Livestock help the world's poor escape poverty

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13 Water and livestock for human development

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Overview

Livestock production, one of the most important agricultural subsectors worldwide, is practiced in rangeland areas and in mixed crop-livestock systems that cover about 60% of the land area of developing countries [well established]. In developing countries cattle, sheep, and goats total about 1.2 billion tropical livestock units (converted at the rate of 250 kilograms of live animal weight per tropical livestock unit). Animal densities are strongly correlated with human densities and are highest in areas of intensified agriculture, especially in and around irrigation systems. Animals are heavily dependent on water for feed production, using an estimated 500 billion cubic meters or more a year for maintenance. Total water needed may be more than double this amount, with drinking water less than 2% of that required for feed production. Inappropriate grazing and watering practices contribute to widespread degradation of water and land resources, particularly around watering sites. Investments in water and livestock have often failed to achieve maximum and sustainable returns because of a lack of integration of the two.

Despite many efforts to develop water and livestock in developing countries over the past 50 years, sustainability and gender-equitable returns on investments have been disappointing [established but incomplete]. Global experience indicates that integrating water and livestock development creates opportunities to sustainably increase benefits in ways that independent development efforts cannot achieve. Without integration, opportunities to achieve maximum and sustainable returns on investments in both sectors will be lost.

Livestock are an important part of global agriculture, providing meat, milk, eggs, blood, hides, cash income, farm power, and manure for fuel and soil nutrient replenishment [well established]. Livestock also have important cultural values and are a means for poor people to accumulate wealth. Large numbers of poor farmers and herders depend on livestock for their livelihoods. Livestock depend on water, but when poorly managed, they contribute to the degradation and contamination of water resources.

Livestock keeping represents a diverse set of geographically varying livelihoods that benefit both poor and wealthy people in rangelands and in rainfed and irrigated crop-livestock farming systems [well established]. Agricultural intensification often correlates with higher livestock densities. Understanding spatial changes in the distribution and structure of livestock production systems in relation to agricultural water can help to identify areas where considerations of livestock-water interactions can enhance the sustainability and returns on livestock investments. South Asia and Sub-Saharan Africa are priority regions for integrating livestock and water development for poverty reductions, but benefits can be expected elsewhere as well.

Rapidly growing demand for meat and milk in urban areas of developing countries will place substantial new demands on agricultural water resources, especially for feed production

Rapidly growing demand for meat and milk in urban areas of developing countries will place substantial new demands on agricultural water resources, especially for feed production [well established]. Meeting this demand will require much more water but will also provide opportunities for rural farmers to generate needed income. This trend may also increase competition for agricultural water, marginalizing some farmers and herders, provoking conflict, and driving them deeper into poverty. Households will need adequate agricultural water to maintain animals that remain important providers of quality nutrition and on-farm power and a preferred means of wealth savings.

A livestock water productivity framework, with a gender dimension, enables a better understanding of livestock-water interactions [established but incomplete]. The framework identifies four basic livestock development strategies that can lead to more productive and sustainable use of water resources: improving the sourcing of animal feeds; enhancing animal productivity (products, services, and cultural values) through better veterinary care, genetics, marketing of animal products, and value-added enterprise; improving watering and grazing practices to avoid degradation of land and water resources; and providing quality drinking water. These strategies are often needed simultaneously.

Little is known about water depleted to produce feed, the efficiency with which feed is converted into animal products and services, and the impact animals have on water resources [established but incomplete]. A seventyfold difference in feed-water productivity (ratio of the benefits of livestock goods and services produced to the water depleted in producing them) is reported in the scientific literature. There are also large variations in animal productivity and animal impacts on water resources. Thus, generalized estimates of livestock water productivity require scrutiny, and global assessments of livestock water productivity are needed. While there is still much to learn about site- and production system-specific policy, technologies, and practices that can lead to increased and sustainable livestock water productivity, integration of existing knowledge of animal production with range and water resources management options affords good opportunities to increase sustainability and the productivity of water used for livestock production.

Drinking water is essential for animal survival, but the amount needed is small compared with other uses of agricultural water [well established]. Investing in drinking water makes strategic sense given the high value of animals and animal products and the small amount of water used. One liter of drinking water provided in areas of surplus feed effectively makes available an additional 100 liters of otherwise unusable agricultural water evapotranspired from rangeland vegetation and greatly increases livestock water productivity. Strategic placement and provision of adequate quality drinking water enables animals, particularly cattle, to source feed in otherwise inaccessible grazing areas and enhances the production of meat and milk. Selecting animals adapted to dryland conditions may reduce the need for drinking water. Careful management of areas adjacent to drinking water is necessary to avoid water and land degradation.

The widespread perception that livestock production is a wasteful use of the world's water resources does not apply to conditions in many developing country contexts [established but incomplete]. Livestock can be efficient and effective users of water when they depend largely on crop residues and by-products and on well managed rangelands unsuitable for crop production. Application of livestock water productivity concepts may lead to some of the greatest enhancements in productivity of future agricultural water use in developing countries. Achieving this requires improved integrated governance of livestock and water resources.

The overarching message of this chapter is that livestock-water interactions are important and under-researched and that huge opportunities exist to improve the productivity of water associated with livestock production. In contrast to the large body of knowledge related to crop-water interactions, research on livestock-water interactions remains in its infancy. Of necessity, this chapter takes a "broad brush" approach and a global overview of some general principles that are likely to be most applicable in the poorest regions of the world, especially in Sub-Saharan Africa. Readers are advised to examine their specific cases and situations in detail, to be vigilant for new and unexpected ways that animals and water use affect each other, and to consult with qualified and diverse disciplinary experts before intervening in national and local contexts.

One of the quickest ways to aggravate poverty is to deprive smallholder livestock keepers and herders in developing countries of their animals

Water, livestock, and human development

Livestock keeping is one of the most important, complex, and diverse subsectors of world agriculture and a primary means of escaping poverty in rural areas. The very poor often do not keep animals, but many would likely do so given the opportunity (van Hoeve and van Koppen 2005). One of the quickest ways to aggravate poverty is to deprive smallholder livestock keepers and herders in developing countries of their animals. Little systematic integration of water and livestock development has taken place, a failure that has undermined investments in both subsectors (Peden and others 2006). Future development of agricultural water will benefit from effective integration and consideration of animal use of and impact on water resources *[established but incomplete]*.

Much popular and environmental literature considers livestock production to be among the greatest threats to sustainable water use over the coming decades. The large volumes of water thought necessary to produce human food from livestock is the major concern. For example, the *Times of India* (2004) reports that one liter of milk requires 3,000 liters of water, and it attributes rapid declines in groundwater to wasteful dairy production. Goodland and Pimental (2000) and Nierenberg (2005) state that producing 1 kilogram (kg) of grainfed beef requires about 100,000 liters of water, while producing 1 kg of potatoes takes only 500 liters. However, SIWI and others (2005) estimate that grainfed beef uses only 15,000 liters of water. Thus, while there is little agreement on the precise amount of water needed for grainfed beef production, the literature does agree that it takes much more water to produce 1 kg of grainfed beef than 1 kg of crops (Chapagain and Hoekstra 2003; Hoekstra and Hung 2003). Much of the literature is flawed, however, in comparing water used for production (kilogram fresh weight) of human foods without correcting for their water content and in using data of questionable relevance to developing countries.

The contributions of livestock to rural livelihoods have been underestimated because of a past focus on productivity, limited consideration of nonmonetized products and services, and neglect of small stock

The water productivities of dry weight protein from crops and animal products differ less than those of fresh weight production. For example, Renault and Wallender (2000) estimate protein water productivity at 41 grams per cubic meter for eggs, 40 for milk, 33 for poultry meat, 21 for pork, and 10 for beef compared with 150 grams per cubic meter for potatoes, 77 for maize, 76 for bean, 74 for wheat, 49 for rice, and 14 for groundnuts. And the 10 grams per cubic meter refers to California grainfed beef. In poverty-prone regions of the world farmers' and herders' cattle graze or feed mostly on crop residues, processes that require much less water than does grain for production.

Furthermore, the amino acid mix of crop proteins is less suitable for human nutrition unless people consume appropriate mixtures of grains and pulses or obtain quality protein from other sources. And some crop foods such as potatoes, although their protein water productivity is high, have a very low protein content. Adults would have to consume 2,700 kilocalories a day of potato energy to obtain minimal daily protein requirements of 75 grams (Beaton 1991). Meat consumed beyond the 75 grams of protein needed daily tends to be used by the human body as an energy source. Thus, the water used to meet the first 75 grams of dietary protein is more effectively used than the water used to produce additional protein if the body converts it to energy. Modest amounts of meat in the diets of African children appear to improve mental, physical, and behavioral development (Sigman and others 2005; Neumann and others 2003), demonstrating that meat should not be evaluated only in terms of weight produced. However, the literature on livestock-water interactions does not address this important topic *[established but incomplete]*.

The contributions of livestock to rural livelihoods have been underestimated because of a past focus on productivity, limited consideration of nonmonetized products and services, and neglect of small stock, such as goats and poultry. But poor and subsistence households obtain multiple benefits from the use of livestock (Shackleton and others 1999; Landefeld and Bettinger 2005).

Beyond meat production and consumption, water used to support animals provides great value. Livestock contribute to the livelihoods of at least 70% of the world's rural poor and strengthen their capacity to cope with income shocks (Ashley, Holden, and Bazeley 1999). They provide milk, blood, manure, hides, and farm power essential to cultivation and marketing of crops. Livestock assets are often an important source of wealth security.

The sale of livestock and livestock products is a vital strategy to enhance income and cope with major or unexpected family expenses. Production of all these vital goods and services depends on water.

This chapter describes the global distribution of livestock production systems and the implications for the use of agricultural water, outlines major trends affecting animal production, and links this distribution and production to the use of agricultural water. It introduces a livestock water productivity framework to help understand how livestock keeping in diverse production systems affects the depletion and degradation of water resources and uses this understanding to suggest strategies and options for more efficient, productive, and sustainable use of water. It concludes with brief case studies of the practical application of these strategies.

The sale of livestock and livestock products is a vital strategy to enhance income and cope with major or unexpected family expenses

This chapter emphasizes animal keeping in developing countries, especially in South Asia and Sub-Saharan Africa, where poverty and livestock keeping converge, and it emphasizes ruminants, particularly cattle, since these are the animals most commonly associated with high rates of water use and degradation. The chapter draws on relevant developed country research when appropriate. Many breeds and species of animals constitute what is collectively known as livestock, but space does not allow discussion of all of them. Poultry and swine are particularly important but are not addressed here in any detail. This study is among the first to examine livestock-water interactions in diverse poverty-stressed developing countries, and much more research is needed to tailor specific policy and research options applicable to national and local areas.

Where are livestock kept by the poor?

Livestock keeping varies greatly by the livelihoods, environments, and cultures in which it takes place. The nature of livestock-water interactions also differs, including livestock use of water resources and impact on them and options for better management of both resources and their interactions. A global assessment requires an understanding of all these variations.

Livestock production systems

This chapter uses Thornton and others' (2002) description of nine livestock production systems and global distributions of tropical livestock units (defined in box 13.1) and poor livestock keepers (table 13.1). Production systems are defined according to water availability, agricultural intensification, and presence of livestock. In addition, "landless" livestock production is rapidly increasing in developing countries. Landless systems include industrial-scale and smallholder production in which animals are confined to pens. The producers, living in livestock-supporting landscapes, neither graze their animals nor produce the feed for them but rather purchase the feed and usually sell animal products for profit. *Poor livestock keepers* are defined as people who live in rural areas, keep livestock, and live below the national poverty lines established by the World Bank for each country. Descriptions of production systems, livestock, and the distribution of poor livestock keepers in the chapter provide a valid broad global overview, but substantive variation will occur at local levels.

box 13.1 Tropical livestock units

Livestock consist of many species and breeds of big and small animals that are raised worldwide in diverse production systems. To enable comparisons and to synthesize results, livestock are converted into tropical livestock units. One tropical livestock unit is equivalent to a 250 kg live-weight animal. The tropical livestock unit is a useful estimator of animal biomass, but it is imprecise because of significant variation of animal weights within species, across herds, and across production systems. For that reason, some sources cited in the chapter use different tropical livestock unit equivalents. The table shows indicative tropical livestock unit equivalents for domestic animals considered in this chapter. Also shown are basal metabolic rates based on Kleiber's "three-quarters law" that underpins discussion on water requirements for livestock feed production (see discussion later in chapter).

Indicative tropical livestock unit equivalents and basal metabolic rates

Species	Tropical livestock units per head	Basal metabolic unit (kilocalories per tropical livestock unit)	Species	Tropical livestock units per head	Basal metabolic unit (kilocalories per tropical livestock unit)
Camel	1.4	4,046	Pig	0.20	6,581
Cattle	1.0	4,401	Sheep or goats	0.10	7,826
Donkey	0.5	5,234	Poultry (chicken)	0.01	13,917

Source: FAO 2004; Kleiber 1975; Jahnke 1982.

Animal census data are notably incomplete for many countries, and methods for conducting them vary. Caution is needed in applying this information to smaller areas.

Developing countries cover about 80 million square kilometers of the world's land area. Of this about 48 million square kilometers are used for livestock keeping (23 square kilometers is rangeland, 20 square kilometers is mixed rainfed crop-livestock production, and 5 square kilometers is mixed irrigated crop-livestock). About half of the rangelands and a third of the mixed rainfed production systems are in Sub-Saharan Africa. Diseases limit animal keeping in very hot and humid areas such as the Amazon and Congo Basins. Extreme aridity, such as in the Sahara Desert, also constrains animal production. Otherwise, livestock are widespread across the developing world.

Landless animal production is most evident in the Indo-Gangetic region of South Asia, China, and Indonesia. It will likely expand in and around urban areas of Sub-Saharan Africa in coming years (Peden and others 2006).

Livestock keepers and their animals

Human and animal demographics vary greatly across production systems and regions of the world. Livestock production systems support about 4 billion people (see table 13.1). Of these, about 1.3 billion (32%) people are poor and about 509 million people (13%) are poor livestock keepers (map 13.1). Sub-Saharan Africa and South Asia are home to 63% (800 million) of the poor and about 68% (344 million) of the poor livestock keepers. About half table **13.1** Area, people, poverty, and livestock within animal production systems of developing country regions

	Sub-Saharan Africa	Central and South America	West Asia and North Africa	East Asia	South-east Asia	South Asia	Newly independent states of Central Asia	Total
Animal production system area (millions of square kilometers)								
Rangeland	8.97	5.47	1.81	4.33	0.21	0.35	2.05	23.19
Mixed irrigated	0.12	0.40	0.83	1.37	0.48	1.52	0.41	5.13
Mixed rainfed	6.53	5.23	1.56	2.47	1.41	1.72	1.01	19.93
Other lands with some livestock	8.45	9.24	8.09	2.80	2.65	0.80	0.57	32.60
Total	24.2	20.3	12.3	11.0	4.8	4.4	4.0	80.8
People and poverty in production systems								
Number of people (millions)	506	329	310	1,187	401	1,256	64	4,053
Number of people below national poverty lines (millions)	268	132	85	111	127	533	17	1,273
Number of poor livestock keepers[a] (millions)	152	45	34	24	52	192	10	509
Share of total who are poor (percent)	53	40	27	9	32	42	27	44
Share of total who are poor livestock keepers (percent)	30	14	11	2	13	15	16	13
Cattle, sheep, and goats (tropical livestock units[b])								
Number (millions)	246	391	57	111	85	276	24	1,190
Density (number per square kilometer)	10.2	19.3	4.6	10.1	17.7	62.7	6.0	14.7
Estimated water needs for maintenance of livestock[c] (billions of cubic meters a year)								
Drinking	2.2	3.7	0.5	1.0	0.8	2.5	0.2	0.9
Feed production	111	176	26	50	38	124	11	536

a. Refer to map 13.1 for geographic distribution.

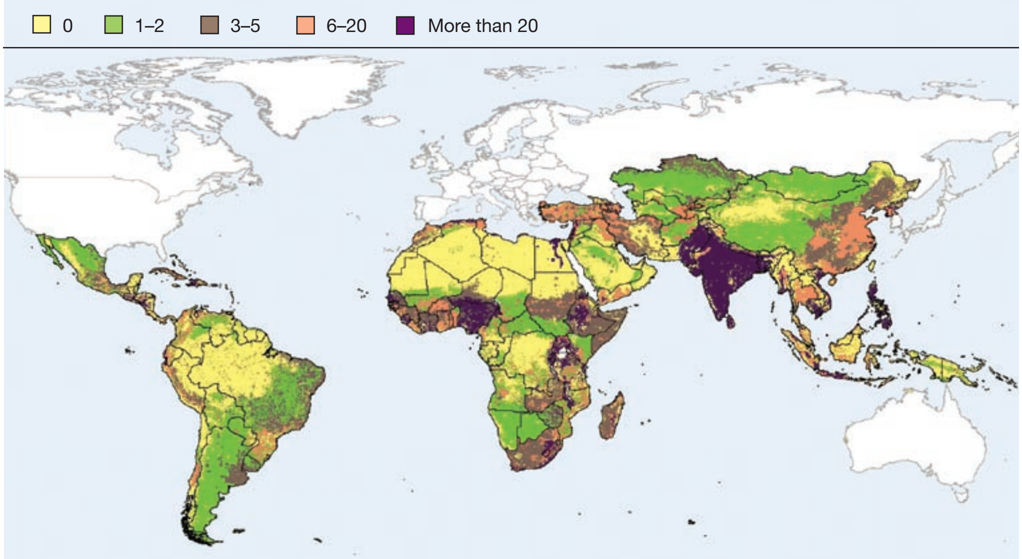
b. One tropical livestock unit = 250 kg of live animal weight.

c. Maintenance refers to minimum amount of water needed to keep animals alive without weight loss but excludes extra feed needed for growth, lactation, and work; see text for explanation.

Source: Adapted from Thornton and others 2002.

of the 500 million people who reside in livestock-producing areas of Sub-Saharan Africa live below the poverty line and about 30% of them are poor livestock keepers. About 40% (533 million) of South Asians are poor and 15% (192 million) are poor livestock keepers. In summary, South Asia has the highest level of absolute poverty and Sub-Saharan Africa has the highest prevalence of poverty. The poor in these two regions, for whom livestock are often very important as both critical livelihood opportunities and constraints, are the focus of this chapter although important livestock-water-poverty interactions are widespread globally.

map **13.1** | **Developing country distribution of livestock keepers who are poor** (per square kilometer)



Source: Thornton and others 2002.

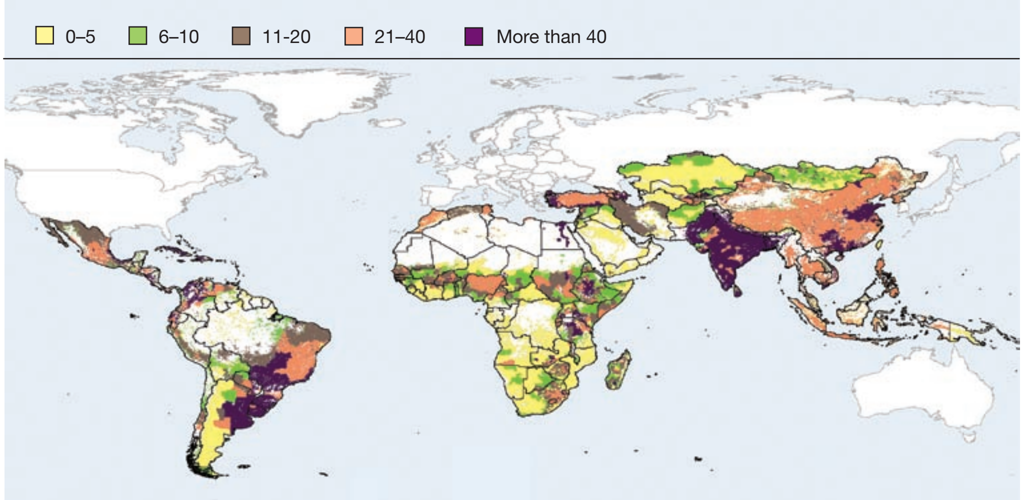
Understanding how livestock, water resources, and poverty are intertwined holds promise of ensuring that livestock and water development can be encouraged in a coherent and balanced way to sustainably improve human well-being.

In many countries livestock holdings are more equitably distributed than land holdings. Livestock have greater economic and social importance in poor households than in less poor ones (Heffernan and Misturelli 2001). For example, in India smallholders with less than 2 hectares (ha) of land make up 62.5% the rural households, possess only 32.8% of the cultivated land, but account for 74% of poultry, 70% of pigs, 67% of bovines, and 65% of small ruminants (Taneja and Brithal 2004). In Ethiopia smallholder farmers account for 98% of milk production (Redda 2002). In North, Central, and South America, most beef is produced on medium-size and large ranches but a significant share is produced on small farms (Jarvis 1986).

Although about 165 million poor livestock keepers live in East and Southeast Asia, the newly independent states of Central Asia, West Asia and North Africa, and Central and South America, they constitute a smaller share of the population in livestock-producing areas compared with South Asia and Sub-Saharan Africa, and average poverty levels are less severe (see table 13.1).

Cattle, sheep, and goats in the production systems of developing countries total about 1.2 billion tropical livestock units (see table 13.1). The convergence of high livestock density (more than 40 tropical livestock units per square kilometer) and poverty occurs mostly in South Asia and Sub-Saharan Africa in a band stretching from Senegal across the Sahel to Ethiopia and southward through East Africa and into Southern Africa (map 13.2).

map 13.2 **Developing country distribution of livestock**
(tropical livestock units per square kilometer)



Source: Thornton and others 2002.

High animal densities also exist in the Cone of South America, Turkey and the eastern Mediterranean, and East Asia, but poverty in these areas is less severe.

The global livestock population requires considerable amounts of water, but estimates of these amounts are crude. When considering livestock and water, most people think of drinking water. Drinking water requirements total about 900 million cubic meters per year within developing country production systems (see table 13.1), assuming a need for about 25 liters a day per tropical livestock unit, though the amount is highly variable. However, by far more water is required to produce feed for animals. Evapotranspiration associated with the production of maintenance feed totals about 450 cubic meters per tropical livestock unit a year, an amount that can underestimate the actual value by as much as 50% depending on animals' growth, reproduction, work, environment, and lactating states. The total water required for cattle, sheep, and goat feed in developing countries will exceed 530 billion cubic meters a year, with additional water required for other livestock species.

Livestock and intensified agriculture

Animal densities are often correlated with human densities, the intensification of agriculture, proximity to markets, and the use of water for crop production (table 13.2; Peden and others 2006). For example, in Africa the highest animal densities are associated with intensive crop production, especially large-scale irrigation systems. This may suggest that livestock keepers are already responding to the driving forces of urbanization, or it may simply be that people and animals are more prevalent where food crop production is highest and where people are wealthy enough to own animals. However, evidence suggests that successful intensification of agriculture, including irrigated crop production, generates new farm income and helps reduce poverty. This enables farmers to invest in livestock as a

table 13.2	African livestock densities in irrigated, rainfed, and rangeland production systems in relation to market access and human density (tropical livestock units per square kilometer)			
	Production system			
Criterion	Mixed irrigated	Mixed rainfed	Livestock dominant	Weighted mean[a]
Market access				
Poor	14.0[b]	14.1	9.7	10.9
Good	38.7	23.0	16.7	21.8
Human population density				
High	45.1	31.2	38.8	33.0
Low	26.1[b]	13.6	10.9	12.1
Weighted mean	32.4	19.7	11.3	

a. Weighted according to total area covered by the associated criterion.
b. Irrigated area was so small that comparison with data in the rest of the table may not be reliable.
Source: Peden and others 2006.

preferred means of wealth savings and an opportunity to further increase income through sales of animal products (chapter 4 on poverty; Peden and others 2006).

In South Asia water and land availability determine the types and numbers of livestock (Chawla, Kurup, and Sharma 2004). In India livestock densities are higher in irrigated areas than in rainfed areas (Sastry 2000; Misra and Mahipal 2000), but the average number of animals per household may be fewer (Chawla, Kurup, and Sharma 2004) and animal feed may be more limiting. Intensification of crop production through the development of agricultural water will attract livestock production and heighten competition for water resources.

Demand for livestock products

World consumption of animal products is growing. Projected demand for animal production and rates of change in demand vary by region (table 13.3). Consumption and production are rising at about 2.5%–4% a year in developing countries, but at less than 0.5% a year in developed ones. Rising demand and consumption are closely linked to the increased purchasing power of rapidly urbanizing populations. In developed countries per capita demand for animal products has leveled off and may decline in the future, reflecting consumers' concern about prices, the ethics of keeping animals, and perceptions about the harmful impact of excessive use of animal products on human health and the environment. Despite faster growth in consumption of meat and milk in South Asia and Sub-Saharan Africa, where poverty and food security remain critical, by 2020 per capita consumption will still be far below levels in developed countries.

Demand for animal products originates in the same markets that drive demand for high-value horticultural crops and other products of intensified agriculture and likely competes for the same agricultural water needed to produce them. Three challenges for the future are allocating water required to satisfy urban demands for both meat and crop

table 13.3 **Projected trends in meat and milk consumption and production, 1997–2020**

Region	Projected annual growth rate 1997–2020 (percent)		Projected amount in 2020 (million metric tons)		Projected per capita amount in 2020 (kilograms a year)	
	Meat	Milk	Meat	Milk	Meat	Milk
Consumption						
China	3.1	3.8	107	24	73	16
India	3.5	3.5	10	133	8	105
Other East Asia	3.2	2.5	5	2	54	29
Other South Asia	3.5	3.1	7	42	13	82
Southeast Asia	3.4	3.0	19	12	30	19
Latin America	2.5	1.9	46	85	70	130
West Asia and North Africa	2.7	2.3	13	42	26	82
Sub-Saharan Africa	3.2	3.3	11	35	12	37
Developing countries	3.0	2.9	217	375	36	62
Developed countries	0.8	0.6	117	286	86	210
World	2.1	1.7	334	660	45	89
Production						
China	2.9	3.2	86	19	60	13
Other East Asia	2.4	3.9	7	3	55	29
India	2.8	1.6	8	172	6	135
Other South Asia	2.6	3.1	4	46	9	92
Southeast Asia	3.1	2.9	16	3	25	5
Latin America	2.2	2.0	39	80	59	121
West Asia and North Africa	2.5	2.6	11	46	18	72
Sub-Saharan Africa	3.4	4.0	11	31	10	30
Developing countries	2.7	3.2	183	401	29	63
Developed countries	0.7	0.4	121	371	87	267
World	1.8	1.6	303	772	39	100

Source: Delgado 2003.

production in intensified agricultural systems; making livestock production a more water efficient and sustainable livelihood option, particularly for the poor; and ensuring that policy focused on meeting demands from urban markets does not divert attention from rural livestock keepers, for whom livestock have many uses beyond the sale of meat and milk.

Livestock water productivity—an integrated approach to managing animal-water interactions

Livestock water productivity is defined as the ratio of net beneficial livestock-related products and services to the water depleted in producing them. It acknowledges the importance of competing uses of water but focuses on livestock-water interaction. Livestock water productivity is a systems concept, with each production system having a unique dynamic structure and mix of processes. Production systems are complex, and an integrating framework can help to identify sets of options to enable more effective and sustainable use of water for livestock. Key livestock water productivity principles are illustrated in figure 13.1.

Regardless of the size of the land area covered, water enters an agricultural system in the form of rain or surface inflow. Water is depleted or lost through transpiration, evaporation, and downstream discharge and cannot be readily used again. Degradation and contamination also deplete water in the sense that the water may be too costly to purify for reuse. Agricultural output depends primarily on transpiration. Animal production depends on the use of feed produced by transpiration (unless it has been imported, in which case the feed incorporates "virtual" water, reflecting transpiration occurring in another country). Introducing animal management practices that promote useful transpiration or infiltration of available water will likely increase livestock water productivity. Livestock water productivity differs from water or rain use efficiency because it looks at water depleted rather than at applied or inflowing water.

> Three basic strategies help to increase livestock water productivity directly: improving feed sourcing, enhancing animal productivity, and conserving water

Three basic strategies help to increase livestock water productivity directly: improving feed sourcing, enhancing animal productivity, and conserving water (see figure 13.1). Providing sufficient drinking water of adequate quality also improves livestock water productivity. However, it does not factor directly into the livestock water productivity equation because water that has been drunk remains inside the animal and thus within the production system, although subsequent evaporative depletion may follow.

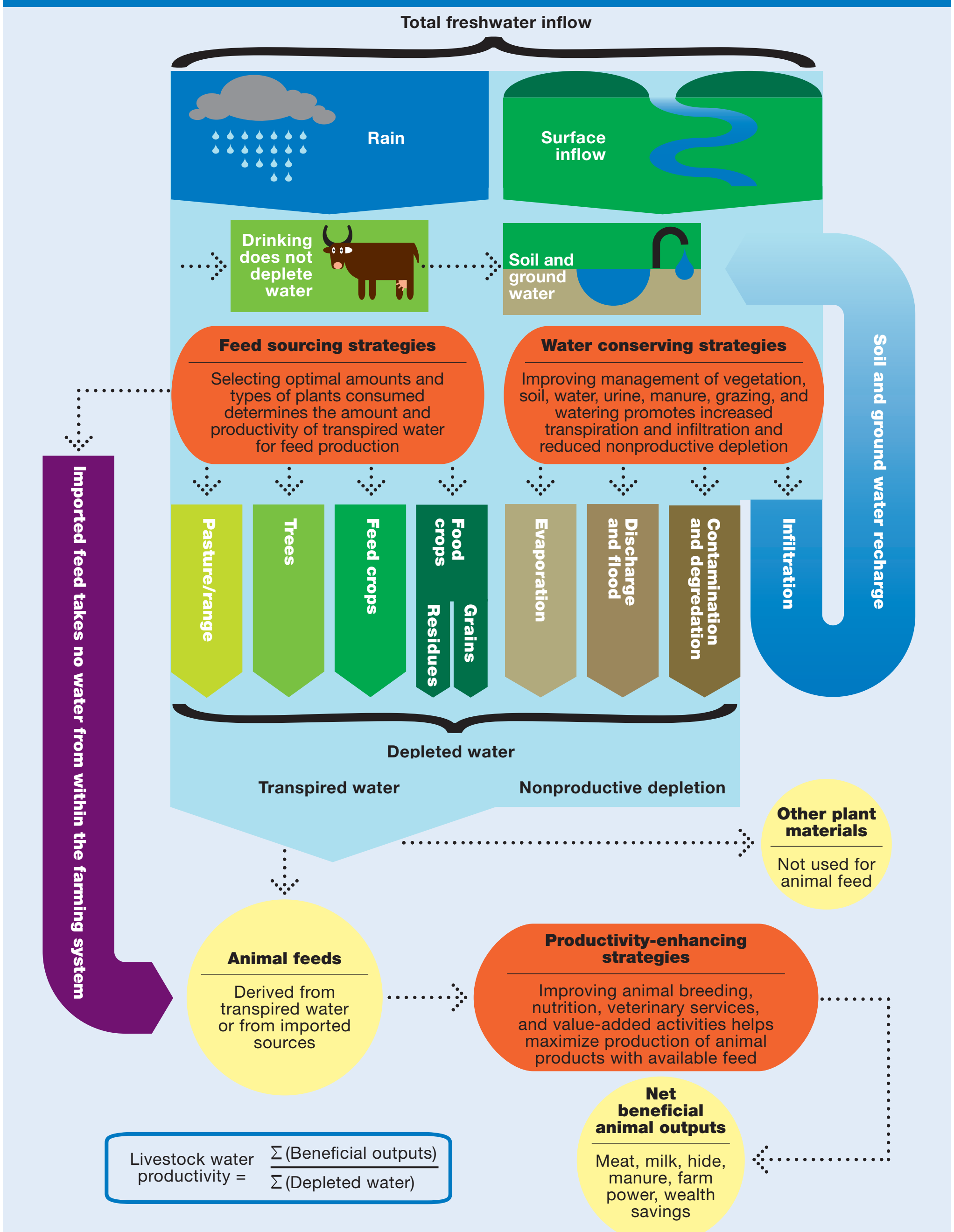
Focusing on a single strategy may not be effective. A balanced, site-specific approach that considers all four strategies will help to increase the benefits derived from the use of agricultural water for the production of animal products and services. Children, women, and men often receive different benefits from animal keeping and have different roles in managing livestock-water interactions, considerations that need to be taken into account in attempts to improve livestock water productivity. Livestock water productivity does not seek to maximize the number of livestock or the production of animal products and services. Rather, it opens opportunities to produce the same benefits with fewer animals and less demand for agricultural water.

Improving feed sourcing

Animal production depends on access to sufficient supplies of quality feed—grains, crop residues and by-products, pasture, tree fodder, and forage crops. Production of feeds is one of the world's largest uses of agricultural water. The entry point for improving global livestock water productivity must be strategic sourcing of animal feed, an issue that has largely been ignored during the past 50 years of research on livestock and water management. Judicious selection of feed sources is potentially one of the most effective ways of improving global agricultural water productivity.

Science-based knowledge of water use for feed remains contradictory and highly variable. The discussion here focuses on three important issues: the water productivity of feeds and forages, conversion of feed to animal products and services, and the distribution of feed resources.

figure 13.1 **A framework for assessing livestock water productivity can help identify options for reducing water depletion and increasing goods and services associated with animal keeping**



Source: Authors' schematization derived from research for the Comprehensive Assessment of Water Management in Agriculture and the Challenge Program on Water and Food of the Consultative Group on International Agricultural Research.

Water productivity of feeds and forages. Available literature indicates that evapotranspired water used to produce 1 kg of dry animal feed is highly variable, ranging from about 0.5 kg per cubic meter of water to about 8 kg (table 13.4). Many factors affect the amount of water depleted through evapotranspiration, including the vegetative leaf area index, animal preferences for specific fodder plants, root depth, rainfall, plant genetics, and soil structure, moisture, and chemistry.

Sala and others (1988) analyzed 9,500 sites throughout the central United States and found that the water productivity of diverse temperate grasslands receiving 200–1,200 millimeters (mm) of annual rainfall was similar, at about 0.5 kg of aerial biomass per cubic meter of evapotranspiration, with productivity slightly higher in wetter sites than in drier ones. The higher levels of water productivity for forage sorghum in Sudan, for various crops and pasture in Ethiopia, and for *Pennisetum* reflect experimental studies in which cumulative evapotranspiration was measured only during plant growth. The remaining cases represent year-round calculations of evapotranspiration in cooler climates where growing seasons were less than one year in length. Clearly, no accurate estimates of evapotranspiration used for feed are possible without standardizing the methodology, but for illustrative purposes we have used the figure of 4 kg per cubic meter. This figure, based on experimental evidence, may overestimate water productivity in the real world. There is great need for a systematic global evaluation of the water productivity of forage plants.

table **13.4** **Dry matter water productivity of selected forage and rangeland vegetation**

Forage and feed plants	Above ground dry matter water productivity (kilograms per cubic meter)	Source
Irrigated forage sorghum, Sudan	6–8[a]	Saeed and El-Nadi 1997
Various crops and pastures, Ethiopia	4[a]	Astatke and Saleem 1998
Pennisetum purpureum (1,200 mm evapotranspiration)	4.33	Ferraris and Sinclair 1980
Pennisetum purpureum (900 mm evapotranspiration)	4.27	Ferraris and Sinclair 1980
Pennisetum purpureum (600 mm evapotranspiration)	4.15	Ferraris and Sinclair 1980
Irrigated alfalfa, Sudan	1.3–1.7	Saeed and El-Nadi 1997
Irrigated alfalfa, Wyoming, United States	1.22–1.47[b]	Claypool and others 1997
Alfalfa, California, United States	1.11	Renault and Wallender 2000
Irrigated pasture, California, United States	0.72	Renault and Wallender 2000
Rangeland, California, United States	0.72	Renault and Wallender 2000
Grasslands, United States (1,200 mm rain)	0.57	Sala and others 1988
Grasslands, United States (900 mm rain)	0.56	Sala and others 1988
Grasslands, United States (600 mm rain)	0.54	Sala and others 1988
Grasslands, United States (300 mm rain)	0.49	Sala and others 1988

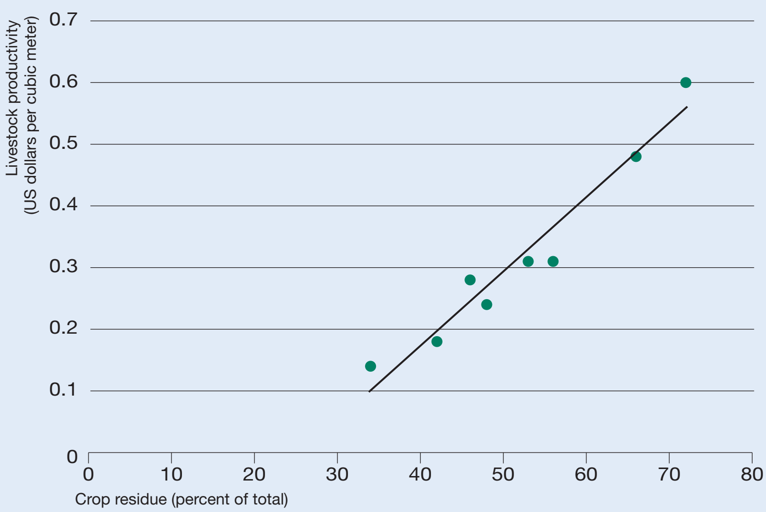
a. Relatively high values may reflect experimental design, ambient temperature, annual versus growing season water budget, leaf area index, solar energy, and other variables.
b. Estimates transpiration rather than evapotranspiration.

Keller and Seckler (2005) suggest that transpiration efficiency (dry matter production per unit of transpired water) is relatively constant for particular plant species and that variability in crop water efficiency depends on site- and season-specific differences in the evaporation component of evapotranspiration. Some opportunity exists to select water-efficient forage species and varieties (Claypool and others 1997). C_4 plants may have higher water productivity than C_3 species.[1] However, reducing the evaporation component of evapotranspiration will be one of the most important and practical pathways for increasing feed water productivity and thus livestock water productivity.

Crop residues and by-products present a unique opportunity for feed sourcing. Because efforts to improve crop water productivity have focused on grains and fruits that people consume, any residues and by-products that can be used by animals represent a potential feed source that requires no additional evapotranspiration. To the extent that animal production can take advantage of this feed source, huge gains in livestock water productivity are possible. Figure 13.2 demonstrates how the livestock water productivity for a group of Ethiopian farmers is positively correlated with the share of crop residues in their animals' diets. Use of crop residues can boost farm income without the use of additional water *[established but incomplete]*.

Theoretically, if livestock production were based solely on the use of crop residues and by-products, water for feed production would be nil. However, this extreme may not be economically and environmentally desirable if sufficient residues and manure are not left

figure **13.2** **Livestock water productivity is positively correlated with the share of animal diets composed of crop residues and by-products in Ethiopia's Awash River Valley**



Note: This example takes into account livestock's multiple values in terms of providing milk, meat, and farm power. Evapotranspiration enabling grain production also results in valuable stover for use as animal feed without using more water.

Source: Authors' analysis based on data from Ayalneh 2004.

in or returned to the soil to maintain soil productivity. Furthermore, crop residues tend to be relatively indigestible and to have lower nutritional quality. These limitations will have to be overcome. Options include making urea-treated silage from residues and providing high-quality supplemental feeds containing limited grains or leguminous forage crops. Studies are needed of the tradeoffs associated with different options for using residues and by-products.

"Improving livestock water productivity requires assessing the feed requirements of livestock and selecting feeds with high water productivity relative to other uses for agricultural water

Conversion of feed to animal products and services. Improving livestock water productivity requires assessing the feed requirements of livestock and selecting feeds with high water productivity relative to other uses for agricultural water. This in turn requires estimates of the feed energy and nutrient needs for maintenance, growth, reproduction, lactation, work, thermoregulation, and symbiotic micro-organisms and parasites of the digestive tract. The digestibility of feed varies between 20% and 70%, and the indigestible component is returned to the ecosystem in the form of manure. Should the transpired water used to produce undigestible feed that ends up as manure be attributed to livestock production when this manure contributes to the fertility replenishment of soil, household fuel, and construction material for homes? In this study we include the value of manure among the benefits attributed to animal production. We could also have reduced the estimated water depleted for animal production. Either way, recognizing the value of manure will lead to increased estimates of livestock water productivity where there is demand for manure. In cases where excess deposition of manure damages the environment, the environmental cost should be included in estimating the net benefits associated with livestock production.

The basal metabolic rate is the intracellular energy consumption of a fasting animal (not in a state of reproduction or lactation) at rest in a thermoneutral environment. In 1932 Kleiber (1932) demonstrated that the basal metabolic rate of mammals ranging in size from mice to elephants is proportional to their live weight$^{0.75}$. Kleiber's "three-quarters law" is the conceptual basis for estimating maintenance feed energy requirements of livestock. The basal metabolic rate is a common denominator for comparing the energy requirements of individual animals of all livestock species, breeds, and age classes. The basal metabolic rate for one animal weighing 250 kg (1 tropical livestock unit) is 4,401 kilocalories (Kcal) a day. The basal metabolic rate per tropical livestock unit can be much greater for small animals than for big animals. The basal metabolic rate of chickens, for example, is about three times that of cattle or camels. The three-quarters law has been confirmed by numerous scientists, but small deviations from this predictor can still be expected *[well established]*.

Taking into account other energy and nutrient needs of livestock is a complex task. Maintenance energy consumption is greater than the basal metabolic rate and includes energy needs for thermoregulation, gut function, loss of energy in urine, and modest work for feeding and drinking. Maintenance energy varies by livestock species and breeds and the environments in which they are kept (tables 13.2 and 13.5).

A synthesis by the International Livestock Research Institute (ILRI) (Fernandez-Rivera 2006) suggests an estimate of animal maintenance energy of 11,000 Kcal per tropical livestock unit per day for grazing cattle in Africa, but diverse environments, species, table 13.5 **Estimated maintenance energy consumption of selected animals**

Animal and location	Maintenance energy[a]	Source
Broiler chickens, United States, at 13°C	157	Sakomura and others 2005
Broiler chickens, United States, at 32°C	127	Sakomura and others 2005
Holstein cattle, Japan	116	Odai 2003
Broiler chickens, United States, at 23°C	112	Sakomura and others 2005
Swine, average	106	NRC 1998
Holstein crossbreed, Thailand	98	Odai 2003
Cows, crossbred, Ethiopia	93	Zerbini and others 1992
Beef cattle	77	NRC 1996
Zebu oxen, Nigeria	76	Dijkman 1993
Mice to elephant, basal metabolic rate	70	Kleiber 1975
Draft oxen, West Africa	56	Fall and others 1997
Zebu oxen, Niger	48	Becker and others 1993

a. Kilocalories divided by live weight$^{0.75}$.

and breeds lead to wide variations. Animals also require additional energy for growth, reproduction, labor, and milk production.

Astatke, Reed, and Butterworth (1986) suggest that digestible energy in African hay is about 1,900–2,000 kcal per kilogram of dry weight and that 1 cubic meter of evapotranspiration will produce about 4 kg of dry weight hay (see table 13.4). Taking the ILRI estimate of 11,000 Kcal per tropical livestock unit per day for maintenance energy, this implies that grazing cattle in Africa would require about 5 kg per tropical livestock unit per day of feed for maintenance. The amount of evapotranspiration required to produce this feed would be about 1.25 cubic meters per tropical livestock unit per day or 450 cubic meters per tropical livestock unit per year. This compares with 25–50 liters a day or 9–18 cubic meters per tropical livestock unit per year for drinking water.

We recognize that actual energy use and water for feed will be about double this when factoring in growth, work, lactation, reproduction, herd structure, and thermoregulation. Considering the range of forage water productivity values cited in table 13.4, the uncertainties in estimating feed intake, and the varying digestibility of animal feeds, any estimates of worldwide use of agricultural water for livestock production are highly uncertain. Nevertheless, we can conclude that water transpired for feed production will be about 50 times or more the amount of drinking water intake. Increasing livestock water productivity will depend strongly on increasing the amount of feed animals use for production relative to the amounts used for maintenance.

Distribution of feed resources. Almost 50 million ha of agricultural land in developing countries is used to produce livestock (see table 13.1), but animal production is not optimally distributed within production systems to take advantage of many feed resources. Some areas are overgrazed, and some have surplus feeds that remain unused. Rangelands and drier rainfed cropping areas often lack drinking water for animals. Without drinking water, livestock, especially cattle, cannot access available forages and crop residues. Feeds that have been produced but cannot be consumed constitute a major loss of potential benefits and productivity of agricultural water. Global, regional, and national map inventories are needed that quantify the gaps between feed production and animal demands for feed. This knowledge can be used to identify options to enhance livestock water productivity by balancing animal stocking rates with sustainable feed supplies. Interventions may include bailing and transporting surplus feed to livestock or providing drinking water (discussed later in this chapter) so that animals can remain near feed sources.

Global, regional, and national map inventories are needed that quantify the gaps between feed production and animal demands for feed to identify options to enhance livestock water productivity

Global use of water for feed production. Global evapotranspiration to produce feed to maintain cattle, sheep, and goats may be about 536 billion cubic meters a year in developing countries. Taking into account water for other livestock species and requirements beyond maintenance, we conclude that water used for global feed production ranges from 1 to 2 trillion cubic meters per year plus that used in developed countries. These estimates remain quite imprecise and are lower than some other estimates *[competing explanations]*.

Enhancing animal productivity

Water transpired to produce maintenance feed is a fixed input required for animal keeping whether or not animals are gaining weight, producing milk, or working. Additional water is needed for production. A key livestock water productivity strategy requires increasing the productivity of each animal. This is the domain of the traditional animal science disciplines of nutrition, genetics, veterinary health, marketing, and animal husbandry. Typical interventions include:

- Providing continuous access to quality drinking water (Muli 2000; Staal and others 2001).
- Selecting and breeding cattle for improved feed conversion efficiency and thus increased livestock water productivity (Basarab 2003).
- Providing veterinary health services as part of investments in irrigation development in dryland areas to reduce the risk of waterborne animal and zoonotic diseases (Peden and others 2006) and to meet animal health safety standards for marketing animals and animal products (Perry and others 2002).
- Adding value to animal products, such as farmers' production of butter (box 13.2).

Conserving water resources

As early as 1958 Love (cited in Sheehy and others 1996, section 2.1.1.2) noted that, "There is a large body of information leading to the conclusion that heavy grazing has had bad hydrologic consequences. It is doubtful that more investigations are needed to emphasize this conclusion." A half century later this still holds true. Sheehy and others (1996), in a comprehensive overview of the impact of grazing livestock on water and associated land resources, conclude that livestock must be managed in ways that maintain vegetative ground cover because vegetation loss results in increased soil erosion, box 13.2 **Integrated water-livestock resources management increases the income and assets of a poor rural household**

Many Ethiopian farmers subsist on less than $300 a year. With support from Sasakawa-Global 2000, a few farmers have adopted household water harvesting systems involving catchment areas of about 2,500 square meters that channel water into underground storage tanks with capacities of about 65 cubic meters each. For one female farmer (photo) this investment eliminated the daily 7 km trek for water. With two underground tanks, she meets her year-round domestic needs, provides drinking water for an improved hybrid milk cow, and provides supplemental irrigation for cash-generating onion, garlic, and citrus crops. Milk production increased from less than 2 liters a day to more than 40 liters a day from her crossbred cow. Time freed up from fetching water enabled her to produce butter and cheese, further increasing the cash generated from each liter of milk. Her children appear healthier and spend more time in school. The integration of dairying into this water harvesting-based livelihood strategy increased the financial, human, social, and physical assets of this poor rural household to a level exceeding that possible through crop production alone.

In the villages the increased cash flow enabled more farmers to diversify their incomes and to open a small shop serving the village area. With year-round income men spend more time at home on productive tasks and less time drinking.

Photo by Don Peden

Household water harvesting integrated with livestock production helped secure family assets and reduce poverty and vulnerability

Source: ILRI 2005.

downslope sedimentation, reduced infiltration, and less pasture production. While they find that low to moderate grazing pressure has little negative impact on hydrology, they also find that there is an optimal or threshold site-specific level of grazing intensity above which water and land degradation become problematic and animal production declines. Within this limit livestock water productivity can be maximized by balancing enhanced leaf to land area ratios that shift water depletion from evaporation to transpiration (Keller and Seckler 2005), with profitable levels of animal production and offtake.

The species composition and stocking levels of grazing animals affect the species composition of the vegetation (Sheehy and others 1996). High grazing pressure causes loss of palatable species suitable for animal production, but very low grazing pressure may encourage encroachment of woody vegetation. Either way, vegetation shifts can reduce the amount of useful vegetation and increase transpiration channeled through plant species that have little value for animals or other users.

Livestock grazing interacts with animal drinking. Cattle, especially, concentrate and often overgraze near water resources, leaving more distant areas undergrazed. Apart from removing vegetation as feed, animals aggravate runoff sedimentation by trampling and trekking on paths. Riparian areas, including streams, natural and artificially created ponds and lakes, wetlands, and irrigation infrastructure are all subject to degradation by inappropriately managed livestock (photos 13.1 and 13.2). Animals potentially affect water resources by causing chemical, physical, and bacteriological changes in water; modifying habitat and associated vegetation; and changing water flow patterns (Sheehy and others 1996).

Although overgrazing is a major threat to water resources, converting grazing land into cropland only within mixed crop-livestock systems presents a greater risk (Hurni 1990). Cultivation exposes soil to erosive rain and lack of vegetation. Under intensified Ethiopian farming systems poor farmers depend on animal power for cultivation (photos 13.3 and 13.4). Without oxen crop production would decline. Oxen are highly dependent on crop residues for feed, which is otherwise in short supply. Under customary land tenure farmers' lands revert to common grazing after crops have been harvested. Farmers' invest heavily in removing all residues from crop lands because if they do not do so neighbors' animals will consume the residues anyway. The production system, and not just the livestock, makes these crop lands highly vulnerable to runoff and erosion, lowering livestock water productivity and putting downstream water resources at risk.

Livestock grazing interacts with animal drinking

Water used for meat processing and rendering (slaughtering animals and fowl, curing, canning meat products, transforming inedible and discarded remains into useful by-products such as lards and oils) is variable, but likely less than 2% of that needed for feed production (World Bank 1998). However, effluents originating from meat processing are often point sources of pollution, potentially degrading water resources and putting human health at risk.

Photo 13.1

Photo by Don Peden

Photo 13.2

Photo by Don Peden

Uncontrolled use of water for livestock drinking contaminates water supplies, degrades riparian vegetation, and puts people's health at risk. Providing watering places that are physically separated from the water supply can restore habitat and improve domestic water quality (see photo 13.7 later in chapter).

Photo 13.3

Photo by Don Peden

Photo 13.4

Photo by Don Peden

Horses, cattle, and buffalo are important sources of farm power for poor farmers. Much of the water used to maintain farm animals is an input to crop production.

Providing sufficient drinking water

Water constitutes about 60%–70% of an animal's live weight (Faries, Sweeten, and Reagor 1997; Pallas 1986). This level must be maintained through water intake from drinking water and the water content of ingested feed. Animals also take advantage of metabolic water that results from intracellular respiration (which consumes oxygen and releases carbon dioxide and water). Animals lose water through evaporation, urine, feces, and lactation. Drinking is not a water-depleting process because the water remains in the production system. However, drunk water may be subsequently depleted through evaporation from pulmonary tissues and sweating. Water lost in urine passes to the soil (at least in pastures) and that lost in milk passes to young animals (unless processed for human consumption) and remains in the system. Subsequent depletion through evapotranspiration and milk export is possible, however.

Livestock drink about 20–50 liters per tropical livestock unit per day

Livestock drink about 20–50 liters per tropical livestock unit per day (table 13.6). Drinking water volumes vary greatly by species and breed, ambient temperature, water quality, levels and water content of feed, and animal activity, pregnancy, and lactation (Pallas 1986; Seleshi, Tegegne, and Tsadik 2003; King 1983). Water drunk per kilogram of food intake ranges from 3.6 liters at ambient temperatures below 15° Celsius (C) to 8.5 liters at temperatures above 27°C (Pallas 1986; Sreeramulu 2004). In tropical areas air temperature may be greater than 32°C, and drinking increases greatly (NRC 1978; Shirley 1985). Thus, in the range of 5°–32°C water intake per degree Celsius per kilogram of dry matter will be about 0.118 liters, and intake above 32°C will be about 1.3 liters. For *Bos taurus* cattle water intake for heifers will be about 5% and for dry cows 10% of animal live weight in rainy and dry seasons, and for *Bos indicus* about half that. Water deprivation

table **13.6** **Estimated water requirement and voluntary intake of livestock under Sahelian conditions and chickens in India** (liters per tropical livestock unit per day)

Animal	Tropical livestock unit per head	Wet season and air temperature of 27°C		Dry season and air temperature of 15°–21°C		Dry season and air temperature of 27°C	
		Needed	Voluntary intake[a]	Needed	Voluntary intake[a]	Needed	Voluntary intake[a]
Sahelian livestock							
Camels	1.6	31	9	23	22	31	31
Cattle	0.7	36	14	29	27	39	39
Sheep	0.1	50	20	40	40	50	50
Goats	0.1	50	20	40	40	50	50
Donkeys	0.4	40	13	30	28	40	40
Indian chickens							
Laying hens[b]	0.01						32
Nonlaying hens[b]	0.01						18

a. Voluntary water intake is the daily amount of water drunk by an animal assuming that liquid water is continuously available to the animal and that feed plants have 70%–75% moisture during the wet season and 10–20% moisture during the dry season.

b. Water in feed is not known.

Source: For livestock, Pallas 1986; for chickens, Sreeramulu 2004.

reduces feed intake and lowers production. For lactating cows water deprivation can greatly lower milk production (Staal and others 2001; Muli 2000).

Lactating cows require additional drinking water. For example, Indian lactating cows drink on average 70 liters of water daily; dry cows drink 45 liters and calves 22 liters (Sreeramulu 2004). In Canada lactating Holstein cows drink on average 85 liters of water daily and dry cows drink 40 liters (Irwin 1992). Drinking water is an important tool for enhancing animal production, but the volume drunk is a small fraction of the total water used for feed production.

Drinking water is an important tool for enhancing animal production, but the volume drunk is a small fraction of the total water used for feed production

Animals adapted to dryland conditions tend to drink less and to have high urinary osmolar concentrations[2] when dehydrated in contrast with those adapted to more temperate conditions (table 13.7). Most domesticated animals can survive about 60 days without feed but less than a week without drinking water. The best adapted species can rely on water in succulent plants and use little or no additional drinking water even in arid environments. Domestication and breeding for productivity may have made livestock more dependent on drinking water and less able to withstand dry conditions.

Feces are a potentially larger source of water loss than urine. Half the body's total water pool can pass through the salivary glands and rumen each day. Therefore the ability to extract and reabsorb fecal water in the colon is important (Seleshi, Tegegne, and Tsadik 2003). *Bos taurus* cattle can reduce fecal moisture content to 60%, sheep to 50%, and camels to 45% (Macfarlane 1964, cited in King 1983). The feces of zebu cattle contain less water than those of European cattle (Quartermain, Phillips, and Lampkin 1957, cited in King 1983), partly explaining the lower water requirement of the zebu (Phillips 1960, cited in King 1983). One-third to one-half of the total daily water loss in cattle is in the feces (Schmidt-Nielsen 1965, cited in King 1983). Animals with high water reabsorption capacity will be better adapted to water-stressed environments and be able to graze farther from drinking water sources.

Cattle prefer to graze close to drinking water. Strategic placement of watering points encourages more complete and uniform grazing of entire pastures. In Missouri cattle production on 65 ha pastures was experimentally sustained and maximized by ensuring that distance to drinking water was less than 244 meters (Gerrish, Peterson, and Morrow 1995).

table **13.7** **Maximal urinary osmolar concentrations of selected East African mammals after severe dehydration**

Animal	Maximal urinary osmolar concentration
Dikdik	4,100
Camel	3,200
Oryx	3,000
Fat-tailed sheep	2,950
Goat	2,800
Impala	2,600
Donkey	1,500
Zebu cow	1,400

Source: Maloiy 1972, as cited in King 1983.

A study in Wyoming found that 77% of cattle grazing took place within 366 meters of the watering source, whereas 65% of available pasture was more than 730 meters from water (Gerrish and Davis 1999). In Sudan, to enable more effective use of vast quantities of underutilized grazing land, the government places priority on the strategic establishment of water harvesting to supply drinking water in pastoral areas.

Livestock water productivity and estimates of the virtual water content of meat and milk

The concept of virtual water attempts to integrate the water productivity of forage and feed with the conversion efficiency of these feeds into meat or milk. The complexity and diversity of livestock production systems create great uncertainty regarding the actual amounts of water used by livestock.

Chapagain and Hoekstra's (2003) estimates of the virtual water content of a number of animal products (table 13.8) generally support the view that animal production requires more water than crop production, but their estimates suggest that water usage is lower than that estimated by others (for example, Goodland and Pimental 2000) *[established but incomplete]*. In our view there are no reliable estimates of livestock water productivity for most situations in which livestock are kept. Existing estimates of water use by livestock have many limitations. Among the most salient are the following:

- Livestock production systems are highly diverse biophysically and socioeconomically and subject to many unresearched factors, making existing estimates of livestock water productivity unreliable generalizations. The knowledge gap is especially large for developing countries, where it impedes the introduction of targeted interventions that could bring about significant gains in agricultural water productivity.
- The water productivity of forage reported in the literature varies at least seventyfold, implying that estimates of livestock water productivity could vary accordingly.

The complexity and diversity of livestock production systems create great uncertainty regarding the actual amounts of water used by livestock

table **13.8** **Virtual water content of sample meat and milk products expressed as livestock water productivity**

Animal product	**Virtual water content expressed as livestock water productivity** (kilograms per cubic meters of freshwater)
Horse meat	0.082
Beef	0.082
Sheep and goat meat	0.118
Pork	0.291
Poultry meat	0.22–0.51
Cow's milk	0.788

Note: These estimates represent fresh weights only and do not examine nutritionally important components of meat and milk. Livestock water productivity is a function of forage water productivity, feed conversion efficiency, values of multiple animal products and services, values of competing uses of water, and the impact of livestock watering and grazing on water resources. Feed conversion efficiency is a function of animal genetics, animal health, availability of drinking water, temperature, work loads, and feed quality.

Source: Chapagain and Hoekstra 2003.

- In rangelands, especially dry ones, forage water productivity is low, but there are few alternate uses of agricultural water, and livestock keeping may be one of the best uses of agricultural water. Furthermore, only a small part of the evapotranspiration typically attributed to pasture production is actually used by grazing animals. Typically, about half of plant biomass production takes place below ground. In well managed pastures only about half of the above biomass is consumed by grazing animals. Of the amount consumed only about half is digested, with the remainder being returned to the soil. Thus, only about one-eighth of depleted evapotranspiration contributes to animal production. The rest contributes to maintaining the pasture ecosystem and providing ecosystem services *[established but incomplete].*
- In irrigated and mixed crop-livestock systems crop residues and by-products have very high water productivity because little or no water is used to produce them and manure provides additional value.
- Developing countries often have large herds with low productivity so that most water depleted by animals is associated with maintenance rather than with the production of goods and services.
- The literature describing water use by livestock usually focuses on meat or milk and ignores the multiple uses of animals, thereby underestimating livestock water productivity, especially in developing countries. For example, without animal power, crop production would decline in some countries.
- The literature describing water use by livestock usually ignores the impact of livestock grazing and watering on water contamination, degradation, and depletion, implying that livestock water productivity may be overestimated. However, the conversion of livestock to annual crop production for the purpose of increasing water productivity may result in lower water productivity because of enhanced depletion through runoff from cropland.
- Our understanding of livestock water productivity is in its infancy, and a transdisciplinary global effort is required to fully and meaningfully asses it worldwide.

> Much new research is required to provide reliable estimates of livestock water productivity

We believe that much new research is required to provide reliable estimates of livestock water productivity *[established but incomplete]*.

Livestock water productivity and gender

Livestock help satisfy poor farmers' demands for financial and natural capital and depend on human and physical capital for their management. Efforts to improve livestock water productivity through feed sourcing, production enhancing, and water conserving and provisioning activities will affect children, women, and men and various ethnic groups uniquely, and the various products and services provided by animals will benefit people differently *[established but incomplete]* (photos 13.5–13.6).

Van Hoeve and Van Koppen (2005) have examined the gender dimensions of the livestock water productivity framework and have concluded that efforts to improve animal production must take into account gender differences within livestock producing communities. A key lesson is the potential of smallholder dairying to enable rural and peri-urban

Photo 13.5

Photo by Don Peden

Photo 13.6

Photo by Don Peden

Children play a major role in caring for grazing livestock in developing countries, which may reduce school attendance

farming women to increase their disposable income through the production and sale of dairy products (see Upadhyay 2004 for India; Muriuki 2002 and Staal and others 2001 for Kenya; Kurwijila 2002 for Tanzania; and box 13.2 for Ethiopia). Such opportunities to improve the livelihoods of women and help bring them out of poverty depend on effective investments in water resources, an issue discussed later in the chapter.

The distribution of labor in livestock raising in India shows the variation in gender roles that is common around the world. Indian women and children dominate many areas of animal production. Women contribute 71% of the labor in the livestock sector (Anthra 1999; Chawla, Kurup, and Sharma 2004; Devendra and others 2000; Ragnekar 1998, as cited in Parthasarathy, Birthal, and Ndjeunga 2005; Upadhyay 2004) and spend 20%–25% of their time attending to livestock. Women influence household decision-making, although following up on decisions is generally left to men. Key tasks shouldered by women include feeding and watering animals kept at home, managing domestic water for all uses including animals, care of sick animals, cleaning sheds and pens, collecting manure and eggs, and selling produce locally. One reason women dominate in animal keeping is that, because they are generally less educated than men, they are assigned to the low-paying, labor-intensive activities. Men tend to handle grazing, watering grazed animals, taking sick animals to veterinary clinics, and selling animal products to agents and in larger, more distant markets. Men also have easier access to critical inputs such as extension, veterinary care, credit, and training.

Applying livestock water productivity principles

Livestock-water interactions have been largely neglected in both water and livestock research and planning (Peden and others 2006). Unlike the case in irrigation and crop sciences, there are few examples of research and assessments that attempt to understand the total water needs of livestock and how animal production affects water resources. The consequence has been lost opportunities to maximize investment returns in past investments in water and livestock development. This chapter has briefly considered the distribution of livestock keeping in developing countries in relation to the need for water, anticipated demand for animal products, and four strategies that can collectively improve livestock water productivity (improving feed sourcing, enhancing animal productivity, conserving water, and providing drinking water). Following are three brief examples drawn from pastoral, rainfed mixed crop-livestock systems, and irrigated mixed systems to illustrate the potential application of these four strategies.

Pastoral market chains

Kordofan and Darfur, Sudan, are homes to pastoralists who depend on grazing livestock, but the markets for their animals are in Khartoum, hundreds of kilometers to the east. Migration corridors supplied with water and feed enable animals to trek to markets and arrive in relatively good condition. Watering points require effective management, such as the provision of drinking troughs, physically separated from wells and other water sources (photo 13.7) to mitigate the degradation of water sources, and vegetation buffers to protect riparian areas. Once in Khartoum buyers fatten animals with crop residues and feed supplements procured from the irrigation systems of the Nile.

This case exemplifies the interconnection of pastoral and irrigated production systems and the need for areawide approaches to their management. Improving feed sourcing, enhancing production, conserving water, and providing drinking water are all important intervention strategies *[established but incomplete]*.


Photo by Don Peden

Photo 13.7 Providing drinking water in troughs helps prevent contamination of well and surface water

Rainfed mixed crop-livestock systems

The Ethiopian highlands are home to millions of poor grain farmers who keep cattle, sheep, goats, equines, and poultry. Feed sourcing is a priority activity, and much value is placed on harvesting crop residues that are widely used by oxen and equines (photo 13.8). Farmers are also taking other steps to improve livestock water productivity such as using veterinary care and improved hybrid dairy cattle and providing water at home (see box 13.2).

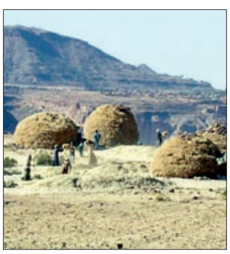


Photo by Don Peden

Photo 13.8 Crop residues help maximize evapotranspiration use by grain crops

Irrigated mixed crop-livestock systems

Gezira, Sudan, Africa's largest contiguous irrigation scheme, was constructed about 1920. For more than 60 years there were no policies or plans to accommodate animal keeping. Now, livestock keeping provides 36% of farm income (Elzaki 2005). In a study on the feasibility of integrating livestock production with irrigated agriculture in Gezira, Elzaki (2005) argues that adding fodder in the crop rotation could increase farm income, provide animal feed, and boost milk production. She stresses the need for improved feed sourcing strategies within irrigation systems and improved veterinary care. She concludes that the main constraint facing improved investment returns in the irrigation system is the unclear and contradictory policy of the Gezira irrigation scheme management and the conflict between animal keepers and crop farmers. Strategic use of crop residues for feed and enhanced productivity of animals are key entry points for increased livestock water productivity, but contamination of water with pathogens now threatens both people and their animals *[well established]*.

Integration of livestock and water management and improved governance

This chapter briefly described the developing country distribution of cattle, sheep, and goats, their implied needs for water resources, and probable trends in demand for animal products. The principles outlined in the chapter presented the basics for a livestock water productivity framework that can help to systematize thinking about the nature of livestock-water interactions. The framework consists of four basin entry points or strategies for improving livestock water productivity. The case examples drawn from East Africa highlight the major differences among production systems and the need for integrated site-specific interventions to ensure that livestock production contributes to sustainable and productive use of water resources and to improved livelihoods of the poor. The existing quantitative data on livestock water productivity are not adequate to characterize livestock use of water on a global scale.

During the past 50 years investments in agricultural water and livestock development often failed to achieve potential and sustainable returns. Evidence suggests that the livestock water productivity approach can help to identify opportunities for integrating livestock and water development for the benefit of both. Realizing these opportunities requires intersectoral and interdisciplinary planning, development, and management of water and livestock resources. Integration demands location-specific adjustments in institutional arrangements and integrated cost-benefit, enterprise budget, and land-use analyses. In communities integration of pasture management and water user associations will be needed. Integrated governance at and across various scales has great potential for increasing the productivity and sustainability of water use and livestock production worldwide *[established but incomplete]*.

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Notes

1. Most broadleaf and temperate zone plants are C_3. C_4 plants such as sugar cane and maize exhibit more efficient photosynthesis than C_3 plants, making them better adapted to very sunny conditions and to higher levels of crop water productivity.

2. In biochemistry this refers to the concentration of osmotically active particles in solution, which may be quantitatively expressed in osmoles of solute per liter of solution. Used here as an indicator of animals' capacity to concentrate urine and reduce water loss through urination.

References

Anthra. 1999. "Role of Women in Animal Husbandry in Orissa." ISPO Gender Study Series. Hyderabad, India.

Ashley, S., S. Holden, and P. Bazeley. 1999. *Livestock in Poverty-focused Development.* Livestock in Development. Crewkerne: United Kingdom.

Astatke, A., and M. Saleem. 1998. "Effect of Different Cropping Options on Plant-available Water of Surface-drained Vertisols in the Ethiopian Highlands." *Agricultural Water Management* 36 (2): 111–20.

Astatke, A., J. Reed, and M. Butterworth. 1986. "Effect of Diet Restriction on Work Performance and Weight Loss of Local Zebu and Friesian x Boran Crossbred Oxen." *ILCA Bulletin* 23 (January): 11–14.

Ayalneh, W. 2004. "Socio Economic and Environmental Impact Assessment of Community Based Small-scale Irrigation in the Upper Awash Basin: A Case Study of Four Community Based Irrigation Schemes." MSc Thesis. Addis Ababa University, School of Graduate Studies, Environmental Science. [www.iwmi.cgiar.org/Assessment/files/pdf/PhDThesis/Wagnew-thesis.pdf].

Basarab, J. 2003. "Feed Efficiency in Cattle." Press release. Alberta Beef Industry Development Fund, Calgary, Canada. [https://mail.une.edu.au/lists/archives/beef-crc-technet/2003-November/000016.html].
Beaton, G. 1991. "Human Nutrient Requirement Estimates: Derivation, Interpretation and Application in Evolutionary Perspective." *Food, Nutrition and Agriculture* 1(2/3): 3–15.
Becker, K., M. Rometsch, A. Susenbeth, U. Roser, and P. Lawrence. 1993. "Characterisation of the Physiological Performance and Determination of the Efficiency of Draught Oxen." In *Adapted Farming in West Africa*. Special Research Program 308. Report of Results, Interim Report 1991–1993. University of Hohenheim, Germany.
Chapagain, A., and A. Hoekstra. 2003. "Virtual Water Trade: A Quantification of Virtual Water Flows between Nations in Relation to International Trade of Livestock and Livestock Products." In A.Y. Hoekstra, ed., *Virtual Water Trade. Proceedings of the International Expert Meeting on Virtual Water Trade*. Value of Water Research Report Series 12. Delft, Netherlands: United Nations Educational, Scientific and Cultural Organization, Institute for Water Education.
Chawla, N., M. Kurup, and V. Sharma. 2004. *State of the Indian Farmer—A Millennium Study: Animal Husbandry*. Vol. 12. New Delhi: Ministry of Agriculture.
Claypool, D., R. Delaney, R. Ditterline, and R. Lockerman. 1997. *Genetic Improvement of Alfalfa to Conserve Water*. Proceedings of the 36th North American Alfalfa Improvement Conference, 2–6 August, Bozeman, Mont.
Delgado, C. 2003. "Rising Consumption of Meat and Milk in Developing Countries Has Created a New Food Revolution." *Journal of Nutrition* 133 (11): 3907S–3910S.
Devendra, C., D. Thomas, M. Jabbar, and E. Zerbini. 2000. *Improvement of Livestock Production in Crop-animal Systems in Agro-ecological Zones of South Asia*. Nairobi: International Livestock Research Institute.
Dijkman, J. 1993. "The Measurement of Draught Ruminant Energy Expenditure in the Field." PhD thesis. University of Edinburgh, Centre for Tropical Veterinary Medicine.
Elzaki, R. 2005. "The Feasibility of Integration of Livestock Production in Irrigated Agriculture in Sudan: Case Study: The Gezira Scheme." PhD Thesis. University of Giessen, Department of Project and Regional Planning.
Fall, A., R. Pearson, P. Laurence, and S. Fernández-Rivera. 1997. *Feeding and Working Strategies for Oxen Used for Draught Purposes in Semiarid West Africa. Nairobi: International Livestock Research Institute.*
FAO (Food and Agriculture Organization). 2004. "Tropical Livestock Units (TLU)." Virtual Livestock Centre, Livestock and Environment Toolbox. Rome. [http://lead.virtualcentre.org/en/dec/toolbox/Mixed1/TLU.htm].
Faries, F., J. Sweeten, and J. Reagor. 1997. *Water Quality: Its Relationship to Livestock*. College Station, Tex.: Texas A&M University System, Texas Agricultural Extension Service.
Fernandez-Rivera, S. 2006. Personal communication summarizing the experience of the International Livestock Research Institute, Addis Ababa, Ethiopia, covering diverse animal feeding trials and production studies conducted in Sub-Saharan Africa.
Ferraris, R., and B. Sinclair. 1980. "Factors Affecting the Growth of Pennisetum purpureum in the Wet Tropics. II. Uninterrupted Growth." *Australian Journal of Agricultural Research* 31 (5): 915–25.
Gerrish, J., and M. Davis. 1999. "Water Availability and Distribution." In J. Gerrish and C. Roberts, eds., *Missouri Grazing Manual*. Columbia, Miss.: University of Missouri Extension.
Gerrish, J., P. Peterson, and R. Morrow. 1995. "Distance Cattle Travel to Water Affects Pasture Utilization Rate." Proceedings of the American Forage and Grassland Council Conference, 12–14 March, Lexington, Ky, 4: 61–65.
Goodland, R., and D. Pimental. 2000. "Environmental Sustainability and Integrity in Natural Resources Systems." In D. Pimental, L. Westra and R. Noss, eds., *Ecological Integrity*. Washington, D.C.: Island Press.
Heffernan, C., and F. Misturelli. 2001. "Perceptions of Poverty among Poor Livestock Keepers in Kenya: A Discourse Analysis Approach." *Journal of International Development* 13 (7): 863–75.
Hoekstra, A., and P. Hung. 2003. *Virtual Water Trade: A Quantification of Virtual Water Flows between Nations in Relation to International Crop Trade*. Value of Water Research Report Series 11. Delft, Netherlands: United Nations Educational, Scientific and Cultural Organization, Institute for Water Education.
Hurni, H. 1990. "Degradation and Conservation of Soil Resources in the Ethiopian Highlands." In B. Messerli and H. Hurni, eds., *African Mountains and Highlands: Problems and Perspectives*. Marceline, Miss.: African Mountains Association.
Irwin, R. 1992. "Water Requirements of Livestock." Rev. ed. Factsheet. Ontario Ministry of Agriculture, Food and Rural Affairs, Ontario.
Jahnke, H. 1982. *Livestock Production Systems and Livestock Development in Tropical Africa*. Kiel, Germany: Kieler Wissenschaftsverlag Vauk.
Jarvis, L. 1986. *Livestock Development in Latin America*. Washington, D.C.: World Bank.
Keller, A., and D. Seckler. 2005. "Limits to the Productivity of Water in Crop Production." In *California Water Plan Update 2005*. Vol. 4. Sacramento, Calif.: California Department of Water Resources.

King, J. 1983. *Livestock Water Needs in Pastoral Africa in Relation to Climate and Forage*. ILCA Research Report 7. Addis Ababa: International Livestock Centre for Africa.

Kleiber, M. 1932. "Body Size and Metabolism." *Hilgardia* 6: 315–53.

———. 1975. *The Fire of Life: An Introduction to Animal Energetics*. New York: Robert E. Krieger Publishing Co.

Kurwijila L. 2002. "An Overview of Dairy Development in Tanzania." In D. Rangnekar D and W. Thorpe, eds., *Smallholder Dairy Production and Marketing Opportunities and Constraints*. Nairobi: International Livestock Research Institute.

Landefeld, M., and J. Bettinger. 2005. "Water Effects on Livestock Performance." Fact Sheet ANR-13-02. Ohio State University, Agriculture and Natural Resources. Columbus, Ohio.

Love, L.D. 1958. "Rangeland Watershed Management." *Proceedings of the Society of American Foresters*: 198–200.

Macfarlane, W. 1964. "Terrestrial Animals in Dry Heat: Ungulates." In D.B. Dill, ed., *Handbook of Physiology-environment*. Washington, D.C.: American Physiological Society.

Maloiy, G.M.O. 1972. "Renal Salt and Water Excretion in the Camel (Camelus dromedarius)." *Symposium of the Zoological Society,* London 21: 243–59.

Misra, A.K. and Mahipal. 2000. "Strategies of Livestock Management for Improving Productivity Under Rainfed Farming Situations." In K.H. Vedini, ed., *Management Issues in Rainfed Agriculture in India*. Hyderabad, India: MANAGE.

Muli, A. 2000. "Factors Affecting Amount of Water Offered to Dairy Cattle in Kiambu District and Their Effects on Productivity." B.Sc. thesis, Range Management, University of Nairobi.

Muriuki, H. 2002. "Smallholder Dairy Production and Marketing in Kenya." In D. Rangnekar and W. Thorpe, eds., *Smallholder Dairy Production and Marketing Opportunities and Constraints*. Nairobi: International Livestock Research Institute.

Neumann, C., N. Bwibo, S. Murphy, M. Sigman, S. Whaley, L. Allen, D. Guthrie, R. Weiss, and M. Demment. 2003. "Animal Source Foods Improve Dietary Quality, Micronutrient Status, Growth and Cognitive Function in Kenyan School Children: Background, Study Design and Baseline Findings." *Journal of Nutrition* 133 (11): 3941S–3949S.

Nierenberg, D. 2005. *Happier Meals: Rethinking the Global Meat Industry*. Worldwatch Paper 171. Washington, D.C.: Worldwatch Institute.

NRC (National Research Council). 1978. *Nutrient Requirements of Dairy Cattle*. 5th ed. Washington, D.C.: National Academy of Science.

———. 1996. *Nutrient Requirements of Beef Cattle*. 7th ed. Washington, D.C.: National Academy of Science.

———. 1998. *Nutrient Requirements of Swine*. 10th ed. Washington, D.C.: National Academy of Science.

Odai, M. 2003. "Energy Requirement for the Maintenance of Dairy Cows in Northeast Thailand." *Jircas Newsletter* 34: 5.

Pallas, P. 1986. *Water for Animals*. Rome: Food and Agriculture Organization.

Parthasarathy, R.P., P. Birthal, and J. Ndjeunga. 2005. *Crop-Livestock Economies in the Semi-Arid Tropics: Facts, Trends, and Outlook*. Hyderabad, India: International Crops Research Institute for the Semi-Arid Tropics.

Peden, D., A. Freeman, A. Astatke, and A. Notenbaert. 2006. "Investment Options for Integrated Water-Livestock-Crop Production in Sub-Saharan Africa." Working Paper 1. Nairobi: International Livestock Research Institute.

Perry, B., T. Randolph, J. McDermott, K. Sones, and P. Thornton. 2002. *Investing in Animal Health to Alleviate Poverty*. International Livestock Research Institute, Nairobi.

Phillips, G. 1960. "The Relationship between Water and Food Intakes of European and Zebu Type Steers." *Journal of Agricultural Science* 54: 231–34.

Quartermain, A., G. Phillips, and G. Lampkin. 1957. "A Difference in the Physiology of the Large Intestine between European and Indigenous Cattle in the Tropics." *Nature* 180 (4585): 552–53.

Ragnekar, S. 1998. "The Role of Women in Smallholder Rainfed Mixed Farming in India." In *Women in Agriculture and Animal Production: Proceedings of a Workshop, Tune, Landboskole, Denmark, 30 March–3 April.*

Redda, T. 2002. "Small-scale Milk Marketing and Processing in Ethiopia." In D. Rangnekar and W. Thorpe, eds., *Smallholder Dairy Production and Marketing Opportunities and Constraints*. Proceedings of a South-South Workshop, 13–16 March 2001. Anand, India and Nairobi: National Dairy Development Board and International Livestock Research Institute.

Renault, D., and W. Wallender. 2000. "Nutritional Water Productivity and Diets." *Agricultural Water Management* 45 (3): 275–96.

Saeed, I., and A. El-Nadi. 1997. "Irrigation Effects on the Growth, Yield and Water Use Efficiency of Alfalfa." *Irrigation Science* 17 (2): 63–68.

———. 1998. "Forage Sorghum Yield and Water Use Efficiency under Variable Irrigation." *Irrigation Science* 18 (2): 67–71.

Sakomura, N., F. Longo, E. Oviedo-Rondon, C. Boa-Viagem, and A. Ferraudo. 2005. "Modeling Energy Utilization and Growth Parameter Description for Broiler Chickens." *Poultry Science* 84 (9): 1363–69.

Sala, O., W. Parton, A. Joyce, and W. Lauenroth. 1988. "Primary Production of the Central Grasslands of the United States." *Ecology* 69 (1): 40–45.

Sastry, N. 2000. "Regional Considerations for Appropriate Livestock Development Strategies in India." *Journal of Indian Veterinary Association* 5 (3): 16–29.

Schmidt-Nielsen, K. 1965. Desert Animals: Physiological Problems of Heat and Water. Oxford, UK: Clarendon Press.

Seleshi, Z., A. Tegegne, and T. Tsadik. 2003. "Water Resources for Livestock in Ethiopia: Implications for Research and Development." In P. McCornick, A. Kamara, and G. Tadesse, eds., *Integrated Water and Land Management Research and Capacity Building Priorities for Ethiopia*. Proceedings of a Ministry of Water Resources, Ethiopian Agricultural Research Organization, International Water Management Institute, and International Livestock Research Institute International Workshop, 2–4 December 2002. Addis Ababa: International Livestock Research Institute.

Shackleton, C., S. Shackleton, T. Netshiluvhi, F. Mathabela, and C. Phiri. 1999. "The Direct Use Value of Goods and Services Attributed to Cattle and Goats in the Sand River Catchment, Bushbuckridge." Report ENV-P-C 99003. Council for Scientific and Industrial Research, Pretoria.

Sheehy, D., W. Hamilton, U. Kreuter, J. Simpson, J. Stuth, and J. Conner. 1996. *Environmental Impact Assessment of Livestock Production in Grassland and Mixed Rainfed Systems in Temperate Zones and Grassland and Mixed-Rainfed Systems in Humid and Subhumid Tropic and Subtropic Zones*. Vol. II. Rome: Food and Agriculture Organization.

Shirley, R. 1985. "Water Requirements for Grazing Ruminants and Water as a Source of Minerals." In L.R. McDowell, ed., *Nutrition of Grazing Ruminants in Warm Climates*. Orlando, Fla.: Academic Press.

Sigman, M., S. Whaley, M. Kamore, N. Bwibo, and C. Neumann. 2005. *Supplementation Increases Physical Activity and Selected Behaviors in Rural Kenyan Schoolchildren*. CRSP Research Brief 05-04-CNP. University of California, Global Livestock Collaborative Research Support Program, Davis, Calif.

SIWI (Stockholm International Water Institute), IFPRI (International Food Policy Research Institute), IUCN (World Conservation Union), and IWMI (International Water Management Institute). 2005. *Let it Reign: The New Water Paradigm for Global Food Security.* Final report to CSD-13. Stockholm: Stockholm International Water Institute.

Sreeramulu, P. 2004. "Fodder, Water and Livestock Issues in Andhra Pradesh, India." Paper presented at a workshop on Fodder, Water and Livestock for Better Livelihoods, 27 August, cosponsored by the Department of Animal Husbandry, Andhra Pradesh, and Water Conservation Mission, Andhra Pradesh. State Management Institute for Livestock Development, Directorate of Animal Husbandry, Hyderabad, India.

Staal, S., M. Owango, G. Muriuki, B. Lukuyu, F. Musembi, O. Bwana, K. Muriuki, G. Gichungu, A. Omore, B. Kenyanjui, D. Njubi, I. Baltenweck, and W. Thorpe. 2001. "Dairy Systems Characterization of the Greater Nairobi Milk-shed." SDP Research Report. Ministry of Agriculture and Rural Development, Kenya Agricultural Research Institute, and International Livestock Research Institute, Nairobi.

Taneja, V.K., and P. S. Birthal. 2004. "Role of Buffalo in Food Security in Asia." *Asian Buffalo* 1 (1): 1–13.

Thornton, P., R. Kruska, N. Henninger, P. Kristjanson, R. Reid, F. Atieno, A. Odero, and T. Ndegwa. 2002. *Mapping Poverty and Livestock in the Developing World*. Nairobi: International Livestock Research Institute.

Times of India. 2004. "Holy Cow! Milk's a Groundwater Guzzler." Times of India Online. 3 June.

Upadhyay, B. 2004. "Gender Roles and Multiple Uses of Water in North Gujarat." Working Paper 70. International Water Management Institute, Colombo.

Van Hoeve, E., and B. van Koppen. 2005. "Beyond Fetching Water for Livestock: A Gendered Sustainable Livelihood Framework to Assess Livestock-Water Productivity." ILRI Working Paper 1. International Livestock Research Institute, Nairobi.

World Bank. 1998. *Meat Processing and Rendering. Pollution Prevention and Abatement Handbook*. Washington, D.C.

Zerbini, E., T. Gemeda, D. O'Neill, P. Howell, and R. Schroter. 1992. "Relationship Between Cardio-respiratory Parameters and Draught Work Output in F1 Crossbred Dairy Cows Under Field Conditions." *Animal Production* 55: 1–10.