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Harnessing benefits from improved livestock water productivity in crop–livestock systems of sub-Saharan Africa: synthesis

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Abstract. The threat of water scarcity in sub-Saharan Africa is real, due to the expanding agricultural needs, climate variability and inappropriate land use. Livestock keeping is the fastest growing agricultural sector, partly because of increasing and changing demands for adequate, quality and diverse food for people, driven by growing incomes and demographic transitions. Besides the economic benefits, rising livestock production could also deplete water and aggravate water scarcity at local and global scales. The insufficient understanding of livestock–water interactions also led to low livestock productivity, impeded sound decision on resources management and undermined achieving positive returns on investments in agricultural water across sub-Saharan Africa. Innovative and integrated measures are required to improve water productivity and reverse the growing trends of water scarcity. Livestock water productivity (LWP), which is defined as the ratio of livestock outputs to the amount of water depleted, could be improved through: (i) raising the efficiency of the water inputs by integrating livestock with crop, water and landscape management policies and practices. Improving feed water productivity by maximising transpiration and minimising evaporation and other losses is critical; (ii) increasing livestock outputs through improved feed management, veterinary services and introducing system-compatible breeds; and (iii) because livestock innovation is a social process, it is not possible to gain LWP improvements unless close attention is paid to policies, institutions and their associated processes. Policies targeting infrastructure development would help livestock keepers secure access to markets, veterinary services and knowledge. This paper extracts highlights from various papers presented in the special issue of *The Rangeland Journal* on technologies and practices that would enable improving water productivity at various scales and the premises required to reverse the negative trends of water depletion and land degradation.

Additional keywords: institutions, interventions, policies.

Water scarcity in crop–livestock systems

Water scarcity is one of the major challenges in sub-Saharan Africa (SSA), threatening livelihoods of people and their environment. The majority of the SSA population is currently residing in regions vulnerable to water shortage and/or where water availability is constrained by low human, institutional and financial capacity (Molden *et al*. 2007). Globally, water scarcity is expected to affect ~67% of the world population by 2050 (Wallace 2000), and food demands are estimated to grow by 70–90% over the same period of time (Molden *et al*. 2007). This may require an extra 5000–6000 km^3/year of water (Falkenmark 2007). This extra water requirement will come from both increased demand for food grains (in SSA for example), and increased demand for feed grains (Bossio 2009). If the productivity of water is not increased in agriculture, this will require a doubling of water needs to grow food. Moreover, new demands on water resources are also now projected to place a significant additional burden on water resources. Biofuels, which are hoped to reduce green house gas emissions and contribute towards energy self-sufficiency for many countries, require more agricultural land and water (de Fraiture *et al*. 2007; Bossio 2009). The same holds true for carbon trading. Competition for water between different uses and users is increasing, with agriculture remaining the largest water user, accounting for ~75% (Wallace 2000). While focusing on increasing agricultural production, there is also a need to balance the water demand for agriculture with terrestrial and aquatic ecosystems (Postel 2000). Improper management of crops and livestock also contributes to land and water degradation (Table 1).

Livestock–water nexus

The livestock sector is the fastest growing agricultural sector globally (Steinfeld *et al*. 2006) supporting ~4 billion people (Thornton *et al*. 2002) and contributing to ~40% of the gross value of agricultural production worldwide. Of these, ~1.3 billion people are poor, and 68% of the poor livestock keepers are living in SSA and South Asia (Peden *et al*. 2007).

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Table 1. The major drivers for low water productivity associated with livestock and crop production at farm and landscape scales in sub-Saharan Africa (A. van Rooyen, pers. comm.)

Drivers	Pathways	Process leading to low water productivity
Livestock	Livestock density beyond carrying capacity	Nutrient mining and water depletion with low livestock productivity
	Poor livestock husbandry	Poor animal performance through disease, poor nutrition and housing (protection against elements)
		Losses through mortality – all water and feed utilised through the animals' life up to that point is lost
		Increased runoff because of overgrazing, physical effects, with increased loss of nutrients
	Inappropriate choice of species	Poor performance of unsuitable breeds and livestock types
	Poor management of intensive peri-urban systems	Water losses through contamination/pollution
	Changes in land use	Conversion of grazing land / rangeland to crop land – cropland not compensating for losses in feed production
		Reductions in ecological goods and services (fuel wood, thatch grass, medicinal plants, fruits and pods, etc.)
Crops	Poor soil, water and nutrient management	Reduced water productivity because of lack nutrients and appropriate varieties
		Losses in crops and biomass through diseases, pests and drought
		Water loss through unproductive evaporation and runoff
	Use of inappropriate species	Poor performance of unsuitable species and varieties, not suited to the agro-ecological conditions and LGP
	Poor post harvesting practices	Loss of crop residues (pests and poor storage technologies) and reduced quality
		Inefficient use of crop residues (CR remain low quality with high wastage)

The livestock number in SSA is projected to increase by 2.5- to 5-fold, from 200 M head in 2005 to 500–970 M head in 2050 (Cork *et al*. 2005), which will increase the pressure further on water and land resources. Also changing nutritional needs, driven by growing incomes and demographic transitions, result in rising needs for livestock products on a global scale (Speedy 2003; Steinfeld *et al*. 2006). According to Peden *et al*. (2007), the annual growth in consumption of animal products was 2–4% in developing countries, while only 0.5% in developed countries. This livestock revolution (Delgado 2003) offers a chance for smallholders to benefit from the rapidly growing market and raise their incomes. However, rising livestock production could also have negative environmental, social and health impacts if not managed well (Steinfeld *et al*. 2006; Peden *et al*. 2007). The major environmental impacts of livestock at local and global scales are land degradation, water depletion and methane emission (Steinfeld *et al*. 2006).

Four mechanisms of how livestock production triggers and aggravates water resource degradation are (Steinfeld *et al*. 2006): (1) to satisfy increasing feed demands, pastures and arable land for growing feeds expand into protected and natural ecosystems; (2) because of overstocking and inadequate watering points, rangelands are becoming degraded; (3) in peri-urban environments soils and water resources are contaminated because of manure and wastewater mismanagement; (4) growing feed crops will demand intensification, which may lead to resource mining and soil degradation.

Although water for livestock drinking and servicing might be the most obvious water use in livestock production systems, it constitutes only a minor part of the total water consumption (Peden *et al*. 2009). The amount of drinking water used varies from 20 to 50 L per day per tropical livestock unit and depends on species, dry matter intake, composition of the feed, water content of the feed, live weight of the animal, level of milk and meat production, physiological status of the animal and the climate in which the livestock is managed (King 1983; Gigar-Reverdin and Gihad 1991). The major water consumption by livestock is related to transpiration used for feed production, amounting to more than 95% of the total water used by livestock (Singh *et al*. 2004; Peden *et al*. 2007). In general terms, livestock systems depending on grain-based feeds, as is the case in the developed world, are more water intensive than systems relying on crop residues and pasture lands, as is the case in SSA and South Asia (Gebreselassie *et al*. 2009). Chapagain and Hoekstra (2003) estimated that producing one kg of beef meat in intensive livestock-production systems require ~12.2 m^3 of water, with some (e.g. Pimentel *et al*. 2004) estimates as high as 100 m^3 of water. However, in cases where livestock are fed with crop residues and graze rangelands, livestock make a very efficient use of the available water (Peden *et al*. 2009). So far, apart from research on land degradation due to grazing and on livestock water requirements for drinking, the research community has paid insufficient attention to livestock–water interactions (Peden *et al*. 2009).

Water productivity in perspective

Recurrent drought is increasing due to expanding agricultural needs, climate change and land degradation. Innovative and integrated measures that would increase water productivity are required to reverse the growing trend of water scarcity. Water productivity (WP), which is defined as the ratio of agricultural outputs to the amount of water depleted, provides a robust measure of the ability of agricultural systems to convert water into food (Kijne *et al*. 2003). It is the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water required to produce those benefits (Molden *et al*. 2007; Peden *et al*. 2009). The concept has been used to quantify the contribution of different sectors of agricultural activity to income and livelihoods, including crop production, livestock (Peden *et al*. 2007) and fish (Kirby *et al*. 2007).

By the same token, livestock water productivity (LWP) (Peden *et al*. 2007, 2009), is instrumental in evaluating the livestock related benefits and services compared to the amount of water used and environmental trade-offs associated with it. It is a systems concept based on water accounting principles (Molden *et al*. 2003) that is applicable to diverse agricultural systems including mixed crop-livestock production and to scales ranging from household to river basin levels (Cook *et al*. 2009).

However, the water accounting model partly failed to capture water outflows facilitated by livestock in terms of runoff, contamination and degradation. The analysis is further complicated by: (1) the limited knowledge about the amount of water used by the different types of feeds originating from various system niches and management practices; (2) differences in the conversion efficiency of different feed types under intensive and extensive livestock production systems and across species and breed; (3) in systems where livestock keepers are mobile and transhumant, the amount of water and other resources used from a given locality remains difficult to establish; (4) partitioning the amount of water lost as unproductive water flows from the system between livestock, crop or other farm related practices is difficult; and (5) the different priorities for livestock products and services differ between different communities and regions. Meat and milk are considered as the major livestock products while in some communities draught power is considered as the major output (Table 2).

The economic and environmental benefits could be realised only with the availability of reliable methodologies for assessing and monitoring benefits. Assessing water productivity in multiple use systems that include livestock is much more complex than assessment of single-use irrigated or rainfed cropping systems (Cook *et al*. 2009). The assessment is not straightforward because, (1) it comprises different components both at the nominator and the denominator side of the ratio, (2) it is strongly scale-dependent, and (3) it depends on the socio-economic group, the agro-ecological zone and the type of livestock production system that is considered in the analysis (Cook *et al*. 2009). In addition, the strong interaction between livestock and water on the one hand, and other natural resources (vegetation, soil, ecosystems, and climate) on the other hand, shapes the interpretation of LWP. The multiple products and services obtained from livestock production systems can be of physical, economical, environmental and socio-cultural nature. Livestock provide food, energy (including draught power for land preparation and threshing, transport, fuel from manure) and enable nutrient cycling (Table 2). Animals provide farmers with a source of income and the possibility of storing wealth, risk spreading and insurance against difficult (drought) periods. Livestock are often considered a status symbol and exchanged as dowry. There are debates on how to establish a common numerator integrating quantitative and social benefits. For instance in the Gumara watershed of the Ethiopian highlands the value of manure, in the form of N, P and K fertiliser followed by traction services, had the highest share of livestock products and services (Haileslassie *et al*. 2009).

Table 2. Different types of livestock benefits in Lenche Dima, northern Ethiopia (Source: Baseline survey; T. Amede, unpubl. data)
Ranking according to priority (1–10), 10 being the most important and 1 being the least important

Types of services	Researchers' perspective	Extension perspective	Farmers' perspective
Plowing	8	9	10
Transportation	5	6	6
Milk for home consumption	3	3	4
Cash income	2	2.5	3
Meat for home consumption	0.5	1	1
Manure	1.5	1	1
Social status	2	3	7

Interventions for enhancing water productivity

There is a huge loss of water in various livestock systems, which is associated with uncontrolled evaporation from grazing and crop lands, water depletion through runoff, water pollution due to urine and feaces, sedimentation of water bodies associated with runoff, and excessive use of chemicals and water contamination by processing and agricultural activities. The uncertainty on the extent of climate change and its effects on water supply and livestock production make it difficult to develop the right adaptive measures (Bruinsma 2003). This would be aggravated by an increasing importance of the livestock sector as livestock production systems could deplete, degrade and pollute enormous quantities of water (Steinfeld *et al*. 2006) unless appropriate policy measures are in place.

Productivity improvements could result from raising the efficiency of the input (e.g. better timing, minimising loss of water) and increasing livestock outputs (Renault and Wallendar 2000). A multi-disciplinary approach, which integrates livestock management with crop, water and landscape management, is needed, as the challenge in integrated water management spans science, technology, policy, and politics (Postel 2000). A shift is required away from actions merely focusing on the supply side or the 'hard path' (de Fraiture *et al*. 2007), which has led to many benefits, but also caused enormous social, economic and ecological costs (Postel 2000) to a demand-oriented intervention. Moreover, a new approach, applying integrated resource management concepts, should pay attention to factors beyond the water sector. The major biophysical, social, institutional and policy components that enable application of LWP concepts (Amede *et al*. 2009) should be applied at farm and landscape scales responding to socio-economic differences and production systems. However, water management interventions developed to address challenges at farm, landscape and higher scales are often poorly adopted and implemented, which leads to high social and environmental costs (World Bank 2005; Molden *et al*. 2007).

A conceptual framework developed by ILRI and it partners (Peden *et al*. 2007) suggested an integration of the livestock component, emphasising feeds and animal outputs, of crop-livestock farming systems with the water inflows and outflows representing the water balance. However, improving LWP includes several challenges, located on different fronts and usually not straightforward to meet. First of all, given the growing water scarcity and the rising demands for animal products (as discussed above), appropriate water allocation is needed in order to both satisfy these demands and at the same time safeguard environmental services. Meeting these competing demands is very challenging and only raising water productivity of livestock systems will probably not be sufficient (Bouman 2007).

The type of interventions (Peden *et al*. 2007, 2009) and entry points to facilitate the adoption of more complex interventions (Amede *et al*. 2009) would vary from system to system and from client to client. The combination of these interventions would also vary in creating benefits to various social groups and gender. The range of water productivity between wealth groups could be much greater than between farming systems (Haileslassie *et al*. 2009). However, the following interventions are considered as cross cutting to improve livestock water productivity across systems and social groups.

Minimising water depletion and degradation through integrated feed systems

As feed production is the largest water consumer in crop-livestock systems, interventions to increase feed water productivity can be strategic and effective in efforts to increase LWP. Recent comprehensive overviews by e.g. Kijne *et al*. (2003), Bouman (2007) and Rockström and Barron (2007) dealt with strategies to improve crop water productivity. Interventions to improve feed water productivity can be grouped under three categories, being crop management, soil management and water management. Agronomic measures directed at healthy, vigorously growing crops favour transpirational, productive water losses over unproductive water losses. Interventions that would maximise transpiration while minimising evaporation together with nutrient management and pest management, are effective in improving water productivity (Rockström and Barron 2007). Agronomic management includes the choice of a crop or a variety responsive to the available water, responsiveness to inputs and resistance to stresses. A good match between the critical growth stages of the feed and the water supply can be achieved by choosing cultivars with flowering time and growth duration fitting to the site conditions (Passioura 2006). A good match is also required between the availability of water-efficient quality feed and the peak demand for feed for the intended objectives of the household; be it draught power, milk for markets or fattening for meat. The choice of a certain cropping system can also influence water productivity as it affects the quantity and quality of forages and crop residues from cropland, fallow land and grazing areas.

In mixed crop–livestock systems, and especially with resource-poor smallholders, crop residues are a major source of fodder for ruminants (Devendra and Thomas 2002). In these systems, dual purpose crops or food-feed crops are very common as the grain can be used for human consumption and the residues for livestock feed (Lenné *et al*. 2003). Because crop residues and other by-products do not consume any additional water, they present a huge opportunity to increase feed water productivity and therefore also LWP (Peden *et al*. 2007). The gap between feed demand and supply was minor for feed quantity (dry matter) but was large with regards to feed quality (Blummel *et al*. 2009). For instance for India, the estimated annual feed dry matter deficit was only 6% while digestible crude protein and total nutrients were estimated to fall short by 61 and 50%, respectively (Blummel *et al*. 2009). The importance of quality differences in crop residue from the same species were confirmed by recent surveys of sorghum stover trading (Blümmel and Rao 2006). This has been clearly practiced by farmers as they allocate crop residues of different qualities for different livestock types (Table 3).

When low quality crop residues are fed to animals, the nutritive value can be improved by adding high quality legume feed (e.g. Singh *et al*. 2003) or by urea treatment of the residues (Schiere *et al*. 2000). By making use of fodder trees within agro-forestry systems different benefits can be obtained simultaneously. Besides providing high quality fodder, multi-purpose trees stabilise the land, decrease erosion, improve soil structure and fertility and increase ecosystem stability (e.g. Roothaert and Franzel 2001).

Appropriate grazing management is primarily intended to maintain a sufficient vegetative ground cover and to preserve and contribute to healthy, productive pastures and rangelands that not only provide biomass for fodder but also environmental services such as biodiversity, protection of downstream water uses (Hadjigeorgiou *et al*. 2005) and ground water recharge. Grazing land degradation is to be avoided, as severe erosion and sediment production from these lands result in sedimentation of reservoirs and rivers, destruction of downstream aquatic ecosystems, disruption of the hydraulic characteristics of water channels and water eutrophication (Steinfeld *et al*. 2006). A pro-active and stimulating grazing management can be achieved through appropriate, adaptive stocking density and herd composition, as these measures influence vegetative ground cover, net primary production and species composition of grazing lands (Hadjigeorgiou *et al*. 2005). Stocking density should be adjusted to water and biomass availability, thus taking into account climate variations and its effects. Closing grazing areas for a certain period (exclosure) allows them to recover and produce more biomass (Asefa *et al*. 2003; Descheemaeker *et al*. 2009). Although it has been demonstrated that overgrazing leads to degraded, unproductive grazing lands (e.g. Asner *et al*. 2004), it must be recognised that moderate grazing intensities can favour high pasture production and more diversified species composition (Asefa *et al*. 2003; Hadjigeorgiou *et al*. 2005). Moreover, zero-grazing with cut and carry of grasses is a technique that can release grazing pressure on pastures (WOCAT 2007). In this system, a limited number of animals can be kept and well fed near the homestead, which also results in

Table 3. Various feed sources for different livestock types in the area in an average year in northern Ethiopia (Source: Baseline survey; T. Amede, unpubl. data)

X, preferred; 0, non-preferred feed sources

Source of feed	Oxen	Milking cow	Dry cow	Goats	Equines
Sorghum stover	X	X	X	X	0
Teff straw	X	X	X	0	0
Chickpea straw	0	0	0	0	X
Maize straw	X	X	0	0	0
Pasture	X	X	0	0	0
Grazing land	X	X	X	X	X
Imported feed	X	X	0	0	X

decreased energy losses, and easier manure collection (but increased labour costs).

Adopting integrated agricultural water management

Animals are often forced to walk long distances to reach water points in drought-prone environments, therefore, spending a lot of the energy acquired from feeds. Although the amount of water needed for drinking is far less compared to the amount needed to produce feed, providing this little volume is a strategic choice (Peden *et al*. 2007): it enables animals to convert feed into animal products and as such makes a large difference to overall LWP. The provision of sufficient watering points is important not only to maintain animal productivity, but also to avoid the concentration of too many animals around one watering point, causing soil and vegetation degradation and water contamination (Peden *et al*. 2007; Wilson 2007). Good watering point management, taking on board access restriction leads to improved water conservation and therefore higher LWP. Water conservation, which involves decreasing the unproductive water losses (runoff, evaporation, conveyance losses, deep percolation) from a system but also increasing the water use efficiency of the respective system components, has the potential to increase the water productivity. For instance *in situ* water conservations measures, like micro-basins, were found to be extremely effective in improving water productivity of degraded farms (Amede *et al*. 2009; Sisay *et al*. 2009).

Water conservation is often achieved through integrated interventions, which simultaneously lead to soil and nutrients conservation, as they are often designed to break the water flow energy and to infiltrate surface water. Within the group of soil and water conservation measures (e.g. see WOCAT 2007 for an overview) a distinction can be made between physical structures on the one hand and vegetation management on the other hand. As changes in vegetation cover also influence evapotranspiration, the overall impacts on the hydrological cycle are quite complex (e.g. see Bruijnzeel 2004 for extensive overviews). Vegetation restoration leads to an increase in infiltration and transpiration and higher water productivity (Descheemaeker *et al*. 2009). In areas where additional lateral water (run-on) infiltrates, source–sink systems are created and up to 30% of the annual rainfall percolates through the root zone and contributes to groundwater recharge. The water stored can be applied to crops to bridge dry spells, used for domestic uses or for human and animal drinking.

Harnessing from healthier and better managed livestock

The choice of animals and the way animals are managed influences overall livestock productivity. There are differences in LWP across feed types, age and weight of dairy cows. The value of LWP tends to increase with increasing age and weight (Gebreselassie *et al*. 2009). Moreover, monogastric species (pigs, poultry) are characterised by a higher feed conversion rate than ruminants. Animal breeding for better feed conversion, higher milk and meat production, and lower energy requirements has been very successful globally, but the use of improved breeds in the tropics has been limited up to the present, as these breeds are often less resistant to the harsh conditions or prevailing diseases (Parthasarathy Rao *et al*. 2005). Cross-breeds with locally adaptive animals through artificial insemination techniques can be an important driver in this matter (Steinfeld *et al*. 2006). Selection should not be directed at productivity only, but take into account also the animals' adaptation to the prevailing environmental conditions.

Healthier, disease-free animals yield higher value products because food safety is an important component of generating higher market prices. In SSA, animal mortality, which could be as high as 40%, the highest being small ruminants (T. Amede, pers. observation; Negassa and Jabbar 2008) seriously undermines all other efforts to increase livestock (water) productivity. Each animal that dies, 'dies' with all the water it has utilised directly and indirectly during its lifespan, thus, reducing the amount of animal products produced on the one side of the ratio and increasing the amount of water used significantly on the other side of the ratio. High livestock mortality rates are caused by several interrelated factors such as feed shortage, water shortage and prevalence of diseases, which negatively affect system stability and increase vulnerability. The low capacity of veterinary health services to respond to disease outbreaks also plays a role. Therefore, investing in veterinary services and disease control are key areas for increased investment. Adequate herd management, comprising improved decision making on animal type and number, off-take rates, slaughtering age and reproduction rates is equally necessary. Reducing mortalities remain the most important point of intervention in most SSA livestock production systems.

Improved and effective institutions

Institutions affecting livestock water in Africa operate under formal or informal rules, which determine who makes decisions, according to which procedures, what actions are permitted, what information must be provided and what payoffs will be assigned to individuals (Wilson 2007). Formal institutions constitute the written or codified rules such as the constitution, judiciary laws, organised markets and property rights. Meanwhile, informal institutions involve rules governed by behavioural norms in society, family, and community, and include sanctions, taboos, traditions and codes of conduct (North 1990).

Because livestock innovation is a social process, it is not possible to gain LWP improvements unless close attention is paid to institutions and their associated processes in target communities (Amede *et al*. 2009). Commitments from institutions are essential to promote water productivity principles and practices (Amede *et al*. 2009). However, the institutionalisation of water productivity concepts demands strong partnerships, directed at poor livestock keepers and the adoption of innovative and integrated water, land and livestock management practices. It also requires development institutions to embark on holistic, client-oriented and demand-driven approaches. Other key areas include empowering local and national institutions to be pro-active, employing participatory approaches (social norms, social interactions, group dynamism, collective action), involving development cadres in adopting and promoting integrated livestock–water–land management interventions and facilitating linkages between researchers, farmers and extension agents for scaling-up to wider communities and systems.

Enabling local institutions is necessary to facilitate resource management (Waters-Bayer and Bayer 2009), provide support in different areas, such as communal resources management, adoption of new technologies and practices, but also in credit facilities and value adding facilities (e.g. butter production), which are important for smallholders' income (Parthasarathy Rao *et al*. 2005). Institutional development should take on board the establishment of markets for both input and output commodities. Regulations can only be enforced if institutions are in place to establish standards, monitor the necessary variables (e.g. water quality, groundwater depletion), issue permits and fine violators. Also, well functioning and respected institutions play an important role in conflict management and communication between different stakeholders or land users (e.g. crop cultivators and pastoralists) (Steinfeld *et al*. 2006).

Institutions are the key to sustainable management of livestock, water and land resources (Amede *et al*. 2009; Waters-Bayer and Bayer 2009), particularly if communities can be convinced to comply with regulations. However, some of the institutional variables are beyond the reach of the communities; they are not decided by the community but influence enactment, awareness of and compliance with regulations. The major institutional gaps are: (1) an absence of a communication platform among institutions working on the different components of livestock and water; (2) narrow agendas of specialised institutions that should be enhanced and broadened to move towards system-oriented engagement; and (3) an absence of functional local institutions in some localities with subsequent paralysis of technology, integration and dissemination.

In general, very different sets of institutions guide the development of the livestock and water sectors. Water development planning in most countries worldwide either ignores or explicitly prohibits animal use of water resources. In SSA, the reality is that livestock are attracted to agricultural water resources regardless of whether or not planners intended to accommodate them. Within an institution vacuum, competition between livestock and crops for water often breaks out into conflict with serious consequences. It is important for formal research to recognise and complement the efforts being made by local households and communities in improving their management of water for crops, livestock and other purposes (Waters-Bayer and Bayer 2009). Specific examples of institutions that matter most for improving water productivity are presented by Amede *et al*. (2009).

Enabling local and national policies

Water policies have not given priority to improved use and management of livestock, and investments are mainly targeting dams for irrigation and hydropower stations. The current strategy of most governments with respect to poor livestock keepers is inclined towards post-disaster intervention rather than towards investing in early warning systems and introducing adaptive mechanisms. Moreover, in SSA, where food security is a priority on the agenda, there is a growing interest in developing irrigation schemes and promoting agricultural technologies, commonly biased towards the crop sector. Policy makers usually have considered the livestock sector as subsidiary to the crop sector (Scoones and Wolmer 2006). Despite the growing market incentives for livestock products nearly all extension packages in this region are crop-biased. The majority of local institutions and their leaders in SSA are not also necessarily aware of the existing livestock-related bylaws and policies, their regulations and implementation mechanisms.

Policies should take into account equity and gender issues (Amede *et al*. 2009) that contribute to sustainable use of resources and to improved livelihoods. Policies should target developing infrastructure, as this is necessary to secure necessities such as access to markets, veterinary and training services. Appropriate land use should be based on land suitability for different agricultural activities (e.g. WOCAT 2007).

Policies promoting sustainable use of water are necessary incentives for smallholders to maintain the long term productivity of water, land and other natural resources. Natural resources are often seriously under-priced, because of overt subsidies and the fact that externalities are not taken into account (Steinfeld *et al*. 2006). Water pricing is advocated as a useful tool to stimulate water conservation, proper allocation of water to its highest value use and cost recovery (Johansson *et al*. 2002), though it could be culturally nuanced in some countries. With correct water rights and water prices defined, water markets can encourage the efficient use of water resources (R. Norton, cited in Steinfeld *et al*. 2006). As the removal of agricultural subsidies and trade liberalisation lead to more correct prices of both inputs and outputs (Costales *et al*. 2006), these measures also contribute to reducing the negative environmental impact of livestock production systems.

Payment for environmental services, e.g. for improved management of upstream watersheds which may result in improved water quality and quantity to downstream users, can have a positive impact on water productivity as it may be an incentive for farmers to adjust their practices (Pagiola *et al*. 2007). However, for such payment schemes to be operational, environmental services have to acquire a proper price reflecting their real value. As such, markets can be established, where beneficiaries pay to providers (Richmond *et al*. 2007). Market incentives could also affect LWP significantly. Herrero *et al*. (2009) found striking differences in livestock drinking water productivity between the two case-study districts in Kenya. Farms in Kiambu achieved more than four times the income than farms in Kajiado per unit of livestock drinking water exploited, as a result of better market access and the production of higher value livestock goods in Kiambu.

The institutional and policy issues will vary greatly and they may have to operate at different scales. The major policy gaps related to livestock-water interactions in SSA could be summarised as follows: (1) livestock policies that would promote livestock productivity through combined access of drinking water and feed are often lacking; (2) policies directed at providing veterinary services and market infrastructure are often inadequate; (3) the livestock agenda is usually not integrated with irrigation development, biofuel investments and re-afforestation; and (4) local and regional policies that would enable local communities to respond to climatic and man-made shocks are lacking. In general, the policies required for poor livestock keepers are those directly or indirectly affecting the different components of LWP. Policies facilitating the integration of crop, livestock, land and water management initiatives are crucial to improve water productivity at farm, landscape and higher levels.

Operationalising livestock–water interventions

The water use and productivity of these mixed crop–livestock farming systems are influenced both by their bio-physical and their socio-political-economical conditions, which strongly interact at different scales (see Amede *et al*. 2009). However, addressing the complex natural resource challenges should start with entry points (Amede *et al*. 2006).

Operationalising water productivity would also demand a different approach, with integration across scales, engagement of multi interested groups and institutions and grass-root supported research and development actions. The following steps could be useful to promote LWP interventions across households and systems.

Identify and introduce attractive entry points

An entry point is an initial action that is strategically applied to assure smooth and effective engagement with communities, institutions or individuals (Amede *et al*. 2009). It could be an intervention in the form of attractive technologies, policies and other incentives. Entry points are essential to build trust between the community and outside actors, arouse their interest and keep their spirit high. Strategically, entry points must have certain properties that will lead to the main objectives of promoting water productivity at farm and higher scales. A step-wise process on how to employ entry points to address more complex system issues over time is presented in Fig. 1.

There is a need to respond to the immediate demands of communities and households while working on long-term and sustainable farming strategies. This will create confidence with farmers and communities and enhance farmer innovation (Amede *et al*. 2006). Farmers may demand improved inputs (e.g. forage seed, water pumps, fertilisers) at the beginning as they were not ready to take risks by adopting new complex technologies and practices. Better availability of fertilisers and precise application (micro dosing) can make substantial contributions to improved crop production and improved stover quality for livestock. Also the temporal variation in water productivity is affected by the farmers' access to resources as this influences decision making on crop rotation and land use (Haileslassie *et al*. 2009). Identifying what innovations farmers are introducing at the local level could also be used as entry points for collaboration in improving local management of the water and other natural resources (Waters-Bayer and Bayer 2009).

Strengthening local governance

Participatory research should evolve from testing technologies (forages and soil and water) towards improved resource governace, which would promote sustainable use of land and water resources at farm, landscape and higher scales. Creating an

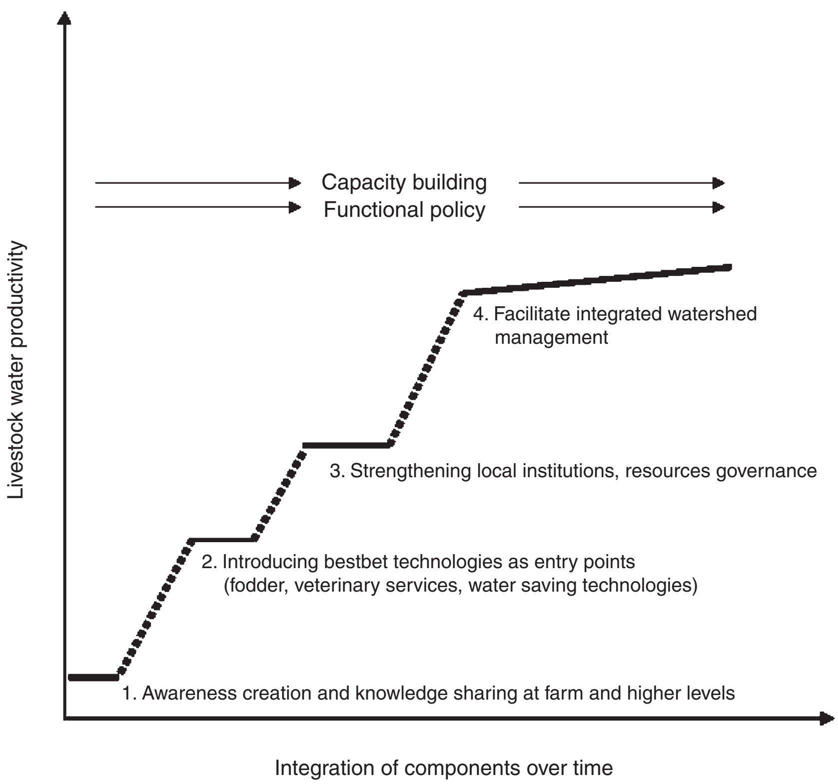

Fig. 1. Step-wise integration of various entry points (technologies and approaches) to improve livestock water productivity at farm and landscape scales (Modified from Amede *et al*. 2006).

innovation system platform whereby innovative farmers are enabled to test, modify and adopt water and livestock technologies is critical (Waters-Bayer and Bayer 2009) to improve sustainable resource governance.

Moving to integrated approaches

By building on the above experience encourage farmers to try more technologies, to modify, adapt and integrate them into their situations and, in the process, to derive many examples of 'win–win' technologies that are useful for various cadres of farmers at farm and watershed scales. Notably, farmers should not be subjected to formal experimentation. In some sites therefore, the researcher's role should change to introducing new ideas rather than designing and control of experimentation, and to monitoring with the aim of understanding farmers' innovations and evaluations, and to support the dissemination and scaling up processes.

Developing decision tools

Farmers and other stakeholders would recognise the need for information management tools which could help them in automating the process of turning the mountains of dispersed data available into useful information (Amede *et al*. 2006). Communities would have made better decisions if the information was gathered, synthesised, analysed in economic and social terms and suggested to the farmer for possible use. Decision guides and other dissemination tools that would help farmers, communities, extension workers and other development actors to value and target interventions at household, farm, landscape and higher scales are required.

Conclusions

Intensification of crop–livestock systems is required to improve productivity of systems and food security and income of rural communities. In contrast, intensification could lead to short-term economic gains and longer term negative environmental implications. We conclude that: (1) increasing water scarcity and growing demands for (animal) feed urge the scientific community to come up with strategies to increase food production without depleting more water while safeguarding the environment; (2) there is a need to develop an institutional platform that would enable specialised institutions (e.g. water sector) to broaden and move towards system-oriented, livestock-inclusive engagement; (3) increasing LWP is an important entry point to improve system productivity, but it is not sufficient to solve the problems of the rural poor unless there is an integrated approach that would enable productive use of water for all purposes; crops, animals, people and environment; and (4) increasing water productivity demands an investment beyond technological interventions. Integrated measures taking on board social, institutional and policy issues are required.

The papers presented in this special issue of *The Rangeland Journal* identified various interventions within three 'technical' domains of livestock water productivity but also indicate the critical institutional and policy issues at various scales. They identified knowledge, institutional and policy gaps and demonstrated that concerted efforts, integrating all components of the water productivity concept will be necessary to achieve improvements. Substantial opportunities also lie in integrating the different agricultural sectors with the water sector at watershed and higher scales.

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