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Environmental Implications of Livestock Series: Goats

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Introduction

This literature review examines the environmental impacts of goats in pastoral and mixed farming systems in developing countries. Even within these two farming systems, the ecological implications of livestock production still vary significantly across countries and regions in Sub-Saharan Africa (SSA) and South Asia (SA). The types and magnitude of the environmental impact of ruminants depends on how much consumption is from grassland grazing, feed crops and feed crop residues.[1] Local climate, soil, and vegetation conditions, however, also determine the severity and pervasiveness of environmental impacts associated with specific livestock species. Decision-maker evaluations of environmental impacts of livestock and resulting mitigation strategies should be site-specific whenever possible.[2,3,4]

The environmental impacts identified in this brief are categorized as being primarily related to either climate change and air pollution, land degradation, biodiversity, or water resources. However, in reality the environmental impacts of livestock do not follow these neat delineations: greenhouse gas emissions cause climate change, which in turn affects biodiversity; soil degradation also reduces water quality; nitrate and sediment pollution of water resources impacts biodiversity, and so on. In addition, to the extent that the need to feed livestock grain and/or crop residues is a driver of expanding crop production in mixed farming systems into lands previously allocated to other uses, this land conversion affects soil, biodiversity, greenhouse gas emissions and water quality.

Two types of interventions to mitigate the negative, and enhance the positive, environmental impacts of livestock are mentioned in this series of briefs: (1) biophysical interventions directed at natural resource components of farming systems, and (2) socio-political-economic interventions directed at individual incentives, policies and institutions.[5] Strategies to mitigate the environmental impacts of livestock production may entail their own risks. For example, increased dietary reliance on crop residues in order to increase the water use efficiency of ruminant livestock may be simultaneously counterproductive to the goal of reducing greenhouse gas emissions because ruminant consumption of residual crop material increases enteric methane production during digestion. [6,7] Furthermore, technologies or interventions that improve the profitability of cattle or other ruminant rearing can increase financial incentives to convert additional lands for grazing or feed production uses.[8]

FAO's Livestock, Environment and Development Initiative team warns that "Increasing herd size generally causes overall increasing (environmental) damages."[9] Most analyses of environmental impacts across livestock types recommend both a reduction in overall meat consumption by those who can nutritionally afford it, and a shift in dietary emphasis from ruminant species (cattle, water buffalo, goats), to monogastric species (poultry).[10,1112] Compared to ruminants, chickens produce lower carbon dioxide, methane, and nitrous oxide emissions, are a less significant driver of human expansion into natural habitat or of overgrazing, have lower impacts on the water cycle, and cause less destruction of natural habitats.[13] The most notable environmental implications of goats stem from their ability to graze on a wide variety of biomass sources in frequently marginal environments.

The briefs included in this "environmental implications of livestock" series (EPAR briefs 155-158) contain context-providing sections entitled "general livestock impacts" for each category of environmental analysis. These general livestock sections are identical across briefs in the series, thus readers who have previously read other briefs in the series may choose to read only the sections on species-specific impacts and the sections on mitigation strategies in the present brief, denoted with an "**." *Appendix 1* contains a summary of the environmental impacts and benefits of each livestock species examined in this series.

Climate Change and Air Pollution

Climate Change: General Livestock Impacts

As a group, livestock-derived foods are more greenhouse gas intensive to produce than crops, with the greatest impacts coming from direct farming activities rather than processing and transport to market.[14] A seminal analysis by the FAO's Steinfeld et al. (2006) estimated that livestock are responsible for 18% of global anthropogenic greenhouse gas emissions.[1] Globally, 25% of all greenhouse gas emissions associated with livestock production is attributable to methane emissions from ruminant digestion and manure, 31% is attributable to nitrous oxide from manure and manure management, and 32% is attributable to land use and land use changes.[15] The remaining 12% stems mainly from emissions associated with animal processing and transport.

Methane is a potent greenhouse gas with a global warming potency of more than 20 times that of a similar amount of carbon dioxide.[16] Ruminants, including bovines, goats and sheep, emit a greater amount of methane during their digestive process than do monogastrics (e.g., chickens and pigs).[17] Meanwhile nitrous oxide emissions, whose primary source is manure management, have more than 300 times the global warming potential of carbon dioxide.[18] Both nitrous oxide and methane may be formed from manure decomposition in anaerobic environments, and specific emission levels depend on how manure is collected, stored and spread, and whether the local climate is arid or humid.[19]

Meanwhile the conversion of forestland to cropland or pastureland contributes to global warming in several ways.[20] First, the land conversion process is frequently accomplished by the burning of forestland, which immediately releases stored carbon dioxide[21] while also limiting the land's long-term carbon storage capacity (since forests have a greater carbon sequestration ability than pasture or croplands)[2].[22] Second, the expansion of agricultural systems into forestland increases the number of livestock raised there, and thus increases greenhouse gas emissions from digestion and manure.[23] Heavy livestock grazing on pastureland further reduces soil carbon: in a study in Argentina, soil organic carbon decreased 25-80% in areas subjected to overgrazing.[24] However, to the extent that continued pastoral grazing helps preserve the 27% of the world's carbon stocks currently in natural grasslands from conversion to other land uses, grazing activities could in theory contribute to carbon sequestration.[25]

In addition to the emissions associated with feed production and land conversion, the post-slaughter livestock processing of each species entails substantial energy consumption, although the amounts reported across studies vary widely.[26] The degradation of unused byproducts of carcass processing, such as intestines, also produces methane.

Monogastric species such as poultry and pigs are more efficient converters of plant energy into animal food products (meat, eggs and dairy) than are ruminants.[27] However, several counterarguments may reduce the gap in production efficiency vis-à-vis greenhouse gas emissions between ruminants and poultry. First, poultry require a more grain intensive diet than ruminants, which raises the opportunity costs of their feed consumption above ruminants. [28] The opportunity costs of livestock consuming grain are high both because it decreases the availability of grains for human consumption, and it reduces the availability of the land used to grow the grain to other uses. Second, draft animals such as cattle and water buffalo can plow fields and thereby increase crop production efficiency[29,30] while limiting the need for tractors or other machinery powered by greenhouse emissions-intensive fuel (although this drafting function also makes it easier to convert land to agricultural uses).[31]

[1] Building upon the work of Steinfeld et al. (2006), a second estimate by Goodland & Anhang (2009) placed the overall contribution of livestock to anthropogenic greenhouse gas emissions at 51%. However, this estimate relied upon a somewhat controversial methodology, and has not been as widely-cited as the estimate of Steinfeld et al.

[2] Likewise, the conversion of pastureland to cropland can entail significant reductions in the land's carbon sequestration ability: 95% of aboveground carbon and 50% of soil carbon may be lost during conversion. (Reid et al., (2004), p. 99).

Third, when cattle eat crop residues which would have otherwise been burned, they reduce the greenhouse gas emissions and other air pollution which would have been produced from the burning.[32]

***Climate Change: Goat- and Ruminant-Specific Impacts*

Our literature review did not encounter any reliable estimates of goat production efficiency vis-à-vis greenhouse gas emissions that were specific to livestock raised in pastoral or mixed rain-fed agricultural systems[3].

The difficulty in obtaining reliable quantifications of emissions associated with livestock rearing due to farm system variability led the International Panel on Climate Change (IPCC) to adopt a standard assumption for emission levels from African ruminants of 32 kg of methane per Tropical Livestock Unit.[33] Hererro et al. (2008) modeled methane emissions in Africa from ruminants. Their study concluded that goats, representing 8.4% of Tropical Livestock Units, were responsible for 7.5% of methane emissions, giving African goats a slightly better-than-average production value per volume of greenhouse gas emissions, relative to African livestock as a whole.[34]

Goats in Africa are estimated to contribute 0.6% of global methane emissions.[35] The IPCC estimates that enteric fermentation from goats produces 5 kilograms of methane annually per animal, as compared to 46-58 kilograms of methane per Indian or African dairy cow, and 27-31 kilograms of methane for other Indian and African cattle[4].[36] In addition, the IPCC estimates that goat manure in developing countries produces an additional 0.11-0.22 kilograms of methane emissions per animal per year.[37] Goats are estimated to excrete 1.37 kilograms of nitrogen annually per animal in Africa and Asia, of which between 15 and 35% may volatilize in the form of ammonia, nitrogen oxides and nitrogen gas[5],[38] causing additional greenhouse gas emissions, as well as land degradation and water pollution.

Other Air Pollution

The volatilization and release of nitrogen from animal production (including crop fertilizers) and processing byproduct (including manure) can also impact air quality.[39] The volatilization of nitrogen leads to the production of ozone and aerosols in the troposphere that can cause respiratory illness, cancer and cardiac disease.[40] Local air quality is also affected by livestock production when people burn forests to convert land to agricultural uses. Disposal of dead animals may also pose air pollution risks if incinerated.[41]

***Mitigation Strategies*

Garnett (2009) categorizes attempts to mitigate the greenhouse gas emissions from livestock into four approaches: (1) improve productivity (2) change management systems (3) manage waste outputs and (4) reduce livestock numbers.[42] Specific suggestions encountered in the literature include the following:

- *Reduce ruminant methane emissions by improving diets* (feed additives and supplements, such as cereal grains and oilseeds).[43] The greatest potential for methane reductions occurred in districts with the poorest livestock feed.[44] However, producing the grain supplements can produce other greenhouse gas emissions that offset these benefits.

- *Make genetic improvements through selective breeding or engineering to render ruminant digestive processes more efficient and less methane-emission intensive.*[45,46] Breeding options include: selecting among or within breeds, selecting large and fast-growing breeds, and manipulating dietary requirements.[47] Genetic improvement options include increasing efficiency and productivity from nutrient and resource inputs, reducing wastage due to disease, death and wasted reproductive cycles, and selection of low-methane emissions traits or breeds.[48] Reduced methane production is usually also associated with increased milk and meat productivity.[49]

- *Encourage households to maintain fewer, but higher-quality,*

[3] The majority of life cycle assessments (LCAs) of livestock-derived food products have focused on intensive agricultural food systems in OECD countries.[3] Since industrial systems differ considerably in their environmental impacts from extensive grazing and mixed rain-fed livestock production, those more-comprehensive assessments are not reported here.

[4] 5 kilograms of methane has a global warming potential equivalent to 100kg, or 0.1 metric tons of carbon dioxide. As a frame of reference, the combustion of one gallon of gasoline is estimated to emit 2.4kg of carbon dioxide. (EPA 2005)

[5] Estimates of N volatilization depend on manure management systems in place. Estimates exclude emissions from anaerobic lagoon systems, which have substantially higher Nitrogen volatilization rates than do other manure management systems.

more productive animals.[50]

- *Develop or utilize digestive microorganisms* that help break down feed into amino acids and nutrients more efficiently and completely.[51]

- *Manage soil nutrients* through a climate and soil-appropriate combination of inorganic fertilizer, mulching, crop residue and manure to sequester carbon and also boost yields.[52]

- *Convert methane and other biogases* recovered from anaerobic digestion of manure into electricity through the use of small-scale digesters.[53]

- *Manage manure to minimize methane and nitrous oxide emissions* from decomposition.[54]

- *Increase vegetative cover*, and employ other land management strategies that increase the carbon sequestration ability of grazing and feed production lands, or which slow the release of stored carbon via respiration, erosion and fire.[55,56] Adopting conservation tillage practices can sequester between 0.1 and 1.3 tons of carbon per hectare per year.[57]

- *Develop dual food/feed crops for mixed rain-fed systems* that reduce methane emissions per unit of feed intake.[58] An example of this type of modification would be to increase the digestibility of maize stover.

- *Reduce the number of sick and unproductive animals* by improving animal nutrition and health.[59]

- *Manage grazing* to reduce methane production by encouraging goats to consume younger, more easily digestible forage. [60]

Land Degradation

General Livestock Impacts

Livestock grazing and trampling have marked effects on vegetative cover, soil quality and nutrient loss due to erosion. Evidence of this impact is found in the 10-20 percent of grasslands worldwide that are degraded due to overgrazing. [61] Overgrazing of pastureland causes soil erosion and releases carbon from decaying organic matter, compacts wet soils and disrupts dry soils. The effects of trampling depend on soil type.[62] Desertification due to overgrazing causes a loss of 8-12 tons of carbon per hectare from soils and 10-16 tons of carbon in above-ground vegetation.[63] In mixed farm systems, land tillage and crop production further compound the loss of native vegetative cover and leads to soil erosion, while soil compaction and soil disruption result in increased runoff and erosion.[64]

***Goat- and Ruminant-Specific Impacts*

Degradation of grasslands and conversion of forestlands that reduce biodiversity, worsen water quality and contribute to climate change are the primary direct environmental impacts of cattle in pastoral and mixed systems[6].[65 66] Because of the low economic value of goats, they are not a major driver of forest clearing, although grazing diminishes the potential for forest re-growth.[67]

Goat trampling has a tendency to alter soil structure. A goat may exert as much downward pressure on soil as a tractor, depending on the animal's distribution of weight across its limbs.[68] Compacted and disrupted soils increase runoff and erosion.[69]

Among ruminants, the degradation from goat overgrazing is most severe because of the species' ability to graze on residual biomass and ligneous species that are left as vegetative cover by other species.[70] The often marginal, low-rainfall environments on which goats are raised are especially sensitive to reductions in vegetative cover from grazing.[71,72] Goats can debark trees and consume vegetation left untouched by other species, and generally exhibit a preference for the most nutritious plant fractions.[73,74] Goat removal of vegetation can have more pervasive impacts than other livestock due to their tendency to range over large distances and their ability to survive without water for longer periods than other livestock.[75] Therefore, close management by goat keepers is especially critical to limiting the scope of their land degradation.[76]

Although goat grazing habits and management regimes renders their impacts relatively severe compared to other ruminants, they are also comparatively efficient users of water and feed resources. Compared to other ruminants, goats have low metabolism, efficient digestion and low

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[6] Soil and water pollution are problems more specific to intensive cattle rearing.

water requirements.[77]

Nonetheless, goats can contribute to nutrient and resource cycling in farming systems. Grazing animals, including goats, as well as cows and water buffalo, can provide positive ecosystem benefits and improve plant species composition by removing biomass that could fuel fires, by controlling vegetative growth, and by dispersing seeds.[78] Soil fertilized with manure has been found to be more fertile and biologically active than soil fertilized with mineral fertilizer alone.[79] Ruminant consumption of crop residues allows for a more complete utilization of the biomass grown on agricultural plots, and converts inedible vegetation into human food.[80,81] However, when fed grains that could otherwise be consumed by humans, livestock reduce food efficiency and increase land converted to produce crops: In general, across livestock species raised for meat production, the ratio of the weight of grain fed relative to the weight of meat produced is generally about three to one, and the ratio of the weight of grain fed to the weight of milk produced is about one to one.[82]

***Mitigation Strategies*

- *Engage in nutrient management strategies* that encompass: (1) effective nutrient cycling between plants, soil and animals, (2) improved plant and animal nutrient retention and efficiency, (3) alternative uses of grazing land and (4) multi-use buffers on grazing or cropland periphery.[83]

- *Increase reliance on forage legumes* as a supplement to ruminant diets heavy in crop residue and grasses. Legume consumption shifts nitrogen excretion from urine to feces, which results in less nitrogen manure volatilizing and being release in water effluent, and more nitrogen being returned to fertilize the soil.[84]

- *Decrease animal morbidity and mortality*.[85,86] Unproductive or unusable livestock represent an investment of feed with low or no output, and producing feed (or grazing of land) is inextricably linked with some degree of land degradation.

- *Implement crop rotation and fallowing of feed crop fields* to increase water retention and decrease nutrient losses, which reduces the variability of maize yields and lessens farmer risks.[87] Cover crops should be planted immediately after crop harvest.[88]

- *Remove grazing from marginal areas* and concentrate it in productive areas where ecosystem resilience and degradation resistance is greatest.[89]

- *Decrease stocking density* to levels appropriate to local biomass and water resource capacity.[90]

- *Support and clearly delineate grazing land and water resource management regimes through local institutions.* [91] Clarify government expectations and penalties for management of communal land, and what resources (i.e. timber, water, and vegetation) can be utilized and extracted and at what times.[92]

- *Minimize animal stress* through brooding, ventilation and healthcare to improve their weight gain and feed efficiency, and thereby lower grain demand and associated land conversion pressures.[93]

Biodiversity

General Livestock Impacts

Converting forests and grasslands for agricultural uses (for direct livestock grazing or feed production) are considered by some to be a paramount threat to biodiversity.[94,95] Biodiversity also may decrease with agricultural intensification, including pesticide application, eliminating wildlife corridors and space between plantings, and displacing traditional crop varieties in favor of uniform improved varieties.[96] In developing countries, an estimated 40% of threats to bird species are attributable to agricultural changes, including land conversion and intensification.[97] Habitat fragmentation exacerbates the negative effects of this land conversion on biodiversity by reducing natural habitat below levels needed to maintain species key to continued ecosystem functioning. [98,99]

Livestock-induced damage to water resources, described in more detail in the section below, is also a significant threat to aquatic biodiversity.[100] Livestock biodiversity itself also declines when farmers adopt commercial livestock breeds with superior production under controlled living conditions.[101] Another indirect pressure occurs through a livestock system's contributions to climate change, which is expected to have negative implications for biodiversity.[102] Invasive alien species which accompany livestock, including parasites, pathogens and plant seeds dispersed in feces, also pose the potential to interrupt natural ecosystems and negatively impact biodiversity.[103]

One positive effect of livestock production for biodiversity is that consuming livestock may reduce pressure to consume endangered meat sources such as bush meat.[104]

***Goat- and Ruminant-Specific Impacts*

Intensive grazing activities reduce native plant populations and vegetative canopy and render land susceptible to desertification, which stimulates further biodiversity loss.[105] Concentrated and persistent grazing in an area can lead less-palatable woody shrubs and trees (left behind by grazing cattle) to out-compete more nutritious feed sources.[106] Grazing also alters plant biomass production, reducing root biomass and increasing foliage biomass, which can reduce plant survival during environmental stresses such as droughts.[107] Furthermore, in some areas native grassland species may be plowed under and replaced with introduced exotic pasture vegetation.[108]

The effects on biodiversity of overgrazing by goats may be especially severe relative to grazing by other livestock species. The ecosystems in the marginal environments frequently grazed by goats are particularly susceptible to vegetation removal.[109]

Conflict between livestock herders and wildlife also has negative consequences for biodiversity when herders kill or restrict the range of predators such as lions, cheetahs, wild dogs, hyenas and leopards in order to protect their stock.[110] Livestock and wildlife may also compete for scarce water resources, [111] with livestock tending to drive wildlife away from watering points during daylight.[112]

Pastoralism can have positive effects on biodiversity by keeping wildlife corridors open.[113] Grazing lands for livestock are generally more compatible with biodiversity maintenance than are lands devoted to crop production.[114] In addition, many species of birds, insects and vegetation have adapted to the open pastureland and cropland habitats provided during the past 10,000 years of human agricultural history.[115] Temporary pastoral settlements may leave behind nutrient-rich hotspots in the soil that provide decades of subsequent favorable conditions for native vegetative growth and habitat development.[116] Moderate grazing can encourage vegetation regrowth, prevent the spread of noxious weeds, and increase local grass species diversity.[117, 118]

***Mitigation Strategies*

McNeely & Scherr (2003) provide six categories of recommendations for reducing the impact of agriculture on biodiversity: "(1) create biodiversity reserves that also benefit local farming communities; (2) develop habitat networks in non-farmed areas; (3) Reduce (or reverse) conversion of wild lands to agriculture by increasing farm productivity; (4) minimize agricultural pollution; (5) Modify management of soil, water, and vegetation resources and (6) Modify farming systems to mimic natural ecosystems."[119] The authors rank intervention types (1), (2), (5) and (6) as having the greatest potential benefits to biodiversity in pastoral and ranching systems, and intervention types (4) and (5) as the most beneficial in rain-fed crop systems. [120] Specific strategies include:

- *Mitigate the environmental problems caused by livestock which indirectly reduce biodiversity*: decrease pressures on climate change, water resources, land conversion and desertification. [121]

- *Expand grazing in specifically designated areas* to maintain ecologically valuable landscapes to wildlife. [122]

- *Intensify crop feed production* to reduce pressures on natural land and habitat, while minimizing the externalities of that crop production.[123]

- *Establish and retain wind breaks, hedgerows and woodlots* within agricultural lands to provide habitat in addition to more tangible on-farm benefits.[124]

- *Engage local farmers in ecosystem management planning* in order to benefit from local knowledge of traditional farming practices and currently-pressing environmental problems, as well as to increase farmer participation in impact mitigation strategies.[125]

- *Use extension professionals* to communicate locally-appropriate strategies to improve agriculture and biodiversity. [126]

Water Resources

General Livestock Impacts

Livestock affects water resources and produces environmental impacts through two channels: (1) The quantity of often scarce water resources required to grow feed crops and sustain livestock animals, and (2) the wastewater created and other water resources degraded by livestock feeding, servicing and processing.[127] Water quality problems can stem from land degradation. Reactive nitrogen and other nutrients lost from soil into water bodies can cause nitrification and eutrophication.[128] Direct deposition of fecal material and runoff of applied fertilizers and wastes reduces water quality.[129] Slaughterhouses which directly discharge wastes into water bodies can lower dissolved oxygen to toxic levels.[130]

The amount of water directly consumed by livestock is dwarfed by the water requirements of their feed crops: 50 to 100 times as much water is required to grow livestock feed crops as is needed to sustain the animals themselves.[131] However, in grazing and mixed farming systems in SSA where native vegetation and crop residues are a major feed component, little or no additional water is allocated to meet feed requirements.[132] In general, the more grain-intensive the livestock feed, the more water-intensive the livestock production.[133]

***Goat- and Ruminant-Specific Impacts*

Goats are more water-efficient that large ruminants such as cattle.[134] Approximately 0.118 kilograms of goat meat can be produced per 1000 liters of water, as compared to .082 kilograms of beef per 1000 liters of water.[135] Lactating goats, weighing an average of 27 kg and producing 0.2 liters of milk per day, required 7.6 liters of water per animal per day in 15 degree Celsius temperatures, and 11.9 liters per day in 35 degree Celsius temperatures.[136] In addition, adult goats require an average of 5 liters per animal per day of water used for service activities such as cleaning, cooling and waste disposal.[137]

Compacted and disrupted soils from grazing activities not only degrade the land but impair water quality by increasing sediment loads and destabilizing stream banks.[138] Increased sediment loads caused by soil erosion can destroy aquatic ecosystem habitats by covering food sources and nesting sites and affect respiration and digestion of aquatic animals, and may eventually lead to eutrophication of water bodies.[139] Water pollution from goat manure is not a major concern in extensive systems.[140] However, the tanning of goat hides also produces wastewater containing chemical toxins such as chromium, which are harmful to humans and wildlife.[141]

***Mitigation Strategies*

Interventions to improve the efficiency of water used by goats:

- *Increase transpiration of feed crops and decrease evaporation.*[142,143] Strategic choices of water-efficient feed crops, including agricultural crop residues, can increase the productive efficiency of livestock water use.[144] However, agricultural crop residues may have less nutritional value for livestock, and residue consumption by livestock produces methane emissions and reduces soil quality if the residues would otherwise be deposited on fields.[145]

- *Engage in agroforestry.* The use of fodder trees and forage legumes can create favorable microclimates which reduce erosion and improve transpiration, soil structure and soil fertility. Agroforestry also enables the production of livestock-consumable biomass from water resources.[146]

Interventions to mitigate water resource degradation:

- *Designate conservation areas* where livestock grazing is only permitted during times of need. [147] Protection of vegetation against grazing pressures increases biomass production (absorbing carbon dioxide), reduces evaporation and runoff, and increases transpiration.[148]

- *Contain and store manure* to minimize runoff into water bodies and to reapply nutrients within the farming system.[149]

- *Control grazing intensity and frequency* to improve vegetation cover, reduce soil erosion, and improve water quality.[150]

- *Establish conservation buffers* around riparian areas in order to reduce sediment loads and erosion by slowing water velocity, stabilizing banks with plant roots, and facilitating plant absorption of soluble materials.[151]

- *Modernize slaughterhouses* to reduce animal waste polluting local waters from carcass processing.[152]

Methodology:

This literature review was conducted using databases and search engines including University of Washington Library, Google Scholar and Google, as well as the following websites: IFPRI, ILRI, WRI, IWMI, African Development Bank, World Bank, UNFAO, UNEP, Millennium Ecosystem Assessment and IPCC. Searches used combinations of the following terms: environment, environmental, environmental impacts, developing world, Sub-Saharan Africa, rain-fed agriculture, grazing, pastoral, emissions, biodiversity, water, water resources, water quality, soil, land, livestock, species comparison, cattle, cows, buffalo, water buffalo, chickens, poultry, beef, goats, bovine, natural resource use, feed conversion efficiency, livestock water productivity, ecological footprint, life cycle assessment, climate change, global warming, air pollution smallholder, sustainability. The methodology also included searching for sources that were identified as central works and examining relevant lists of works cited. This literature review draws upon over 50 cited sources, and relied in equal parts on peer-reviewed publications and publications from major international organizations, especially FAO, ILRI and IFPRI.

Please direct comments or questions about this research to Leigh Anderson, at eparx@u.washington.edu

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Appendix 1: Comparison of Livestock Impacts (where available)

Environmental Impact	**Extent of Negative Environmental Impacts**	**Expert Rankings by Livestock**	**Environmental Benefits**
Greenhouse Gas Emissions	*Cattle:* 46-58 kg/methane/head/yr from enteric fermentation for Indian/African dairy cows; 27-31 kg/methane/head/yr for other cattle. 5-6kg methane/head/year from manure. *Goats:* 5kg methane/animal/yr from enteric fermentation. 0.11-0.22kg/methane/head/yr from manure decomposition. *Chickens*: No methane emissions from enteric fermentation. 0.02kg/head/year from manure. *Water Buffalo*: 55-77 kg/methane/head/yr from enteric fermentation. 4-5kg methane/head/year from manure.	*Cattle* and/or *Buffalo* have greatest lifecycle greenhouse gas emissions, *chickens* have lowest emissions.	Livestock consumption of crop residues reduces alternative burning of biomass. *Cattle & Buffalo* can replace draft and farm machinery emissions.
Manure Management and Nitrogen Retention	*Cattle:* 0.34-0.63kg/head/year N excretion, 22-50% volatilization rate. *Goats:* 1.37 kg/head/yr N excretion, 15-35% N volatilization rate. *Chickens*: 06.-1.1 kg/head/yr N excretion, 50-55% N volatilization rate. *Water Buffalo*: 0.32kg/head/year N excretion, 30-45% volatilization rate.		Proper manure management fertilizes soils.
Feed Conversion	*Cattle:* 7kg grain/1kg meat. *Chickens*: 2 kg/grain/1kg meat or eggs.	*Chickens* most efficient.	
Land Degradation		*Goat* grazing most damaging, followed closely by *cattle/ water buffalo*; *chickens* least damaging. *Cattle* drive most land conversion.	Grazing removes fire-inducing biomass, disperses seeds. Manure fertilizes soil. Retention of grazing lands prevents conversion to more-damaging land uses.
Biodiversity			Grazing can provide habitat and increase species diversity in ecosystems adapted to frequent grazing. Livestock production reduces bush meat consumption.
Livestock-Water Productivity	*Cattle:* 0.082kg meat/1000 L water. *Goats:* 0.118kg meat/1000 L water. *Chickens*: 0.22-0.51kg meat/1000 L water		
Water Quality		*Buffalo* spend most time in water bodies, *cattle* and *goat* grazing also causes water quality impairment.	

Endnotes

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