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Environmental Implications of Livestock Series: Chickens

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Introduction

This literature review examines the environmental impacts of chickens 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 chickens can increase the incentives to convert additional lands for 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] The FAO concludes that the "environmental damage caused by poultry is much less than that caused by other species, although it may be locally important."[13] 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.[14]

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.[15] 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.[16] 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.[17] Ruminants, including bovines, goats and sheep, emit a greater amount of methane during their digestive process than do monogastrics (e.g., chickens and pigs).[18] Meanwhile nitrous oxide emissions, whose primary source is manure management, have more than 300 times the global warming potential of carbon dioxide.[19] 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.[20]

Meanwhile the conversion of forestland to cropland or pastureland contributes to global warming in several ways.[21] First, the land conversion process is frequently accomplished by the burning of forestland, which immediately releases stored carbon dioxide[22] while also limiting the land's long-term carbon storage capacity (since forests have a greater carbon sequestration ability than pasture or croplands)[2].[23] 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.[24] 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.[25] 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.[26]

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.[27] 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.[28] 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. [29] 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[30,31] 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).[32]

[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.[33]

Climate Change: Chicken-Specific Impacts

Poultry systems are the most efficient livestock in terms of meat and protein production per unit of greenhouse gas emissions.[34] One reason for this efficiency is that poultry production does not produce methane emissions due to enteric fermentation. However, like ruminant livestock, chicken manure contains methane and nitrous oxide.[35] A second, related reason for the relative efficiency is that 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.[36]

Our literature review did not encounter any reliable estimates of chicken production efficiency vis-à-vis greenhouse gas emissions that were specific to livestock raised in pastoral or mixed rain-fed agricultural systems[3]. However, the IPCC estimates low levels of methane emissions from chicken manure in developing countries: 0.02kg of methane per chicken annually[4].[37] Chickens are estimated to excrete between 0.6 and 1.1kilograms of nitrogen annually per animal in Africa and Asia, of which between 50 and 55% may volatilize in the form of ammonia, nitrogen oxides, nitrous oxide and nitrogen gas[5].[38] Due to the multiple pathways of nitrogen volatilization, nitrogen loss has environmental implications not only in terms of greenhouse gas emissions, but for 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 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:

- *Make genetic improvements through selective breeding or engineering to improve feed conversion efficiency.*[43,44] Breeding options include: selecting among or within breeds, selecting large and fast-growing breeds, and manipulating dietary requirements.[45] Genetic improvement options include increasing efficiency and productivity from nutrient and resource inputs, and reducing wastage due to disease, death and wasted reproductive cycles.[46]

- *Decrease chicken morbidity and mortality.*[47,48] Broiler mortality across the production cycle in developing countries is estimated at five percent, and layer chicken mortality at eight percent.[49] Dead animals represent an inefficient investement of feed crop resources, and the incineration of dead infected livestock poses additional air pollution risks.[50] For example, approximately one third of poultry producers in the Philippines, 10% of which are small independent producers, dispose of dead poultry through incineration. [51]

- *Reduce deforestation through agricultural intensification of chicken feed crop production.*[52] The greenhouse gas emissions associated with chemical fertilizer production and application[6] - one option for driving intensification- are outweighed by the sequestered

[3] The majority of life cycle assessments (LCAs) of livestock-derived food products have focused on intensive agricultural food systems in OECD countries (De Vries & Boer (2010), p. 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] .02 kilograms of methane has a global warming potency equivalent to 0.4kg, or 0.0004 metric tons of carbon dioxide. As a frame of reference, the combustion of one gallon of gasoline is also 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.

[6] When applied at optimal levels that minimize nutrient erosion from the soil and nitrogen volatilization.

carbon and avoided emissions associated with new deforestation.[53]

- *Encourage households to maintain fewer, but higher quality, more productive animals*.[54]

- *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.[55]

- *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.[56,57] Adopting conservation tillage practices can sequester between 0.1 and 1.3 tons of carbon per hectare per year.[58]

- *Use feed additives* to increase nitrogen uptake efficiency and minimize nitrogen excretions.[59]

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

Chicken-Specific Impacts

The soil degradation effects of poultry production are generally smaller in magnitude than for other livestock species due to their short reproductive cycles, their synergistic consumption of household wastes as feed, and their small land requirements.[65] Poultry's major impacts on land degradation come from producing their grain-intensive feed. However, the effects of producing grain in mixed farming and grazing systems is tempered by the many smallholder poultry producers who mainly rely on grains as a feed supplement to chicken scavenging.[66]

When fed grains that could otherwise be consumed by humans, livestock reduce food efficiency and increase land converted to crop production: 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. Chickens, however, may need to consume only two kg of grain to produce one kg of meat or one kg of eggs.[67, 68]

Poultry manure is widely viewed as a valuable fertilizer, and is sold in many developing countries, although transportation costs largely limit manure sales to local markets.[69] However, chicken manure has a high nitrogen-phosphorous ratio, and phosphorous build-up from applying poultry manure can impact certain soils.[70]

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.[71]

- *Introduce leguminous or other nitrogen-fixing plant species and establish agro-forestry regimes* to restore nitrogen and carbon to degraded soils.[72]

- *Apply manure and wastewater to cropland*, which can help replenish soil nutrients.[73] Poultry manure has high nitrogen, phosphorous and potassium content.

- *Decrease animal morbidity and mortality*.[74,75] 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.[76] Cover crops should be planted immediately after crop harvest.[77]

- *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.[78] To reduce animal stress, ensure that bird housing provides ample fresh air supply, appropriate air temperature and humidity, and adequate lighting.[79] Heat stress inhibits bird immune function, suppresses feed consumption, and reduces production performance.[80]

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.[81,82] 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.[83] In developing countries, an estimated 40% of threats to bird species are attributable to agricultural changes, including land conversion and intensification.[84] 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.[85,86]

Livestock-induced damage to water resources, described in more detail in the section below, is also a significant threat to aquatic biodiversity.[87] Livestock biodiversity itself also declines when farmers adopt commercial livestock breeds with superior production under controlled living conditions.[88] Another indirect pressure occurs through a livestock system's contributions to climate change, which is expected to have negative implications for biodiversity.[89] 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.[90]

One positive effect of livestock production for biodiversity is that consuming livestock may reduce pressure to consume endangered meat sources such as bush meat.[91]

Chicken-Specific Impacts

Chicken production poses a particular threat to avian biodiversity. Chickens are susceptible to viruses, such as H5N1, which have the potential to transmit to wildlife.[92] Fleas on poultry may also act as vectors of disease transmission to avian wildlife.[93]

Livestock consumption of fishfeed and fishmeal also creates significant pressures on ocean biodiversity.[94] Poultry consume 24 percent of global fishmeal production.[95]

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."[96] 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.[97] 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.[98]

- *Expand grazing in specifically designated areas* to maintain ecologically valuable landscapes to wildlife.[99]

- *Intensify crop feed production* to reduce pressures on natural land and habitat, while minimizing the externalities of that crop production.[100]

- *Establish and retain wind breaks, hedgerows and woodlots* within agricultural lands to provide habitat in addition to more tangible on-farm benefits.[101]

- *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.[102]

- *Use extension professionals* to communicate locally-appropriate strategies to improve agriculture and biodiversity. [103]

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.[104] Water quality problems can stem from land degradation. Reactive nitrogen and other nutrients lost from soil into water bodies can cause nitrification and eutrophication.[105] Direct deposition of fecal material and runoff of applied fertilizers and wastes reduces water quality.[106] Slaughterhouses which directly discharge wastes into water bodies can lower dissolved oxygen to toxic levels.[107]

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.[108] 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.[109] In general, the more grain-intensive the livestock feed, the more water-intensive the livestock production.[110]

Chicken-Specific Impacts

Not including the water requirements of the feed crops, broiler chickens require 17.7 liters of water per 100 animals per day at 15 degree Celsius temperatures, and 62 liters of water at 35 degree temperatures. Egg-laying chickens require slightly less water, at 13.2 liters per day in 15 degree Celsius temperatures and 50.5 liters in 35 degree temperatures.[111] In addition, service activities require about 1 liter of water per 100 chicks per day in grazing systems for both broiler and laying hens, and 9 (broiler) to 15 (laying hens) liters of water per day per 100 adult chickens.[112]

Chicken are more water-efficient than ruminants.[113] Approximately 0.22-0.51 kilograms of poultry meat can be produced per 1000 liters of water, as compared to .082 kilograms of beef per 1000 liters of water.[114] Including feed production water requirements, the water inputs required to produce one kilogram of chicken eggs range from 2,000-4,700 liters, and 1,028-7,702 liters per kilogram of broiler chicken meat.[115]

Applying chicken manure to crop fields can improve water quality (and crop yields) relative to commercial fertilizer use.[116] However, high phosphorous levels in chicken manure can lead to post-application phosphorous runoff, stimulating eutrophication.[117]

Mitigation Strategies

Interventions to improve the efficiency of water used by chickens:

- *Increase transpiration of feed crops and decrease evaporation.*[118,119] Strategic choices of water-efficient feed crops can increase the productive efficiency of livestock water use.[120]

- *Provide chicken housing that provides optimal production temperature and humidity.*[121]

Interventions to mitigate water resource degradation:

- *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.[122]

- *Modernize slaughterhouses* to reduce animal waste polluting local waters from carcass processing.[123]

- *Modify feed to reduce phosphorous concentrations in manure.*[124]

- *Utilize improved planting methods* including raising beds and minimizing tillage in feed crop production.

- *Modernize slaughterhouses* to reduce animal waste pollution of local waters from carcass processing.[125]

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, Millenium 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

Sources:

Amede, T., Geheb, K. & Douthwaite, B. (2009). Enabling Uptake of Livestock-Water Productivity Interventions in the Crop-Livestock systems of Sub-Saharan Africa. *The Rangeland Journal 31,* pp. 223-230

Amede, T., Tarawali, S., & Peden, D. (2011) Improving Water Productivity in Crop-Livestock Systems of Drought-Prone Regions. Expl. Agriculture 47 (S1), 1-5exple

Asner, G. & Archer, S. (2010) Livestock and the Global Carbon Cycle. In: *Livestock in a Changing Landscape: Drivers, Consequences and Responses, Vol. 1* Island Press; Eds: Steinfeld, H., Mooney, H., Schneider, F., & Neville, L.

Blake, R.W., & Nicholson, C.F. (2004). Livestock, Land Use Change, and Environmental Outcomes in the Developing World. *Responding to the Livestock Revolution: The Role of Globalization and Implications for Poverty Alleviation. Eds. Owens et al.* Nottingham University Press, U.K.

Bryan, E., Ringler, C., Okoba, B., Koo, J., Herrero, M. & Silvestri, S. (2011) Agricultural Management for Climate Change Adaptation, Greenhouse Gas Mitigation, and Agricultural Productivity: Insights from Kenya. *IFPRI Discussion Paper 01098, June 2011*

Carrete, M., Serrano, D., Illera, J., Lopez, G., Vogeli, M., Delgado, A., & Tella, J. (2009). Goats, Birds and Emergent Diseases: Apparent and Hidden Effects of Exotic Species in an Island Environment. *Ecological Appliations 19* ,4, 840-853

Clay, J. (2004). World Agriculture and the Environment: A Commodity-by-Commodity Guide to Impacts and Practices. Island Press. Washington D.C.

Delgado, C., Narrod, C., & Tiongco, M. (2008). Determinants and Implications of the Growing Scale of Livestock Farms in Four Fast-Growing Developing Countries. *IFPRI Research Report 157*

Delve, R., Cadisch, G., Tanner, J., Thorpe, W., Thorne, P. & Giller, K. (2001). Implications of Livestock Feeding Management on Soil Fertility in Smallholder Farming Systems of Sub-Saharan Africa. *Agriculture, Ecosystems and Environment 84*, 227-243

Descheemaeker, K., Amede, T., & Haileslassie, A. (2009). Livestock and Water Interactions in Mixed Crop-Livestock Farming Systems of Sub-Saharan Africa: Interventions for improved Productivity. *IWMI Working Paper 133*

Descheemaeker, K., Amede, T., & Haileslassie, A. (2010). Review: Improving Water Productivity in Mixed Crop-Livestock Farming Systems of Sub-Saharan Africa. *Agricultural Water Management 97*, pp. 579-586.

Descheemaeker, K., Amede, T., & Mapedza (2010b). Three Ways to Improve Livestock Water Productivity in Ethiopia. Poster Prepared for the *International Livestock Research Institute Annual Program Meeting, April 2010.*

De Haan, C., Steinfeld., H. & Blackburn, H. (1997) Livestock & The Environment: Finding a Balance. Report of Study by FAO, USAID and the World Bank.

De Vries, M. & de Boer, I.J.M. (2010) Comparing Environmental Impacts for Livestock Products: A Review of Life Cycle Assessments. *Livestock Science 128*, 1-11

Duetsch, L., Falkenmark, M., Gordon, L., Rockstrom, J. & Folke C. (2010). Water-Mediated Ecological Consequences of Intensification and Expansion of Livestock Production. In: *Livestock in a Changing Landscape: Drivers, Consequences and Responses, Vol. 1* Island Press; Eds: Steinfeld, H., Mooney, H., Schneider, F., & Neville, L.

Ecos Magazine. (1985). Buffalo in the Top End. Ecos Magazine

Winter 1985, 44 p. 3-12

Ehui, S. & Pender, J. (2005). Resource Degredation, Low Agricultural Productivity, and Poverty in Sub-Saharan Africa: Pathways out of the Spiral. *Agricultural Economics*, 32 s.1, 225-242.

Elferink, E. & Nonhebel, S. (2007). Variations in Land Requirements for Meat Production. *Journal of Cleaner Production 15*, 1778-1786

United States Environmental Protection Agency (EPA) (2005). Emissions Facts: Average Carbon Dioxide Emissions Resulting From Gasoline and Diesel Fuel. Accessed 25 July 2011. http://www.epa.gov/otaq/climate/420f05001.htm

Food and Agriculture Organization of the United Nations. (FAO) (2009). The State of Food and Agriculture 2009: Livestock in the Balance.

FAO Regional Office for Asia and the Pacific (2000). Water Buffalo: An Asset Undervalued. Accessed 7/19/2011 http://www.aphca.org/publications/files/w_buffalo.pdf

Galloway, J., Dentener, F., Burke, M., Dumont, E., Bouwman, A., Kohn, R., Mooney, H., Seitzinger, S. & Kroeze C. (2010). The Impact of Animal Production Systems on the Nitrogen Cycle. In: *Livestock in a Changing Landscape: Drivers, Consequences and Responses, Vol. 1* Island Press; Eds: Steinfeld, H., Mooney, H., Schneider, F., & Neville, L.

Garnett, T. (2009). Livestock-related Greenhouse Gas Emissions: Impacts and Options for Policy Makers. *Environmental Science & Policy 12*, 491-503

Gerber, P. Wassenaar, T., Rosales, M. Castel, V. & Steinfeld, H. (2007). Environmental Impacts of a Changing Livestock Production: Overview and Discussion for a Comparative Assessment with Other Food Production Sectors. In D.M. Bartley, C. Brugere, D. Soto, P. Gerber and B. Harvey (eds.) Comparative Assessment of the Environmental Costs of Aquaculture and other Food Production Sectors: methods for Meaningful Comparison. FAO/WFT Expert Workshop. 24-28 April 2006, Vancouver, Canada. FAO Fisheries Proceedings. No. 10. Rome, FAO. 2007. 37-54.

Gerber, P., Vellinga, T., & Steinfeld, H. (2010). Issues and Options in Addressing the Environmental Consequences of Livestock Sector's Growth. *Meat Science 84*, pp 244-247.

Gerber, Vellinga, T., Opio, C., Henderson, B. & Steinfeld, H. (2010b). Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment. Report Prepared by the FAO, Animal Production and Health Division.

Godfray, C., Beddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas., S. & Toulmin, C. (2010) Food Security: The Challenge of Feeding 9 Billion People. *Science 327*, 812-818

Goodland, R. & Anhang, J. (2009). Livestock and Climate Change. *World Watch* November/December 2009.

Goodland, R. (2010). Livestock and Climate Change: Critical Comments and Respones. *World Watch* March/April 2010.

Green, R., Cornell, S., Scharlemann, J. & Balmford, A. (2005) Farming and the Fate of Wild Nature. *Science 307*, 550-555

Harper, L., Denmead, O., Freney, J. & Byers, F (1999). Direct Measurements of Methane Emissions from Grazing and Feedlot Cattle. *Journal of Animal Science 77*, 1392-1401

Hererro M., Thornton, P., Kruska, R., & Reid, R. (2008). System Dynamics and the Spatial Distribution of Methane Emissions from African Domestic Ruminants to 2030. *Agriculture, Ecosystems and Environment 126*, 122-137

Hererro, M. Thornton, P., Gerber, P. & Reid, R. (2009) Livestock, Livelihoods and the Environment: Understanding the trade-offs. *Current Opinion in Environmental Sustainability 2009, 1:* 111-120

Herrero, M., & Thornton, P. (2009) Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen; Mitigating Greenhouse Gas Emissions from Livestock Systems. *FOCUS 16*, 6

IPCC (2006). IPCC guidelines for national greenhouse Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html. Accessed 26 July 2011.

Kryger, K., Thomsen, K., Whyte, M. & Dissing, M. (2010). Smallholder Poultry Production-Livelihoods, Food Security and Sociocultural Significance. FAO Smallholder Poultry Production Paper No. 4. Rome.

McNeely, J., & Scherr, S. (2003). Ecoagrciulture: Strategies to Feed the World and Save Wild Biodiversity. Island Press; Washington D.C.

Nicholson, C., Blake, R., Reid, R., & Schelhas, J. (2001). Environmental Impactrs of Livestock in the Developing World. *Environment 43,* 2-17

Ogri, O. Environmental Problems Associated with Livestock Production in Tropical Africa. *The Environmentalist 19*, 137-143

Pitesky, M., Stackhouse, K., & Mitloehner, F. (2009). Clearing the Air: Livestock's contribution to Climate Change. *Advances in*

Agronomy 103, (ed: Donald Sparks), 1-40

Powers, W. & Angel, R. (2008). A Review of the Capacity for Nutritional Strategies to Address Environmental Challenges in Poultry Production. *Poultry Science 87*, 1929-1938

Reid, R., Thornton, P., McRabb, G., Kruska, R., Ateino, F., & Jones, P. (2004). Is it Possible to Mitigate Greenhouse Gas Emissions in Pastoral Ecosystems in the Tropics? *Environment, Development and Sustainability 6*, 91-109

Reid, R., Bedelian, C., Said, M., Kruska, R., Mauricio, R., Castel, V., Olson, J. & Thornton, P. (2010). Global Livestock Impacts on Biodiversity. In: *Livestock in a Changing Landscape: Drivers, Consequences and Responses, Vol. 1* Island Press; Eds: Steinfeld, H., Mooney, H., Schneider, F., & Neville, L.

Scherr, S. & McNeely, J. (2008). Biodiversity Conservation and Agricultural Sustainability: Towards a New Paradigm of 'Ecoagriculture' Landscapes. *Philisophical Transactions of the Royal Society of Biological Sciences 363,* 477-494

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. (2006). Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations.

Steinfeld, H. & Wassenaar, T. (2007). The Role of Livestock Production in Carbon and Nitrogen Cycles. *Annual Review of Environment and Resources 32*, 271-294

Strauch, A., Kapust, A., & Jost, C. (2009) Impact of Livestock Management on Water Quality and Streambank Structure in a Semi-Arid, African Ecosystem. *Journal of Arid Environments 73,* 795-803

Subak, S. (1999). Global Environmental Costs of Beef Production. *Ecological Economics 30*, 79-91

Thornton, P. & Gerber, P, (2010). Climate Change and the Growth of the Livestock Sector in Developing Countries. *Mitigation and Adaptation Stratgies for Global Climate Change 15*, 169-184

Thorpe, A. (2009). Enteric Fermentation and Ruminant Eructation: The Role (and Control?) of Methane in the Climate Change Debate. *Climactic Change 93*, 407-431

Wall, E., Simm, G. & Moran, D. (2009). Developing Breeding Schemes to Assist Mitigation of Greenhouse Gas Emissions. *Animal 4:*3, 366-376

White, T. (2000). Diet and the Distribution of Environmental Impact. *Ecological Economics 34* (234). 145-153

Xin, H., Gates, R. Green, A., Mithoehner, F., Moore, P. & Wathes, C. (2010). Environmental Impacts and Sustainability of Egg Production Systems. *Poultry Science 90*, 1, 263-277

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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[1] Steinfeld et al. (2006), p.34
[2] Nicholson et al. (2001), p. 16
[3] Gerber et al. (2010b). p. 12
[4] Blake & Nicholson, (2004), p. 135
[5] Descheemaeker et al. (2009), p. 13
[6] Bryan et al. (2011) p. 37
[7] Descheemaeker et al. (2010) p. 580
[8] Blake & Nicholson (2004), p. 142
[9] Gerber et al (2007), p. 42
[10] Reid et al. (2010), p.130
[11] Godfray et al. (2010), p. 816
[12] De Vries & De Boer (2010), p. 1, 9
[13] FAO (2009), p. 73.
[14] FAO (2009), p. 74
[15] Garnett (2009), p. 492
[16] Hererro & Thornton (2009), p. 1
[17] Nicholson et al. (2001) p. 14
[18] Steinfeld et al. (2006), p.83
[19] Nicholson et al. (2001) p. 14
[20] Steinfeld et al. (2006), p.83
[21] Goodland & Anhang (2009), p.13
[22] Blake & Nicholson (2004), p. 138
[23] Blake & Nicholson (2004), p. 138
[24] Blake & Nicholson (2004), p. 138
[25] Steinfeld & Wassenaar (2007), p. 275
[26] Thornton & Gerber (2010) p. 180
[27] Steinfeld et al. (2006), p. 99
[28] Garnett (2009), p. 495
[29] Garnett (2009), p. 495
[30] Garnett (2009), p. 495
[31] De Vries & de Boer (2010), p.3
[32] Thorpe (2009), p. 427
[33] Gerber et al (2007), p. 49
[34] Thornton & Gerber, (2010), p, 180
[35] Wall et al. (2009), p. 367
[36] Garnett (2009), p. 495
[37] IPCC (2006), p. 40
[38] IPCC (2006), p.59, 67
[39] Delgado et al. (2008), p.64
[40] Galloway et al. (2010), p. 92
[41] Delgado et al. (2008), p.63
[42] Garnett (2009), p. 498
[43] Steinfeld et al. (2006), p.120
[44] Clay (2004), p. 483
[45] Wall et al., (2009), p. 367
[46] Wall et al., (2009), p. 367
[47] Wrobleski (2011), p. 11
[48] Amede et al. (2009) p. 224
[49] Delgado et al. (2008), p.63
[50] Delgado et al. (2008), p.63
[51] Delgado et al. (2008), p.78
[52] Steinfeld et al. (2006), p.115
[53] Steinfeld et al. (2006), p.116
[54] Bryan et al. (2011) p. 37
[55] Bryan et al. (2011) p. 35
[56] Hererro et al (2009), p. 118

[57] Thornton & Gerber (2010) p. 176
[58] Pitesky et al. (2009), p. 26
[59] Powers & Angel (2008), p. 1930
[60] Steinfeld & Wassenaar (2007), p. 290
[61] FAO (2009), p. 68
[62] Steinfeld et al. (2006), p. 67
[63] Steinfeld et al. (2006), p. 93
[64] Steinfeld et al. (2006), p. 67
[65] Steinfeld et al. (2006), p.13, 31
[66] Kryger et al. (2010), P. 3
[67] White (2000), p. 140
[68] Clay (2004), p. 465
[69] Delgado et al. (2008), p.70
[70] Xin et al., (2010), p.265, 273
[71] Blake & Nicholson (2004), p. 142
[72] Steinfeld et al. (2006), p.119
[73] Steinfeld et al. (2006), p.136
[74] Wrobleski (2011), p. 11
[75] Amede et al. (2009) p. 224
[76] Bryan et al. (2011) p. 26
[77] Clay (2004), p. 481
[78] Steinfeld et al. (2006), p. 172
[79] Xin et al., (2010), p.271
[80] Xin et al., (2010), p.271
[81] Steinfeld et al. (2006), p. 185
[82] McNeely & Scherr (2003), p. 55
[83] Steinfeld et al. (2006), p. 186
[84] Green et al (2005), p. 551
[85] Steinfeld et al. (2006), p. 189
[86] McNeely & Scherr (2003), p. 60
[87] Steinfeld et al. (2006), p. 185
[88] Steinfeld et al. (2006), p. 208
[89] Steinfeld et al. (2006), p. 195
[90] Steinfeld et al. (2006), p. 197
[91] Clay (2004), p. 471
[92] Steinfeld et al. (2006), p. 198
[93] Carrete et al. (2009), p. 848
[94] Steinfeld et al. (2006), p. 206
[95] Steinfeld et al. (2006), p. 206
[96] McNeely & Scherr (2003), p. 109
[97] McNeely & Scherr (2003), p. 110
[98] Steinfeld et al. (2006), p. 217
[99] Steinfeld et al. (2006), p. 217
[100] Steinfeld et al. (2006), p. 217
[101] Scherr & McNeely (2008), p. 484
[102] McNeely & Scherr (2003), p. 233
[103] McNeely & Scherr (2003), p. 241
[104] Duetsch et al (2010), p. 98
[105] Galloway et al. (2010), p. 92
[106] Steinfeld et al. (2006), p. 145, 156
[107] Steinfeld et al. (2006), p. 150
[108] Descheemaeker et al. (2010) p. 580
[109] Descheemaeker et al. (2010) p. 580
[110] Descheemaeker et al. (2009) p. 8
[111] Steinfeld et al. (2006), p.129
[112] Steinfeld et al. (2006), p.130
[113] Descheemaeker et al. (2009) p. 8

[114] Peden et al., (2007), p. 507
[115] Duetsch et al. (2010), p. 100-101
[116] Xin et al., (2010), p.265
[117] Xin et al., (2010), p.265, 273
[118] Amede et al. (2009) p. 224
[119] Duetsche et al. (2010), p. 108
[120] Descheemaeker et al. (2010) p. 582
[121] Xin et al., (2010), p.271
[122] Steinfeld et al. (2006), p. 178
[123] Clay (2004), p. 469
[124] Xin et al., (2010), p.265, 273
[125] Clay (2004), p. 469