# 9

# Livestock and water in the Nile River Basin

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## Key messages

- Domestic animals contribute significantly to agricultural GDP throughout the Nile Basin and are major users of its water resources. However, investments in agricultural water development have largely ignored the livestock sector, resulting in negative or sub-optimal investment returns because the benefits of livestock were not considered and low-cost livestock-related interventions, such as provision of veterinary care, were not part of water project budgets and planning. Integrating livestock and crop development in the context of agricultural water development will often increase water productivity and avoid animal-induced land and water degradation.
- Under current management practices, livestock production and productivity cannot meet projected demands for animal products and services in the Nile Basin. Given the relative scarcity of water and the large amounts already used for agriculture, increased livestock water productivity (LWP) is needed over large areas of the basin. Significant opportunities exist to increase LWP through four basic strategies. These are: (i) utilizing feed sources that have inherently low water costs for their production; (ii) adoption of the state-of-the-art animal science technology and policy options that increase animal and herd production efficiencies; (iii) adoption of water conservation options; and (iv) optimally balancing the spatial distributions of animal feeds, drinking water supplies and livestock stocking rates across the basin and its landscapes. Suites of intervention options based on these strategies are likely to be more effective than a single-technology policy or management practice. Appropriate interventions must take account of spatially variable biophysical and socio-economic conditions.
- For millennia, pastoral livestock production has depended on mobility, enabling herders to cope with spatially and temporally variable rainfall and pasture. Recent expansion of rain-fed and irrigated croplands, along with political border and trade barriers, has restricted mobility. Strategies are needed to ensure that existing and newly developed cropping practices allow for migration corridors along with water and feed availability. Where pastoralists have been displaced by irrigation or encroachment of agriculture into dry-season grazing and watering areas, feeds based on crop residues and by-products can offset loss of grazing land.

- In the Nile Basin, livestock currently utilize about 4 per cent of the total rainfall, and most of this takes place in rain-fed areas where water used is part of a depletion pathway that does not include the basin's blue water resources. In these rain-fed areas, better vegetation and soil management can promote conversion of excessive evaporation to transpiration while restoring vegetative cover and increasing feed availability. Evidence suggests that livestock production can be increased significantly without placing additional demands on river water.

## Introduction

Pastoralists in the Nile River Basin had kept cattle as long as 10,000 years ago (Hanotte *et al.*, 2002). These early bovines (*Bos taurus*) evolved through domestication from wild aurochs (*Bos primigenius*) either in northeastern Africa or in the Near East. Zebu (*Bos indicus*) reached Egypt during the second millennium BC with further introductions of Zebu from the East African coastal region in subsequent centuries. Over thousands of years, livestock-keeping has formed core sets of livelihood strategies and cultural values of the Nile's peoples and nations. Livestock have played a major role in shaping landscapes and land use systems as well as current demands for, and patterns of, use of agricultural water in the basin. Taking into account this history remains paramount for peaceful and sustainable human development in the Nile. Given the rapidly increasing human population in the basin, this requires optimal use of agricultural water resources (Chapter 3).

The contribution of agriculture to total GDP in most Nile countries has declined over the past few decades because of increased income generated in the service and industrial sectors of country economies. Nevertheless, agriculture, including livestock and fisheries, remains an important component of regional food security. Currently, livestock contribute 15–45 per cent of agricultural GDP in the Nile riparian nations (Peden *et al.*, 2009a), although estimated GDP for the actual basin land areas within countries is not known. Vast land areas within the basin are sparsely inhabited and unsuitable for crop production, but livestock-keeping remains the most suitable agricultural livelihood strategy. Non-livestock contributions to agricultural GDP concentrate in higher rainfall areas and near urban market centres. But even there, livestock remain important, particularly in rain-fed, mixed crop-livestock farming. Across the Nile Basin, livestock populations are rapidly growing in response to increasing African demand for meat and milk products. For example, Herrero *et al.* (2010) predicted that total livestock numbers are expected to increase by 59 per cent between 2000 and 2030 with the greatest percentage increase occurring in the swine populations (Table 9.1).

*Table 9.1* Estimated and projected population numbers and percentage changes of livestock populations for the period 2000–2030 in Nile riparian countries

| *Year* | *Livestock numbers (thousands)* | | | | | |
|---|---|---|---|---|---|---|
| | *Cattle* | *Chicken* | *Goats* | *Pigs* | *Sheep* | *Total* |
| 2000 | 66,560 | 96,540 | 51,970 | 1820 | 53,420 | 272,310 |
| 2030 | 111,320 | 17,1510 | 73,290 | 6230 | 68,580 | 432,960 |
| Projected increase (%) | 67.2 | 77.7 | 41.0 | 242.3 | 28.4 | 59.0 |

*Source:* Data extracted from Herrero *et al.*, 2010

Despite the importance of the livestock sector to poor rural people, animal production has failed to achieve sustainable returns for poor livestock raisers, owing to several key constraints. Chief among them are water scarcity, and the failure of policy-makers to recognize the importance of livestock and to support livestock production through appropriate policies and interventions (IFAD, 2009). Notwithstanding the dependence of livestock and people on water resources, evidence shows that, for the most part, livestock have largely been ignored in water planning, investment, development and management (Peden *et al.*, 2006). Not only does livestock-keeping make important contributions to farm income, but investing in herds of cattle, sheep and goats is also a preferred form of wealth-savings for diverse Nile populations. One consequence of successful investing in agricultural water for poverty reduction is the tendency for farmers to use newly generated income to purchase and accumulate domestic animals. Safeguarding farmers' assets including livestock or alternatives to them is therefore required.

This chapter summarizes research undertaken by the CGIAR Challenge Program on Water and Food (CPWF) on Nile Basin livestock water productivity (Peden *et al.*, 2009a). The starting point is an overview of livestock distributions and production across the entire river basin. The chapter continues with a description of livestock water productivity (LWP), a concept that is useful for identifying opportunities for more effective use of water by animals. Based on CPWF research in Ethiopia, Sudan and Uganda, the chapter then highlights some key water–livestock interactions characteristic of major production systems. It concludes with a discussion of options for making better use of agricultural water through better livestock and water management. The purpose of this chapter is to share insights on livestock–water interactions, with a view to making better integrated use of basin water resources, improving livestock production and LWP, rehabilitating degraded croplands, pastures and water resources, and contributing to improved livelihoods, poverty reduction and benefit-sharing.

A work of this nature could not cover all aspects of livestock-keeping, and thus focuses on cattle, sheep and goats. We recognize that poultry, swine, equines, camels, buffalo and beekeeping are also important, and further consideration of them will be necessary in future research and development. The basin contains many exotic and imported breeds that vary in their effectiveness to use water efficiently and sustainably, but this topic was beyond the scope of this CPWF research. This chapter also does not address, in deserved detail, the increasing trend towards industrialization of livestock production occurring near rapidly growing urban centres and the engagement in international trade.

## Livestock distributions, populations, and demand for animal products and services

Livestock-keeping is the most widespread agricultural livelihood strategy in the Nile Basin. Domestic animals are kept within diverse agro-ecologies and production systems. This diversity generates varying animal impacts on water demand and the sustainability and productivity of water resources adjacent to pasturelands and riparian areas. Livestock production systems are defined in terms of aridity and the length of the growing season (Seré and Steinfeld, 1995; van Breugel *et al.*, 2010). Rain-fed production systems cover about 94 per cent of the basin, of which about 61 per cent is classified as livestock-dominated or grazing land and about 33 per cent as mixed crop–livestock production (Table 9.2; Figure 9.1). Livestock are kept virtually wherever crops are grown, but vast areas of rangeland are not suitable for crop production, leaving animal production as the only viable form of agriculture, even if at very low levels of intensity. Irrigated areas are small amounting to less than 2 per cent of the land area, but even there, livestock are typically important assets for irrigation farmers (Faki *et al.*, 2008; Peden *et*

*al.*, 2007). Urban areas, protected forests and parks are also present but make up a minute percentage of the Nile's land area and are not discussed in this chapter.

*Table 9.2* Livestock production systems in the Nile River Basin showing their defining aridity classes and lengths of the growing season

| *Production system* | | *Unique code* | *Area ($km^2$)* | *Basin land area (%)* | *Aridity* | *Length of the growing season (days $yr^{-1}$)* |
|---|---|---|---|---|---|---|
| Rain-fed | Grazing | LGHYP | 935,132 | 31.2 | Hyper-arid | 0–1 |
| | Grazing | LGA | 758,593 | 25.3 | Arid–semi-arid | 1–180 |
| | Grazing | LGH | 123,618 | 4.1 | Humid | >180 |
| | Grazing | LGT | 13,749 | 0.5 | Temperate | >180 |
| | Sub-total | | 1,831,092 | 61.1 | | |
| Rain-fed | Mixed | MRA | 608,547 | 20.3 | Arid–semi-arid | 1–180 |
| | Mixed | MRT | 228,005 | 7.6 | Temperate | >180 |
| | Mixed | MRH | 155,575 | 5.2 | Humid | >180 |
| | Mixed | MRHYP | 6381 | 0.2 | Hyper arid | 0–1 |
| | Sub-total | | 998,508 | 33.3 | | |
| Irrigated | Mixed | MIHYP | 35,322 | 1.2 | Hyper arid | 0–1 |
| | Mixed | MIA | 2842 | 0.1 | Arid–semi-arid | 1–180 |
| | Sub-total | | 38,164 | 1.3 | | |
| Wetlands, forest and parks | | Other | 110,512 | 3.7 | Various | Variable |
| Urban with >450 persons $km^{-2}$ | | | 20,170 | 0.7 | Various | Not relevant |
| Total land area of the Nile Basin | | | 2,998,446 | 100.0 | | |

*Notes:* Unique codes are used in other tables and figures in this chapter. Urban areas are not shown on maps in this chapter. 'Mixed' refers to mixed crop-livestock production. Codes beginning with LG, MR and MI refer to livestock dominated grazing areas, rain-fed mixed crop–livestock systems and irrigated mixed crop–livestock farming, respectively. Codes ending in HYP, A, H and T refer to hyper-arid, arid/semi-arid, humid and temperate climatic regions, respectively. 'Other' refers to lands designated for non-agricultural uses including forests, wetlands, parks, and wildlife reserves

*Source:* Peden *et al.*, 2009a

The Nile's livestock production systems are dispersed unevenly across the basin, with arid systems concentrated in the northern two-thirds of the basin (Figure 9.1), an area occupied largely by Sudan and Egypt. Mixed crop–livestock production systems are common in the southern countries around the great lakes and in the Ethiopian Highlands. Irrigated systems are found mostly in the Nile Delta and along the banks of the Nile River in Sudan. At the map scale used in Figure 9.1, small-scale household and community-scale irrigation based on water harvesting and stream diversion is not included in irrigation and falls within rain-fed agriculture for the purpose of this chapter.

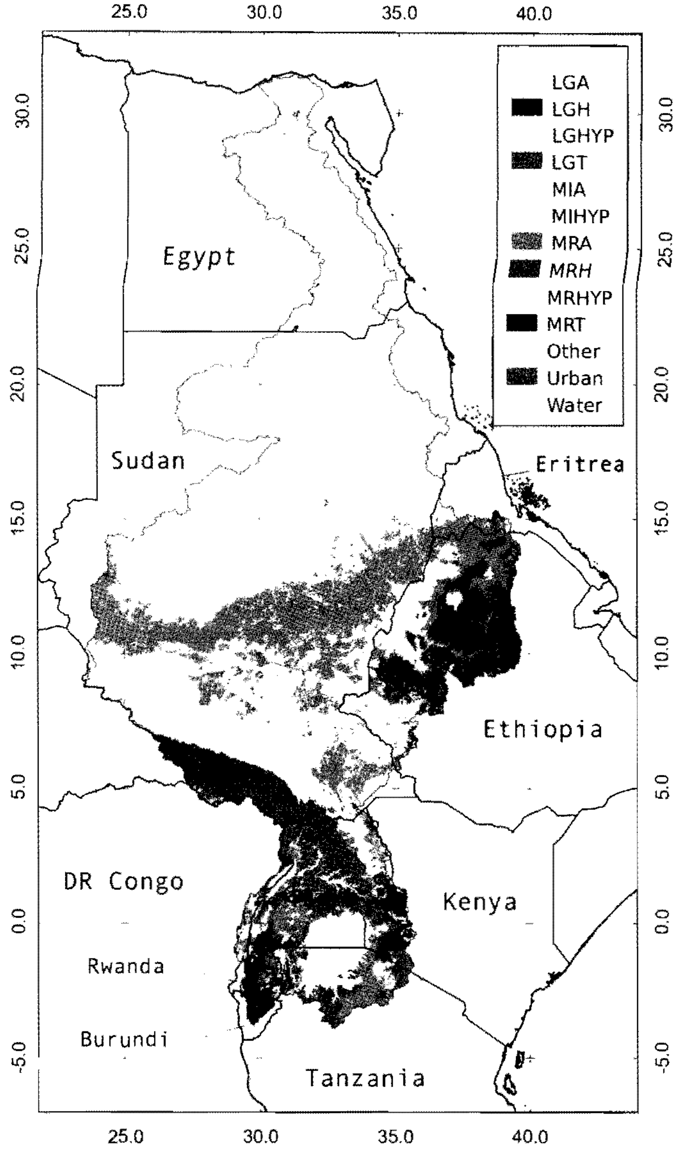


*Figure 9.1* Spatial distribution of livestock production systems in the Nile Basin described in Table 9.2
*Sources:* Peden *et al.*, 2009a, b; van Breugel *et al.*, 2010

In 2000, the Nile Basin was home to about 45 million sheep, 42 million goats, 67 million cattle and 173 million people (Table 9.3). Also present are millions of swine, poultry, camels and buffalo, which, although locally important, are not considered in this chapter. These estimates are totals for animals residing within basin parts of riparian nations and are thus lower than those reported in Table 9.1 for the entire land area of the Nile riparian states. Because animals

of different species have different weights, Table 9.3 also shows tropical livestock units (TLU), which give a weighted total for livestock biomass. Overall, about 56 million TLU live within the Nile Basin. Assuming that an average person weighs 50 kg, five persons would be equivalent to one TLU, and the Nile's human population would be equivalent to about 35 million TLU or about 63 per cent of the domestic animal biomass (cattle, sheep and goats). These values suggest that basin-wide animal demand for feed by weight is at least equal to human food requirements. As will be shown, this has implications for agricultural water use in the Nile Basin.

Four production systems (MRA, LGA, MRT, MRH) contain 86 per cent of the animal TLU within about 58 per cent of the Nile's land area. The vast hyper-arid livestock system of Sudan and Egypt has very low animal densities, but because the area is large, the total livestock biomass is large, numbering about 1.2 million TLU. The highest livestock densities (TLU·km$^{-2}$) are found in the irrigated and urban areas of the basin, while the lowest animal densities are found in the livestock-dominated grazing lands. In general, high livestock and human densities are positively correlated.

*Table 9.3* Estimated populations and densities of sheep, goats, cattle and people within the Nile Basin production systems defined in Table 9.2 and ranked in decreasing order by TLU density

| *LPS* | *Number (millions$^{-1}$)* | | | | | | *Mean density (number km$^{-2}$)* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Sheep* | *Goats* | *Cattle* | *TLU* | *Persons* | *Persons (TLU)* | *Sheep* | *Goats* | *Cattle* | *Animals (TLU)* | *Persons* | *Persons (TLU)* |
| MIHYP | 1.8 | 1.3 | 2.3 | 1.9 | 32.7 | 6.5 | 51 | 34 | 64 | 53 | 926 | 185 |
| MIA | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | <0.1 | 31 | 32 | 63 | 50 | 86 | 17 |
| MRT | 5.0 | 4.1 | 13.0 | 10.0 | 35.0 | 7.0 | 22 | 18 | 57 | 44 | 15 | 3 |
| URBAN | 0.7 | 0.8 | 0.8 | 0.7 | 43.5 | 8.7 | 34 | 41 | 38 | 34 | 2156 | 431 |
| MRA | 16.1 | 14.2 | 22.3 | 18.6 | 18.3 | 3.7 | 26 | 23 | 37 | 31 | 30 | 6 |
| MRH | 1.1 | 3.3 | 6.1 | 4.7 | 20.8 | 4.2 | 7 | 21 | 39 | 30 | 134 | 27 |
| LGT | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | <0.1 | 15 | 20 | 23 | 20 | 15 | 3 |
| LGA | 15.2 | 12.6 | 17.1 | 14.8 | 9.4 | 1.9 | 20 | 17 | 22 | 19 | 1 | <1 |
| OTHER | 0.8 | 1.0 | 1.8 | 1.4 | 6.4 | 1.3 | 7 | 9 | 16 | 13 | 58 | 12 |
| MRHYP | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.1 | 17 | 21 | 11 | 11 | 57 | 11 |
| LGH | 1.7 | 1.7 | 1.2 | 1.2 | 0.8 | 0.2 | 14 | 14 | 10 | 9 | 7 | 1 |
| LGHYP | 2.7 | 1.9 | 2.1 | 1.9 | 5.5 | 1.1 | 3 | 2 | 2 | 2 | 6 | 1 |
| Total | 45.4 | 41.5 | 67.2 | 55.7 | 173.2 | 34.6 | 15 | 13 | 22 | 18 | 58 | 12 |

*Notes:* 'Urban' refers to urban and peri-urban areas. Core urban populations have higher and lower human and livestock densities, respectively. Codes beginning with LG, MR and MI refer to livestock-dominated grazing areas, rain-fed mixed crop–livestock systems and irrigated mixed crop–livestock farming, respectively. Codes ending in HYP, A, H and T refer to hyper-arid, arid/semi-arid, humid and temperate climatic regions, respectively. 'Other' refers to lands designated for non-agricultural uses including forests, wetlands, parks, and wildlife reserves

*Source:* Peden *et al.*, 2009a

Current livestock and human population numbers and densities also vary greatly among Nile riparian nations (Table 9.4; Figure 9.2). Basin-wide, an estimated 67, 45, 41 and 173 million cattle, sheep, goats and people, respectively, were living in the river basin in 2000. Egypt and Ethiopia were the two most populous countries, while Rwanda and Burundi had the

highest densities of people (302 and 284 persons km$^{-2}$, respectively). In terms of livestock, Sudan alone contained more than half of the Nile Basin's cattle, sheep and goats. Ethiopia ranked second in terms of livestock numbers. However, Kenya had the highest animal density. Although not described herein, swine, camels, equines, poultry, fish and bees contribute to human livelihoods and place increasing demands on land and water resources.

*Table 9.4* Estimated populations and densities of sheep, goats, cattle and people within the basin portion of Nile riparian countries hand-ranked according to human density

| *Country* | *Land area (km$^2$)* | *Number (millions$^{-1}$)* | | | | *Density (number km$^{-2}$)* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Cattle* | *Sheep* | *Goats* | *Persons* | *Cattle* | *Sheep* | *Goats* | *Persons* |
| Rwanda | 20,681 | 0.7 | 0.2 | 0.83 | 6.2 | 36 | 12 | 40 | 302 |
| Burundi | 12,716 | 0.2 | 0.1 | 0.46 | 3.6 | 15 | 9 | 36 | 284 |
| Kenya | 47,216 | 4.2 | 1.4 | 1.58 | 12.1 | 89 | 30 | 34 | 257 |
| Egypt | 285,606 | 2.8 | 3.1 | 1.97 | 64.9 | 10 | 11 | 7 | 227 |
| Uganda | 204,231 | 5.0 | 1.3 | 2.97 | 23.6 | 24 | 6 | 15 | 114 |
| DR Congo | 17,384 | 0.1 | <0.1 | 0.10 | 2.0 | 3 | 2 | 6 | 113 |
| Tanzania | 85,575 | 5.5 | 0.8 | 2.89 | 7.4 | 64 | 9 | 34 | 86 |
| Ethiopia | 361,541 | 14.0 | 5.4 | 3.72 | 25.9 | 39 | 15 | 10 | 70 |
| Eritrea | 25,032 | 0.9 | 0.7 | 0.83 | 01.1 | 34 | 29 | 33 | 46 |
| Sudan | 1,932,939 | 33.9 | 32.2 | 26.07 | 27.2 | 17 | 17 | 13 | 14 |
| Total | 2,992,921 | 67.1 | 45.2 | 41.4 | 173.2 | 22 | 15 | 14 | 58 |

*Sources:* Peden *et al.*, 2009a, b; van Breugel *et al.*, 2010

The rapidly growing human population in the Nile riparian countries drives increasing demand for meat and milk; a force catalysed and amplified by urbanization and increased discretionary income of urban dwellers. In response, animal population projections suggest that livestock numbers will rise from 272 million in 2000 to about 434 million in 2030, a 59 per cent increase in the next 20 years (Table 9.2). In addition, demand for poultry and fish is also increasing. Simultaneously, grazing lands are being cultivated, implying a trend toward intensification of animal production within mixed crop-livestock systems. Without increased efficiency and effectiveness of water use, water demand for livestock will also similarly rise. One key implication is the need for Nile countries to integrate livestock demands on water resources within the larger set of pressures being placed on basin water resources.

## Water use and availability for Nile livestock

Without adequate quality and quantity of drinking water, livestock die. Given about 56 million cattle, sheep and goats TLU (Table 9.2) and drinking water requirements of about 50 l day$^{-1}$TLU$^{-1}$, their annual intake would amount to about 1 billion m$^3$ yr$^{-1}$, or about 0.05 per cent of the total basin rainfall. The actual voluntary and required drinking water intake varies from about 9 to 50 l day$^{-1}$ TLU$^{-1}$ under Sahelian conditions, depending on the type of animal, climatic conditions, feed water content, and animal management practices (Peden *et al.*, 2007). Feed production requires much more water than meeting drinking water demand. Livestock TLU consume about 5 kg day$^{-1}$ TLU$^{-1}$ of feed on a maintenance diet that theoretically utilizes

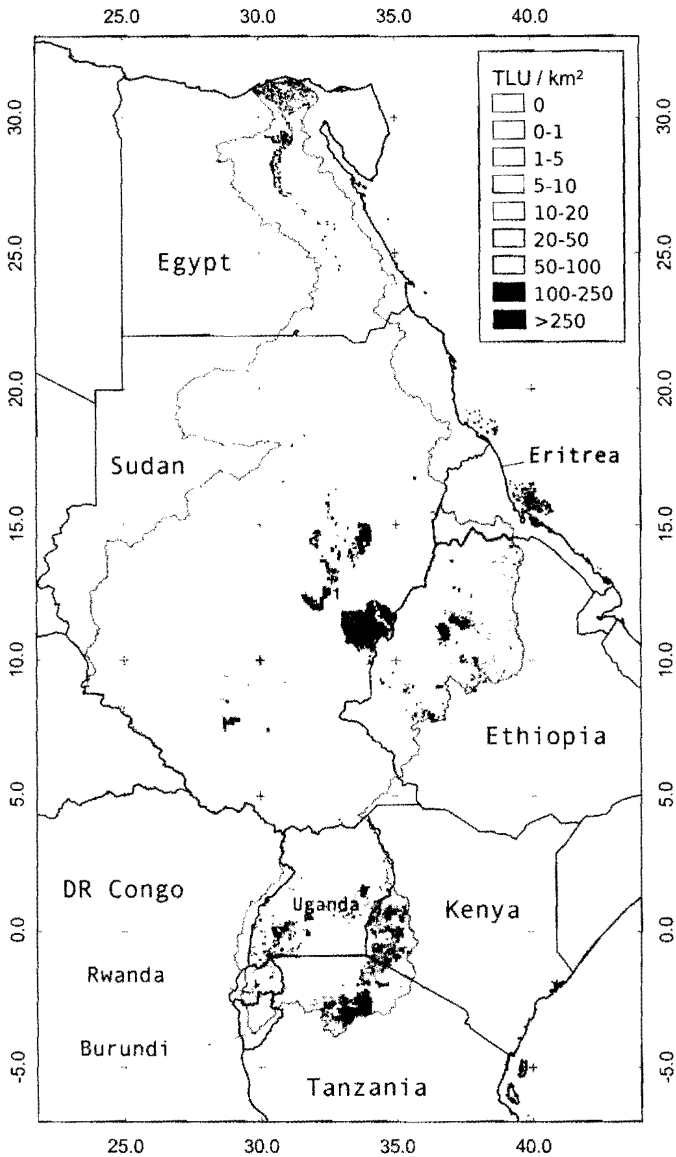


*Figure 9.2* Estimated livestock densities (TLU km⁻²) in the Nile Basin in 2005
*Sources:* Peden *et al.*, 2009a, b; van Breugel *et al.*, 2010

about 450 m$^3$ of depleted evapotranspiration for its production (Peden *et al.*, 2007), an amount about 90 times greater than the daily water intake. Additional feed for production, work, lactation and reproduction involves the use of a greater amount of water. The actual water cost of feed production is spatially variable depending on the type of animal, feed and vegetation management, and climatic conditions (Peden *et al.*, 2009a). Under harsh arid conditions in Sudan, water for feed production may reach 400 times the amount of drinking water used (Faki

*et al.*, 2008). The Nile's livestock use about 4 per cent of basin's rainfall for feed production, but this varies greatly across production systems (Table 9.5). Livestock water use amounts to the equivalent of about 65 and 40 per cent of annual rainfall in the hyper-arid and arid irrigated areas, respectively; however, much of the feed comes from crop residues and forages produced through irrigated farming. In terms of rain-fed agriculture, feed production utilizes less than 12 per cent of the rainfall in mixed crop–livestock and livestock-dominated production systems based on the premise that water used to grow crops is assigned solely to the crop and not to residues consumed by animals. These values give no indication of the efficiency or productivity of agricultural water depleted for animal production, and they do not take into account the magnitude of demand for water for nature and non-livestock human uses. Therefore, assessments of livestock water productivity are needed. Although some water is used for processing of animal products, the amount is small, but locally important, when it results in contamination harmful to people and the environment.

*Table 9.5* Estimated water depleted to produce feed for cattle, goats and sheep in the Nile portion of riparian production systems and countries (million $m^3$ $yr^{-1}$)

| *Nile riparian country* | *MIHYP* | *MIA* | *LGHYP* | *LGT* | *MRHYP* | *MRA* | *MRT* | *LGA* | *MRH* | *LGH* | *Whole basin* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sudan | 277 | 161 | 6112 | 6 | 55 | 14,481 | 21 | 20,459 | 8 | 1 | 41,581 |
| Ethiopia | 0 | 0 | 0 | 48 | 0 | 2203 | 8464 | 857 | 204 | 26 | 11,802 |
| Kenya | 0 | 0 | 0 | 140 | 0 | 163 | 2218 | 4 | 786 | 1 | 3312 |
| Uganda | 0 | 0 | 0 | 13 | 0 | 490 | 576 | 183 | 1708 | 136 | 3106 |
| Tanzania | 0 | 0 | 0 | 71 | 0 | 777 | 121 | 103 | 1835 | 9 | 2916 |
| Egypt | 1359 | 0 | 327 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 1690 |
| Eritrea | 0 | 0 | 2 | 4 | 0 | 579 | 121 | 253 | 0 | 0 | 959 |
| Rwanda | 0 | 0 | 0 | 0 | 0 | 127 | 466 | 0 | 80 | 0 | 673 |
| Burundi | 0 | 0 | 0 | 0 | 0 | 1 | 191 | 0 | 26 | 0 | 218 |
| DR Congo | 0 | 0 | 0 | 0 | 0 | 4 | 20 | 0 | 14 | 3 | 41 |
| Total | 1636 | 161 | 6441 | 282 | 59 | 18,825 | 12,198 | 21,859 | 4,661 | 3 | 66,125 |
| Rainfall (billion $m^3$) | 2.5 | 0.4 | 54.5 | 3.2 | 0.8 | 450.2 | 294.6 | 565.8 | 198.1 | 158.7 | 1728.8 |
| Percentage of rainfall | 65.4 | 40.3 | 11.8 | 8.8 | 7.4 | 4.2 | 4.1 | 3.9 | 2.4 | <1.0 | 3.8 |

*Notes:* Codes beginning with LG, MR and MI refer to livestock-dominated grazing areas, rain-fed mixed crop–livestock systems and irrigated mixed crop–livestock farming, respectively. Codes ending in HYP, A, H and T refer to hyper-arid, arid/semi-arid, humid and temperate climatic regions, respectively. 'Other' refers to lands designated for non-agricultural uses including forests, wetlands, parks, and wildlife reserves

*Source:* Peden *et al.*, 2000a

Providing water for livestock depends on the availability of water within the context of competing uses, especially for meeting other human needs as well as those of nature. The United Nations World Health Organization indicates that an acceptable minimum renewable freshwater threshold (in terms of both blue and green water) to satisfy human food production and domestic needs is 2000 $m^3$ $person^{-1}$ $yr^{-1}$ (Khosh-Chashm, 2000). Average annual rainfall per

capita across the Nile is about 11,000 $m^3$, but it varies greatly among the countries and livestock production systems (Figure 9.3). Egypt is the only riparian country that falls below the 2000 $m^3$ $person^{-1}$ $yr^{-1}$ threshold, demonstrating its reliance on river inflow to meet water demand. Sudan and Ethiopia have the highest levels of renewable freshwater per capita. Population pressure can be expected to push several countries toward the threshold, regardless of any changes in rainfall caused by climate change. Rwanda, Burundi and Kenya may be most vulnerable.

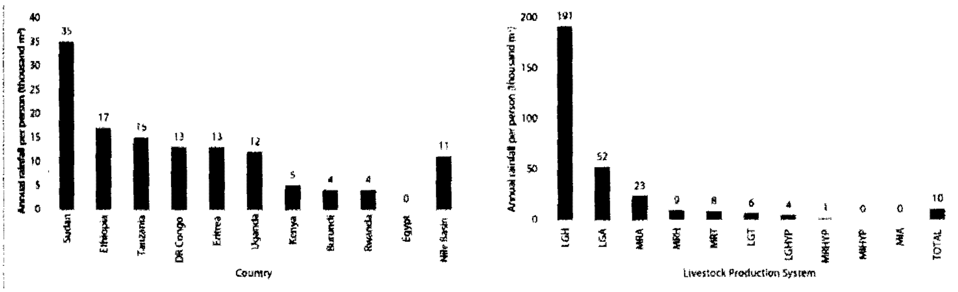


*Figure 9.3* Annual rainfall per capita within the basin part of the Nile's countries and livestock production systems

*Source:* Derived from van Breugel *et al.*, 2010

The highest per capita rainfall occurs in the humid grazing lands (LGH) and the arid and semi-arid grazing areas (LGA), while the lowest amounts are in the more densely populated, mixed crop–livestock systems, especially in humid and temperate regions. The key point is that water scarcity in rain-fed areas reflects both the abundance of rainfall and the human population density. Although access to, and the cost of, developing rainwater resources may be constraints, the greatest potential for livestock development may exist in livestock-dominated arid, semi-arid and humid landscapes. The future of livestock development will depend on rainwater management that promotes high agricultural water productivity.

## Livestock water productivity

Livestock water productivity (LWP) is the ratio of net beneficial livestock-related products and services to the amount of water depleted in producing these benefits (Peden *et al.*, 2007, 2009a, b). LWP is a systems concept based on water accounting principles, integrates livestock-water interactions with our collective understanding of agricultural water use, and is applicable to all agricultural systems ranging from farm to basin scales. The distinction between production and productivity is important but often confused. Here, we are concerned with productivity, the benefits gained per unit of water depleted, whereas production is the total amount of benefits produced. Both are important, but high levels of LWP and animal production are not necessarily correlated. LWP differs from water or rain use efficiency because it looks at water depletion rather than water input. As a concept, LWP is preferable to water or rain use efficiency because it does not matter how much water is used as long as that water can be used again for a similar or a higher-value purpose. The water productivity concept helps to focus on preventing or minimizing water depletion.

Livestock provide multiple benefits, including production of meat, milk, eggs, hides, wool and manure, and provision of farm power. Although difficult to quantify, the cultural values gained from animals are important. Accumulating livestock is also a preferred means for people to accumulate wealth. CPWF research in the Nile used monetary value as the indicator of goods and services derived from livestock.

Water enters an agricultural system as rain or surface inflow. It is lost or depleted through evaporation, transpiration and downstream discharge. Depletion refers to water that cannot be easily reused after prior use. Degradation and contamination deplete water in the sense that the water may be too costly to purify for reuse. Transpiration is the primary form of depletion without which plant growth and farm production are not possible. Livestock production is not possible without access to feed derived from plant materials. Thus, like crop production, livestock production results in water depletion through transpiration. In the Nile riparian countries, strategies are needed to ensure that effective, productive and sustainable water management underpins crop and animal production through increased LWP. LWP differs from water or rain use efficiency because it looks at water depletion rather than water input.

Four basic strategies help to increase LWP directly: improving feed sourcing, enhancing animal productivity, conserving water, and optimal spatial distribution of animals, drinking water and feed resources over landscape and basin mosaics (Figure 9.4; Peden *et al.*, 2007). Providing sufficient drinking water of adequate quality also improves LWP. However, drinking water does not factor directly into the LWP calculations because water consumed remains temporarily inside the animal and its production system.

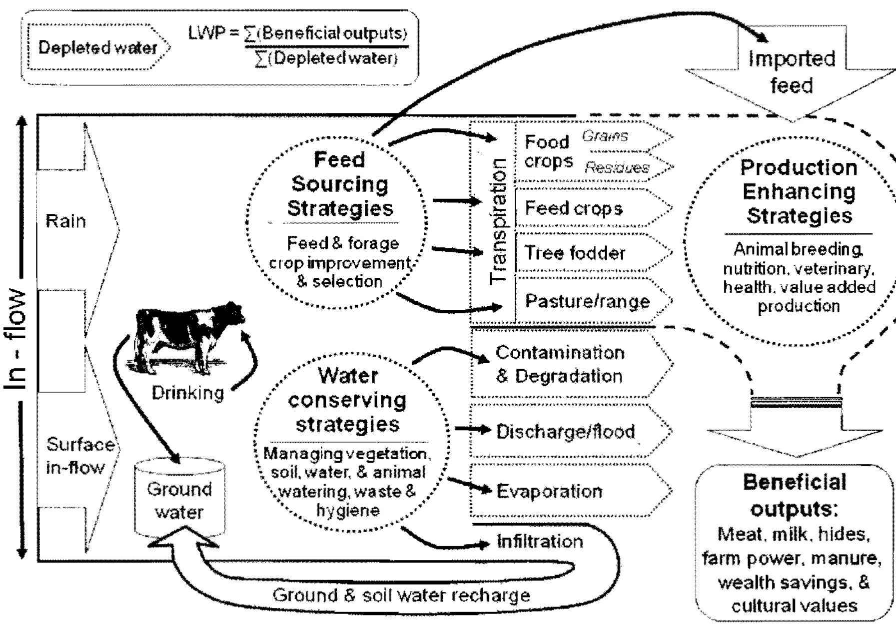


*Figure 9.4* Livestock water productivity assessment framework based on water accounting principles enables identification of key strategies for more sustainable and productive use of water

## Feed sourcing

The first strategy for enhancing LWP is feed sourcing and management. The photosynthetic production of animal feed is the primary water cost associated with livestock-keeping. Thus, increasing LWP requires selecting quality pasture, feed crops, crop residues and by-products that have high crop water productivity (CWP). Any measures that help to increase CWP will also lead to higher LWP (Chapter 8). However, estimates of water used for feed production are highly variable, context-specific and limited in number. Science-based knowledge of water use for feed remains contradictory.

Maximum practical feed water productivity in rain-fed dry matter production is about 8 kg $m^{-3}$, but in practice it is often less than 0.5 kg $m^{-3}$ (Table 9.6; Peden *et al.*, 2007). Variability is due to many factors such as inconsistent methodologies, varying concepts of water accounting and the reality of particular production systems. For instance, examples from the literature often estimate CWP on the basis of fresh rather than dry weights, a practice that will overestimate water productivity and make comparisons meaningless. Typically, the water cost of producing below-ground plant materials is ignored, failing to recognize water's role in maintaining soil fertility.

*Table 9.6* Example of estimates of dry matter water productivity of selected animal feeds

| *Feed source* | *Feed water productivity (kg $m^{-3}$)* | *Reference* |
|---|---|---|
| Various crops and pastures, Ethiopia | 4 | Astatke and Saleem, 1998 |
| *Pennisetum purpureum* (1200 mm $yr^{-1}$ ET) | 4.3 | Ferris and Sinclair, 1980 |
| Irrigated alfalfa, Sudan | 1.2–1.7 | Saeed and El-Nadi, 1997 |
| Grasslands, United States | 0.5–0.6 | Sala *et al.*, 1988 |
| Various food crops and residues, Ethiopia | 0.3–0.5 | Haileslassie *et al.*, 2009a |
| Mixtures of maize, lab-lab and oats vetch | <0.5 | Gebreselassie *et al.*, 2009 |

*Source:* Summary of examples cited in Peden *et al.*, 2007

The prime feed option for increasing LWP is the use of crop residues and by-products. When crops are grown for human food, taking advantage of their residues and by-products imposes little or no additional water cost beyond what the crop itself requires. In contrast, using irrigation water to produce forage results in a comparatively high water cost and, thus, relatively low LWP.

Importation of feed effectively transfers the water cost of feed production to distant areas, reducing local demand for agricultural water. If insufficient water is available for feed production, animals must move to new feed sources or rely on imported feed associated with virtual water (Chapagain and Hoekstra, 2003). For example, dairy production in Khartoum takes advantage of crop residues produced in large-scale irrigation on the Blue Nile. The low nutritional value of crop residues limits their effectiveness as animal feeds. However, this can be overcome with modest supplements of high-quality feed such as grain and forage legumes and using technologies that increase digestibility of roughages.

## Enhancing animal productivity

Water transpired to produce maintenance feed is a fixed input for animal production. Livestock require additional water to produce the feed required to gain weight, produce milk, work and reproduce. Enhancing LWP requires a higher ratio of energy use for production than that used for maintenance. Traditional off-the-shelf Animal Science interventions of nutrition, genetics, veterinary health, marketing and animal husbandry help to increase LWP (Peden *et al.*, 2007). Typical interventions include:

- Providing continuous quality drinking water (Muli, 2000; Staal *et al.*, 2001).
- Selecting and breeding livestock for improved feed conversion efficiency (Basarab, 2003).
- Providing veterinary health services to reduce morbidity and mortality (Peden *et al.*, 2007; Descheemaeker *et al.*, 2010a, 2011) and meet safety standards for marketing animals and animal products (Perry *et al.*, 2002).
- Adding value to animal products, such as farmers' production of butter from liquid milk.

## Conserving water resources

Agricultural production and the sustainability of natural and agro-ecosystems are dependent on transpiration (T). Here we define water conservation as the process of reducing water loss through non-production depletion pathways. Water depleted through evaporation and discharge does not contribute to plant production, although it may do so downstream. One effective way to increase agricultural water productivity, including LWP, is to manage water, land, vegetation and crops in ways that convert evaporation and excessive run-off to T. Proven means to increase transpiration, CWP and LWP include maintaining high vegetative ground cover and soil-water-holding capacity, water harvesting that enables supplemental irrigation of feeds including crops that produce residues and by-products, terracing and related measures that reduce excessive run-off and increasing infiltration, and vegetated buffer zones around surface water bodies and wells.

Sheehy *et al.* (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, down slope sedimentation, reduced infiltration, and less production of pasture. 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, LWP 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 off-take.

The type, mix and density of grazing animals affect the species composition of the vegetation (Sheehy *et al.*, 1996). High grazing pressure causes loss of palatable and nutritional species, but very low grazing pressure encourages encroachment of woody vegetation. Maintaining higher water productivity depends on having both palatable vegetation and the presence of domestic animals that utilize the pasture.

## Strategic allocation of livestock, feed and drinking water across landscapes

At landscape and large river-basin scales, suboptimal spatial allocation of livestock, pasture and drinking water leads to unnecessarily low LWP and severe land and water degradation. Faki *et*

*al.* (2008) and Peden *et al.* (2007, 2009a, b) show, especially for cattle, that LWP is low near drinking water sources because of animal weight loss, morbidity and mortality associated with shortages of feed and pastures and increased risk of disease transmission. LWP is also low far from water because trekking long distances between feeding and watering sites reduces animal production (van Breugel *et al.*, 2010; Descheemaeker *et al.*, 2010b). Over vast areas, moving animals, feed and water from areas of surplus to places of scarcity can help maintain an optimal spatial balance and maximize LWP.

## *Livestock demand management*

The four LWP enhancing strategies depicted in Figure 9.4 take a *supply-side* approach to animal production. If livestock keepers respond to increased LWP by simply keeping larger herds, requiring more feed, water and other inputs, no additional water will become available to meet other demands that can benefit people or nature. Ultimately, some limits to livestock production are needed. Two *demand-side* approaches to production require further research. The first is restricting livestock use of land to levels above which environmental sustainability and positive synergies with other livelihood strategies are lost. This might involve including environmental costs of livestock production in the prices of animal products and services. The second is adopting policy that ensures equitable access to animal products and services and limits consumption of meat and milk to levels that enhance human nutrition while discouraging increasing incidence of diabetes and obesity. Promotion of alternatives to animal products and services also helps to limit demand. Livestock provide energy for farm power and fuel. Alternative energy sources can be procured that will reduce demand for animals and, by implication, water resources. Throughout the Nile Basin, livestock keepers maintain large herds for drought insurance, social status and wealth savings (Faki *et al.*, 2008). Finding alternatives for these culturally important livestock services could reduce pressure on feed and water resources.

## Case studies from the Nile Basin

The water required to produce food for the Nile's population of 173 million (Table 9.5) is about 1300 $m^3$ per capita, or 225 billion $m^3$ for the entire basin, assuming all food is produced within the basin.

Six livestock production systems cover 60 per cent of the Nile Basin's land area (1799 million $km^2$) and support about 50 and 90 per cent of its human and livestock (cattle, sheep and goats) biomass, respectively. They receive about 1680 billion $m^3$, of rain or about 85 per cent of the basin's total. Of this, about 1027 billion $m^3$ are depleted as evapotranspiration (ET), water that does not enter the Nile's blue water system. Making the best use of this ET in rain-fed areas affords great opportunity to reduce agricultural demand on the Nile's water resources. Production of feed for cattle, sheep and goats utilizes about 77 billion $m^3$, or 3.9 per cent of the total basin rainfall for feed production through ET. This implies that about 1190 billion $m^3$ are directly lost to the atmosphere without contributing directly to production of these three animal species. Some of this water supports crops, poultry, equines, swine, and crops in mixed crop-livestock systems. Maintenance of ecosystems also requires up to 90 per cent of green water flow (Rockström, 2003). However, the high degree of land degradation with its attendant low level of vegetative ground cover implies that much of the 1190 billion $m^3$ is lost as non-productive evaporation. *Vapour shifts* (the conversion of evaporation to T) can realize 50 per cent increases in CWP from about 0.56 to 0.83 kg $m^{-3}$ in rain-fed tropical food crop production (Rockström, 2003) by maximizing infiltration and soil water-holding capacity and

by increasing vegetative cover. This increase in CWP would also lead to a similar increase in crop residues for animal feed without additional water use. Similar increases are possible in LWP in rangelands (Peden *et al.*, 2009a). In highly degraded landscapes, WP gains may be higher as suggested by Mugerwa (2009). Thus rehabilitating degraded grazing lands and increasing provision of livestock and ecosystems goods and services are possible. Combining feed, animal and water management could lead to a doubling of animal production without placing extra demand on the Nile's blue water resources.

CPWF research assessed LWP at four sites in Ethiopia, Sudan and Uganda that represent four of the basin's major production systems (Peden *et al.*, 2009a). Due to agro-ecological diversity, LWP varied greatly among sites. The highest LWP was observed in the densely populated mixed crop-livestock systems of the Ethiopian highlands while the lowest was found in Uganda's Cattle Corridor (Figure 9.5) These analyses suggest that LWP increases as a result of agricultural intensification. The following sections highlight selected conditions and potential interventions that may help improve LWP and more generally make more effective and sustainable use of water in the Nile Basin.

## Ethiopia

Temperate rain-fed mixed crop–livestock systems (MRT) dominate the highlands of Ethiopia, Kenya, Uganda, Rwanda and Burundi. MRT accounts for 7.6, 18, 24 and 17 per cent of the Nile Basin area, TLU (cattle, sheep and goats), rural human population and rainfall, respectively. Annual rainfall exceeding 800 mm, dense human and animal populations, intensified rain-fed cropping, high levels of poverty and food insecurity, and vulnerability to severe soil erosion and loss of water through excessive run-off and downstream discharge prevail. These areas, along with remnants of forests and montane pastures, serve as water towers for the entire Nile Basin and provide Sudan and Egypt with significant amounts of water.

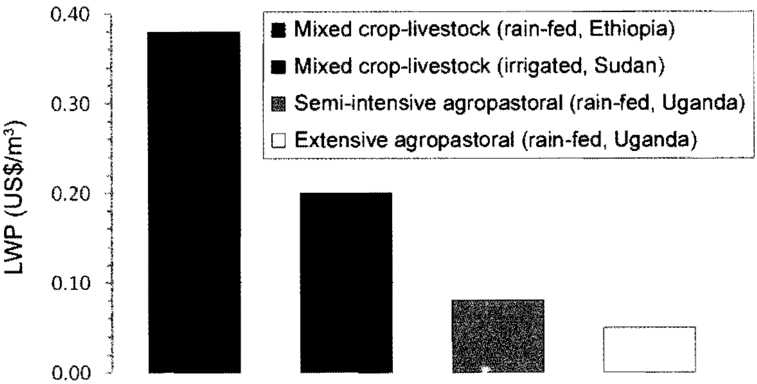


*Figure 9.5* LWP estimates for four production systems in Ethiopia, Sudan and Uganda

*Source:* Peden *et al.*, 2009a

Livestock-keeping is an integral part of Ethiopian rain-fed grain farming. Cattle, sheep, goats, equines and poultry contribute to rural livelihoods. Livestock productivity, in terms of production per animal, is low. For example, milk yields range from 0.6 to 1.8 $l{\cdot}cow^{-1}{\cdot}day^{-1}$ and the average live weight of mature cattle reaches only about 210 $kg{\cdot}head^{-1}$ (Peden *et al.*, 2009a).

CPWF research focused on farming systems in the Gumera watershed which drains into the eastern shore of Lake Tana (Alemayehu *et al.*, 2008) and spans elevations ranging from 1900 to 3700 m above sea level. This watershed contains four farming systems: rice, teff–millet, barley–wheat and potato–barley, which occupy lower to higher elevations in that order. Cattle are dominant in lower areas while sheep are more prevalent at higher elevations. Equines and goats are found throughout. Although both human and animal densities are high (Tables 9.3 and 9.4), households are poor typically owning less than 4 TLU each. Farm production is low and land degradation severe. Rainwater is plentiful, but not well utilized.

Haileslassie *et al.* (2009a, b) assessed LWP in the Gumera watershed based on multiple livestock benefits including meat, milk, traction and manure (Table 9.7). These estimates are consistent with other estimates and suggest that in monetary terms, LWP compares favourably with crop water productivity. However, observed physical water productivity for crops (CWP) was low, averaging about 0.4 kg $m^{-3}$ implying substantive scope for improvement that would translate into a corresponding increase in LWP. Observed monetary CWP and LWP in the Gumera watershed were low ranging from US\$0.2 to US\$0.5$\cdot m^{-3}$ for crops and US\$0.1 to US\$0.6 $m^{-3}$ for livestock.

Relatively wealthy farmers appeared to exhibit higher CWP and LWP than poor farmers. Although researchers have operated on the premise that increasing agricultural water productivity contributes to poverty reduction, evidence also suggests that farmers with greater wealth are better able to make investments in farming that lead to higher profits. Numerous opportunities exist to increase LWP in the Ethiopian Highlands.

*Table 9.7* Livestock and water productivity by farming household health class in three farming systems of the Gumera watershed, Blue Nile Highlands and Ethiopia

| | *Production system* | *Wealth group* | | | *Weighted mean* |
|---|---|---|---|---|---|
| | | *Rich* | *Medium* | *Poor* | |
| CWP (kg $m^{-3}$) | Potato–barley | 0.5a | 0.3b | 0.4b | 0.5 |
| | Barley–wheat | 0.5a | 0.3b | 0.4b | 0.4 |
| | Teff–millet | 0.4a | 0.3a | 0.3b | 0.3 |
| | Rice | 0.5 | 0.5 | 0.5 | 0.5 |
| CWP (US\$ $m^{-3}$) | Potato–barley | 0.5a | 0.2b | 0.3b | 0.3 |
| | Barley–wheat | 0.5a | 0.3b | 0.3b | 0.3 |
| | Teff–millet | 0.2ab | 0.3a | 0.2b | 0.2 |
| | Rice | 0.4a | 0.3b | 0.2c | 0.3 |
| LWP (US\$ $m^{-3}$) | Potato–barley | 0.5a | 0.5a | 0.4a | 0.5 |
| | Barley–wheat | 0.5a | 0.5a | 0.6a | 0.5 |
| | Teff–millet | 0.6a | 0.3b | 0.2c | 0.3 |
| | Rice | 0.4a | 0.3a | 0.1b | 0.3 |

*Note:* Letters a, b and c indicate sets of estimated water productivity values within which differences were not significant ($p = 0.01$)

*Source:* Haileslassie *et al.*, 2009b

One opportunity to increase water productivity focuses on mitigating the impact of traditional cultivation and livestock keeping on run-off and erosion. These two production constraints vary with scale, cropping patterns, land-use and tenure arrangements of the pasturelands. The most severe run-off and erosion are commonly linked to cultivation of annual crops because bare soil is highly vulnerable to erosive forces of rainfall (Hellden, 1987; Hurni, 1990). Communally owned pasture with unrestricted grazing was the next most vulnerable (Table 9.8) with rainy season run-off and soil loss estimated at 10,000 $m^3$ $ha^{-1}$ and 26.3 t $ha^{-1}$, respectively. Effective by-laws controlling stocking rates on community pastures reduced run-off and erosion by more than 90 per cent. Privately owned grazing land fared even better. In all cases, the severity of resource degradation was correlated with the steepness of hillsides. These observed trends confirm other studies (such as Taddesse *et al.*, 2002) and support the view that water depleted through downslope discharge does not contribute in a positive way to increasing water productivity. Descheemaeker *et al.* (2010a, 2011) also concluded that providing drinking water to livestock at individual households, increasing feed availability and quality and promoting land rehabilitation would greatly increase LWP.

*Table 9.8* Run-off volume and sediment load of the main rainy season from pastures having different ownership patterns and slopes

| *Pattern of pastureland ownership* | *Slope (%)* | *Run-off volume ($m^3$ $ha^{-1}$)* | *Sediment load (t $ha^{-1}$)* |
|---|---|---|---|
| Communally owned and open unrestricted grazing | <10 | 10,125.0 | 26.3 |
| | 15–25 | 12,825.0 | 45.27 |
| Communally owned pasture supported with local by-laws | <10 | 3307.5 | 7.84 |
| | 15–25 | 4927.5 | 14.24 |
| Privately owned enclosed pasture | <10 | 1147.5 | 1.65 |
| | 15–25 | 1687.5 | 3.39 |
| Cropland (Hellden, 1987) | <10 | | 29.4 |
| | 10–15 | | 69.6 |
| Standard error of the mean | | 607.5 | 1.47 |

*Source:* Alemayehu *et al.*, 2008

## Sudan

Most of the Nile Basin's livestock reside in Sudan (Table 9.4), where they sustain millions of poor farmers and herders, contribute about 20 per cent of national GDP, and form a significant part of Sudan's non-oil exports. This section describing livestock in Sudan takes a broad-brush review of secondary information and includes selected specific surveys, in contrast to more detailed work undertaken in smaller areas in Ethiopia and Uganda. The majority of the country's domestic animals (including sheep, goats, cattle, camels and equines) are found in the Central Belt of Sudan (Figure 9.6), an area composed of arid and semi-arid livestock-dominated and mixed crop–livestock systems (LGA and MRA), irrigated (MIH and MIA) and urban livestock production in the Nile Basin (Figure 9.1). Rainfall ranges from below 100 mm $yr^{-1}$ in its far north to about 800 mm $yr^{-1}$ in its far south. Limited surface water is locally available from the Nile, its tributaries and other seasonal rivers. The Central Belt encompasses 13 states,

covers 75 per cent of the area of the Sudan, accommodates 80 per cent of its people and 73 per cent of its total livestock, and sustains most of the crop production. The belt's link to the Nile Basin is strong in terms of livestock production in schemes irrigated from the Nile, livestock mobility between rain-fed and irrigated areas and livestock trade with other Nile Basin countries (Faki *et al.*, 2008). For example, the only practical way livestock can access vast grazing lands during the more favourable rainy season is by having access to the relatively nearby Nile's blue water system in dry periods. Transhumance and nomadic modes of production, thriving on natural pastures, is the ruling practice, but cropland expansion increasingly impedes pastoral mobility. Modern sedentary dairy farms exist in the vicinity of towns and big settlement areas.

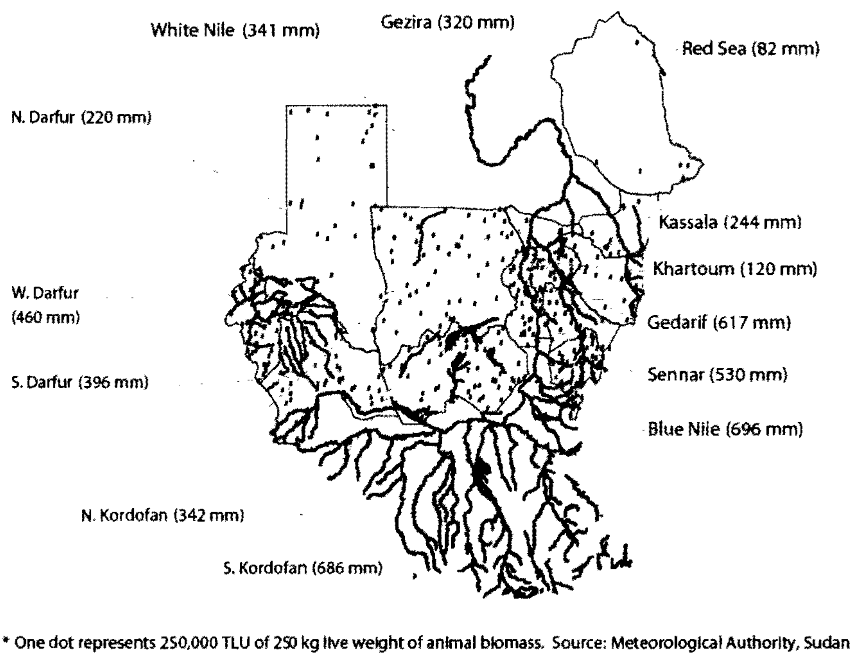


*Figure 9.6* Sudan's Central Belt with spatial distribution of livestock (TLU), rivers and streams, and average rainfall from 1978 to 2007 in states' capitals

Milk and meat productivity and production are low and variable due to lack of feed and drinking water, low fertility, and high morbidity and mortality rates (Faki and van Holst Pellekaan, 2007; Mekki, 2005; Wilson, 1981; Mufarrah, 1991). In general, animal production underperforms relative to the potential of both the breeds of animals kept and the capacity of the environment where they are raised, implying considerable potential for improvement. Low off-take confirms the legacy of animal hoarding by pastoral communities, a tendency motivated by perceived need for prestige, insurance against drought, and a wealth savings strategy. Poor market access for transhumant herders also discourages investment in animal production. Other important constraints to animal production include increasing barriers to pastoral migration, lack of secure land tenure and water rights, water regulatory and management institutions that

largely ignore the needs of the livestock sector, encroachment of irrigated and mechanized rain-fed agriculture into rangelands, and a breakdown in the traditional means for conflict resolution.

Feed and water shortages are the major biophysical constraints to livestock production. For example, in 2009, feed balances were negative in nine of the 13 states and in surplus in only North Darfur and Red Sea states (Figure 9.7). Access to drinking water is vital for livestock production. Without drinking water, livestock die. All states in the Central Belt except for Khartoum and Red Sea also suffer from shortages of drinking water for livestock for at least part of the year (Table 9.9). In brief, shortages in drinking water and long treks in high temperatures to find watering sites increase heat stress, consume excessive metabolizable energy and expose animals to increased feed shortages and disease risks, when large numbers concentrate around the few available water sources, including the Nile's lakes and rivers, wells and hafirs.

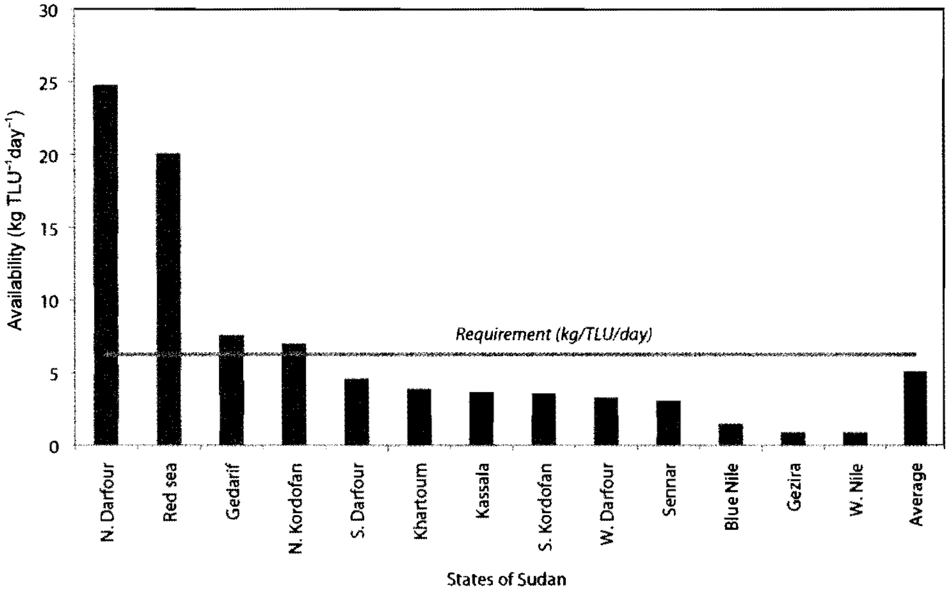


*Figure 9.7* Feed balances in terms of dry matter feed by state across Sudan's Central Belt in terms of requirements versus availability

*Notes:* Feed balances are calculated according to daily feed dry matter (DM) requirements. Dotted line, 6.25 kg $TLU^{-1}$ $day^{-1}$, assuming 2.5 per cent DM of animal weight per day

*Sources:* DM assumption based on Ahmed El-Wakil, personal communication. Data on pasture availability are from the Range Department of the Ministry of Agriculture, provided by Mr Mohamed Shulkawi

LWP in Sudan is much lower than its potential. In monetary terms, LWP derived from live animals and milk sales provides a useful overall productivity indicator, although it does not include other benefits that domestic animals provide. For example, in 2009, LWP was substantially higher than irrigated production in rain-fed areas (Table 9.10). In rain-fed areas, LWP was higher in good seasons compared with drought years. In irrigated areas, LWP may increase slightly during good years compared with drought periods. With estimates of US\$0.17 and US\$0.23 $mm^{-1}$ of rain in Kordofan and Gezira, respectively, crop water productivity was lower

*Table 9.9* Average daily rural livestock drinking water availability, demand and balance ($m^3$ $day^{-1}$) in different states within Sudan's Central Belt (2007)

| | *Available water* | *Average drinking demand* | *Peak drinking demand* | *Balance at average demand* | *Balance at peak demand* |
|---|---|---|---|---|---|
| Red Sea | 126,410 | 20,075 | 31,677 | 106,335 | 94,733 |
| Khartoum | 83,210 | 24,979 | 28,083 | 58,231 | 55,127 |
| Gedarif | 55,096 | 66,417 | 85,896 | −11,321 | −30,800 |
| Kassala | 43,972 | 61,441 | 86,709 | −17,469 | −42,737 |
| Sennar | 32,839 | 71,622 | 92,136 | −38,783 | −59,297 |
| North Darfur | 52,448 | 87,478 | 115,947 | −35,030 | −63,499 |
| White Nile | 48,184 | 118,823 | 156,805 | −70,639 | −108,621 |
| Gezira | 61,507 | 140,928 | 170,469 | −79,421 | −108,963 |
| Blue Nile | 19,133 | 151,871 | 203,441 | −132,738 | −184,309 |
| South Darfur | 51,088 | 187,184 | 235,637 | −136,096 | −184,549 |
| West Darfur | 29,495 | 172,336 | 229,290 | −142,842 | −199,795 |
| Greater Kordofan | 244,488 | 335,245 | 464,446 | −90,757 | −219,959 |
| Total | 847,870 | 1,438,399 | 1,900,536 | −590,530 | −1,052,669 |

*Note:* Average demands are 25, 30, 4 and 4 l $day^{-1}$ for cattle, camels, sheep and goats, respectively; at peak summer months, the corresponding values are 35, 65, 4.5 and 4.5 l $day^{-1}$. Human rural requirements are 20 l $day^{-1}$ $person^{-1}$, according to the Ministry of Irrigation

*Source:* Available water computed from data of the Ministry of Irrigation; livestock in 2007 estimated from data of MoARF, 2006; requirements are calculated according to Payne, 1990

than LWP. The prime entry point for increasing LWP in Gezira is through improved water use efficiency in irrigation. Increased expansion of watering points and better management of adjacent grazing lands constitute a key starting point for increasing LWP in Kordofan. High LWP relative to CWP in the good and normal seasons partially reflects the higher prices for animal sourced food products relative to crops. In poor seasons, higher mortality and morbidity and lower prices reduce LWP. In all cases, lack of feed and water along with poor animal and rangeland management contributes to lower than optimal LWP whereby most water used supports animal maintenance rather than reproduction and growth or is lost through non-productive depletion such as excessive evaporation and surface water run-off.

*Table 9.10* Monetary rainwater use efficiency (RUE) for livestock in selected rain-fed and irrigated areas (US$ $mm^{-1}$of rain equivalent $TLU^{-1}$)

| *Area (state)* | *RUE (good season)* | *RUE (normal season)* | *RUE (poor season)* | *Mean crop RUE* |
|---|---|---|---|---|
| Kordofan (rain-fed) | 0.75 | 0.42 | 0.26 | 0.17 |
| Gezira (irrigated) | 0.20 | 0.23 | 0.28 | 0.23 |

*Notes:* Exchange rate of 2.2 Sudanese pounds per United States dollar. Methodological difference implies these estimates are not directly comparable to other LWP estimates in this chapter based on US$ $m^{-3}$. Figure 9.4 provides an estimate of LWP from Gezira in 2009 using units of US$ $m^{-3}$. RUE serves as a useful proxy for LWP in very dry areas where ET and rainfall are almost equal. These estimates are based on a synthesis of secondary information and are not comparable with LWP estimates based on volume of water depleted; error estimates are not available

*Source:* Peden *et al.*, 2009a

One key challenge faced by both the water and livestock sectors in Sudan's economy is increasing the water productivity of livestock. Multiple intervention options and opportunities exist and must be tailored to meet specific local needs. Some focus on water management. Others focus on livestock development. Yet others act indirectly on water and livestock. All address four LWP strategies (feed sourcing, enhancing animal productivity, conserving water, and spatially optimizing the distribution of animals, feed and drinking water), plus the adoption of livestock and water demand management practices. Selected examples of each follow.

## *Feed sourcing*

Prior to the 1900s, pastoralism prevailed in the Central Belt of Sudan. In the early 1900s, irrigation development took place along the Nile River systems, particularly in the Gezira state. More recently, large-scale mechanized grain production evolved in Gederif state. Both of these developments displaced herding practices. However, both also provide opportunities for livestock development through the use of crop residues (Figure 9.8).

*Figure 9.8* Large quantities of crop residues produced in Sudan's large-scale irrigation schemes and rainfed, mechanized grain farms support animal production in feedlots near Khartoum

One advantage of using crop residues for feed lies in the fact that this feed source requires little or no additional water for production compared with that used to produce the crop. Dual-purpose crops are more water-productive than either food crops or feed crops by themselves (Peden *et al.*, 2007). As previously noted, the Nile's large-scale irrigated agriculture supports the

basin's highest livestock densities, largely due to the abundance of crop residues and to a lesser extent due to irrigated forage. The Gezira's large human population generates a high demand for livestock and livestock products. Thus, demand for animal feed exceeds supply. In Gederif, large quantities of crop residues are also available, but, in contrast to Gezira, lack of drinking water restricts livestock-keeping so that feed supply exceeds local demand. Options to increase water productivity through the use of crop residues include provision of nutritional supplements to enable greater residue digestibility by ruminants. In Gezira, strengthening irrigation water management policy and practice that accommodate livestock and crop production is needed in large-scale irrigation. In Gederif, there is a need to either provide drinking water for livestock or transport the feed to locations where animal demand for feed is high.

### *Enhancing animal productivity*

Maximum LWP is only possible when individual animals and herds are productive, healthy and kept in stress-free environments. Premature death and disease result in reduced or zero benefits from animals and animal products. Throughout the Central Belt of Sudan, high levels of mortality and morbidity keep LWP low. Long treks during dry seasons for drinking water subject animals to heat stress and exertion that divert energy from weight gains, lactation and reproduction. A primary LWP-enhancing option lies in the provision of husbandry practices that prevent disease transmission, veterinary care that improve animal health, and living conditions that reduce stress and unnecessary expenditure of energy. Examples of interventions include measures that protect herders' migration routes (Peden *et al.*, 2009a), provision of safe drinking water by use of troughs that spatially separate animals from drinking water sources (Figures 9.9 and 9.10) and veterinary care for waterborne diseases such as fascioliasis (Goreish and Musa, 2008).

### *Conserving water*

Inappropriate watering practices (Figure 9.10a) lead to high risk of disease transmission. Separating animals from the hafir (reservoir) and pumping water to drinking troughs help maintain high-quality drinking water (Figures 9.10b, c).

### *Optimizing the spatial distribution of animals feed and drinking water over landscapes*

Water depleted through evapotranspiration during production of feed sources on rangelands is lost for productive purposes when underutilized by livestock (Faki *et al.*, 2008; Peden *et al.*, 2009a). Consequently, LWP is low in grazing lands located far from drinking points because livestock, particularly cattle, cannot utilize otherwise available feed resources. We recognize that this water not used by livestock may contribute in other ways to ecosystem services. Conversely, LWP is also low in grazing lands with poor feed availability near watering points. Without adequate feed, they lose weight and become more susceptible to waterborne diseases characteristic of large numbers of animals concentrated around watering points in dry seasons. The primary intervention opportunity lies in distributing livestock, grazing land and drinking water resources over large areas in a manner that maximizes animal production but does not lead to degradation of feed and water resources. Collaborative multi-stakeholder action to place effective limits on herd sizes can help to ensure maximum productivity and sustainability accompanied by investments in optimally distributed watering points and satellite monitoring of seasonally variable rangeland conditions.

*Figure 9.9* Sudan's pastoralists trek a long distance to find drinking water. Thirsty animals queue for extensive periods waiting for a chance to quench their thirst. High concentrations of animals quickly deplete feed resources near watering points while water deprivation, energy loss through trekking, limited feed and heat stress all lower animal production and LWP

## *Demand management*

The Central Belt of Sudan is a prime example of the tendency of some livestock keepers to hoard animals as means for securing wealth and enhancing prestige, culturally important processes that consume large quantities of water. Strictly in terms of achieving goals for water development for food production and environmental sustainability, we argue that water used to enable hoarding is suboptimal. In terms of the LWP assessment framework (Figure 9.4), we hypothesize that, in future, LWP should be evaluated based on the value rather than volume of water depleted. In effect, introduction of water pricing could serve as an important option of increasing agricultural water productivity.

## *Need for better integration of livestock and water development*

Growing domestic and export demand for livestock products, now encouraged by high-level policy, will place substantial new demands on agricultural water resources. This, however, provides opportunities to farmers, but may also increase competition for agricultural water, provoke conflict and aggravate poverty (Peden *et al.*, 2007). Increased livestock water productivity through application of the foregoing four strategies is required. To achieve a positive future outcome, there is great need for better integration of livestock, crop and water development and management. In Sudan's Central Belt, water supply is, on the whole, more limiting than fodder, particularly because fodder production and utilization are also highly dependent on access to water. In turn, evidence suggests current investment returns from water development in Africa are suboptimal (World Bank, 2008). Yet, proactive inclusion of livestock in irrigation development can significantly and sustainably increase farm income. Integration must take into account diverse disciplines such as hydrology, agronomy, soil science, animal nutrition, veterinary medicine, water engineering, market development, diverse socio-economic sciences and financial planning. Integration must simultaneously address local, watershed, landscape and basin scales and accommodate the need for biophysical, spatial and livelihood diversity as it seeks to establish prosperity and environmental sustainability.

a

b

c

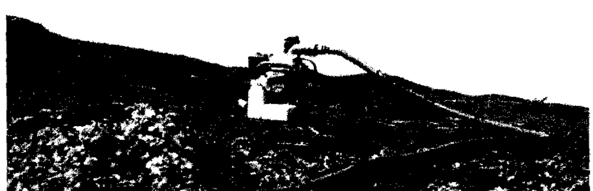

*Figure 9.10* In Sudan, water harvesting systems based on reservoirs, known as hafirs, and adjacent catchments are important sources of drinking water for livestock. (a) In some cases, uncontrolled free access to water creates hot spots for transmission of waterborne diseases and causes rapid sedimentation of water bodies. (b, c) Restricting animal access to open water and pumping water into drinking troughs help prevent animal disease and extend the useful lifespan of the infrastructure

## Uganda

CPWF research on livestock and water in Uganda focused on the country's Cattle Corridor that comprises rain-fed, mixed crop-livestock systems in a relatively humid area (Figure 9.1). The Cattle Corridor stretches from the north-east, through central to south-east Uganda, covering about 84,000 km$^2$, or 40 per cent of the country's land area, and mostly falling within the Nile Basin. This area is highly degraded and the stocking rate is 80 per cent less than the land's potential carrying capacity. Overgrazing and charcoal production led to loss of much pasture and soil. Without adequate vegetation cover, rain washes soils downslope filling water bodies such as ponds and lakes. When small amounts of rain fall on bare clay soil, the clay expands sealing the soil surface preventing infiltration. Lost rainwater provides little value locally, but contributes to downstream flooding. Termites are prevalent and quickly consume virtually all useful plant materials including forage on which livestock depend. Damage from termites is most serious during the dry season, creating extensive patches of bare ground which often force the cattle owners to migrate in search of new pasture.

Some livestock keepers have constructed ponds known as *valley tanks* to provide domestic water and livestock drinking. Sediments from degraded upslope pastures fill valley tanks, reducing their water-holding capacity and limiting their usefulness in dry seasons. Without drinking water, herders are forced to migrate with their animals to the Nile's Lake Kyoga for watering where they are at high risk to waterborne diseases and, at high densities, they quickly deplete feed supplies. Resulting feed deficiency aggravates disease impact while overgrazing threatens riparian habitats and water quality.

The Makerere University team, in collaboration with the Nakasongola District administration and livestock-keeping communities, undertook an integrated systems approach to (i) reseeding degraded pastures, (ii) managing the valley tank and pasture complex, and (iii) enhancing quality and quantity of water in the valley tanks for livestock and domestic use.

### Reseeding degraded pastures

Reseeding degraded pastures in 2006 was the first attempted intervention designed to restore pasture productivity and to prevent sedimentation of downstream valley tanks, but it completely failed due to the aggressive and destructive power of termites that devoured all new plant growth. After consultation with CPWF partners, the researchers learned that a similar problem was solved in Ethiopia by applying manure to the land before reseeding activities commenced. The second experimental reseeding began in 2007 using a formal replicated field experiment. The innovation included treatments with two weeks of night corralling of cattle in fenced areas located on former, highly degraded pastureland that lost all vegetative ground cover. This new study included six treatments with three replicates each:

- fencing plus manuring (FM);
- fencing exclosures only (FO);
- fencing plus reseeding (FR);
- fencing plus manure left on soil surface plus reseeding (FMRs);
- fencing plus manure incorporated into the soil plus reseeding (FMRi); and
- the control with no manuring, fencing or reseeding (C).

Estimates of pasture production were made during the following 15 months.

Application of manure, combined with fencing and reseeding enabled pasture production

to increase from zero to about 4.5 and 3.1 t ha$^{-1}$ in the wet and dry seasons, respectively (Table 9.11; Figure 9.11). The yearly total biomass production reached 7 t ha$^{-1}$. Fencing and reseeding had no lasting positive impact without prior application of manure through night corralling of cattle. Vegetative ground cover was higher in the wet season than in the dry season. Vegetative ground cover and production in the controls were zero in both dry and wet seasons. Numerous efforts have been made in the past to reseed degraded pasture in the Cattle Corridor. The tipping point that led to successful rehabilitation of the rangeland was the application of manure. Ironically, while overgrazing played a key role in degrading the system, manure from livestock was the key that enabled system recovery.

*Figure 9.11* Night corralling of cattle prior to reseeding degraded rangeland (left) enabled the establishment of almost complete ground cover and annual pasture production of about 7 t ha$^{-1}$ within one year in Nakasongola, Uganda.

*Table 9.11* Impact of reseeding, fencing and manuring on rehabilitation of degraded pastures in Nakasongola, Cattle Corridor, Uganda

| *Season* | | *Treatment* | | *Vegetative ground cover (%)* | *Dry matter production* |
|---|---|---|---|---|---|
| | *Fencing* | *Manure* | *Reseeding* | *(t ha$^{-1}$ season$^{-1}$)* | |
| Wet | No | No | No | 0 | 0 |
| | Yes | Yes | Yes | 98 | 4.5 |
| | Yes | Yes | Yes | 77 | 2.7 |
| | Yes | Yes | No | 88 | 3.7 |
| | Yes | No | Yes | 50 | 1.9 |
| | Yes | No | No | 29 | 1.6 |
| Dry | No | No | No | 0 | 0 |
| | Yes | Yes | Yes | 71 | 3.1 |
| | Yes | Yes | Yes | 51 | 2.5 |
| | Yes | Yes | No | 71 | 3.3 |
| | Yes | No | Yes | 28 | 1.7 |
| | Yes | No | No | 14 | 1.2 |

*Notes:* Significant differences are as follows. Vegetative cover: seasons ($p<0.001$), treatments ($p>0.05$) and season treatment interaction ($p<0.001$). Dry matter production: seasons ($p<0.001$) and treatments ($p<0.05$)

*Source:* Mugerwa, 2009

The mechanisms by which manuring led to rangeland recovery in Uganda are complex. Responses may differ elsewhere. Termite damage is most apparent in overgrazed rangelands during dry seasons where loss of vegetation cover greatly reduces infiltration of rainwater and constrains plant growth even though termite activity enhances infiltration (Wood, 1991). This Ugandan experience suggests that termites prefer to consume non-living organic materials, but feed on live seedlings when land has become highly degraded. One hypothesis is that, during the dry season, natural die-back of pasture species' roots provides sustenance to termites averting their need to consume living plant materials. Once rangelands have been restored, the newly established pasture supports termite activity, processes that actually generate ecosystem services.

Agricultural water productivity of the grazing land was essentially zero because rainfall was depleted through evaporation or downstream discharge rather than through transpiration, a key driver of primary production. Within one year, vegetative ground cover increased from zero to almost 100 per cent, implying a huge opportunity to capture and utilize rainwater more effectively in the upper catchments.

## *Catchment and valley tanks management*

Valley tanks are a major source of water for both livestock and people in the Cattle Corridor. Seasonal siltation and fluctuations in the quality and quantity of water greatly affect livestock production and LWP. Prevailing grazing and watering practices led to water depletion through enhanced contamination, run-off, discharge and evaporation, and decreased LWP and ecosystem health. Reseeding pastures aided by manuring affords a great opportunity to increase feed production and reduce sedimentation of the valley tanks and soil movement farther downstream. Providing a year-round drinking water supply mitigates the need for counterproductive and hazardous treks to alternative drinking sites along the Nile River.

The Makerere research team assessed the impact of improving vegetative cover and pasture production on water volume and quality down slope in valley tanks (Zziwa, 2009). Valley tanks with upslope vegetation retained water throughout the year-long study while those down slope from degraded pasture dried out before the end of the dry season (Figure 9.12). Water harvested from unvegetated catchments and open gullies had higher turbidity, faecal coliforms and sediment loads compared with vegetated ones. The unvegetated valley tanks received 248 $m^3$ of silt reducing the storage capacity by 18 per cent during the study whereas the vegetated reservoir received only 7 $m^3$ of sediment. Correcting for the volume of the reservoirs, the ratio of the storage capacity at the start of the study to the volume of sediment accumulated was 5.6 and 266. This implies that vegetated, well-managed catchments might sustain reservoirs for many decades, but sediments from degraded upslopes could completely fill valley tanks within 5 or 10 years. Zziwa (2009) also indicated that vegetated catchments help maintain the quality of water in valley tanks in terms of $NH_4^+$, $NO_2^-$, $NO_3^-$, turbidity and faecal coliform counts. Zziwa (2009) also concluded that the presence of abundant duck weed (*Lemna* spp.) is associated with higher water quality and suggests that livestock keepers could harvest *Lemna* spp. and use it as a high-quality feed supplement (Leng *et al.*, 1995).

## *Opportunities to increase water productivity of livestock*

The Ugandan case study shows that increasing LWP is possible through conservation of water resources that enables regeneration of feed supplies and sustains drinking water supplies. Moreover, effective pasture-reservoir systems mitigate the need for herders to trek to the Nile

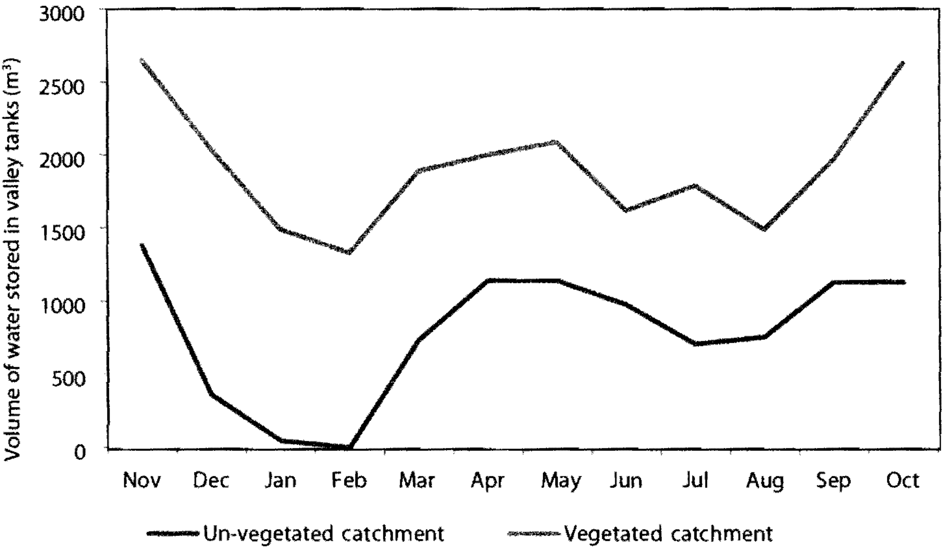


*Figure 9.12* Comparison of impact of vegetated and un-vegetated catchments on water storage in valley tanks (November 2006 to October 2007)

River during the dry season thereby safeguarding animal health and reducing pressure on the river's riparian resources. Overgrazing aggravated by charcoal production has eliminated ground cover flipping the agro-ecosystem into a state of low productivity from which recovery was difficult. Identifying the ecological lever enabling rehabilitation of the system was a major breakthrough enabling the conversion of evaporation and excessive run-off into transpiration and vegetative production. Large-scale adoption of the lessons learned in the Cattle Corridor could make a major contribution to reversal of desertification and improvement of livelihoods in the Nile Basin.

## Conclusions

Livestock water productivity (LWP) is a systems concept. Increasing LWP requires understanding of the structure and function of agro-ecological systems. In most of the Nile's production systems, livestock are raised on already degraded land and water resources. Often, human livelihood systems are vulnerable or broken due to poverty, inequity and lack of access to livelihood assets. Degraded systems have frequently passed tipping points and are trapped in states of low productivity. Thus, increasing LWP is a matter of rehabilitation rather than one of sustainable management of the status quo. For example, the Cattle Corridor case study demonstrated the value of identifying key constraints to system improvement. In this case, providing manure for termites unlocked the potential for agro-ecosystem restoration.

Although controlling termites is not a quick fix for the broad challenges of land and water degradation, this innovation from Uganda serves as an example suggesting that opportunities exist to increase water productivity in ways that promote agriculture, improve livelihoods and contribute to combating desertification.

Because livestock production systems are highly variable in terms of biophysical and socio-economic conditions, intervention options to increase LWP must be tailored to spatially varying local, regional, national and basin-specific scales. Nevertheless, key intervention options for increasing LWP include:

- Producing pasture, crop residues and crop by-products using palatable and nutritious plant species utilizing agronomic practices that foster high crop water productivity (CWP).
- Adopting appropriate state-of-the-art animal science technologies that promote high feed conversion efficiencies, low mortality and morbidity, efficient herd management, marketing opportunities for livestock, and provision of essential farm inputs such as veterinary drugs and credit.
- Managing rain-fed croplands and pasturelands to maximize production, subject to maintaining high levels of transpiration, infiltration, biodiversity and soil health along with low levels of excessive run-off, evaporation and soil water-holding capacity.
- Adopting water demand management planning tools such as water pricing to encourage rational use of water for livestock production and provision of alternatives to livestock hoarding as a means to secure wealth.
- Ensuring coherent policies, institutional and financial arrangements at local, regional and national scales are conducive to increasing LWP and more importantly to ensuring equitable and sustainable food security and livelihoods.

CPWF research suggests that it is not sufficient to focus on single interventions aimed at increasing LWP. In most cases, multiple interventions addressing two or more LWP enhancing strategies are needed. Selecting appropriate feed sources, enhancing animal production and conserving water resources are required simultaneously. In most cases, interventions will require expertise from diverse academic and practical disciplines. For example, water conservation will involve governance, gender analyses, economics, soil science, crop science, animal sciences, engineering and hydrology.

LWP is a characteristic of livestock production systems ranging from local basin scales. Improving LWP at one scale may decrease LWP at another. By reducing water depletion due to downstream discharge or down-slope run-off, upstream areas may increase LWP. However, such action may reduce LWP downstream. At the level of the whole basin, spatial allocation of benefits derived from water may make it possible to increase overall benefits for diverse stakeholders. For example, the historical development of large-scale irrigation systems in Sudan marginalized herders while providing new opportunities for crop production. Nearly a century later, the irrigation systems show capacity to greatly strengthen the livestock sector through animal production within the schemes, provision of crop residues and by-products to nearby herders, and supply of quality feeds for dairy production near Khartoum. Realizing this potential will require greater integration of the water, crop and livestock sectors at national, state and local levels.

Finally, emerging research on livestock in the Nile Basin suggests that activities undertaken to increase LWP are highly compatible with, and perhaps identical to, the two priority development goals of reversing desertification and providing more water for agricultural production. The relatively arid rain-fed livestock-based and mixed crop–livestock systems receive about $10^{12}$ $m^3$ of rainfall. Much of this water never reaches the blue water systems of the Nile because it is depleted by evaporation. Shifting this evaporative loss to transpiration is potentially a major pathway for not only increasing LWP but also driving primary production to enable greater rain-fed crop production and rehabilitation of degraded lands.

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