Water requirements for livestock production: a global perspective

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Summary

Water is a vital but poorly studied component of livestock production. It is estimated that livestock industries consume 8% of the global water supply, with most of that water being used for intensive, feed-based production. This study takes a broad perspective of livestock production as a component of the human food chain, and considers the efficiency of its water use. Global models are in the early stages of development and do not distinguish between developing and developed countries, or the production systems within them. However, preliminary indications are that, when protein production is adjusted for biological value in the human diet, no plant protein is significantly more efficient at using water than protein produced from eggs, and only soybean is more water efficient than milk and goat and chicken meat.

In some regions, especially developing countries, animals are not used solely for food production but also provide draught power, fibre and fertiliser for crops. In addition, animals make use of crop by-products that would otherwise go to waste. The livestock sector is the fastest-growing agricultural sector, which has led to increasing industrialisation and, in some cases, reduced environmental constraints. In emerging economies, increasing involvement in livestock is related to improving rural wealth and increasing consumption of animal protein. Water usage for livestock production should be considered an integral part of agricultural water resource management, taking into account the type of production system (e.g. grain-fed or mixed crop–livestock) and scale (intensive or extensive), the species and breeds of livestock, and the social and cultural aspects of livestock farming in various countries.

Keywords

Livestock production – Protein, biological value – Virtual water – Water – Water efficiency – Water pricing – Water quality – Water usage.

Introduction

Limited availability of water or the presence of contaminants in the supply have a significant impact on animal health and productivity. The water demands of livestock may also compete with those of the human population and water required for crop production. Crops can make direct use of rainfall or stored water through irrigation, whereas animals consume crops or pastures, leading to potential reductions in water efficiencies for food production. This water must be added to the water directly consumed by the animals to maintain life as well as to the water used during product processing. This apparent 'inefficiency' of water use has been highlighted in recent accounting models of global water use (20).

This paper considers the role of livestock production and the efficiency of its water usage in producing protein for human consumption. The issues of water efficiency (20) and the role of livestock in environmental pollution (49) have been used to question the continued role of livestock as a human food source (44). Models of water efficiency are in an early stage of development, compared to those of livestock pollution, but water efficiency issues have the potential to gravely affect livestock production. The current models imply that livestock production is an efficient source of human food. However, unfavourable perceptions could lead to reduced demand by consumers and policy planners, who may believe that the negatives of livestock production far outweigh the positives, in both the developed and developing worlds. If this attitude towards livestock production is allowed to go unchallenged, it will have severe long-term implications for livestock producers and professionals, such as farmers, veterinarians and production specialists. Veterinarians have long played a role in ensuring that livestock have access to clean and adequate water supplies but, to date, have been reluctant to enter the broader debates of water competition between different production systems and efficiency of water use by livestock.

This paper highlights the background to the role of livestock production in the global economy and provides a broad overview of water usage by livestock. The authors propose an alternative way of assessing the efficiency of water use by livestock: through the concept of human, dietary utilisable protein. This approach has not been considered by previously published models.

All the global models are in the early stages of development and do not specifically address the issues of developed and developing countries, or their various production systems. However, the models are starting to highlight the role of global trade in effective water transfer between countries. At this point, they are not appropriate for considering the inherent complexity of livestock usage of water, which varies significantly between regions, due to historical differences, as well as differences in production systems and species. The authors recognise that such considerations must be included in more detailed studies of water use in the future.

Global water resources

Freshwater resources are not evenly distributed. More than 2.3 billion people in 21 countries live in water-stressed basins; 1.7 billion live under conditions of water scarcity; and a billion people do not have sufficient access to clean water. By 2055, 64% of the world's population will be living in water-stressed basins and 33% in areas of absolute water scarcity (49). Much of the predicted growth in

livestock production will take place within these areas of water stress. The impact of the livestock sector on water resources is often not well understood, with a primary focus on usage at the animal level. The livestock sector uses more than 8% of the global water used, with the major portion going to irrigate feed crops for livestock (7% of the global usage). However, the proportion of water used by livestock industries varies greatly between countries and production systems, just as the type and scale of livestock enterprise vary greatly. In many countries, allocating water to various industries is not possible and thus the development of various new modelling approaches is needed to address these deficiencies. Overall, water used for product processing, drinking and servicing livestock is insignificant at global levels (less than 1% of global water), but it may be important in dry areas, in terms of the proportion of water used (e.g. livestock drinking water represents 23% of the total amount of water used in Botswana) (49).

Water requirements for livestock

Background

In livestock, water constitutes approximately 98% of all molecules in the body (37). Water is needed to regulate body temperature, as well as for:

– growth, reproduction and lactation

– digestion, metabolism, excretion and hydrolysis of protein, fat and carbohydrates

– regulation of mineral homoeostasis

– lubricating joints

– cushioning the nervous system

– transporting sound

– eyesight.

Water is an excellent solvent for glucose, amino acids, mineral ions, water-soluble vitamins and metabolic waste transport in the body. Water requirements are influenced by several factors, including:

– rate and composition of weight gain

– pregnancy

– lactation

– activity

– type of diet

– feed intake

– environmental temperature.

Restricting the water intake in livestock reduces feed intake. There is no evidence to suggest that livestock will

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'luxury-consume' water beyond their requirements or that increasing water consumption beyond these requirements will stimulate dry matter intake and/or production (8, 23, 29). Livestock spend between 10 and 15 minutes per day drinking water and it is their single largest intake, with dairy cows consuming up to 171 kg/day (30), compared to the considerably longer time frames and lower quantity required for daily feed intake.

The water content of feed is highly variable and may range from as low as 5% in some dried grains or seeds to about 90% in early-growth pastures and succulent species. This component of water intake creates specific problems for estimating water consumption by grazing animals where there are large seasonal fluctuations in the water content of the consumed feed. Intensively managed livestock are, for the most part, fed dry rations and a number of algorithms have been developed to predict water consumption within these intensive animal industries (37). Thus, the water intake from feeds plus the free water consumed is approximately equivalent to the livestock's overall requirement for water. Total water intake can be predicted from knowledge of free water intake, body weight, dry matter intake and dry matter content, with free water also being determined from dry matter intake, dry matter content, crude protein content and time of year (21).

Catabolism of fat, carbohydrate and protein produces 1,190 g, 560 g and 450 g of water/kg, respectively, and these metabolic waters are important sources for all animals. In the case of some desert species, such as the kangaroo rat, metabolic water helps to meet the total water requirements without the need for free, external drinking water (34). The role of metabolic water in grazing animals under harsh seasonal conditions has not been thoroughly evaluated and is often intertwined with changes in feeding behaviour, to meet water requirements without requiring free water consumption (33). This internal water source may play a role in extending the foraging range of livestock and thus reducing water requirements and the frequency of returns to watering points in adapted breeds.

Animals lose water principally through:
– milk, when lactating
– urine
– faeces
– evaporation from the body surface
– the respiratory tract.

Under severe stress, cattle and other species may also lose significant amounts of water through drooling.

The relative importance of these routes of water loss differs significantly between species. In ruminant livestock, the loss of water through faeces is similar to the water lost through urinary output (38). Although urine is predominantly water, current estimations of urinary output in cattle are based on dry matter intake, crude protein intake and live weight (16) and, in the case of dairy cattle: dry matter intake, sodium and potassium in the diet, and milk production (3). Faecal water content in lactating cows can be estimated, using dry matter intake, dry matter content and milk production (21). The high-fibre diets of ruminants require more water in the faeces to carry the ingesta through the gastro-intestinal tract than in non-ruminants. However, fibre is not the sole difference, as cattle faeces contain 75% to 85% moisture, compared to sheep and goat faeces, which have 60% to 65% water. The ability of sheep and goats to re-absorb water in the lower gut and excrete drier faecal pellets, instead of wet, loose faeces, may account for some of the differences in water intake between ruminant species. Water losses from the respiratory tract and by cutaneous evaporation are also highly variable between species. Cutaneous evaporation is important in cattle and sheep, whereas pigs and poultry are more dependent on respiratory water loss for cooling at high temperatures (34).

Direct consumption

It is necessary to recognise that there is no single water requirement for a species or an individual. The amount of water consumed depends on a number of factors, such as body weight, physiological state (stage of pregnancy, lactation, etc.), diet, temperature, frequency of water provision, type of housing, environmental stress, etc. The state of knowledge of the determinants of water intake varies greatly from species to species but, in all cases, the predictions developed should be used as an approximate guide to the amount of water consumption, not an absolute predictor of water intake.

Ruminants

The National Research Council (NRC) in the United States publishes nutritional standards for livestock which contain tables for the estimated daily free water intakes of livestock by age and physiological state. As water requirements are affected by a large number of factors, these standard tables emphasise that water consumption cannot be predicted accurately, despite the development of equations to estimate water consumption for a range of livestock classes in intensive livestock systems. These water-intake calculations are only for the free water that livestock require on a daily basis, to ensure their day-to-day survival. The daily drinking water requirements for a range of beef cattle categories have been calculated by the NRC (37), based on live weight and temperature. However, this information should be treated with caution, since the calculations are derived from a limited data set and water intake has been shown to be difficult to predict across a wide range of circumstances. The most commonly used

prediction equations that are broadly applicable were developed in the 1950s, with subsequent predictions of water intakes being limited to specific circumstances or cattle type.

The commonly used equations to predict water intake were developed by Winchester and Morris (52), and are based on animal type, dry matter intake (DMI) and temperature (T), with e, as a base of the natural logarithm, as follows:

water intake (*Bos taurus*, litres/day) = DMI × (3.413 + 0.01595 ($e^{0.17596T}$)

water intake (*Bos indicus*, litres/day) = DMI × (3.076 + 0.008461($e^{0.17596T}$)

Water consumption is influenced by a number of other factors, apart from those used by Winchester and Morris (52). Hicks *et al.* (19) were able to predict water intake using the following equation, which includes rainfall and dietary salt content:

water intake (litres/day) = −6.10 + (0.708 × maximum temperature [°C])

 + (2.44 × DMI) − (0.387 × rainfall [mm/day])

 − (4.44 × dietary salt [%])

Meyer *et al.* (31) developed the following prediction equation for water intake in growing bulls:

water intake (kg/day) = −3.85 + 0.507 × average ambient temperature (°C) + 1.494 × DMI (kg/day) − 0.141 × roughage part of diet (%) + 0.248 × dry matter content of roughage (%) + 0.014 × body weight (kg)

The water intake in dairy cows is higher, due to the water requirements for lactation. A number of equations have been developed to predict the intake of drinking water by lactating dairy cows and these are based on a range of variables that have been shown to affect water intake. Four of the equations for predicting drinking water intake (kg/day) in lactating dairy cows are listed below, where:

MY = milk yield

DM% = dietary dry matter percentage

JD = Julian Day (1 January = JD 1; ….; 31 December = JD 365)

AT = average ambient temperature

BW = body weight

Na = sodium intake.

The four equations are as follows:

i) the Castle and Thomas equation (10):
 = 2.53 × (MY, kg/d) + 0.45 × (DM%) − 15.3

ii) the Murphy *et al.* equation (32):
 = 0.90 × (MY, kg/d) + 1.58 × (DMI, kg/d) + 0.05 × (Na, g/d) + 1.20 × (average minimum daily temperature, °C) + 15.99

iii) the Holter and Urban equation (21):
 = 0.6007 × (MY, kg/d) + 2.47 × (DMI, kg/d) + 0.6205 × (DM%) + 0.0911 × (JD) − 0.000257 × (JD)^2 − 32.39

iv) the Meyer *et al.* equation (30):
 = −26.12 + 1.516 × (AT, °C) + 1.299 × (MY, kg/day) + 0.058 × (BW, kg) + 0.406 × (Na, g/day)

The impact of the water content in grazed pastures is highlighted by Stockdale and King (50). Lactating dairy cows grazing pasture only consumed 38% of their total water intake by drinking. The rest of their water requirements were met from the pasture, where:

water intake (litres/day) = −9.37 + 2.30 × (DMI, kg/day) + 0.053 × (DM% of diet).

The water intake prediction for these grazing, lactating cattle did not include a factor for milk yield, unlike the prediction models above for water intake in lactating cattle fed on dry rations.

Forbes (15) established a relationship between dry matter intake (DMI), average weekly temperature (T) and water intake in sheep:

water intake (litres/day) = (DMI, kg/day) × (0.18 × T + 1.15)

Water intake changes with physiological state. Water intake increases in the third month of gestation, is doubled by the fifth month, and is greater for ewes bearing twins. It is estimated that lactating ewes require 100% more water than non-lactating ewes. Sheep may consume 12 times more water in summer than in winter, subsisting on once-a-day watering when temperatures are below 40°C. This water adaptability is further highlighted by Brown and Lynch (7), who reported the survival of grazing, lactating ewes, which did not have access to drinking water, for a period of 22 months in a temperate environment. The ewes adapted to the lack of drinking water by reducing faecal and urinary water losses, reducing their feed intake and behavioural changes.

There are significant variations in water intake between livestock species and breeds. Zebu cattle may have a lower water intake than European breeds (4, 6, 12, 38, 39, 52). However, when data from a number of these experiments are adjusted to a constant body size and dry matter intake, these differences become negligible. However, Beatty *et al.* (4) found that there were different rates of change in water intake with core body temperature in *Bos indicus* and *Bos*

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taurus, suggesting intrinsic differences in water demand from these cattle types. Peden *et al.* (38), citing others, suggests that such differences may be related to the lower water content of *B. indicus* faeces. In cattle, one-third to one-half of daily water loss occurs in the faeces and small changes in faecal moisture content can have a significant impact on water demand. MacFarlane *et al.* (26) found similar differences between sheep breeds, in that the water turnover of merino sheep was 9.4 litres/day, when grazing on saltbush, whereas in Leicester sheep, it was 13.7 litres/day. McGregor (27) also found that, on average, merino sheep consumed significantly less water than angora goats while grazing the same pasture.

In all, sheep may need up to 40% less water per kg of dry matter than cattle. In the temperature range between −17°C and 27°C, the estimated requirement for cattle was 3.5 litres to 5.5 litres water/kg DM. At about the same temperature range, sheep needed only 2.0 litres to 3.0 litres water/kg DM (33).

Monogastrics

Although water is an important nutrient, there has been surprisingly little research conducted on the water requirements of pigs (36). Care must also be taken to distinguish between water requirements and water consumption in pigs, as most watering systems for pigs can let significant amounts of water go to waste, due to behavioural patterns at water points. This water loss is not a biological requirement for production but a behaviour response to confinement that can be overcome by good housing design. If it is not taken into account, it can lead to significant overestimations of water consumption in pigs. Pigs provided with nipple drinkers can waste between 15% and 42% of the water provided, depending on pig size, nipple height and water-flow rates (25). To avoid these problems, the best estimates of pig water requirements are obtained by measuring water turnover rates, using labelled water. Yang *et al.* (53) determined the water requirements of pigs under confined and dry feeding conditions as being approximately 120 ml/kg for growing pigs (30 kg to 40 kg) and 80 ml/kg of body weight for non-lactating adult pigs (157 kg).

Shaw *et al.* (47) found that excessive protein in the diet tended to increase average water intake but lowering the protein content did not reduce the intake. The daily water intake was significantly correlated with the daily intake of sodium and potassium. However, on the whole, dietary strategies have a limited impact on water consumption in pigs.

The NRC (36) has summarised water requirements for pigs. Suckling pigs drink water within one to two days of being born. In the first four days of life, pigs consume between 0 and 200 ml/day with an average daily consumption of 46 ml per pig. If the temperature is raised from 20°C to 28°C, water intake increases almost four-fold in this class of pig.

In weaner pigs, from three to six weeks of age, water consumption is related to daily feed intake (DFI) where:

water intake (litres/day) = $0.149 + (3.053 \times [DFI, kg])$

Pigs of between 20 kg and 90 kg body weight, with an unrestricted allowance of dry feed up to 3 kg/pig daily and free access to water, consumed, on average, a water-to-feed ratio of 2.56:1 from 10 to 22 weeks of age. From 16 to 18 weeks of age, the maximum average daily intakes of water and feed were 7.0 kg/pig and 2.7 kg/pig, respectively.

Non-pregnant gilts consumed 11.5 litres of water daily, whereas gilts in advanced pregnancy consumed 20 litres. In lactating sows, the daily water consumption has been shown to vary from 12 litres to 40 litres/day, with a mean intake of 18 litres/day. Boars of 70 kg to 110 kg can consume up to 15 litres of water/day at 25°C compared with about 10 litres of water/day at 15°C.

Little published research is available on the water intake for poultry. The NRC (35) summarised what little there is, and the water intakes for chickens and hens are shown in Table I. Water intake is influenced by water-to-feed ratios, feed form and crude protein content and temperature, and these must be taken into account when considering the water consumption data in Table I.

Table I

Water consumption by poultry at different ages under moderate ambient temperatures

Adapted from the National Research Council (34)

Age (weeks)	Broiler chicken (ml/bird/week)	White leghorn hens (ml/bird/week)	Brown egg-laying hens (ml/bird/week)
1	225	200	200
2	480	300	400
3	725		
4	1,000	500	700
5	1,250		
6	1,500	700	800
7	1,750		
8	2,000	800	900
10		900	1,000
12		1,000	1,100
14		1,100	1,100
16		1,200	1,200
18		1,300	1,300
20		1,600	1,500

Water quality

Livestock need water of similar quality to that required by humans. However, like water intake requirements for livestock, water quality requirements are poorly researched and usually defined by acceptability and their effects on livestock performance. Water quality is defined by the presence or absence of certain substances, by taste, smell, turbidity and electrical conductivity.

Tables have been drawn up as guidelines to assess water quality for livestock. These tables are available for most categories of livestock but, in many cases, have been strongly influenced by the United States Environmental Protection Agency (EPA) recommendations for humans (51). Publications differ significantly on the guidelines for upper concentrations for livestock (Table II), due, in part, to the limited amount of information available on the impact of substances in water on animal performance.

Information is also limited on the interactions between contaminants in the water supply and the effects, at various concentrations, of these contaminants on animal performance. Socha *et al.* (48) summarised the upper levels and maximum upper levels for livestock, while the EPA enforceable or secondary standards (whichever are higher) for human drinking are also illustrated in Table II. Kamphaes *et al.* (22) reviewed various water standards, since published sources recommend differing and contradictory water quality standards for some species, while other species have varying tolerances to different water contaminants. The recommended maximum contaminants for irrigation waters are also shown. Although the maximum allowable amounts for these contaminants are higher than those permitted for drinking water, they are not significantly higher and, in most cases, these amounts are used for livestock drinking water, as well as providing water for forage production.

Table II
Water quality guidelines for upper and maximum upper levels for livestock, along with the United States Environmental Protection Agency standards for human drinking water and irrigation water

Elements	EPA standards[a]	Upper level[b]	Maximum upper level[b]	Irrigation standards[c]
Aluminium (ppm)	0.2	5.0	10.0	20.0
Arsenic (ppm)	0.01	0.2	0.2	2.0
Barium (ppm)	2.0	1.0	1.0	2.0
Bicarbonate (ppm)		1,000	1,000	
Boron (ppm)		5.0	30.0	
Cadmium (ppm)	0.005	0.005	0.05	0.05
Calcium (ppm)		100	300	
Chlorine (ppm)	250	100	300	
Chromium (ppm)	0.1	0.1	1.0	1.0
Copper (ppm)	1.3	0.2	0.5	5.0
Fluoride (ppm)	4	2.0	2.0	15.0
Iron (ppm)	0.3	0.2	0.4	20.0
Lead (ppm)	0.015	0.05	0.1	10.0
Magnesium (ppm)		50	100	
Manganese (ppm)	0.05	0.05	0.5	10.0
Mercury (ppm)	0.002	0.01	0.01	
Molybdenum (ppm)		0.03	0.06	0.05
Nickel (ppm)		0.25	1.0	2.0
Nitrate nitrogen (ppm)	10.0	20	100	
pH	6.5 to 8.5	6.0 to 8.5	8.5	
Phosphorus (ppm)		0.7	0.7	
Potassium (ppm)		20	20	
Selenium (ppm)	0.05	0.05	0.1	0.02
Silver (ppm)	0.1	0.05	0.05	
Sodium (ppm)		50	300	
Sulphates (ppm)	250	50	300	
Total bacteria (nos/100 ml)		1,000	1,000	
Total dissolved solids (ppm)	500	960	5,000	
Vanadium (ppm)	0.01	0.1	0.1	

(a) Adapted from the United States Environmental Protection Agency (51)
(b) Adapted from Shaw *et al.* (47)
(c) Adapted from Renault & Wallender (44)

EPA: Environmental Protection Agency
ppm: parts per million
nos: numbers

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When the upper contaminant limits are exceeded, there is an impact on livestock production but the effects of this on animal performance are debatable. Until further research is carried out, the exact cause of the impact on livestock production is open to speculation. In some cases, excessive levels may have no direct production effects but reduce water palatability. Water consumption is thus lowered, reducing performance but not leading to animal toxicity problems from the contaminants. In other cases, excessive concentrations can lead to toxicity problems, particularly in the case of trace elements and bacteria, resulting in reduced performance and, in cases of prolonged exposure, death. In extreme cases, there can also be large variations in the availability of minerals supplied in the diet and through drinking water that need to be accounted for to calculate the total intake of minerals. For example, copper supplied in drinking water, administered in gelatine capsules, incorporated during plant growth or sprayed onto feed has been shown to have different availabilities in cattle (11, 46). There are also strong interactions between a number of minerals consumed by livestock which, without a balanced intake, can lead to symptoms of excess or deficiency, depending on the circumstances. The links between water, livestock and human health are poorly researched, except in the case of disease transmission, which is beyond the scope of this paper. The element limits placed on water for livestock consumption are intended to maintain livestock health and production and, where these limits are exceeded, appropriate testing and remedial action should be undertaken. One of the first steps is to determine whether the water supply is the actual cause of the problem, since, in the majority of cases, water is usually not the main source of problems in livestock health.

Virtual and developed water content

A number of water accounting systems are used to determine water usage by industries. The 'virtual water' concept has recently gained wide acceptance. This accounts for water available per unit of area regardless of source, compared to more restricted systems, such as 'developed water'. Developed water is a narrower concept and refers to waters that are accessed by engineering works and which can be used either by livestock or humans. In other words, developed water is water that is brought into use by human efforts and does not include rainwater. Virtual water is a broad-scale, global water-use concept, developed to place all industries and countries on an equal basis when describing their use of water as part of global trading and environmental accounting systems. Virtual water content has been devised as a tool to estimate the amount of water used to produce different products and services, and to help plan the best use of scarce water supplies.

Virtual water content is the difference between the total water volume used from domestic water resources in the national economy and the volume of virtual water exported to other countries in domestically produced products. The virtual water content of primary crops is calculated on the basis of crop water requirements and yield. The virtual water content of live animals is calculated on the virtual water content of their feed and the volumes of drinking and service waters consumed during their lifetime. The final water content in the finished product is significantly less than the water used to produce the product, hence the concept of virtual water content (20). This concept is used to describe the total use of water by livestock industries, compared to other agricultural industries. The resultant virtual water content for a range of agricultural products is shown in Table III.

Table III

Average virtual water content of selected agricultural products in developed country production systems
Adapted from Hoekstra and Chapagain (20)

Product	World average virtual water content (l/kg)
Paddy rice	2,291
Wheat	1,334
Soybean	1,789
Sorghum	2,853
Cotton lint	8,242
Coffee (roasted)	20,682
Beef	15,497
Pork	4,856
Goat meat	4,043
Sheep meat	6,143
Chicken meat	3,918
Eggs	3,340
Milk	990

The virtual water content of listed agricultural products varies widely from country to country. This is not shown below but has been calculated by Hoekstra and Chapagain (20). These differences are due to differences in stocking rates and degrees of intensification used by the livestock industries in the countries concerned. Countries with large export industries of animal products are net exporters of virtual water. Of the water used by cattle in their lifetime, approximately 1% of the 15,497 litres/kg of product produced is directly consumed as drinking water.

Virtual water content does not consider whether the rainfall is directly harvestable for human consumption or not. It is a system to account for water usage in industries on an equitable basis. The virtual water model indicates that animal production may use approximately 45% of the global water budget for food production. However, a large proportion of this water usage is not environmentally or

directly significant to humans, as evapo-transportation (ET) by grazed grasslands and non-cultivated fodder land used for grazing represents a large share of this virtual water content. This ET water generally has little-to-no opportunity cost for humans and, indeed, the amount of water lost in the absence of grazing might not be any lower than under grazing situations.

Renault and Wallender (44) calculated total water productivity, as well as water requirements, on the basis of the energy and protein produced for a range of Californian agricultural products. In the human food chain, livestock production is predominantly for protein production (especially in developed countries). Thus, water usage calculated on protein production is a more equitable evaluation of livestock water productivity in food production. The water productivity for a range of products (the amount of water used per unit of energy or protein produced) is shown in Table IV.

The two publications that calculate water use provide similar virtual water contents for whole products. However, water efficiency for protein production narrowed the differences between some plant and livestock products. These crude protein contents need to be considered for their value in the human diet, since various sources of proteins vary greatly in their concentrations of amino acids. Thus, the protein source has a significant impact on the nutritional value of the proteins supplied and their contribution to human growth and development. A number of systems have been developed to calculate the nutritional value of protein types in human nutrition.

Table IV
Virtual water content in terms of mass, protein and energy for various staple food products produced using intensive systems in California
Adapted from Renault and Wallender (44)

Product	Virtual water content		
	l/kg product	l/kcal energy	l/kg protein content
Wheat	1,159	0.44	13,514
Rice	1,408	0.50	20,408
Maize	710	0.30	12,987
Potatoes	105	0.18	6,667
Groundnuts	2,547	0.42	9,090
Beans	2,860	1,188	13,158
Tomatoes	130	0.71	15,385
Onions	147	0.44	11,765
Beef	13,500	9.80	100,000
Pork	4,600	2.45	47,619
Poultry meat	4,100	3.03	30,303
Eggs	2,700	1.79	24,390
Milk	790	1.52	25,000

The biological value of proteins is one method for determining the nutritional value of proteins for humans. These calculations provide a way of converting protein production to 'usable protein outcome for humans' for comparative purposes. The effect of weighting the biological value of proteins in relation to water efficiency, for a number of countries, is shown in Table V. The virtual water content for each product in Table V was extracted from Hoeskstra and Chapagain (20), where water usage per kg of biological value protein was calculated using protein biological values reported by the Food and Agriculture Organization of the United Nations (FAO) (14) and the protein contents used by Renault and Wallender (44).

On the whole there are no significant differences between countries in their efficiency of water use for protein production (adjusted for biological value), which averages 50,908 litres/kg biological valued protein. However, the water efficiencies of the countries that principally use intensive livestock production systems ranged from 34,497 litres/kg in the United States to 88,484 litres/kg biological valued protein in Mexico. Water efficiency for protein production ranged from 8,952 litres for soybeans to 175,631 litres for beef protein. Beef was significantly less water efficient than the other protein sources evaluated in Table V and, over all, animal products required more water than plant-based proteins. Producing one kg of animal protein requires more water than one kg of plant protein (67,637 litres/kg as against 25,593 litres/kg of biological valued proteins, respectively). There were no plant protein sources considered in Table V that were significantly more water efficient than egg protein, and only soybeans were a more water-efficient source of protein than milk, goat meat or chicken meat (when protein production was compared on the basis of biological value). Sheep and pork protein, although more water efficient than beef, used significantly more virtual water than plant protein sources to produce a kg of protein, adjusted for biological value.

These water efficiencies for protein production must be considered within the context of a much wider range of countries, livestock systems and environments than those that have been evaluated in Table V. In poverty-prone regions of the world, ruminants are grazed or fed mostly on crop residues, requiring much less water than those in the developed world, where grain or irrigated forages are commonly used as cattle feed. Of the livestock industries examined, beef production has the highest demand for water, regardless of whether water productivity is calculated by the methodologies of Renault and Wallender (44), Hoekstra and Chapagain (20) or protein biological value. This is, in part, probably due to the common use of irrigated fodder in intensive systems, longer turnover times in beef production, and the use of higher rainfall grazing areas for beef production instead of small ruminants. The longer turnover times are a function of a longer gestation

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period, lower reproductive rates and longer growing time to market than other livestock species. However, humans require only 75 g of protein per day, with consumed protein above this amount being converted into energy. Thus, the water used to meet this first 75 g of dietary protein can be obtained efficiently from animal products, as long as no excessive protein is consumed to be converted to energy. A modest amount of animal protein in the diet of African children appears to improve mental, physical and behavioural developments (43). These benefits have not been included in calculations of water productivity for livestock production.

In an earlier attempt to estimate developed water use, a static model was constructed to determine water usage by the cattle industry in the United States (5). Water usage included not only water consumed directly by various classes of cattle but also water used to irrigate crops consumed by cattle, water applied to irrigated pastures, and water used to process animals for marketing. This model estimated that 3,682 litres of developed water was used per kg of boneless beef meat produced in the United States, with irrigation as a major contributor to water usage in beef production. This study showed that more intensive irrigation practices or decreased use of water for irrigation would be the most practical approaches to reduce water requirements for beef production. Sensitivity analysis in the model suggested that errors in the model's parameters would not result in large changes in water requirements. A 10% improved dressing percentage or percentage yield in boneless carcasses saved 316 litres/kg of beef. Similarly, a 10% increase in the number of animals being lot fed saved 193 litres/kg of beef and a 10% reduction in irrigation

water saved 163 litres/kg of beef. The direct daily consumption of water by cattle accounted for 3.0% of the total water usage in the beef industry, while production with irrigation accounted for 96.7% and meat processing accounted for 0.3%.

The countrywide livestock-water-usage model developed by Beckett and Oltjen (5) relies on standard feeding tables with average water intakes for different classes of animals. The model makes no allowance for differences in feed quality, feed intake, climate effects or breed differences and there is only limited consideration of physiological status. This model provides an overview of water usage and highlights the significance of water in the production of feed but has limited potential to further identify opportunities to improve water efficiency at an individual enterprise level. The virtual water model concept has further limitations as it is a macro-global accounting system but it does highlight the issues of water demand in animal feed production. To be useful for individual businesses, the appropriate algorithms for water use must be developed and incorporated into existing enterprise models.

These models all deal with the role of livestock in the production of, principally, meat and milk but do not take into account the other uses of livestock in many countries. A significant proportion of the world crop production is dependent on animal draught power, without which crop productivity would decline significantly. Livestock also provide fertiliser and fuel, and make use of fibrous plants and crop by-products that are effectively not considered by the current water accounting models.

Table V

Litres of water used to produce 1 kg of protein (adjusted for biological value) from 11 countries, and the average quantity of water required to produce those products along with the least significant difference values (p = 0.05)

Adapted from Hoekstra and Chapagain (20)

Product	Virtual water content of products (l/kg biologically available protein)												
	USA	China	India	Russia	Indonesia	Australia	Brazil	Japan	Mexico	Italy	Netherlands	Average	LSD
Soybean	6,756	9,460	14,907	14,217	7,338	7,613	3,890	8,408	11,484	5,440		8,952	25,173
Wheat	15,258	12,401	29,726	42,684		28,540	29,043	13,191	19,158	43,510	11,125	24,464	25,173
Maize	14,968	24,514	59,290	42,761	39,333	22,773	36,119	45,699	53,382	16,223	12,489	33,414	24,002
Rice	25,417	26,334	56,815	47,864	42,860	20,375	61,440	24,341	43,498	33,471		38,241	25,173
Sorghum	10,577	11,673	54,821	32,219		14,622	21,763		16,393	7,872		21,242	28,144
Eggs (whole)	14,650	34,443	73,067	47,725	52,392	17,891	32,376	18,279	41,496	13,476	13,622	32,674	24,002
Milk	25,703	36,982	50,629	49,741	42,271	33,839	37,019	30,030	88,092	31,842	23,706	40,896	24,002
Chicken meat	23,817	36,409	77,125	57,455	55,321	29,051	39,011	29,679	49,978	21,913	22,152	40,174	24,002
Goat meat	30,726	39,819	51,712	52,739	45,292	38,273	41,623	25,522	102,208	41,673	27,825	45,219	24,002
Sheep meat	59,588	51,862	66,717	75,978	59,379	69,259	62,479	35,601	168,267	75,490	52,819	70,676	24,002
Pork	54,974	30,802	61,257	96,782	54,862	82,321	67,122	69,128	91,376	88,841	52,800	68,206	24,002
Beef	131,529	125,218	164,319	209,641	147,729	170,600	169,094	109,855	376,472	211,026	114,455	175,631	24,002

LSD: least significant difference
USA: United States of America

The rainfall component in the virtual water model uses average precipitation rates but rainfall is highly variable between years. This variation has been shown significantly to affect livestock populations in the long term. In a southern Ethiopian study, Angassa and Oba (2) concluded that droughts triggered a significant long-term decline in the cattle populations of both communally and range-managed systems. Rainfall variability has significant effects on breeding females and immature animals that account for much of its impact on long-term population trends. Angassa and Oba recommended that these cattle losses and their economic consequences could be minimised by effective drought-management strategies. The ranch management system run by the government has lower overall calving rates and a similar inability to buffer its livestock against droughts as the communally managed system. Similar responses to drought among livestock populations have been reported from other arid regions of the world.

Water economics

Intensive animal industries

To deliver improvements in water efficiency in livestock industries, Steinfeld *et al.* (49) emphasised the pricing of water, mainly to rationalise water usage for irrigation in feed production. A secondary effect of price rises would be to reduce water pollution problems associated with animal production. Water pollution by livestock is well documented and procedures to reduce such problems have been ongoing. The implications of changes in water costs for animal production are not well understood. Higher prices for fresh water or for all water use, as with the virtual water concept, may have significant economic repercussions. In a majority of cases, the direct use of fresh water by livestock does not create a high level of output per unit of water, as most of the water is used to keep the animals alive rather than for production. The exception occurs in some developed countries in which irrigation water is used to grow forage crops in intensive animal production systems.

The impact of water pricing on the economic viability of animal industries has not been extensively studied. Pluske, among others (40, 41, 42), investigated the effect of water prices on intensive pig, cattle and sheep industries, as part of a programme to use water recovered from beneath rural towns affected by rising saline water tables. These economic models were developed to investigate the potential of such intense animal industries to pay for the extracted water, on the basis of full cost recovery for the water used. However, the models only account for the water used directly by these industries, and make no attempt to include water usage outside the operation, since all feed stocks were assumed to have been sourced externally. These models did include costs for handling and disposing of waste materials and thus take the costs of pollution into account through the requirement to clean the water before releasing it from the site. Based on costs and operations in rural Western Australia, intensive piggery operations and beef feedlots were the most sensitive to water pricing, followed by sheep feedlots. Water costs at AUS$1.20/kL in intensive piggeries accounted for approximately 5.4% of total operating costs. A price rise to AUS$2.08 resulted in the piggery being just viable (internal rate of return of 5%). However, production and environmental factors also affected the economic viability of the operation, with water consumption varying by 400% for sucker pigs when temperatures increased from 20°C to 28°C.

For beef feedlots, a change of price to AUS$1.90/kL and/or a slight change in the water used on the lot, due to temperature changes from the greenhouse effect, could see the net benefits from the industry fall to zero. On beef feedlots, water represented 2.26% of operating costs, whereas on sheep feedlots, it reached 2.5% of operating costs. On sheep feedlots, water prices had to increase to AUS$6.70/kL before the net present value declined to zero. The area specified in the model is predicted to undergo increased temperatures of approximately 2°C and reduced rainfall by 20%, using current greenhouse change models. This would lead to a 17.2% increase in water use on cattle feedlots, and a 4.6% increase on sheep feedlots. The larger increases on beef feedlots are due to the higher water requirements of cattle for consumption, cooling and dust control. These models are the first attempts to include water consumption and price in conventional animal production models but these models need considerable development of the algorithms predicting water consumption in all aspects of the feedlot operation.

Irrigated pasture and/or feed production systems for livestock production are an even more intensive form of animal production. These systems are the largest users of water in the livestock industries, and offer considerable opportunities to improve the efficiency of water use. Economic modelling of irrigated pasture systems is well developed but has not, until now, highlighted animal product returns per unit of water. Comparison with other agricultural pursuits for irrigation water suggests that livestock production under irrigation can be as profitable as crop and/or horticultural production. In the dairy sector of Kenya, it has been found that irrigating fodder for dairying improves farmers' net incomes and compares favourably with vegetable production. These returns did not consider the income generated from the manure produced by the dairy industry, nor the income generated from goats and chickens, which consume the by-products of the dairy operation (28). In developed countries, irrigation for livestock production is also profitable in maintaining higher rates of animal production through periods of low rainfall or to overcome limitations in the water-holding capacity of

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some soil types. To maximise returns in these systems, the successful integration of plant and animal management is required (13). There has been little attention paid to water productivity in these systems. Since irrigators are the largest users of water, the livestock sector offers extensive opportunities for improvements in water productivity. The literature indicates that the amount of evapo-transpired water used to produce dry animal feed is highly variable, ranging from about one to eight litres. Many factors affect the amount of water depleted through evapo-transpiration (38), including:

– the vegetative leaf area index

– animal preferences for specific fodder plants

– root depth

– rainfall

– plant genetics

– soil structure, moisture and chemistry.

Grazing industries

When it comes to either mixed farming or pastoral systems, there are no reliable algorithms to accurately predict water consumption for grazing animals, except in the case of dairy cattle. There is a complex interaction between temperature, pasture growth phase, animal intake and physiological state that has not been documented sufficiently, under a wide enough range of circumstances, to successfully develop the algorithms to confidently predict water intake. The measurements required are not difficult and predictions of water usage could then be included in existing grazing models to predict animal performance and profitability. Until this framework is developed, the best ways to improve efficient water use for grazing livestock will remain undetermined (45). Direct water use in these situations is for drinking purposes only and constitutes a small component of world water usage, compared to the virtual water content in grazing systems. However, water pricing, even for drinking purposes only, may have a significant impact on the profitability of grazing enterprises, as seen in the preliminary modelling for intensive animal industries.

Mixed farming systems are the largest category of livestock production in both the developed and developing world. Mixed farming systems are those in which more than 10% of the dry-matter feed for animals comes from crop by-products or more than 10% of the total value of production comes from non-livestock farming activities. In a closed system, mixed farming is a benign form of agricultural production, with crop residue wastes being used by livestock and livestock waste being returned to the crops as fertiliser. Maximising the water efficiency of the mixed farming system will improve the water productivity of both livestock and cropping systems (38). This integrated

system will need a multi-disciplinary approach to deal with the interactions between the plant and livestock systems and determine their interdependence, if the result is to be a productive system with a range of product outcomes. Livestock provide not only meat and milk, but also draught power for cropping and transport, fertiliser from their manure and financial security for harsh times.

The water efficiency of grazing cattle can be improved by better use of rain-fed pastures. There is a long tradition of countries developing water points to enable the better utilisation of under-used grazing lands and to allow the movement of livestock across a country by the strategic placement of watering points. In the case of ruminants, better placing of watering points encourages livestock to graze the available pasture more uniformly as they prefer to graze close to their drinking water supplies. In Missouri, cattle production on 65 ha of pasture was experimentally sustained and production was maximised by ensuring that the distance to the nearest drinking water was less than 244 m (18). Gerrish and Davis (17) found that 77% of cattle grazing took place within 366 m of the water source but that 65% of the available pasture in the paddock was more than 730 m from the watering point. The costs associated with including extra water points have not yet been considered but are being investigated in the extensive grazing lands of northern Australia (33, 34). Improving access to water will have a significant impact on the virtual water content of pasture-grazed livestock, if pasture use can be economically increased from 10% to 20% in these extensive grazing lands (38).

Role of livestock in the community

Placing such investigations of livestock and water in perspective also demands consideration of the broader roles of animals in relation to human well-being. People and livestock have a long historical association but, until the early 1980s, diets containing daily consumption of milk and meat were largely confined to citizens of countries of the Organisation for Economic Co-operation and Development, and a small wealthy class elsewhere. This has changed rapidly, with the livestock sector currently growing faster than other forms of agriculture in almost all countries. Much of this change, especially in emerging economies, is accompanied by industrialisation of animal production to escape most of the environmental constraints that have shaped animal production over the millennia (49). However, the major proportion of milk, meat and cereals in developing countries still comes from mixed crop–livestock systems.

Between 1980 and 2002, meat consumption doubled from 14 kg to 28 kg per capita in developing countries, with

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considerable variation in and among these countries. In the same period, meat supply from developing countries has tripled, from 47 million tonnes to 137 million tonnes. This growth is led by east Asia – mainly the People's Republic of China (China). Over this 22-year period, China alone accounted for 57% of the increase in total meat production in developing countries. Over the same period, milk production expanded by 118%, with 23% of that increase coming from India. However, during this period, wool production declined by 19.6%, with China being the only significant wool producer to show an increase in production (49).

In some developing countries, livestock production has shifted towards monogastrics, with pigs and poultry accounting for 77% of the expansion in production. Total meat production in developing countries more than tripled between 1980 and 2004. The growth in ruminant production was only 111%, with that of monogastric production expanding by more than four-fold over the same period. It is important to note that these figures mask considerable diversity within and among countries. However, in developed countries, total livestock production increased by only 22% between 1980 and 2004. In these countries, there was a differential growth between livestock sectors, with ruminant production declining by 7% and pig and poultry production increasing by 42% (49).

The overall increase in demand for livestock products is expected to continue for another ten to 20 years. If past trends continue, most of this demand will be met through an expansion of livestock industries within countries and not through imports. A report by Steinfeld *et al.* (49) found that, in developing countries, net imports accounted for only about 0.5% of total meat supplies, and 14.5% of milk supplies. However, the trade in livestock products has been increasing much faster than the trade in feed supplies. For feed grains, the traded share of total production has remained stable, in the range of 20% to 25%, over the past decade. The share of traded meat increased from 6% in 1980 to 10% in 2002, and the share of milk rose from 9% to 12% over the same period.

As an economic activity, the livestock industry sector generates about 1.4% of the world's gross domestic product (GDP) and the growth rate for this sector was about 2.2% over the ten-year period between 1995 and 2005. However, this growth rate is faster than that of agriculture in general, which is declining, in relative terms, as part of the overall GDP. On average, globally, livestock industries make up 40% of the agricultural GDP, typically rising to 50% to 60% in most industrial countries. The contribution of livestock production is much more important than its modest contribution to the overall economy would suggest.

At a local level, livestock production is a key element in the fight against poverty as approximately one quarter of the global poor (2.8 billion, living on less than US$2 per day) are livestock keepers. Livestock rearing does not require formal education or large amounts of capital, and often no land ownership; it is frequently the only economic activity accessible to poor people in developing countries. The role of livestock in reducing poverty has been clearly shown in a recent study in India (1). There was a faster decline in rural poverty in states that experienced faster growth in agriculture and/or the livestock sector. Figure 1 illustrates the relationship between the incidence of rural poverty and the share of the livestock sector in the total agricultural output for the major states of India. Improvements in disease control, animal breeding and husbandry will add significantly to the economies of livestock production in these communities.

These results from the Indian sub-continent are supported by reports from Africa (9) and Peru (24). In Peru, a study of poverty dynamics found that diversification of income through livestock, and intensification of livestock activities through improved breeds, had helped many households to escape poverty. Likewise, in Kenya, non-poor households sold four times as many types of livestock and livestock products as did the poor. The importance of livestock production and marketing was independent of farm size, with increasing household wealth over a seven-year period being associated with an increase in animal-based, income-earning activities. Also in Kenya, smallholder dairying has enabled rural and peri-urban farming women to increase their disposable income through the production and sale of dairy products (38).

As well as being associated with increased economic well-being, livestock products have a significant impact on human health. Animal-sourced foods are particularly appropriate for combating malnutrition and a range of other nutritional deficiencies in populations that have difficulties consuming large quantities of food. However, excessive consumption of animal products is also associated with adverse effects on human health (41). Animal products as a supplement to existing base diets can measurably enhance the nutritional quality of diets for young, pregnant and lactating women and people living with human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS) (43).

Conclusion

This review highlights the importance of considering water use for livestock production systems, within the context of livestock water productivity and water use efficiency. The productivity of water in livestock production is dependent on factors such as the type and scale of livestock
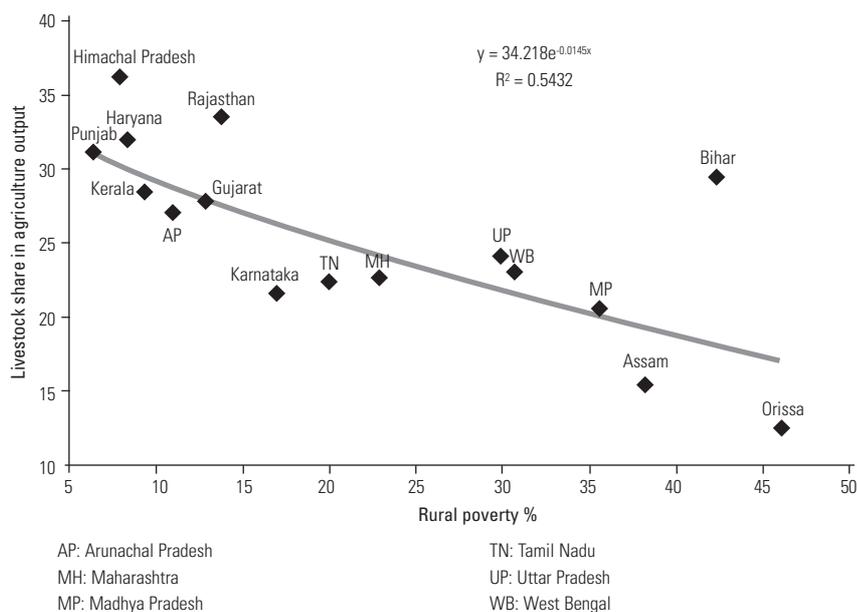
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Fig. 1
Poverty and livestock output across major Indian states, 1999 to 2000 (1)

production systems, the type of livestock farming (species and breeds) and environmental conditions (e.g. soil type and amount of rainfall). Understanding the relative importance of these factors to livestock water productivity under diverse production systems and in specific locations will help us to develop appropriate strategies to improve water use efficiency and conserve land and water resources for sustainable livestock farming. Since poor water quality can potentially affect livestock performance and thus sustainable livestock production systems, it is important to develop integrated, soil-animal management practices that avoid degradation of land and water resources. The complexity and diversity of livestock production systems make it difficult to generalise from the existing estimates of livestock water productivity with any accuracy, without taking into account the factors stated above and highlighted by Peden *et al.* (38) and Kijne *et al.* (23), in case studies from Africa and South Asia.

Livestock farming is likely to compete with other farming sectors for water because of increasing pressures from global climate change and the variability of water availability and distribution. The challenge for the future is to optimise livestock water productivity by improving animal productivity within the framework of integrated soil-water-animal management, under both rain-fed and irrigated conditions.

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L'utilisation de l'eau dans le secteur de l'élevage : une perspective mondiale

A.C. Schlink, M.-L. Nguyen & G.J. Viljoen

Résumé

L'eau est une ressource vitale pour la production animale, bien que peu étudiée. On estime que le secteur de l'élevage consomme chaque année environ 8 % de l'approvisionnement mondial en eau ; l'essentiel de cette consommation est absorbé par les élevages intensifs hors sol. Dans cette étude, les auteurs considèrent la production animale en tant qu'elle constitue un maillon de la chaîne alimentaire de l'homme, et posent la question de la rationalisation de l'utilisation de l'eau dans ce secteur. Les modèles disponibles au niveau mondial

sont de conception récente et n'établissent pas encore de distinction entre les pays développés et les pays en développement, ni entre les différents systèmes de production appliqués dans chaque pays. Néanmoins, les résultats préliminaires des analyses effectuées d'après ces modèles font apparaître que si la production de protéines est ajustée à leur valeur biologique nutritionnelle pour l'homme, l'efficience de l'utilisation de l'eau associée à la production de protéines d'origine végétale n'est pas significativement plus élevée que celle associée aux protéines contenues dans les œufs, et seule celle du soja s'avère plus élevée que celles du lait et de la viande de chèvre et de poulet.

Dans certaines régions, notamment dans les pays en développement, les animaux ne sont pas uniquement utilisés pour la production d'aliments mais aussi pour l'énergie, les fertilisants et les fibres ; ils permettent également d'écouler les sous-produits des cultures fourragères, qui autrement seraient perdus.

L'élevage est le sous-secteur agricole dont la croissance a été la plus rapide, entraînant une forte industrialisation avec parfois des contraintes environnementales limitées. Dans les économies émergentes, l'accroissement de l'activité liée à l'élevage est associé à une amélioration du niveau de vie dans les zones rurales et à une consommation accrue de protéines d'origine animale. L'utilisation de l'eau dans la production animale devrait être considérée comme une partie intégrante de la gestion agricole des ressources en eau, dans laquelle seraient pris en compte le type de système de production (alimentation à base de grains ou systèmes mixtes récolte/élevage), l'échelle de production (intensive ou extensive), les espèces et les races d'animaux, ainsi que les aspects sociaux et culturels de l'élevage de bétail dans les différents pays.

Mots-clés

Eau – Eau virtuelle – Efficience de l'utilisation de l'eau – Prix de l'eau – Production animale – Protéine – Qualité de l'eau – Utilisation de l'eau – Valeur biologique.

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Necesidades de agua para la producción pecuaria desde una perspectiva mundial

A.C. Schlink, M.-L. Nguyen & G.J. Viljoen

Resumen

El agua es un componente vital, aunque poco estudiado, de la producción pecuaria. Se calcula que el sector ganadero consume un 8% de las existencias mundiales de agua, mayormente en explotaciones intensivas de engorde. Los autores examinan la producción pecuaria desde una perspectiva general, considerándola un componente de la cadena alimentaria humana y analizando la eficiencia con que en este sector se utiliza el agua. Los modelos mundiales, todavía rudimentarios, no permiten distinguir entre países desarrollados y en desarrollo o entre un sistema de producción y otro. Aun así, los datos preliminares indican que, tras ajustar la producción de proteínas con respecto al valor biológico de éstas para la dieta humana, ninguna proteína de origen vegetal presenta una utilización del agua sensiblemente más eficiente que las proteínas del huevo, y sólo la soja es más eficiente que la leche y la carne de cabra y de pollo.

En algunas regiones, sobre todo en los países en desarrollo, los animales no sirven solamente para obtener alimentos, sino que también proporcionan fuerza de tracción, abono para los cultivos, y fibra; asimismo los animales permiten eliminar los subproductos agrícolas que de otra manera acabarían convertidos en desechos.

El ganadero es el sector agrícola que crece con más rapidez, lo que ha llevado a una creciente industrialización y también, en ciertos casos, a una relajación de los requisitos ambientales. En las economías emergentes, el creciente protagonismo de la ganadería viene ligado al aumento de la riqueza rural y del consumo de proteínas animales. El uso del agua con fines de producción pecuaria debería considerarse parte integrante de la gestión de los recursos hídricos en la agricultura, teniendo en cuenta el tipo de sistema productivo (por ejemplo, ganado alimentado con cereales o con cultivos mixtos), la escala de producción (intensiva o extensiva), la especie y raza del ganado y los aspectos sociales y culturales ligados a la producción ganadera en diversos países.

Palabras clave

Agua – Agua virtual – Calidad del agua – Determinación del precio del agua – Eficiencia en el uso del agua – Producción ganadera – Proteína – Usos del agua – Valor biológico.

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