2. Smallholder profit improvements

For livestock keepers, the main incentive to move towards more intensified systems is to achieve higher income, or to reduce risk, especially where land or labour are scarce. Often, intensification leads to a higher level of production, with greater output resulting in higher revenues (Ali et al., 2000). In addition, the livestock enterprise may also become more efficient, producing more or the same level of outputs with fewer inputs, resulting in improved profits for the household and reduced negative environmental impacts (Dayanandan, 2011; Herrero et al., 2013b). Finally, managing adverse conditions, for instance through insurance, can allow livestock keepers to avoid catastrophic losses (Chantarat et al., 2013; Jensen et al., 2015).

However, the success of applying any package of intensifying technologies is dependent on various characteristics of the specific livestock system. For instance, several studies have found that smallholder dairy cattle systems which have adopted improved animals and are managing them effectively, experience production increases, more efficient input use and growing profits (Dayanandan, 2011; Islam et al., 2008, 2010; Mondal et al., 2010). Whilst another study found no differences in enterprise profits or household income of smallholder dairy producers in Kenya, both regarding scale (small versus medium) and system (intensive versus extensive) (Ojango et al., 2012). Previous studies have even shown higher costs of milk production in most intensive systems, compared to semi extensive and extensive systems (Staal et al., 2003). Differences in methodology may partly explain such results (Ndambi et al., 2017). Similarly, in a pig production system in Vietnam with limited access to inputs, raising indigenous breeds (requiring less inputs) provided greater economic benefits to smallholders, compared to improved breeds, who's production potential was severely limited by inadequate feed and health care (Lemke et al., 2006). Various economic responses at the household level to situational characteristics are also illustrated by Marshall (2014). Overall however, the long term sustainability of intensifying production relies mainly on the opportunity to market any additional produce profitably, in order to improve smallholder incomes (Pretty et al., 2011; Loos et al., 2014; Ouma et al., 2007).

3.3. Gender equality

For women in LMICs livestock are an important resource. Whilst it is often difficult for women to purchase land and other physical assets, or to access finance, there are more opportunities to acquire livestock (including receipt of gifts or family inheritance, through development projects, or market purchases) (Kristjanson et al., 2014; Rubin et al., 2010). There is evidence that women's improved access or control of assets has broad positive household welfare implications; including food security, child education and nutrition, as well as the wellbeing of the women themselves (Smith et al., 2003; Quisumbing, 2003). For instance this is evident in rural Malawi, where women were observed to be more likely to prioritise household needs with their spending patterns (Fisher et al., 2010). In Kenya the perception of the purpose of rearing livestock was also observed to differ by gender; men perceived livestock as long term investment, whilst women viewed the animals as a means to ensure household food security (Heffernan et al., 2003).

Interventions towards the SI of livestock systems may not benefit women and men equally. In some circumstances a shift towards a more intensified system could negatively affect women. For instance a review of African backyard poultry systems found that it was men who make decisions and control associated income, despite women providing the majority of care (Gueye, 2000). Likewise in Kenyan dairy systems men were seen to control livestock trading and decisions, including use of related income; whilst women were largely responsible for the milking (Valdivia, 2001). Therefore with this common high reliance on the labour of women for livestock production (Kristjanson et al., 2014), there is a risk that SI intervention that increases the demands of livestock management may increase the workloads of women and girls (Wangui, 2008), without commensurate enhanced access to and control of benefits from increased production.

There is also suggestion that women are more constrained to accessing resources or services that may be associated with SI interventions (FAO, 2011). In addition to social and gender norms, this could be due to long working hours, illiteracy, a neglect of women's needs in intervention design (Kristjanson et al., 2014), or resource and service institutions being dominated by men (Upadhyay, 2005). This gender inequality translates in men being more likely to have improved breed animals than women in Kenya and Rwanda (EADD, 2009). In Tanzania, even though women and men were both involved in animal health management and had similar knowledge of diseases, Galiè et al. (2017) show how animal diseases impact the food security of women in particular, with women facing more constraints than men in accessing vet services, information on diseases, and animal medicines.

Where women are able to improve the productivity of the systems under their control they may have more produce to sell. However, they are then often faced with market access challenges (FAO, 2011); regularly confined to informal trading and unable to benefit from formal markets (Njuki et al., 2011a; Johnson et al., 2015; Njuki and Sanginga, 2013). Examples have also suggested that as livestock systems become more productive and increase in income generation, they become more economically attractive to men and women lose control of assets and associated incomes (Kristjanson et al., 2014; Walugembe et al., 2016; Deere et al., 2013). Evidence then suggests that this could have negative consequences to the overall welfare of households (Njuki et al., 2011b; Quisumbing, 2003; Smith et al., 2003).

In a nutshell, a decision to promote increased livestock productivity may not benefit all household members, and has the risk of increasing rather than reduced gender inequalities. In addition the complexities of livestock production systems in LMICs require interpretation at local scales for successful SI intervention (Galiè et al., 2015).

3.4. Human nutrition and food security

Livestock produce has a significant role in maintaining food and nutritional security for people in LMICs (Herrero et al., 2014; Randolph et al., 2007). Both energy and protein dense, animal source food, even in small quantities, is important in supporting vulnerable people; including children, mothers and those with HIV/AIDS (Ndlovu, 2010; Moreki et al., 2010; Neumann et al., 2003). Livestock produce simultaneously provides many essential micro-nutrients that are difficult to obtain from plant based foods alone (Allen, 2002; Murphy and Allen, 2003). For some communities livestock produce is critical, for instance milk can constitute more than half of pastoralists dietary energy intake (Cossins and Upton, 1988; Fielding et al., 2000).

With this importance of livestock for food and nutritional security in mind, at a regional food security level (perhaps the perspective of government policy makers) smallholder system intensification resulting in greater total quantities of food available for populations is likely to be favoured. Whilst at a household level realisation of food and nutritional security is commonly a function of increased incomes, through effective market access (Renkow et al., 2004; Ahmed et al., 2000), risk management (both real and perceived) (Dorward, 1996; Knight et al., 2003), and the proportion of household income controlled by women (Njuki et al., 2011b; Njuki and Sanginga, 2013). It cannot be assumed that increasing production will result in increased food security for producing households. For instance intensification could extenuate the daily trade-off faced by smallholder producers, whether to sell produce for income, or to consume produce for direct nutritional value (Herrero et al., 2014; Kristjanson et al., 2014). Njuki et al. (2016) report negative effects of dairy intensification on child nutrition during intermediate stages; as women's workload increased without being able to afford hired labour, resulting in less time spent with young children.

3.5. Food safety and zoonotic diseases

Past reviews have suggested that due to the concentration of efforts on food security to ease the malnutrition of growing populations in LMICs, food safety and zoonotic diseases have not been priorities and are commonly underappreciated (Randolph et al., 2007). The impact of zoonoses on human health can be captured as disability-adjusted life years (DALYs). In LMICs 10% of total DALYs lost (26% of those related to infectious disease) are estimated to be associated with zoonoses (Grace et al., 2012a); whilst globally the 13 most prolific of zoonoses are annually responsible for over 2 million human deaths (Grace et al., 2012b). SI interventions must therefore consider the inherent link between human food consumption and human health. For instance, increasingly urban meat markets have been found to be vending produce of 'unacceptable quality' with high incidences of gastrointestinal illness. Interestingly women's involvement in the meat processing was seen to improve food safety (Grace et al., 2012c). Another example of food safety concerns is that of the occurrence of mycotoxins (e.g. aflatoxins) produced by fungi, on many staple human food and livestock feed crops. Aflatoxin contamination of feedstuffs can disrupt livestock production (Atherstone et al., 2016); with further suggested food safety concerns for humans consuming contaminated animal source foods (e.g. milk) (Herzallah, 2009; Marshall et al., 2016; Nidhina et al., 2017; Walte et al., 2016). With increasing levels of system intensification, greater number and movement of animals (Hall et al., 2004), increasing urban produce processing (Cole et al., 2008) and a greater reliance on processed feed crops rather than natural pastures to raise livestock (Szonyi et al., 2015), if unchecked the status of food safety in LMICs could worsen.

3.6. Cultural acceptance and multi-functional livestock values

Livestock reared by smallholders in LMICs often have roles beyond that of solely food production; for instance provision of draught power and manure for crop-livestock mixed systems, as well as capital asset values (Ejlertsen et al., 2013). In addition there are less tangible values, including dowry payments, status symbols, and ethnic identity (Crane, 2010; Weiler et al., 2014; Ouma et al., 2003). There are even cultural preferences for certain livestock phenotypes (Maichomo et al., 2009). At the household level such perceptions could represent significant trade-offs with maximising livestock productivity and need to be considered in associated SI interventions.

3.7. Risk

Livestock keepers in LMICs often experience high levels of vulnerability, and are generally limited in their coping mechanisms (Marshall et al., 2009). Therefore, their primary strategy is generally to be risk averse (Andrieu et al., 2015); in some circumstances managing risk can be a higher priority than increased production (Ejlertsen et al., 2013). It is suggested that in the foreseeable future climate change will increase the vulnerability of livestock keepers in LMICs (Havemann and Muccione, 2011; Hoffmann, 2010). There are examples of specific interventions developed with an aim to reduce climate-related risk while encouraging productivity increases, with particular focus on pastoralists; the index-based livestock insurance is one such example (Takahashi et al., 2016). However, if SI interventions in such situations are narrowly focused on increasing productivity through increasing input and management requirements, there is considerable potential for losing much of a system's resilience. For instance, indigenous livestock breeds are generally considered to be more adapted to challenging local environments (such as limited and low quality feed, high disease pressure, and high temperatures) (Berman, 2011), and whilst livestock keepers may recognise the higher productive potential of 'improved breeds', they are also aware of their lack of resilience. Similar to the studies discussed above in the section *'Smallholder profit improvements'*, higher producing animals are not always optimal in supporting smallholder livelihoods. In addition the assumption that efficiencies of SI will result in less animals being reared may be rebutted if livestock keepers maintain large herds, or increase herd sizes, as a long recognised and widely adopted strategy for resilience to climate-related shocks (Kinsey et al., 1998; Næss and Bårdsen, 2013). Considering risk at farm level is likely to introduce a further level of trade-offs for SI interventions and is of particular importance in systems where resilience must be maintained or improved (Marshall, 2014; Anderson, 2003).

As mentioned above, intensification of livestock production is often based on improved market access. Market dynamics in LMICs, such as the growth of supermarkets, may offer an opportunity for smallholders to participate and benefit (Markelova and Mwangi, 2010). Effectively accessing markets, for instance through producer groups, can provide smallholders with improvements in productivity, income and food security and some value chain benefits (Markelova and Mwangi, 2010; Bernard and Spielman, 2009). However, increased market involvement and commercialisation may introduce unacceptable risks. Smallholders may find themselves more vulnerable to both input and output price volatility (Barrett and Luseno, 2004; Riwthong et al., 2017). Increasingly specialised market-orientated production systems are more vulnerable to drought or disease (Wiggins et al., 2011). Small scale farmers are also likely to begin engaging with much larger actors (e.g. importers, traders and retailers) who have much larger capital assets and political influence, putting the farmers in a weak negotiating position (Wiggins et al., 2011). The benefit from commercialization is unlikely to be evenly distributed amongst smallholders, with less commercial systems being pushed out of markets and out of business (examples of this have been seen in horticultural exports from Kenya and Senegal, and pineapples from Ghana) (Wiggins et al., 2011). To remain competitive production systems are likely to increase reliance on inputs, which can have unrecognised negative impacts. For example, Thai agricultural systems experiencing increased commercialisation greatly increased reliance on pesticides, with significant health implications for the farmers themselves (Riwthong et al., 2017).

4. Using trade-off information for sustainable intensification

4.1. Hierarchy of stakeholder perspectives

Agricultural systems could be described as sub-systems nested in a 'hierarchy' of broader systems (e.g. farms in communities, communities in regions, regions in nations, and finally a global perspective). At each level the number of stakeholders, objectives and perspectives increases (Giller et al., 2008). If these are not considered and effectively integrated into development decisions intervention recommendations are likely to be impractical (Tittonell, 2013). At the national and global levels minimising environmental impact and maintaining food security are likely to be major objectives, therefore decisions made at these levels are likely to give them a greater weight in comparison to others (Gerber et al., 2013; Havlik et al., 2014; Herrero et al., 2013b; Smith, 2013). Despite the influence of policy level decisions (for instance provision of farm subsidies) (Dorward and Chirwa, 2014), many decisions shaping production systems will be made at the farm level (Del Prado et al., 2013). At this end of the 'hierarchy' risk averse livestock keepers deal with spatially and temporally heterogeneous systems; objectives may be varied, multiple, and differentiated by gender, wealth or other socio-economic groups (Andrieu et al., 2015; Ejlertsen et al., 2013; Marshall et al., 2011; Tittonell, 2013). For instance in Kenyan mixed systems smallholders identified food supply as their key objective for system improvements. However, manure supply and milk sale income were also consistently valued. Demand for both low yield zebu cattle, with cultural value, and high yielding breeds further illustrated their diverse objectives (Waithaka et al., 2006). Within studied smallholder systems in The Gambia, of the livestock species reared by households, larger bodied cattle had higher savings and insurance value compared to the small ruminants (which representing a more disposable asset were more valued for income). This phenomenon was more pronounced to household with comparatively less wealth (Ejlertsen et al., 2013). Individual stakeholders with different perceptions about 'their' systems and attitudes to risk further complicate attempts to define the 'most appropriate' course of action (Ahmadi et al., 2015; Garforth, 2015). Recognising and engaging with stakeholders at the multiple levels to effectively weight indicators and evaluate results in context, is critical to the success of development interventions at the farm level (García De Jalón et al., 2014; Tittonell, 2013).

4.2. Approaches for making decisions in complex systems

In an agricultural development scenario encompassing the complexities of varying stakeholder aims and potential negative trade-offs, traditional single objective decision making (to minimise or maximise an element of the system) becomes redundant. There are however methods to analyse such trade-offs and attempt to reach the 'most appropriate' decision (Klapwijk et al., 2014). A review of the 'state-of-the-art' methods for trade-off analysis discussed four techniques: i) participatory methods, ii) empirical analysis, iii) simulation models, and iv) optimisation models (Klapwijk et al., 2014).

Participatory methods recognize the importance of involving stakeholders (including both actors and those who will be influenced by any change) in the analysis. Tools such as fuzzy cognitive mapping, resource flow mapping, or role playing, can capture normative aspects of production systems, which models may miss (Crane, 2010; Klapwijk et al., 2014). An example of the application of participatory methods in development is provided by the CGIAR Climate Change, Agriculture, and Food Security (CCAFS) work on policy to ensure food security under climate change in East Africa (Chaudhury et al., 2012). Participatory methods produce qualitative data where trade-offs cannot be quantified.

Empirical approaches allow quantitative assessment. Data can be generated to consider a system experiencing different conditions and trade-off analysis is based on the measurement of identified indicators. It is suggested that the strength in this approach is an ability to use existing observable variation in the system to explore the outcomes of any system changes (Klapwijk et al., 2014). The resultant limitation is that the analysis is constrained to the data collected from the system (Klapwijk et al., 2014), though the collected data can also be used to support other approaches (e.g. simulation modelling). This approach was employed for the case study presented below in the section *'Case study: trade-off analysis for Senegalese cattle systems'*.

Increasingly complex methodologies for trade-off analysis include both simulation and optimisation modelling. Methods such as multiple agent models (simulation modelling) and multiple criteria decision analysis (MCDA) (optimisation modelling) have the ability to observe potential scenarios (Klapwijk et al., 2014). Simulation modelling allows both short and long term trade-offs to be considered; an example is provided by work in Zimbabwe to investigate the impact on agricultural productivity if crop farmers decided to continue to allow, or stop, livestock grazing crop residues (Rufino et al., 2011). MCDA generally employs mathematical modelling and software to consider all defined indicators, objectives and scenarios to suggest optimal results (Kumar et al., 2017). With benefits of transparency and a shared framework for assessing complex systems, the use of MCDA in agricultural system decision making has been encouraged (Lairez et al., 2017). There are also cautionary notes; for instance practitioners should not 'drown' in complex methods and lose focus on end users or the decisions to be made (Lairez et al., 2017). A study applied the MCDA approach to Italian poultry production systems to rank different management styles by sustainability. Human food needs, environmental impact, economic feasibility and animal welfare were all considered; however the results of the study only demonstrated that the ranking of options depended on which stakeholder was being considered (Castellini et al., 2012). In addition decisions based on optimisation models generally assume stakeholder actions are optimal and based on economic rationale. However, for stakeholders in agricultural systems, particularly in LMICs, this is not always the case (Klapwijk et al., 2014; Ejlertsen et al., 2013).

A systems thinking approach (where different system parts and the relationships between them are identified and considered) is important for any development project to be successful in application, sustainable or scalable (Woog et al., 2006). Broader experience across the implementation of the UN Sustainable Development Goals suggests that systems thinking needs to become part of practice rather than an extra development competency (Reynolds et al., 2018). A mix of the discussed methods would improve this, for instance the use of participatory methods to help define trade-off analysis indicators for empirical, simulation or optimisation approaches (Rufino et al., 2011). The EXTRAPOLATE (EX-ante Tool for RAnking POLicy AlTErnatives) tool provides an example methodology for combining participatory and empirical methods in project or policy assessment (Robinson, 2013). Several authors have also emphasised that trade-off analysis should be used for 'discussion support' rather than 'decision support' (Smith et al., 2017; Klapwijk et al., 2014; Tittonell, 2013). Table 2 summarises some example studies that have employed trade-off analyses for agricultural development scenarios.

4.3. Trade-off management

It is worth considering that alongside the recognition of the various objectives in a production system, and the indicators associated with these (Smith et al., 2017), in certain situations there may be options to alleviate negative trade-offs. These are likely to exist at the different hierarchical levels and will further influence the interpretation of a trade-off analysis. For instance, studies have shown that specific food safety concerns (e.g. aflatoxin contamination) can be cost-effectively managed both pre and post crop harvesting (Wu and Khlangwiset, 2010); but there are likely challenges to implementing identified approaches across the large informal sectors in LMICs (Grace et al., 2015).

There are also examples of efforts to address the trade-offs introduced through gender inequalities. In an assessment of the SI of cereal production in Burkina Faso it was demonstrated that addressing an extension service male bias and improving women's access to resources (including credit and equipment) and income, contributed to greater gender equality of interventions (Theriault et al., 2017). Women's groups can offer an opportunity for successful delivery of extension services (Kristjanson et al., 2014). In Senegalese Fulani communities, it is women who have control over milk production (Dieye et al., 2005); with the support of NGOs and development agencies women have also established mini-dairies with milk sourced from

Table 2
Summarised examples of some studies employing trade-off analysis methods to agricultural development scenarios.

Country/system	Details	Trade-off analysis methods employed	Key findings	Ref.
The Gambia/mixed systems with forest management	Assessed the trade-offs between natural forest resources, endemic (trypanotolerant) ruminants and incomes.	Participatory methods	Cropping is the most important for incomes, although is declining with increased income from logging and forest clearing. This has natural resource degradation implications. There is a shift away from endemic ruminants, in favour of higher productivity breeds, as forest clearing reduces tsetse fly pressures.	(Zaibet et al., 2010)
Tanzania/mixed system with dairy production	Assessed Climate Smart Agriculture technology implementation for return on investment in face of climate change.	Simulation model	Improved feed: • Increased income for all households • Reduced poverty for households with improved breeds • Improved food security for households with traditional breeds • GHG emissions reduced in all households	(Shikuku et al., 2017)
Kenya/mixed systems	Assessed climate change adaptation strategies by considering impacts under different management strategies.	Simulation model	Required adaptations to climate change include: • Improved crop varieties • Improved livestock breeds and feeding	(Claessens et al., 2012)
Kenya/mixed systems with maize focus	Assessed the strategies for optimal allocation of finance, labour and nutrient resources; whilst considering short and long term objectives.	Optimisation modelling	• Identified indicator thresholds • Investment should favour increased labour, over nutrient use. • Results specific to particular systems	(Tittonell et al., 2007)
Brazil/beef systems	From both an economic and environmental perspective, compared pasture management approaches relative to traditional methods.	Optimisation modelling	Largely through soil organic carbon sequestration, improved pasture management has both economic and environmental benefits.	(De Oliveira Silva et al., 2017)

contract farmers (Corniaux, 2003). Baltenweck and Mutinda (2013) discussed learnings from the East Africa Dairy Development project where there were successes in supporting both improved dairy productivity and gender equity. They effectively summarized how intervention can be successful if appropriately conducted using the following phrases: “Know Her” conduct gender analysis at the various value chain levels; “Design for Her” gender mainstream project objectives; and “Be accountable to Her” *ex-post* monitoring of gender issues (Baltenweck and Mutinda, 2013). Evidently there is suggestion that such institutional change can be realised with effective social analysis. To be successful this requires bottom-up engagement with stakeholders, and for SI researchers and actors with technical backgrounds, to collaborate effectively to tackle complex social issues previously seen as outside their remit (Kantor, 2013).

4.4. Average benefit versus variation in benefit

When assessments are made of the most appropriate course of action with regards to production improvement it is important to not only look at average benefits for a population, but also variation across systems or household populations. For example, in some situations a livestock development intervention resulting in a high average household benefit (or other indicator) but with a large variance around this may be less attractive that an intervention resulting in a less-high average household benefit but with a lower variance. This would particularly be the case if being at the lower end of the benefit distribution resulted in, for example, a household re-entering a state of poverty. Such analysis can be difficult due to the high data requirements and a high level of assumptions required in performing such analysis. However examples of such analyses are emerging in the literature, such as that of Claessens et al. (2012) who used a model (called the Trade-off Analysis Model for Multi-Dimensional Impact Assessment) to perform *ex-ante* impact assessments of climate change and adaptation strategies for a population of small-scale farmers. The model simulates technology adoption and impact in a population of heterogeneous farms, with the output allowing the distribution in responses (such as economic impact at farm level) to be examined. Moving forward, the increased use of approaches allowing for examination of the distribution of responses, rather than just the average response, is highly recommended (Antle, 2011).

5. Case study: trade-off analysis for Senegalese cattle systems

As a case study example of a (partial) empirical trade-off analysis, we present a recent study that compared different, low to medium input, household dairy systems in Senegal (Marshall et al., 2017). The systems were defined by type of cattle breed kept by the household and level of cattle management. Cattle breeds ranged from the indigenous Zebu animals, which are highly adapted to the local environmental conditions but have low milk yields, to exotic *Bos taurus* dairy cattle, which have high milk yields but are poorly adapted to the local environmental conditions. The different management levels primary reflected the level of supplementary feed provided to the animals (feed being a key constraint to livestock production in Senegal (Tebug et al., 2015)). The project sites were located in two semi-arid regions of Senegal (specifically the Thiès and Diourbel regions) where the different household dairy production systems were already in existence prior to the project start, in part due to government subsidized programs providing access to the exotic dairy cattle. Project data, which included both economic and production data at the individual animal or household dairy enterprise level (as appropriate), was obtained by monitoring 220 rural or peri-urban dairy cattle keeping households within these sites. The data was collected by 14 enumerator visits at roughly equal time intervals over an almost two year period (from March 2013 to April 2015). Collectively the project households had more than 3200 cattle. For more detail see Marshall et al. (2017) and Tebug et al. (2016).

Whilst the study did not include all the relevant aspects of the trade-off analysis, it did consider many aspects beyond milk yield (which is often the primary focus when comparing different dairy systems in LMICs). The additional aspects considered included; profit to the dairy cattle keeping households; benefit to cost ratio of the dairy cattle keeping households; breed preference of both women and men livestock keepers; environmental sustainability in terms of greenhouse gas emission intensity; food safety in terms of aflatoxin contamination; and gender issues in relation to increasing the level of market orientation of

Table 3
Summary of examined trade-offs for different dairy cattle-production systems in the study sites in Senegal., as defined by breed-type kept and level of management. Cells highlighted are favourable. Reproduced from Marshall et al. (2017).

Breed type	*Zebu*	*Zebu*	*Zebu x Guzerat*	*Zebu x Guzerat*	*Zebu x Bos taurus*	*Zebu x Bos taurus*	*High Bos taurus*
Management level[a]	*	**	*	**	**	***	****
Milk yields (litres milk offtake per 365 day lactation)	307	899	408	907	931	1,863	2,251
Profit of the household dairy enterprise ($/cow/annum)[b]	113	267	122	352	388	838	703
Benefit to cost ratio of the household dairy enterprise[b]	1.22:1	1.32:1	1.23:1	1.44:1	1.47:1	1.66:1	1.41:1
Breed preference – male/ female dairy cattle keepers[c]	+/+	+/+	+/+	+/+	+++/+++	+++/+++	++/+
Environmental sustainability – greenhouse gas emission intensity (kg CO_2 equivalent/kg protein)	*338*	*190*	*307*	*165*	*188*	*110*	*108*
Level of supplementary feeding with aflatoxin contaminated feed (reduced food safety)	Low	Medium	Low	Medium	Medium	High	Very high
Women control the income from the sale of milk in the majority of households	Yes	Yes	Yes	Yes	No	No	No

[a] The higher the number of asterisk (*) the better the level of animal management; reflective of the investment in animal feed.
[b] Assumes a herd size of 8 cows (and followers); no transhumance; natural mating for Zebu and Zebu by Guzerat and artificial insemination for Zebu x *Bos taurus* and high *Bos taurus*.
[c] The higher the number of plus signs (+) the stronger the preference for that breed.

the household dairy enterprise. An additional element of food quality in terms of milk fat and protein content was also intended to be included, but these results were inconclusive.

Results of the study are summarized in Table 3. In summary, of the seven different household dairy systems compared, one system (the indigenous Zebu crossed with exotic *Bos taurus* dairy cattle under good management) was promising from multiple angles. This system produced good milk yields, the highest household profit as well as highest household benefit to cost ratio. In addition the cross-breed animals were highly preferred by both women and men dairy cattle keepers. The greenhouse gas emission intensity was low (i.e. favourable). However for this cross-bred to be kept in Senegal, where the climatic conditions result in low quantity and poor quality pastures, the cattle need supplementary feed, much of which is contaminated with aflatoxins (Grace et al., 2015; Marshall et al., 2016). As previously noted, this creates a human food safety risk as the aflatoxins are passed into milk which humans consume. Furthermore, the households practicing this system tended to fall into a 'higher' market orientation category (study households were categorised as higher or lower market orientated based on volume of milk produced and sold). In the majority of higher market oriented households it was men who controlled the income from the sale of milk, as compared to women in the lower market oriented households (Walugembe et al., 2016). Whilst this latter result requires further investigation, it suggests that practicing this system may lead to negative impacts on broader household welfare (Smith et al., 2003; Quisumbing, 2003). The main practical implications of these results are that indigenous Zebu by *Bos taurus* crossbred animals, kept under good management, represent a promising dairy system as s long as measures are put in place to ensure a year-round supply of safe (non-aflatoxin contaminated) animal feed; and potential gender equality issues associated with increasing market orientation of household dairy enterprises are addressed.

In terms of methodology, this study used a combined approach of direct assessments (e.g. milk yield, farmer breed preferences) and modelling (e.g. household profit and greenhouse gas emission intensity) with the modelling benefiting from having a good subset of input parameters well estimated from the study data. Additionally this study combined expertise from a range of scientific backgrounds (including animal sciences, agricultural economics, and social scientists, particularly gender experts). Limitations of this trade-off analysis (as completed to-date) are that: it has not yet covered all relevant trade-offs (for example, other aspects of environmental sustainability); the focus was on average response for the various systems without considering the variability around these, which would be particularly important to risk-adverse livestock keepers such as those who are particularly poor (Andrieu et al., 2015); and sensitivity analysis has not been performed, which may be important in terms of the emphasis the users of the evidence base place on the different trade-off components considered. Efforts to fill these gaps will be undertaken in the future.

Results of the study were summarized in a brief for policy makers (Marshall et al., 2017), as well as extension material for farmers, with the aim of providing these and other actors with an evidence base on which to make better informed decisions. The effective interpretation of such results is still complicated by the various dimensions and options: a clear course of action is not the result. In considering these results the stakeholders will need to be flexible, willing and open-minded to recognize different objectives, consider solutions to observed negative trade-offs and the employment of methods for effective decision making.

6. Conclusions – the importance of a holistic approach to agricultural development

As a paradigm SI provides a framework for agricultural development initiatives. However, with increased understanding and pressure from practitioners SI has evolved; with an increasing recognition that to successfully guide development a broad perspective (including environmental, economic and social aspects) is required. This paper has discussed the increased complexity in choosing an appropriate course of action, when additional objectives and perspectives are included in a trade-off analysis. There are a selection of tools available to perform trade-off analyses and assist in effective decision making; but a fundamental requirement appears to be an assurance that an element of systems thinking becomes part of everyday practice rather than an add-on or after thought.

Acknowledgements

The Senegal Diary Genetics project was funded by the Ministry for Foreign Affairs of Finland and carried out within the framework of the Finnish development co-operation, under the FoodAfrica program and the CGIAR Research Program on Livestock. CGIAR Research Program on Livestock and Fish. We would like to gratefully acknowledge those involved in availing the data used in the case-study, in particular the cattle farmers in Thies and Diourbel regions, Senegal, for their participation in the project. The opinions expressed in this publication are solely those of the authors and does not in any way constitute the official opinion of any above-mentioned organisations.

Conflict of interest

Authors declare that they have no conflict of interest.

References

Ahmadi, B.V., Moran, D., Barnes, A.P., Baret, P.V., 2015. Comparing decision-support systems in adopting sustainable intensification criteria. Front. Genet. 6, 1–5.

Ahmed, M.M., Jabbar, M., Ehui, S., 2000. Household-level economic and nutritional impacts of market-oriented dairy production in the Ethiopian highlands. Food Nutr. Bull. 21, 460–465.

Alexandratos, N., J. Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working Paper No. 12-03. Food and Agriculture Organization of the United Nations, Rome, Italy.

Ali, M.H., Miah, A.G., Ali, M.L., Salma, U., Khan, M.A.S., Islam, M.N., 2000. A comparative study on the performance of crossbred and indigenous (Zebu) cows Under the small holder dairy farming condition in Gaibandha District. Pak. J. Biol. Sci. 3, 1080–1082.

Allen, L.H., 2002. Forging effective strategies to combat iron deficiency: iron supplements scientific issues concerning efficacy and implications for research and programs. J. Nutr. 132, 813S–819S.

Anderson, J.R., 2003. Risk in rural development: challenges for managers and policy makers. Agric. Syst. 75, 161–197.

Andrieu, N., Descheemaeker, K., Sanou, T., Chia, E., 2015. Effects of technical interventions on flexibility of farming systems in Burkina Faso: lessons for the design of innovations in West Africa. Agric. Syst. 136, 125–137.

Antle, J.M., 2011. Parsimonious multi-dimensional impact assessment. Am. J. Agric. Econ. 93, 1292–1311.

Atherstone, C., Grace, D., Lindahl, J., Kang'ethe, E.K., Nelson, F., 2016. Assessing the impact of aflatoxin consumption on animal health and productivity. Afr. J. Food Agric., Nutr. Dev. 16, 10949–10966.

Baldi, A., Gottardo, D., 2017. Livestock production to feed the planet. Animal protein: a forecast of global demand over the next years. Relations 5, 1.

Baltenweck, I., Mutinda, G., 2013. Gender in the East Africa Dairy Development Project. Livestock and Fish Gender Working Group Workshop and Planning Meeting. East African Dairy Development, Addis Ababa, Ethiopia.

Barrett, C.B., Luseno, W.K., 2004. Decomposing producer price risk: a policy analysis tool with an application to northern Kenyan livestock markets. Food Policy 29, 393–405.

Berman, A., 2011. Invited review: are adaptations present to support dairy cattle productivity in warm climates? J. Dairy Sci. 94, 2147–2158.

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

Blümmel, M., Zerbini, E., Reddy, B.V.S., Hash, C.T., Bidinger, F., Khan, A.A., 2003. Improving the production and utilization of sorghum and pearl millet as livestock feed: progress towards dual-purpose genotypes. Field Crops Res. 84, 143–158.

Campbell, B.M., Thornton, P., Zougmoré, R., Van Asten, P., Lipper, L., 2014. Sustainable intensification: what is its role in climate smart agriculture? Curr. Opin. Environ. Sustain. 8, 39–43.

Castellini, C., Boggia, A., Cortina, C., DAL Bosco, A., Paolotti, L., Novelli, E., Mugnai, C., 2012. A multicriteria approach for measuring the sustainability of different poultry production systems. J. Clean. Prod. 37, 192–201.

Chantarat, S., Mude, A.G., Barrett, C.B., Carter, M.R., 2013. Designing index-based livestock insurance for managing asset risk in Northern Kenya. J. Risk Insur. 80, 205–237.

Chaudhury, M., Vervoort, J., Kristjanson, P., Ericksen, P., Ainslie, A., 2012. Participatory scenarios as a tool to link science and policy on food security under climate change in East Africa. Reg. Environ. Change 13, 389–398.

Claessens, L., Antle, J.M., Stoorvogel, J.J., Valdivia, R.O., Thornton, P.K., Herrero, M., 2012. A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modeled data. Agric. Syst. 111, 85–95.

Cole, D., Lee-Smith, D., Nasinyama, G., 2008. Healthy City Harvests: Generating Evidence to Guide Policy on Urban Agriculture. CIP/Urban Harvest and Makerere University Press, Lima, Peru.

Cook, S., Silici, L., Adolph B., Walker, S., 2015. Sustainable intensification revisited. IIED Issue Paper. IIED, London.

Corniaux, C., 2003. La filière lait et produits laitiers dans la région de Saint-Louis. ISRA/CIRADPSI, Saint-Louis, Sénégal.

Cossins, N.J., Upton, M., 1988. The impact of climatic variation on the Borana pastoral system. Agric. Syst. 27, 117–135.

Crane, T.A., 2010. Of models and meanings cultural resilience in social – ecological systems. Ecol. Soc. 15, 19.

Dayanandan, R., 2011. Production and marketing efficiency of dairy farms in highland of Ethiopia–an economic analysis. Int. J. Enterp. Comput. Bus. Syst. 1.

De Oliveira Silva, R., Barioni, L.G., Hall, J.A.J., Moretti, A.C., Veloso, R.F., Alexander, P., Crespolini, M., Moran, D., 2017. Sustainable intensification of Brazilian livestock production through optimized pasture restoration. Agric. Syst. 153, 201–211.

Deere, C.D., Oduro, A.D., Swaminathan, H., Doss, C., 2013. Property rights and the gender distribution of wealth in Ecuador, Ghana and India. J. Econ. Inequal. 11, 249–265.

Del Prado, A., Crosson, P., Olesen, J.E., Rotz, C.A., 2013. Whole-farm models to quantify greenhouse gas emissions and their potential use for linking climate change mitigation and adaptation in temperate grassland ruminant-based farming systems. Animal 7, 373–385.

Dieye, P.N., Ly, C., Sane, F.C.N., 2005. Etude des services d'élevage dans la filière laitière au Sénégal. Pro-Poor Livestock Policy Initiative (PPLPI) Internal Report. Food and Agriculture Organization of the United Nations, Rome.

Dorward, A., Chirwa, E., 2014. The rehabilitation of agricultural input subsidies? IIED Working Paper: Food and Agriculture. IIED, London.

Dorward, A.R., 1996. Modelling diversity, change and uncertainty in peasant agriculture in Northern Malawi. Agric. Syst. 51, 469–486.

EADD, 2009. East Africa Dairy Development Project Baseline Surveys Report No. 6.: Gender, Dairy Production and Marketing. East Africa Dairy Development.

Ejlertsen, M., Poole, J., Marshall, K., 2013. Traditional breeding objectives and practices of goat, sheep and cattle smallholders in The Gambia and implications in relation to the design of breeding interventions. Trop. Anim. Health Prod. 45, 219–229.

FAO, 2009. The state of food and agriculture: livestock in the balance. The State of Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 2011. State of food and agriculture 2010–2011 women in agriculture. The State of Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2012. Livestock sector development for poverty reduction: an economic and policy perspective. Livestock's many virtues. In: Otte, J., Costales, A., Dijkman, J., Pica-Ciamarra, U., Robinson, T., Ahuja, V., LY, C., Roland-Holst, D. (Eds.), Pro-Poor Livestock Policy Initiative. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 2015. In: Rapsomanikis, G. (Ed.), The Economic Lives of Smallholder Farmers: An Analysis Based on Household Data from Nine Countries. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 2016. The contributions of livestock species and breeds to ecosystem services. Ecosystem Services and Biodiversity. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 2018. Shaping the future of livestock: sustainably, responsibly, efficiently. The 10th Global Forum for Food and Agriculture (GFFA). Food and Agriculture Organization of the United Nations, Berlin.

Fielding, W., Gullick, C., Coutts, P., Sharp, B., 2000. In: FIELDING, W., SHARP, B. (Eds.), An Introduction to the Food Economy Research in Southern Sudan 1994–2000. World Food Programme; Save the Children, Nairobi.

Fisher, M., Reimer, J.J., Carr, E.R., 2010. Who should be interviewed in surveys of household income? IFPRI Discussion Paper 00949. International Food Policy Research Institute.

Galiè, A., Distefano, F., Kangogo, D., Mattioli, R.C., Wieland, B., Baltenweck, I., 2017. Gendered perspectives on smallholder cattle production and health management in three sites in Tanzania. J. Gend. Agric. Food Secur. 2, 43–65.

Galiè, A., Mulema, A., Benard, M.A.M., Onzere, S.N., Colverson, K.E., 2015. Exploring gender perceptions of resource ownership and their implications for food security among rural livestock owners in Tanzania, Ethiopia, and Nicaragua. Agric. Food Secur. 4.

García De Jalón, S.G., Iglesias, A., Cunningham, R., Pérez-Díaz, J.I., 2014. Building resilience to water scarcity in southern Spain: a case study of rice farming in Donana protected wetlands. Reg. Environ. Change 14, 1229–1242.

Garforth, C., 2015. Livestock keepers' reasons for doing and not doing things which governments, vets and scientists would like them to do. Zoonoses Public Health 62, 29–38.

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G., 2013. Tackling Climate Change Through Livestock – A Global Assessment of Emissions and Mitigation Opportunities. Food and Agriculture Organization of the United Nations, Rome, Italy.

Gill, M., Smith, P., Wilkinson, J.M., 2010. Mitigating climate change: the role of domestic livestock. Animal 4, 323–333.

Giller, K.E., Leeuwis, C., Andersson, J.A., Andriesse, W., Brouwer, A., Frost, P., Hebinck, P., Heitkonig, I., Van Ittersum, M.K., Koning, N., Ruben, R., Slingerland, M., Udo, H.M., Veldkamp, T., Van De Vijver, C., Van Wijk, M.T., Windmeijer, P., 2008. Competing claims on natural resources what role for science? Ecol. Soc. 13 (online).

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philos. Trans. R. Soc. B 369.

Grace, D., Gilbert, J., Randolph, T., Kang'ethe, E., 2012a. The multiple burdens of zoonotic disease and an Ecohealth approach to their assessment. Trop. Anim. Health Prod. 44, S67–S73.

Grace, D., Mahuku, G., Hoffmann, V., Atherstone, C., Upadhyaya, H.D., Bandyopadhyay, R., 2015. International agricultural research to reduce food risks: case studies on aflatoxins. Food Secur. 7, 569–582.

Grace, D., Mutua, F., Ochungo, P., Kruska, R., Jones, K., Brierley, L., Lapar, L., Said, M., Herrero, M., Phuc, P.D., Thao, N.B., Akuku, I., Ogutu, F., 2012b. Mapping of poverty and likely zoonoses hotspots. Zoonoses project 4. Report to Department for International Development, UK. Zoonoses Project 4. International Livestock Research Institute, Nairobi, Kenya.

Grace, D., Olowoye, J., Dipeolu, M., Odebode, S., Randolph, T., 2012c. The influence of gender and group membership on food safety: the case of meat sellers in Bodija market, Ibadan, Nigeria. Trop. Anim. Health Prod. 44, S53–S59.

Gueye, E.H.F., 2000. Women and family poultry production in rural Africa. Dev. Pract. 10, 98–102.

Gupta, S., 2016. Clever eating. Nature 531, S12–S13.

Hall, D.C., Ehui, S., Delgado, C., 2004. The livestock revolution, food safety, and small-scale farmers: why they matter to us all. J. Agric. Environ. Ethics 17, 425–444.

Hassen, I.W., Dereje, M., Minten, B., Hirvonen, K., 2016. Diet transformation in Africa: the case of Ethiopia. Ethiopia Strategy Support Program. IFPRI.

Havemann, T., Muccione, V., 2011. Mechanisms for Agricultural Climate Change Mitigation Incentives for Smallholders (CCAFS Report No. 6). CGIAR Research

Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.
Havlik, P., Valin, H., Herrero, M., Obersteiner, M., Schmid, E., Rufino, M.C., Mosnier, A., Thornton, P.K., Bottcher, H., Conant, R.T., Frank, S., Fritz, S., Fuss, S., Kraxner, F., Notenbaert, A., 2014. Climate change mitigation through livestock system transitions. PNAS 111, 3709–3714.
Heffernan, C., Misturelli, F., Pilling, D., 2003. Livestock and the poor: findings from Kenya, India, and Bolivia. Animal Health Programme. Department for International Development, London.
Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., Rufino, M.C., 2013a. The roles of livestock in developing countries. Animal 7, 3–18.
Herrero, M., Havlik, P., Mcintire, J., Palazzo, A., Valin, H., 2014. African Livestock Futures: Realizing the Potential of Livestock for Food Security, Poverty Reduction and the Environment in Sub-Saharan Africa. Office of the Special Representative of the UN Secretary General for Food Security and Nutrition and the United Nations System Influenza Coordination (UNSIC), Geneva, Switzerland.
Herrero, M., Havlik, P., Valin, H., Notenbaert, A., Rufino, M.C., Thornton, P.K., Blummel, M., Weiss, F., Grace, D., Obersteiner, M., 2013b. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. PNAS 110, 20888–20893.
Herrero, M., Thornton, P.K., Gerber, P., Reid, R.S., 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Curr. Opin. Environ. Sustain. 1, 111–120.
Herrero, M., Thornton, P.K., Kruska, R., Reid, R.S., 2008. Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. Agric. Ecosyst. Environ. 126, 122–137.
Herrero, M., Thornton, P.K., Notenbaert, A., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., Van De Steeg, J., Lynam, J., Parthasarathy Rao, P., Macmillan, S., Gerard, B., McDermott, J., Sere, C., Rosegrant, M., 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science 327, 822–825.
Herzallah, S.M., 2009. Determination of aflatoxins in eggs, milk, meat and meat products using HPLC fluorescent and UV detectors. Food Chem. 114, 1141–1146.
Hoffmann, I., 2010. Climate change and the characterization, breeding and conservation of animal genetic resources. Anim. Genet. 41, 32–46.
Hristov, A.N., 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., Oosting, S., 2013. Mitigation of greenhouse gas emissions in livestock production – a review of technical options for non-CO_2 emissions. In: Gerber, P.J., Henderson, B., Makkar, H.P.S. (Eds.), FAO Animal Production and Health Paper. Food and Agriculture Organization of the United Nations, Rome, Italy.
IFAD, 2015. Smallholder Livestock Develop: Scaling Up Note. International Fund for Agricultural Development, Rome, Italy.
Islam, M.M., Topader, A.H., Rob, A., 2010. Comparative study on the cost benefit between indigenous and cross bred cows reared in rural area of Dinajpur District. Bangladesh J. Anim. Sci. 39, 191–196.
Islam, S., Goswami, A., Mazumdar, D., 2008. Comparative profitability of cross breed and indigenous cattle in West Bengal. Indian Res. J. Ext. Educ. 8, 28–30.
Jensen, N., Barrett, C., Mude, A., 2015. The favourable impacts of index-based livestock insurance: evaluation results from Ethiopia and Kenya. ILRI Res. Brief 52.
Johnson, N., Njuki, J., Waithanji, E., Nhambeto, M., Rogers, M., Kruger, E.H., 2015. The gendered impacts of agricultural asset transfer projects: lessons from the Manica smallholder dairy development program. Gend. Technol. Dev. 19, 145–180.
Kantor, P., 2013. Transforming Gender Relations: Key to Positive Development Outcomes in Aquatic Agricultural Systems. Brief: AAS-2013-12. CGIAR Research Program on Aquatic Agricultural Systems, Penang, Malaysia.
Kinsey, B., Burger, K., Gunning, J.W., 1998. Coping with drought in Zimbabwe: survey evidence on responses of rural households to risk. World Dev. 26, 89–110.
Klapwijk, C.J., Van Wijk, M.T., Rosenstock, T.S., Van Asten, P.J.A., Thornton, P.K., Giller, K.E., 2014. Analysis of trade-offs in agricultural systems: current status and way forward. Curr. Opin. Environ. Sustain. 6, 110–115.
Knight, J., Weir, S., Woldehanna, T., 2003. The role of education in facilitating risk-taking and innovation in agriculture. J. Dev. Stud. 39, 1–22.
Kristjanson, P., Waters-Bayer, A., Johnson, N., Tipilda, A., Njuki, J., Baltenweck, I., Grace, D., Macmillan, S., 2014. Livestock and women's livelihoods. In: Quisumbing, A., Meinzen-Dick, R., Raney, T., Croppenstedt, A., Behrman, J., Peterman, A. (Eds.), Gender in Agriculture: Closing the Knowledge Gap. Food and Agriculture Organization of the United Nations, Rome, Italy.
Kumar, A., Sah, B., Singh, A.R., Deng, Y., He, X., Kumar, P., Bansal, R.C., 2017. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew. Sustain. Energy Rev. 69, 596–609.
Lairez, J., Feschet, P., Botreau, R., Bockstaller, C., Fortun-Lamothe, L., Bouvarel, I., Aubin, J., 2017. The multicriteria assessment of livestock systems to support their evolution: issues, challenges and interrogations. INRA Prod. Anim. 30, 255–268.
Lemke, U., Kaufmann, B., Thuy, L.T., Emrich, K., Valle Zárate, A., 2006. Evaluation of smallholder pig production systems in North Vietnam: pig production management and pig performances. Livest. Sci. 105, 229–243.
Loos, J., Abson, D.J., Chappell, M.J., Hanspach, J., Mikulcak, F., Tichit, M., Fischer, J., 2014. Putting meaning back into “sustainable intensification”. Front. Ecol. Environ. 12, 356–361.
Maichomo, M.W., Kosura, W.O., Gathuma, J.M., Gitau, G.K., Ndung'u, J.M., Nyamwaro, S.O., 2009. Economic assessment of the performance of trypanotolerant cattle breeds in a pastoral production system in Kenya. J. South Afr. Vet. Assoc. 80, 157–162.
Markelova, H., Mwangi, E., 2010. Collective action for smallholder market access: evidence and implications for Africa. Rev. Policy Res. 27, 621–640.
Marshall, K., 2014. Optimizing the use of breed types in developing country livestock production systems: a neglected research area. J. Anim. Breed. Genet. 131, 329–340.
Marshall, K., Missohou, A., Tebug, S., Kagera, I., Grace, D., Lindahl, J., 2016. Aflatoxins in dairy cattle feed in Senegal. In: TROPENTAG. ILRI, Vienna.
Marshall, K., Okeyo, A.M., Johnson, N., 2009. Translating animal breeding research into the real world: use of the sustainable livelihoods framework. In: Walkden-Brown, S.W., Van Der Werf, J.H.J., Nimbkar, C., Gupta, V.S. (Eds.), Proceedings of the Helen Newton Turner Memorial International Workshop. ACIAR, Pune, Maharashtra, India, pp. 190–198.
Marshall, K., Quiros-Campos, C., Van Der Werf, J.H.J., Kinghorn, B., 2011. Marker-based selection within smallholder production systems in developing countries. Livest. Sci. 136, 45–54.
Marshall, K., Tebug, S., Salmon, G.R., Tapio, M., Juga, J., Missohou, A., 2017. Improving dairy cattle productivity in Senegal. ILRI Policy Brief. ILRI, Nairobi, Kenya, pp. 22.
Mayberry, D., Ash, A., Prestwidge, D., Godde, C.M., Henderson, B., Duncan, A., Blummel, M., Ramana Reddy, Y., Herrero, M., 2017. Yield gap analyses to estimate attainable bovine milk yields and evaluate options to increase production in Ethiopia and India. Agric. Syst. 155, 43–51.
McDermott, J.J., Staal, S.J., Freeman, H.A., Herrero, M., Van De Steeg, J.A., 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livest. Sci. 130, 95–109.
Moll, H.A.J., Staal, S.J., Ibrahim, M.N.M., 2007. Smallholder dairy production and markets: a comparison of production systems in Zambia, Kenya and Sri Lanka. Agric. Syst. 94, 593–603.
Mondal, R.K., Sen, S., Rayhan, S.J., 2010. A comparative economic analysis of local breed and cross breed milk cow in a selected area of Bangladesh. J. Sci. Found. 8, 23–29.
Moreki, J.C., Dikeme, R., Poroga, B., 2010. The role of village poultry in food security and HIV/AIDS mitigation in Chobe District of Botswana. Livest. Res. Rural Dev. 22.
Murphy, S.P., Allen, L.H., 2003. Nutritional importance of animal source foods. J. Nutr. 133, 3932S–3935S.
Næss, M.W., Bårdsen, B.J., 2013. Why herd size matters – mitigating the effects of livestock crashes. PLoS One 8, e70161.
Ndambi, A., Zijlstra, J., Ngigi, M., Van Der Lee, J., Kilelu, C., 2017. Calculating on-farm cost of milk production in Kenya: assessing the suitability of five methods being used in Kenya. In: 3R Kenya Project. Wageningen Livestock Research.
Ndlovu, L., 2010. The role of foods of animal origin in human nutrition and health. In: Swanepoel, F., Stroebel, Moyo, S. (Eds.), The Role of Livestock in Developing Communities: Enhancing Multifunctionality. The Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands.
Neumann, C.G., Bwibo, N.O., Murphy, S.P., Sigman, M., Whaley, S., Allen, L.H., Guthrie, D., Weiss, R.E., Demment, M.W., 2003. Animal source foods improve dietary quality, micronutrient status, growth and cognitive function in Kenyan school children: background, study design and baseline findings. J. Nutr. 133, 3941S–3949S.
Nidhina, N., Bhavya, M.L., Bhaskar, N., Muthukumar, S.P., Murthy, P.S., 2017. Aflatoxin production by Aspergillus flavus in rumen liquor and its implications. Food Control 71, 26–31.
Njuki, J., Kaaria, S., Chamunorwa, A., Chiuri, W., 2011a. Linking smallholder farmers to markets, gender and intra-household dynamics: does the choice of commodity matter? Eur. J. Dev. Res. 23, 426–443.
Njuki, J., Poole, J., Johnson, N., Baltenweck, I., Pali, P., Lokman, Z., Mburu, S., 2011b. Gender, Livestock and Livelihood Indicators. ILRI, Nairobi, Kenya.
Njuki, J., Sanginga, P.C., 2013. Women, Livestock Ownership and Markets: Bridging the gender gap in Eastern and Southern Africa. Routledge, London.
Njuki, J., Wyatt, A., Baltenweck, I., Yount, K., Null, C., Ramakrishnan, U., Webb Girard, A., Sreenath, S., 2016. An exploratory study of dairying intensification, women's decision making, and time use and implications for child nutrition in Kenya. Eur. J. Dev. Res. 28, 740–772.
O'Mara, F.P., 2011. The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. Anim. Feed Sci. Technol. 166–167, 7–15.
Ojango, J.M., Kinuthia, E., Baltenweck, I., 2012. Cost of Milk Production in Kenya – Round 2 of the Survey. East African Dairy Development (EADD) Project, Nairobi, Kenya.
Opio, C., Gerber, P.J., Mottet, A., Falcucci, A., Tempio, G., Macleod, M., Vellinga, T., Henderson, B., Steinfeld, H., 2013. Greenhouse Gas Emissions from Ruminant Supply Chains – A Global Life Cycle Assessment. Food and Agricultural Organization of the United Nations, Rome, Italy.
Ouma, E.A., Obare, G.A., Staal, S.J., 2003. Cattle as assets: assessment of non-market benefits from cattle in smallholder Kenyan crop-livestock systems. In: Proceedings of the 25th International Conference of Agricultural Economists (IAAE). Durban, South Africa.
Ouma, R., Njoroge, L., Romney, D., Ochungo, P., Staal, S., Baltenweck, I., 2007. Targeting Dairy Interventions in Kenya: A Guide for Development Planners, Researchers and Extension Workers. SDP/KDDP, Nairobi, Kenya.
Pica-Ciamarra, U., Nouala, S., Kim, S., 2011. Livestock and Livelihoods in the IGAD Region: A Policy and Institutional Analysis. IGAD LPI Working Paper No. 01 - 11. FAO, Rome, Italy.
Pretty, J., Toulmin, C., Williams, S., 2011. Sustainable intensification in African agriculture. Int. J. Agric. Sustain. 9, 5–24.
Quisumbing, A.R., 2003. Household Decisions, Gender, and Development: A Synthesis of Recent. Research. International Food Policy Research Institute (IFPRI), Washington, D.C.
Randolph, T.F., Schelling, E., Grace, D., Nicholson, C.F., Leroy, J.L., Cole, D.C., Demment, M.W., Omore, A., Zinsstag, J., Ruel, M., 2007. Invited review: role of livestock in human nutrition and health for poverty reduction in developing countries. J. Anim. Sci. 85, 2788–2800.
Renkow, M., Hallstrom, D.G., Karanja, D.D., 2004. Rural infrastructure, transactions costs and market participation in Kenya. J. Dev. Econ. 73, 349–367.
Reynolds, M., Blackmore, C., Ison, R., Shah, R., Wedlock, E., 2018. The role of systems

thinking in the practice of implementing sustainable development goals. In: Filho, W.L. (Ed.), Handbook of Sustainability Science and Research. Springer, Hamburg, Germany.
Rivera-Ferre, M.G., López-I-Gelats, F., Howden, M., Smith, P., Morton, J.F., Herrero, M., 2016. Re-framing the climate change debate in the livestock sector: mitigation and adaptation options. WIREs Clim. Change 7, 869–892.
Riwthong, S., Schreinemachers, P., Grovermann, C., Berger, T., 2017. Agricultural commercialization: risk perceptions, risk management and the role of pesticides in Thailand. Kasetsart J. Soc. Sci. 38, 264–272.
Robinson, T., 2013. EXTRAPOLATE: Supporting priority setting in value chains. Livestock and Fish Value Chain Coordinator's meeting. International Livestock Research Institute, Nairobi, Kenya.
Rubin, D., Tezera, S., Caldwell, L., 2010. A calf, a house, a business of one's own: microcredit, asset accumulation, and economic empowerment in GL CRSP projects in Ethiopia and Ghana. Global Livestock CRSP.
Rufino, M.C., Dury, J., Tittonell, P., VAN Wijk, M.T., Herrero, M., Zingore, S., Mapfumo, P., Giller, K.E., 2011. Competing use of organic resources, village-level interactions between farm types and climate variability in a communal area of NE Zimbabwe. Agric. Syst. 104, 175–190.
Rufino, M.C., Rowe, E.C., Delve, R.J., Giller, K.E., 2006. Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. Agric. Ecosyst. Environ. 112, 261–282.
Salmon, G.R., Marshall, K., Tebug, S.F., Missohou, A., Robinson, T.P., Macleod, M., 2017. The greenhouse gas abatement potential of productivity improving measures applied to cattle systems in a developing region. Animal 1–9.
Shikuku, K.M., Valdivia, R.O., Paul, B.K., Mwongera, C., Winowiecki, L., Läderach, P., Herrero, M., Silvestri, S., 2017. Prioritizing climate-smart livestock technologies in rural Tanzania: a minimum data approach. Agric. Syst. 151, 204–216.
Smith, A., Snapp, S., Chikowo, R., Thorne, P., Bekunda, M., Glover, J., 2017. Measuring sustainable intensification in smallholder agroecosystems: a review. Glob. Food Secur. 12, 127–138.
Smith, L.C., Ramakrishman, U., Ndiaye, A., Haddad, L., Martorell, R., 2003. The Importance of Women's Status for Child Nutrition in Developing Countries. International Food Policy Research Institute, Washington, DC.
Smith, P., 2013. Delivering food security without increasing pressure on land. Glob. Food Secur. 2, 18–23.
Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., Mccarl, B., Ogle, S., O'mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., Mcallister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith, J., 2008. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. B 363, 789–813.
Smith, P., Olesen, J.E., 2010. Synergies between the mitigation of, and adaptation to, climate change in agriculture. J. Agric. Sci. 148, 543–552.
Staal, S., Poole, J., Baltenweck, I., Mwacharo, J., Notenbaert, A., Randolph, T., Thorpe, W., Nzuma, J., Herrero, M., 2009. Targeting strategic investment in livestock development as a vehicle for rural livelihoods. BMGF-ILRI Project on Livestock Knowledge Generation. ILRI, Nairobi, Kenya.
Staal, S.J., Waithaka, M., Njoroge, L., Mwangi, D.M., Njubi, D., Wokabi, A., 2003. Costs of milk production in Kenya: estimates from Kiambu, Nakuru and Nyandarua Districts. The Smallholder Dairy (Research and Development) Project (SDP). Nairobi, Kenya.
Steinfeld, H., Gerber, P.J., Wassenaar, T., Castel, V., Rosales, M., De Haan, C., 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations, Rome, Italy.
Szonyi, B., Gizachew, D., Tegegne, A., Hanson, J., Grace, D., 2015. Aflatoxin contamination of milk and feeds in the Greater Addis Ababa milk shed in Ethiopia. ILRI Res. Brief 46.
Takahashi, K., Ikegami, M., Sheahan, M., Barrett, C.B., 2016. Experimental evidence on the drivers of index-based livestock insurance demand in Southern Ethiopia. World Dev. 78, 324–340.
Tebug, S.F., Kamga-Waladjo, A.R., Ema, P.J., Muyeneza, C., Kane, O., Seck, A., Ly, M.T., Lo, M., 2015. Calf management practices, challenges and opportunities in traditional cattle production systems in the Peanut Basin of Senegal. Trop. Anim. Health Prod. 47, 797–804.
Tebug, S.F., Missohou, A., Sabi, S.S., Juga, J., Poole, E.J., Tapio, M., Marshall, K., 2016. Using body measurements to estimate live weight of dairy cattle in low-input systems in Senegal. J. Appl. Anim. Res. 46, 87–93.
The Montpellier Panel, 2013. Sustainable Intensification: A New Paradigm for African Agriculture. Agriculture for Impact, London.
The Royal Society, 2009. Reaping the benefits: science and the sustainable intensification of global agriculture. London.
The World Bank, 2007. Agriculture for Development: World Development Report 2008. The International Bank for Reconstruction and Development/The World Bank, Washington DC.
Theriault, V., Smale, M., Haider, H., 2017. How does gender affect sustainable intensification of cereal production in the West African Sahel? Evidence from Burkina Faso. World Dev. 92, 177–191.
Thompson, D.M., Serneels, S., Kaelo, D.O., Trench, P.C., 2009. Maasai Mara – land privatization and Wildlife decline can conservation pay its way. In: Homewood, K., Kristjanson, P., Trench, P.C. (Eds.), Staying Maasai? Livelihoods, Conservation and Development in East African Rangelands. Springer, New York.
Thornton, P.K., 2010. Livestock production: recent trends, future prospects. Philos. Trans. R. Soc. B 365, 2853–2867.
Thornton, P.K., Gerber, P.J., 2010. Climate change and the growth of the livestock sector in developing countries. Mitig. Adapt. Strateg. Glob. Change 15, 169–184.
Thornton, P.K., Kruska, R., Henninger, N., Kristjanson, P., Reid, R.S., Atieno, F., Odero, A.N., Ndegwa, T., 2002. Mapping Poverty and Livestock in the Developing World. International Livestock Research Institute, Nairobi, Kenya.
Tittonell, P., 2013. Towards ecologically intensive smallholder farming systems: design, scales and trade-offs evaluation. In: Vanlauwe, B., Van Asten, P., Blomme, G. (Eds.), Agro-Ecological Intensification of Agricultural Systems in the African Highlands. Routledge, London.
Tittonell, P., Van Wijk, M.T., Rufino, M.C., Vrugt, J.A., Giller, K.E., 2007. Analysing trade-offs in resource and labour allocation by smallholder farmers using inverse modelling techniques: a case-study from Kakamega district, western Kenya. Agric. Syst. 95, 76–95.
Traore, S.A., Markemann, A., Reiber, C., Piepho, H.P., Valle Zarate, A., 2017. Production objectives, trait and breed preferences of farmers keeping N'Dama, Fulani Zebu and crossbred cattle and implications for breeding programs. Animal 11, 687–695.
Turner, M.D., Mcpeak, J.G., Ayantunde, A., 2014. The role of livestock mobility in the livelihood strategies of rural peoples in semi-arid West Africa. Hum. Ecol. 42, 231–247.
Udo, H.M.J., Aklilu, H.A., Phong, L.T., Bosma, R.H., Budisatria, I.G.S., Patil, B.R., Samdup, T., Bebe, B.O., 2011. Impact of intensification of different types of livestock production in smallholder crop-livestock systems. Livest. Sci. 139, 22–29.
Udo, H.M.J., Cornelissen, T., 1998. Livestock in resource-poor farming systems. Outlook Agric. 27, 237–242.
UN, 2017. World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. United Nations, Department of Economic and Social Affairs, Population Division, New York, USA.
Upadhyay, B., 2005. Women and natural resource management: illustrations from India and Nepal. Nat. Resour. Forum 29, 224–232.
Valdivia, C., 2001. Gender, livestock assets, resource management, and food security: lessons from the SR-CRSP. Agric. Hum. Values 18, 27–39.
Van Ittersum, M.K., Van Bussel, L.G.J., Wolf, J., Grassini, P., Van Wart, J., Guilpart, N., Claessens, L., De Groot, H., Wiebe, K., Mason-D'croz, D., Yang, H.S., Boogaard, H., Van Oort, P.A.J., Van Loon, M.P., Saito, K., Adimo, O., Adjei-Nsiah, S., Agali, A., Bala, A., Chikowo, R., Kaizzi, K., Kouressy, M., Makoi, J.H.J.R., Ouattara, K., Tesfaye, K., Cassman, K.G., 2016. Can sub-Saharan Africa feed itself? PNAS 113, 14964–14969.
Waithaka, M.M., Thornton, P.K., Herrero, M., Shepherd, K.D., 2006. Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya. Agric. Syst. 90, 243–271.
Walte, H.G., Schwake-Anduschus, C., Geisen, R., Fritsche, J., 2016. Aflatoxin: food chain transfer from feed to milk. J. für Verbrauch. und Lebensm. 11, 295–297.
Walugembe, M., Tebug, S.F., Tapio, M., Missohou, A., Juga, J., Marshall, K., Rothschild, M.F., 2016. Gendered intra-household contributions to low-input dairy in Senegal. Anim. Ind. Rep.
Wangui, E.E., 2008. Development interventions, changing livelihoods, and the making of female Maasai pastoralists. Agric. Hum. Values 25, 365–378.
Weiler, V., Udo, H.M.J., Viets, T.C., Crane, T.A., De Boer, I.J.M., 2014. Handling multifunctionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya. Curr. Opin. Environ. Sustain. 8, 29–38.
White, D.S., Peters, M., Horne, P., 2013. Global impacts from improved tropical forages: a meta-analysis revealing overlooked benefits and costs, evolving values and new priorities. Trop. Grassl. – Forrajes Trop. 1, 12–24.
WHO, 2003. Availability and changes in consumption of animal products [Online]. Available: ⟨http://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html⟩, (Accessed 12 March 2018).
Wiggins, S., Argwings-Kodhek, G., Leavy, J., Poultonc, C., 2011. Small farm commercialisation in Africa: Reviewing the issues. Future Agricultures Research Paper 023.
Wilson, T., Pearson, R.A., Bradbear, N., Jayasuriya, A., Laswai, H., Mtenga, L., Richards, S., Smith, R., 2005. Livestock products – valuable and more valuable. In: Owen, E., Kitalyi, A., Jayasuriya, N., Smith, T. (Eds.), Livestock and Wealth Creation: Improving the Husbandry of Animals kept by Resource-Poor People in Developing Countries. Nottingham University Press, Nottingham, UK.
Woog, R., Cavana, R.Y., Roberts, R., Packham, R., 2006. Working at the interface between systems and complexity thinking: insights from a market access design project for poor livestock producers. Syst. Res. Behav. Sci. 23, 727–741.
Wu, F., Khlangwiset, P., 2010. Health economic impacts and cost-effectiveness of aflatoxin-reduction strategies in Africa: case studies in biocontrol and post-harvest interventions. Food Addit. Contam. 27, 496–509.
Wu, G., 2016. Dietary protein intake and human health. Food Funct. 7, 1251–1265.
Zaibet, L., Traore, S., Ayantunde, A., Marshall, K., Johnson, N., Siegmund-Schultze, M., 2010. Livelihood strategies in endemic livestock production systems in sub-humid zone of West Africa: trends, trade-offs and implications. Environ. Dev. Sustain. 13, 87–105.