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Climate Change Impacts on Livestock Production and Adaptation Strategies: A Global Scenario

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Importance of livestock in present and future and how climate change can affect it

Globally, livestock contributes 40% to agricultural GDP, employs more than a billion people and creates livelihoods for more than 1 billion poor (Steinfeld *et al.* 2006). From a nutritional standpoint, livestock contributes about 30% of the protein in human diets globally, and more than 50% in developed countries. In many developing countries, livestock was also considered to be the backbone of agriculture, as they provided draught power and farmyard manure, often the sole source of crop nutrition, before promotion of modern agriculture in the middle of the 20th century. As outlined in the livestock revolution scenario (Delgado et al. 1999) consumption of animal products will rise particularly in so-called developing countries in response to urbanization and rising incomes. While the increasing demand for livestock products offers market opportunities and income for small holder producers and even landless, thereby providing pathways out of poverty (Kristjianson, 2009), livestock production globally faces increasing pressure because of negative environmental implications particularly because of greenhouse gas emissions (Steinfeld et al. 2006). Besides green house gases, high water requirement in livestock production systems is a major concern.

The relationships between livestock and the environment are complex and appear to be viewed very differently from developed and developing country perspectives. The FAO report, *Livestock's Long Shadow,* focused on the effects of livestock on the environment (Steinfeld et al. 2006). The climate change impacts of livestock production (calculated in Steinfeld et al. (2006) at 18% of the total global greenhouse gas emissions from human sources) have been widely highlighted, particularly those associated with rapidly expanding industrial livestock operations in Asia. Yet, in smallholder crop-livestock and agro-pastoral and pastoral livestock systems, livestock are one of a limited number of broad-based options to increase incomes and sustain the livelihoods of an estimated 1 billion people globally, who have a limited environmental footprint. Livestock are particularly important for increasing the resilience of vulnerable poor people, subject to climatic, market and disease shocks through diversifying risk and increasing assets. Given that almost all human activity is associated with GHG emissions, those from livestock in these systems are relatively modest when compared to the contribution that livestock make to the livelihoods of this huge number of people. This complex balancing act of resource use, GHG emissions and livelihoods is almost certain to get more rather than less complicated. The demand for energy supply through biofuels is yet another factor that is putting increased pressure on the natural resource base and the balance between different natural resource uses, especially in mixed crop-livestock systems.

Unfortunately, in the past most of the livestock owners in India as well as the development agencies engaged in livestock development, were not aware of the extent of potential damage caused by livestock through emission of greenhouse gases. In the absence of efficient livestock extension and veterinary services, there has been severe genetic erosion, resulting in low productivity. This compelled small farmers to expand their herd size, resulting in shortage of fodder and feed. As it was not economically viable to feed low productive livestock, farmers facing shortage of fodder let them out for free grazing on common lands and forests which suppressed the productivity further, while accelerating the pressure on bio-diversity. In the absence of a national policy on control of livestock population, there has not been any pressure on the livestock owners either to cull their uneconomic animals or to control their herd size. With the growing threat on food security arising due to global warming, small farmers dependent on rainfed agriculture are likely to be affected more severely, which may compel them to shift over to livestock husbandry for their livelihood. Therefore, the development strategy should be to promote the productivity of livestock, while reducing the population and conserving water and fodder resources.

As livestock is an important source of livelihood, it is necessary to find suitable solutions to convert this industry into an economically viable enterprise, while reducing the ill-effects of global warming. In relation to climate change, livestock will have to play a dual role: one of mitigation and one of adaptation.

Adaptation of livestock systems to climate change

Feeds and water

Water scarcity has become globally significant over the last 40 years or so, and is an accelerating condition for 1-2 billion people worldwide (MEA 2005). The Comprehensive Assessment of Water Management in Agriculture (CA) (2007) states that if today's food production and environmental trends continue into the future, they will lead to crises in many parts of the world. The CA calls for concerted action to improve water use in agriculture, if the freshwater challenges of future decades are to be overcome. The localised impacts of global change on water resources are starting to receive attention, but in the same way as for localised agricultural impacts, there is a great deal of work that needs to be done. The response of increased temperatures on water demand by livestock is well-known. For *Bos indicus*, for example, water intake increases from about 3 kg per kg DM intake at 10°C ambient temperature, to 5 kg at 30°C, and to about 10 kg at 35°C (NRC 1981). The impacts of climate change on water supply changes in livestock systems, however, are not well-studied. The key contribution of groundwater to extensive grazing systems will probably become even more important in the future in the face of climate change, although the impacts on recharge rates of the aquifers involved are essentially unknown (Masike 2007).

However, one of the most evident and important effects of climate change on livestock production is mediated through changes in feed resources. Although indirect, effects on feed resources can have a significant impact on livestock productivity, the carrying capacity of rangelands, the buffering ability of ecosystems and their sustainability, prices of stovers and grains, trade in feeds, changes in feeding options, greenhouse gas emissions, and grazing management. The main pathways in which climate change can affect the availability of feed resources for livestock are as follows:

1. Land use and systems changes: as temperature increases and rainfall increases or decreases (depending on location) and becomes more variable, the niches for different crops and grassland species change. For example, in parts of East Africa, reductions in the length of growing period are likely to lead to maize being substituted by crop species more suited to drier environments such as sorghum and millet (Thornton and Herrero 2008). These land-use changes can lead to a different composition of animal diets and to a change in the ability of smallholders to manage feed deficits in the dry season. These two effects can have substantial effects on animal productivity and on the maintenance of livestock assets.

*2. **Changes in the primary productivity of crops, forages and rangelands:*** this is probably the most visible effect of climate change on feed resources for ruminants. However, the effects are different depending on location, production system and on crop and pasture species. In C4 plant species, increases in temperature up to 30-35°C will in general increase the productivity of crops, fodders and pastures, as long as the ratio of evaporation to potential evapotranspiration and nutrient availability do not significantly limit plant growth. In C3 plants such as rice and wheat, temperature effects have a similar effect but increases in CO_2 levels will also have a significant (positive) impact on the productivity of these types of crops (IPCC, 2007). For food-feed crops, since harvest indexes change with the amount of biomass produced, the end result for livestock production is a change in the quantity of grains and stovers and availability of metabolisable energy for dry season feeding.

*3. **Changes in species composition:*** Species composition in rangelands and some managed grasslands is an important determinant of livestock productivity. As temperature and CO_2 levels change, the optimal growth ranges for different species also change, species alter their competition dynamics, and the composition of mixed grasslands changes. For example, in the temperate regions and subtropics, where grasslands often contain C3 and C4 species, some species are more prominent than others in the summer, while the balance of the mix reverts in winter. Small changes in temperature alter this balance significantly and often result in changes in livestock productivity. The proportion of browse in rangelands may increase in the future as a result of increased growth and competition of browse species due to increased CO_2 levels (Morgan et al. 2007).

*4. **Quality of plant material:*** Higher temperatures increase lignification of plant tissues and therefore reduce the digestibility and the rates of degradation of plant species (Minson, 1990). This leads to reduced nutrient availability for animals and ultimately to a reduction in livestock production, which may have impacts on food security and incomes through reductions in the production of milk and meat for smallholders.

Livestock genetics and breeding

Traditionally, the selection of animals in tropical breeds has been an adaptive one, but in recent times, market pull has stimulated a rapidly changing demand for higher production that could not be met quickly enough by breed improvement of indigenous animals. Widespread cross-breeding of animals, mostly with "improver" breeds from temperate regions, crossed with local animals, has occurred-often with poor results. Little systematic study has been conducted on matching genetic resources to different farming and market chain systems from already adapted and higher producing tropical breeds. However, given the even greater climatic variability and stresses anticipated, this is a logical response to the adaptive challenges that will be faced. The greatest role for using adaptive traits of indigenous animal genetic resources will be in more marginal systems in which climatic and other shocks are more common. Indigenous breeds, which have co-evolved in these systems over millennia and have adapted to the prevalent climatic and disease environments, will be essential (Baker and Rege, 1994). These systems are under substantial pressure arising from the need for increased production as well as land-use changes. Under these circumstances, ensuring continuing availability of these adapted animal breeds to meet the needs of an uncertain future is crucial. The adaptive challenge will be to improve productivity traits while maintaining adaptive traits. This co-evolution will take place at different speeds within different systems. Within this context, there will be a constant need to improve productivity since increasing demand will need to be supplied from a relatively constant land and water resource base. Current animal breeding systems are not sufficient to meet this need and the improvement of breeding programs under different livestock production and marketing contexts is a critical area for new research.

The preservation of existing animal genetic diversity as a global insurance measure against unanticipated change has not been as well appreciated as has that for plants, although the recent report on the state of the World's animal genetic resources (FAO 2007) and the accompanying Interlaken Declaration have highlighted this important issue. When conservation through use is insufficient (as is the widespread situation with indiscriminant cross-breeding), *ex-situ*, especially *in vitro*, conservation needs to be considered as an important component of a broad-based strategy to conserve critical adaptive genes and genetic traits.

Livestock (and Human) Health

The major impacts of climate change on livestock and human diseases have been on diseases that are vector-borne. Increasing temperatures have supported the expansion of vector populations into cooler areas, either into higher altitude systems (for example, malaria and livestock tick-borne diseases) or into more temperate zones (for example, the spread of bluetongue disease in northern Europe). Changes in rainfall pattern can also influence an expansion of vectors during wetter years. This may lead to large outbreaks of disease, such as those seen in East Africa due to Rift Valley Fever virus, which is transmitted by a wide variety of biting insects.

An example is the complexity of climate change influences with other factors associated with vector populations of tsetse flies in sub-Saharan Africa (McDermott et al. 2001). Tsetse flies transmit African trypanosomes widely in livestock (ruminants, equids, and pigs). Predictions of climate and population change on tsetse density indicates that tsetse populations and animal trypanosomosis will decrease most in semi-arid and sub-humid zones of West Africa and in many but not all areas of Ethiopia and eastern and southern Africa through a combination of population pressure on savannah species and climate change pressure on riverine species. Helminth infections, particularly of small ruminants will be greatly influenced by changes in temperature and humidity. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock. Areas becoming more arid would only be suitable for camels and small ruminants. If these species are forced to aggregate around water points, the incidence of parasitic diseases could increase.

Changes in cropping patterns and livestock systems

With changes in climate there is likely to be a shift if cropping patterns. Jones and Thornton (2003) have suggested that in areas of Africa where cropping is marginal, changes in climate by 2050 may result in increased probability of crop failure and an increased reliance on livestock farming. Many of these areas are already characterized by high levels of poverty and vulnerability.

Livestock contribution to climate change and strategies for counteracting negative environmental effect caused by livestock.

While climate change will affect the way livestock is produced and will also decrease and increase the role and importance of livestock for livelihoods depending on localities, livestock does also contribute to climate change. As cited by Gill and Smith (2008), in 2005 agriculture in general contributed about 10 to 12% or between 5.1 and 6.1 gigatons (Gt) of CO_2 equivalents to human-induced GHG emissions globally. Enteric CH_4 production, that is the CH_4 released mainly from the digestive tract of ruminants, was estimated at 1.9 Gt of CO_2 equivalents, representing about 37% of agriculture contribution to GHG. However, these estimates did not include carbon emissions from fossil fuel used in cropping, animal housing and land change use. Considering carbon emissions along the entire commodity chains, Steinfeld et al. (2006) estimated that livestock contribute about 18% to the global warming effect. These contributions are of course significant, and require urgent attention.

Feed mitigation options for reducing carbon emission

Considerable efforts have been expended in reducing carbon emission from livestock, even before the awareness of climate change took hold, simply because feed carbon losses to the environment reduce feed conversion efficiency. The mechanisms that result in enteric carbon emissions are, therefore, quite well understood. Put simply, digestion in the rumen is characterized by feed conversion to short chain fatty acids (SCFA), the 2, 3 and 4-carbon acids, acetate, propionate and butyrate which provide the primary energy source for ruminants, microbial biomass (MBP) which is the major or even only source of protein and finally the gases, mainly CO_2 and CH_4 which are digestive waste products and obviously of major environmental concern. Since diversion of feed carbon away from gaseous losses has livestock nutritional and environmental benefits, considerable research was invested in devising feeding strategies that achieve this, and our knowledge about the underlying causes is expansive (Van Soest, 1994). Briefly, high proportional feed conversion into MBP, that is a high efficiency of microbial production (EMP), and high proportion of propionate in the SCFA, reduce digestive carbon losses (see Figure 1).

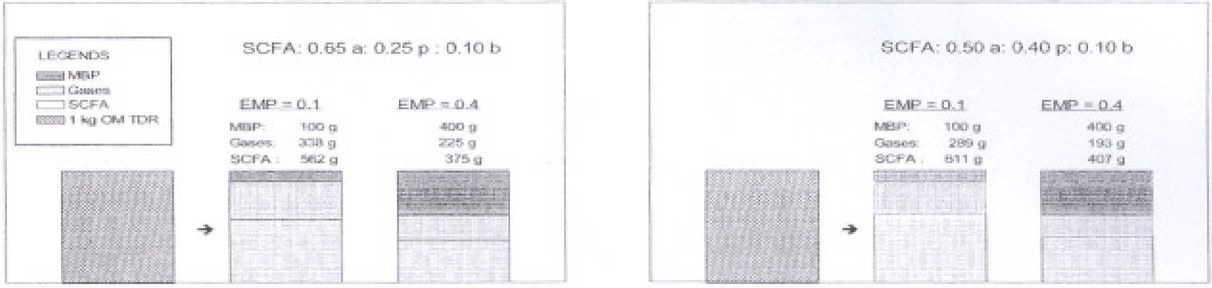

Figure 1: Partitioning of one kg of organic matter truly degraded in the rumen (OMTDR) under varying efficiencies of microbial production (EMP) and acetate (a), propionate (p) and butyrate (b) proportions (from Blümmel *et al.* 2001)

Thus total feed loss into gases (including fermentative H_2O) under high EMP and high proportional propionate production per kg feed digested in the rumen is only 193 g compared to 338 g under low EMP and proportional high acetate production (Figure 1). Increasing EMP and proportional propionate concomitantly has very substantial effect on enteric carbon emission (see also Figure 2).

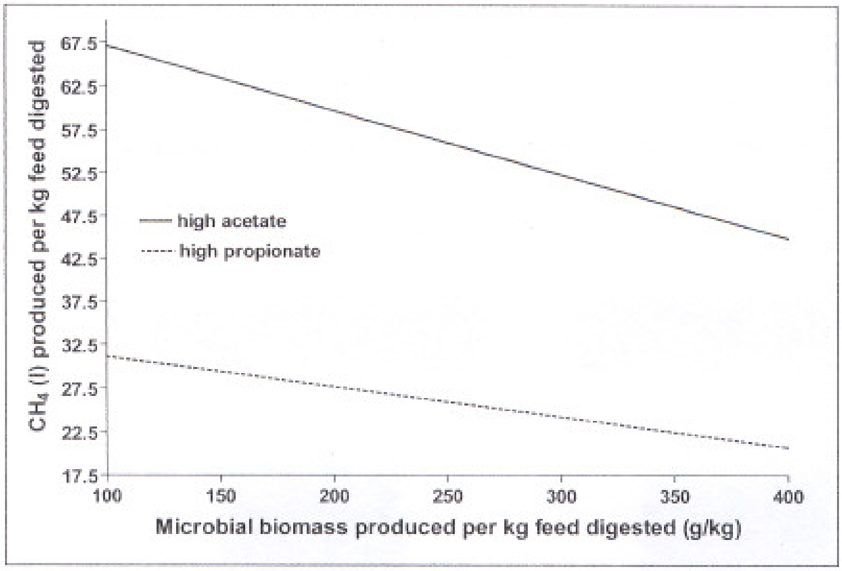

Figure 2: Methane production from 1 kg of feed digested in the rumen in relation to SCFA proportion and EMP (modified from Blümmel and Krishna 2003)

Clearly, increasing proportional propionate production will have the most substantial effect on methane emission relative to feed digested. While under proportional high acetate production methane emission could range from about 45 to 70 liter per kg digested feed depending on EMP, only about 20 to 30 liter of methane are produced under high proportional propionate production (Figure 2). In other words methane emissions could be halved. From a mere technical feed perspective, high proportional propionate production can be "simply" achieved by increasing the proportion of concentrate in the diets. In fact this approach is frequently recommended for reduction of methane emissions from livestock (for review see Martin et al. 2008). There are, however, severe draw backs associated with increased concentrate feeding to ruminants, particularly in developing countries (see also below). First, food security might be in jeopardy and food prices might increase, further burdening poor people. Also, natural resource usage of land, water and biomass is more efficient where livestock production (mainly from ruminants but not only) is based on by-products such as crop residues that do not contain human edible nutrients or on biomass harvest – through grazing and otherwise - from areas not suitable for arable land.

Besides shifting from acetate to propionate production through increase feeding of concentrate, a range of interventions have been proposed to alter the fermentation products outlined in Figure 1 for reduced carbon losses for example through use of synthetic and natural feed additives (Martin *et al.* 2008). There might be also scope for introducing new species of anerobic bacteria, capable of breaking fibre, without or with low emission of CH$_4$. This calls for a search of such bacteria and to introduce it in the digestive system of ruminants. A similar strategy was adopted for eliminating the ill-effects of feeding leucaena, where mimosine was converted into DHP (3,4 – Dihydroxy pyridone) which is a goitrogen. However, anerobic bacteria found in ruminants of certain countries could convert DHP into harmless compounds. Subsequently, this bacteria was isolated and introduced in the digestive system of ruminants in these countries, particularly, Australia (Hegde and Gupta 1994; Jones and Lowry 1984).

Effect of increasing milk production per animal on feed resource requirements and greenhouse gas emissions'

"Environment-Friendly' development of livestock production systems demands that the increased production be met by increased efficiency of production and not through increased animal numbers (Leng, 1993). Feeding strategies that increase the efficiency of production by producing more from fewer animals and less feed will result in reduced green house gas emissions. This can be demonstrated by analyzing livestock population in India and their respective level of productivity. Thus, in India in 2005/2006 the proportion of milch animals relative to total livestock numbers was less than 0.25. In addition, the daily milk yield of cross bred, local cows and buffalo was low, averaging on a 365 days lactation basis 6.44, 1.97 and 4.3 liters, respectively. The mixed herd mean milk yield can be calculated as 3.61 liters. This low productivity resulted – across the three types of livestock – in a ratio of feed metabolizable energy (ME) for maintenance and production of 1.9: 1, see Table 1.

Table 1: Summary of total livestock population, milch animal and their production and feed requirements for maintenance and production in India in 2005/2006.

	Cross Bred Cows	Local Cows	Buffalos	Total
Milch animals	8 216 000	28 370 000	33 137 000	69 759 000
Total animals	28 391 000	155 805 000	101 253 000	285 449 000
Milk yield (kg/d)	6.44	1.97	4.4	3.6 (mean)
ME required (MJ 10^9)				
Maintenance	148.0	423.3	601.2	1172.5
Production	122.6	136.4	370.8	629.8

Adopted from Blümmel *et al.* (2009)

By increasing daily milk production in a herd model (of a mixed cross-bred, local cow, buffalo population) from 3.61 to 6, 9, 12 and 15 liter per day energy expended for maintenance becomes less than energy expended for production, see Table 1. As a result the same amount of milk can be produced by less numbers of livestock leading to drastically reduced emissions of methane (see Figure 3 and 4).

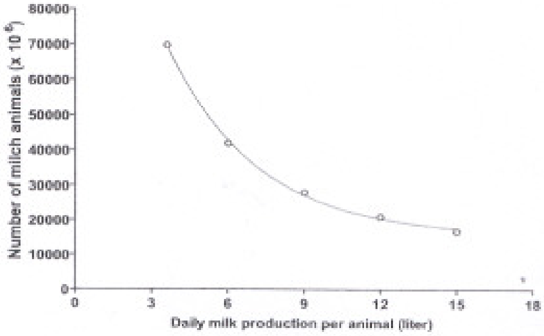

Figure 3: Relations between average daily milk production and livestock numbers

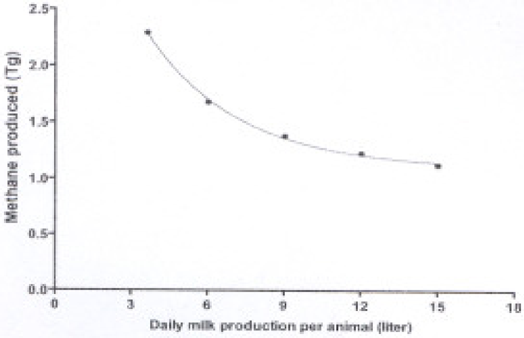

Figure 4: Relations between average daily milk production and methane emissions

Adopted from Blümmel et al. (2009)

Increasing milk productivity can be accomplished by improving the intake of feed, nutrient density of the diet (quality) or a combination of both. In the Indian context the option of improving the intake of feed (DMI > 3% of body weight) is limited due to the nature of the diet where crop residues are predominant feed resources and greens and concentrates constitute a minor proportion (Ramachandra *et al.* 2007). Assuming that there would not be any import of feed ingredients, the second option of improving the quality of diets is very limited due to limited availability of concentrate ingredients and preferential use of concentrate ingredients in the poultry sector. Allocation of additional land and water for feed/fodder cultivation is also ruled out due to competition from the food and commercial crops. In view of the above, improving the average productivity of animals from the present level to 6 liters/day appears to be more feasible while achieving 9 liters/day would be difficult due to shortage of concentrates (Ramachandra *et al.* 2007). For achieving an average productivity level of 9 liters /day with a diet of metabolizable energy content of the diet of 7.36 ME, the dry matter intake (DMI) should be around 3.6% of the body weight. Achieving a DMI of 3.6% in milch animals with a metabolizable energy content of the diet of 7.36 ME would be difficult and the diet quality would need to be improved by increasing the proportion of concentrates. Achieving high DMI is possible with an increase in the proportion of the concentrate in the diet as in the case of feed blocks where concentrate constitutes around 50% of the diet. The total feed requirement for achieving 9 liters/day on diets with a metabolizable energy content of 7.36 and 8.50 MJ works out to be 146 and 126 million tons corresponding to 3.6 and 3.1% DMI of body weight respectively. While achieving a DMI of 3.1% with better quality diet (8.5MJ ME) is feasible the, concentrate requirement would work out to be 63 million tons and concentrate availability would be a constraint. Looking into the potential availability of total concentrates at the national level, the available concentrate of 35 million tons (Ramachandra *et al.* 2007) will not be sufficient to achieve the average productivity level of 9 liters/day. Limited concentrate availability will further constraint options of mitigating CH_4 emissions by shifting from acetate to propionate production.

With current feed resources and no changes in the ratio of milk to no-milk producers the achievable level of milk production appears therefore to be between 6 and 9 liters per day (for more detailed reasoning see Blümmel et al. 2009). In fact long term field studies from 1997 to 2001 of BAIF (Gokhale *et al.* 2007) show average milk yields (converted to 365 days lactation) in cross-bred cows of 7.7 (on irrigated area) to 8.5 (irrigated area) liter per day. This was achieved by providing critical breeding and health care services coupled with regular guidance on feeding and culling of animals. The experience of BAIF, a leading NGO engaged in promoting dairy husbandry, has confirmed that with ownership of high yielding cattle and buffaloes, farmers prefer to adopt stall feeding, maintain a smaller herd and try to meet the fodder shortage by bringing marginals lands under drought-prone fodder crops. This experience can be widely replicated across the developing countries for providing livelihood to small farmers (Hegde 2006). Thus an effective extension network will have to be established to create greater awareness among small farmers to adopt best practices in livestock husbandry to increase the production, without increasing the population.

CONCLUSION

As livestock is, and will remain, an important source of livelihood, it is necessary to find suitable solutions to convert this industry into an economically viable enterprise, while reducing the ill-effects of global warming. In relation to climate change, livestock is part of the problem but also part of the solution where cropping becomes too risky and where livestock will serve as an important tool for risk mitigation and diversification. Increasing the efficiency of livestock production, that is harvesting higher productivity from fewer numbers of livestock will play a key role in mitigating environmentally adverse effects from livestock. There are, however, ceilings to this approach mainly defined by feed resources. Feeding of livestock should not lead to competition for human food sources and should be based on converting non-human edible feed sources into human edible ones. Some trade-offs between positive and negative effects of livestock have to be accepted.

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