Emission of Green House Gases from Grasslands and their Mitigation

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ABSTRACT

The concentrations of green house gases (GHG) in the atmosphere began in pre-industrial times and it continues to increase. This could result into an alarming increase in temperature of up to 5.4^{0}C by year 2100 due to a net global annual GHG emission of H 4.5-6.5 Gt C equivalent. About 18% of the world's GHG are contributed by livestock and related activities on grasslands that are spread over almost 35 million Km$^{2.}$These grasslands give livelihood to over a billion people most of who are poor. Twenty to 70% of the land surface area is degrading often due to overgrazing caused by increased demand for meat and milk, among other factors. A right set of policies that incentivises appropriate management of the grasslands have the potential to reduce up to 30% of the GHG globally. This can be achieved by mainly focussing on reduction in deforestation for pastures, silvo-pastoral improvements and reduction in enteric fermentation in animals, and appropriate manure and fertilizer management, especially on extensive grasslands. Reduction in GHG emissions will also depend upon the level of resource use efficiencies achieved, added intensification to reduce pressure on grasslands, and success or failure of appropriate market and regulatory policy interventions.

Keywords: Climate change, Greenhouse gases, Livestock production and management, Pasture and fodder crops management, Rangelands, Sequestration, Soil organic carbon.

Introduction

The concentration of Green House Gases (GHG) in the atmosphere has been on the rise since beginning of the industrial revolution (circa, 1750). This got further accentuated by massive deforestation that followed colonization of the world by European countries (Table 1). GHG regulates the temperature of the earth at around 14-15^{0}C.This includes an increase of average global temperatures by 0.6^{0}C since year 1800. The rise in temperature is expected to continue, and is projected to be in the range of 1.4 to 5.8^{0}C by year 2100 (UNFCC, 2005). A predicted rise over 2^{o}C in temperature is likely to have disastrous consequences for the earth and its environment.

This article presents the contribution of GHG from grasslands as a result of livestock activities and recommends technical and policy options for their mitigation globally. It is based on information available to FAO in its database (FAO, 2014) and its other publications[2] as well as other sources given in references.

[1]This invited key note article for the XXIII International Grasslands Congress (IGC), being held in New Delhi India from Nov. 20-24, 2015, represents the views of the authors only and not that of the FAO/UN. For FAO-UN's official views, refer to "Livestock's Long Shadow-environmental issues and options", published in 2006 by FAO Rome. Most data on the subject for this article, are also drawn from this report.

[2]The FAO publication "*Livestock's Long Shadows-environmental issues and options*" is specially recommended (Steinfeld et al, 2006) for further details.

Table 1. Concentration of important GHG (in parts per billion, ppb) and their Global Warming Potential (GWP) in the atmosphere (Blasing, 2014)

Green House Gasses (GHG)	Pre-Industrial (~1750), ppb	Current (~ 2013), ppb	Global Warming Potential (GWP)[1]
Carbon dioxide, CO_2	0.277	0.395	1
Methane, CH_4	697	1,762	28
Nitrous oxide, N_2O	271	324	296

[1]100 year time horizon

Extent of global emissions

Most GHG are contributed into atmosphere by soil organic matter (SOM) oxidation/erosion and respiration by all living organisms (Table 2). The same are taken out of the atmosphere mostly by plant photosynthesis followed by diffusion into the oceans. The balance of GHG is a net annual increase of about 4.5-6.5 billion (giga) tons (Gt) of carbon (C) (or 16.5-23.8 Gt of CO_2 eq/year). This is what causes the rise in temperatures or increased global warming. Other estimates put it at a higher maximum 9-11 Gt C eq/year. Action is required to meet this imbalance so that global warming can be checked.

Forests, crop and grasslands are all sinks of GHG. Hence, they do not emit any GHG or cause global warming; rather they sequester GHG. It is the unsustainable forestry (e.g. deforestation, poor management), agriculture (by loss of soil organic matter (SOM), about 50% of which is soil organic carbon (SOC)) and livestock production activities on grasslands that cause emissions into the atmosphere. Fossil fuel burning also contribute to GHGs to a-high extent (Table 2). Hence,GHG mitigation strategies need to focus on management of the earth by these human induced or anthropogenic factors.

Extent of grasslands and their degradation

The earth's total land mass (134.05 million Km^2) consists of about 30-31% forest areas (FAO, 2010), 26% grasslands, 10-11% crop lands and 6.8% other land uses (wastelands, settlements, water bodies etc) as shown in Table 3 (Panunzi, 2008). It is the major storehouse of GHG. For example, the top one meter of the world's land mass stores 1,417 billion (giga) tons (Gt)of carbon (C) out of which 456 Gt is stored in the top 30 cm itself. This is many more times the total atmospheric GHG. However, over 52% of the land mass is degrading globally and 20% has already degraded. This includes 73% of the 34.5(excluding 0.5 of feed crops) million Km^2 of the pastures and rangelands in dry areas. This phenomenon is explained mostly by: (i)

Table 2. Atmospheric carbon sources and sinks (Steinfeld *et al.*, 2006)

Source/Sink of the GHG	Estimated Carbon (C)eq in billion (or giga) Tons (Gt)/year	
	Into atmosphere	Out of atmosphere
Fossil Fuel Burning	4-5	
SOM oxidation/ erosion	61-62	
Respiration by all organisms	50	
Deforestation	2	
Photo-syntheses		110
Diffusion into oceans		2.5
Total	117-119	112.5
Global net increase into atmosphere (1 CO_2=3.67 C)	+4.5 to 6.5 or average~ 5.5 (20 Gt CO_2eq), (but may be upto + 9 to 11 (33 to 40 Gt CO_2eq)	

Table 3: Extend of grasslands in the world in year 2000

Land Type	**Approx. World Wide Areas**	
	Million Km2	**% of Global**
Global Land Mass	134.05	100
Agricultural Areas (including grasslands)	49.64	37.00
-Crop Lands	*14.64*	*10.92*
Grasslands	35.00	26.11
a) Pasture/ range lands	*34.5*	
b) Fodder Crops (approx)	*0.5*	
Grasslands as % of Agricultural Areas		*70.51*
Forest Areas	40.00	30-31
All other land uses (approx.)	9.1	6.8

overgrazing, compaction and erosion in Asia, and (ii) by pasture area expansion in Latin America (e.g. Amazon in Brazil).This long shadow of livestock production on the grasslandshas affected 23 of the 35 global hotspots for biodiversity loss (Mittermeier *et al.*, 2004). It also consumes 8% of the global fresh water supplies. A developing country like India has only 3.9% of its area under pasture/ rangelands while about 5% additional area is already wasteland. Eighty per cent of India's pasture/rangelands are already degraded as 90% of about 512 million livestock graze extensively, thereby turning pastures into wastelands (CSE, 1999).

Grassland's socio-economic contribution

Grasslands constitute the main basis for livestock production, providinglivelihood to around a billion of the 6.7 billion world population, out of which about 0.8 billion are poor. Globally grasslands employ about 1.3 billion people and represents about 40% of the agricultural gross domestic product (GDP) (representing 1.5% of total GDP) and almost 30% of world's economic output. Also, 33% of the world's protein intake is from this sector. With the urban population projected to increase from present 50% (of 6.7 billion) to 60% by year 2030 (FAO, 2006), the demand on the grasslands is going to further increase.

Grasslands GHG sequestration potential and livestock's contribution to emission

The land mass acts as a GHG sink. The agricultural areas (including grasslands and wastelands) have a potential to sequester 26-31% (Table 4) of the 4.5-6.5 Gt C eq/year net GHG emissions (Table 2) or atleast 10-12% (including 50% and 60% of global CH_4 and N_2O, respectively) depending on the management practices used to rebuild soil organic matter/carbon (SOM/SOC) (Steinfed et al, 2006). SOM oxidation/erosion process emit GHGat a global annual rate of 61-62 Gt C eq/year (Table 2). Lal (2004) considers the potential of the world's agricultural areas (including grasslands) carbon sink capacity to be almost 50% of the global GHG net emissions. This, by use of recommended technologies/practices to manage them well depending on soils and their management, climate, rehabilitation (and intensification) of pasture and wastelands (Darmouth College, 2014; Nair *et al.*, 2009; Sinha *et al.*, 2000; Smith *et al.*, 2008), livestock feed/manure/fertilizer management etc.Pastures can contribute, on an average, up to 30% to the agricultural sector sequestration potential if managed well, including through further intensification. Schuman *et al.* (1999) estimate the GHG sequestration potential of grasslands to be 10-

Table 4. GHG Sequestration potential of grasslands (FAO, 2014)

Items	GHG Sequestration, Gt CO_2eq/year	Sequestration potential, %
Overall Agriculture sector GHG on-farm emissions sequestration potential	5.1-6.1	26-31 % (atleast 10-12%) of Global GHG
Global C sequestration average potential of grasslands(all climates)	1-3	Average 30% of Agricultural Sector GHG
-Grasslands C sequestration (on Farm) (Temperate/Sub Temp. climate)	0.175 ±1.05	˜10-34% of Agricultural Sector GHG
-Grasslands C sequestration (on farm+ off farm) (Temperate/Sub Temp. climate)	0.8 (drained organic soils) 0.27 (mineral soils)	

34% (counting on and off farm) based on their data for European conditions which is well within range of an average 30% of agricultural lands globally.

Emissions by various livestock production cycles on grasslands

The livestock production cycle entails various on-farm and off-farm activities which produce CO_2,

CH_4 and N_2O contributing to global GHG annually. Fig. 1 shows[4] these emission for different activities in the cycle on a global basis.

As we can see, the major sources of GHG emission in Gt CO_2eqare: 34% from deforestation for creating grasslands, 25% from enteric fermentation in animals as methane and 30.5% from manures as both methane and nitrous oxide[5]. Thus the major focus to reduce GHG emissions from livestock activities should be on: (i) reducing deforestation for pasturelands, (ii) limiting enteric fermentation in animals and, (iii) managingmanuresand fertilizer (contributing 2%) better.

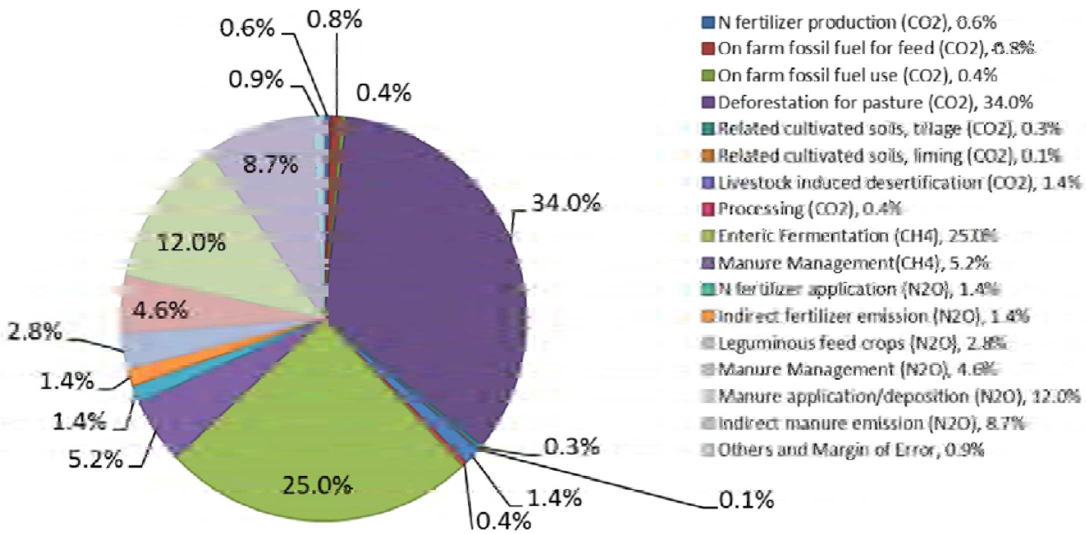

Fig. 1. Annual GHG emissions in livestock production cycle activities

[4]The emissions from respiration and absorption is balanced out and livestock related transportation is almost zero hence not shown in this Fig.

[5]A total of 5.2% of CH4 and 4.6% N2O during manure management, 12% N_2O during manure application and 8.7% N_2O emitted indirectly.

Table 5. Livestock activities life cycle impact on GHG emissions

Type of GHG emission in livestock activities globally	**Approximate annual emissions, Gt CO_2eq/year (figures with (*) include land use and changes category)**			
	Extensive systems	**Intensive systems**	**Total**	**% of Livestock total (7.1*)**
Global anthropogenic emission	**33(40)**			
CO_2	(1.8)	0.13(0.9*)	2.7	38
CH_4	1.77	0.4	~2.2	31
N_2O	1.4	0.8	2.2	31
Total emission from Livestock activities	3.2 (5*)	1.4 (2.1*)	~4.6 (7.1*)	
Livestock activities as % of Global	**10 (13*)**	**4 (5*)**		**14 (18*)**
% emission by livestock activities	70	30		

Livestock activities (Table 5) emit almost 12-18% of GHG globally (Steinfed et al, 2006), majority (70%) of which is from extensive grasslands. The intensive livestock production contributes only 30% of it. Also, only 38% of livestock produced emission are in CO_2 form (*vis a vis* a total of about 60% present in the atmosphere) while 31% are methane and nitrous oxide each. Thus free animal grazing on rangeland (extensive systems), manure and fertilizer management in addition to halting deforestation for grasslands (and for any other use) should receive priority for GHG reduction from animal activities on grasslands. Intensification of livestock production systemswill reduce pressure on grasslands thus produce less GHG.

The global GHG net emission by livestock includes 9% at production level (7% by land use changes i.e. forest conversion for pastures) increases to 18% during entire livestock system's life cycle. This includes 65% of N_2O mostly from manure, 37% of CH_4 as part of agriculture sector emission and64% of anthropogenic ammonia emission which directly contributes to acid rains. Incidentally, this level is higher than the emission of entire road transport sector.

Recent changes in livestock sector impacting grasslands

With the increase in purchasing power of people in emerging countries especially, Brazil, China and India, there has been an increase in consumption of meat and milk. This trend is expected to continue for next decade or two (FAO, 2006) and exacerbate the problem of GHGs.

Since year 1970, worldwide meat production has increasedthree Folds and milk

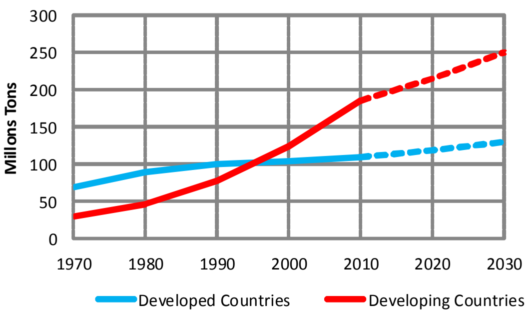

Fig. 2: Past and projected (dotted) meat production in developed and developing countries

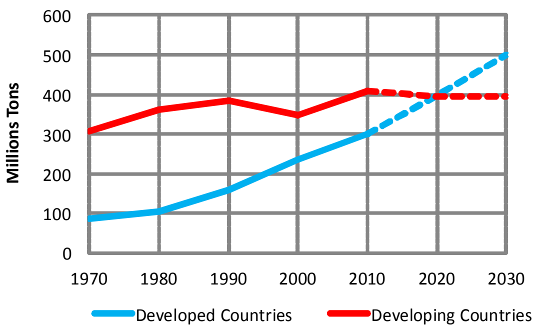

Fig. 3: Past and projected (dotted) milk production in developed and developing countries

production has doubled (FAO, 2014). Since 2000, while increase in developed countries in meat production (Fig. 2) was modest, 50% of the increase came from China, mostly in the form of poultry and pigs. In milk production, while developed countries are expected to make strides (Fig. 3), 33% of increase in milk production was achieved by India. These have resulted in: (i) deforestation of the Amazons in Brazil for meat, and (ii) continued degradation of pasture lands in India, since both countries practice extensive free grazing. In developed countries, however, the increase in production is achieved through intensification and industrialization. The US-EPA (2014) report on IPCC Land Use, Land-Use Changes and Forestry category (IPCC, 2006) for 2012 in USA, shows a decrease of 0.1 million Km^2(out of a total 8.03 million Km^2 of all land uses) of agricultural and pasture lands. Converted to forestry, this resulted into a net carbon sequestration of 2.3 million tons. From 1990 to 2012, about 10 million Km^2 area under crop and grass landsare reported to be converted to mainly forestry and some to settlements. However, latest satellite image analysis (SWCS, 2015) for USA shows that almost 0.03 million Km^2 (77% from grasslands) was converted to crop lands (corn and Soybean) for bio-fuels between 2008-2012. Thus, the bio fuel policy has implications for GHG emission as it is often at the cost of grasslands in the USA.Even though these crops also sequester carbon, it does so less than the grasslands (potentially 0.5-0.8 verses 1.7 Tons/ha/year C eq) due to much less soil organic matter (SOM) incorporation.

Technical measures to mitigate GHG emissions in grassland and in livestock management

A list of proposed measures for mitigating GHG emissions from grassland, their apparent effects on reducing emissions of individual gases (mitigating effect) and an estimate of scientific confidence that the proposed practice can reduce overall net emissionsbased on meta analysis of 150 studies globally with agreement in 74% studies made by Soussana *et al*. (2010) is adapted in Table 6. An estimate of SOC sequestration in Tons/ha/year C eq. in top 30 cm of soils, is also given from various sources, studies, models (Soussana *et al*., 2010, Lal, 2004, Steinfeld, 2006 IPCC, 2003. 2007 etc). These studies show that up to 1.7 T/ha/year C eq. of GHG can be mitigated by grasslands globally *vis a vis* only 0.9 by other arable lands.

Table 7 (Soussana *et al*., 2010) informs of the GHG mitigation effect of various livestock management improvements, measures and practices. It is noteworthy, however, that while sequestration is for sure expected, it is not possible to easily quantify how much as the data is not easily available. There is a need for further work to harmonize these data with information that may be scattered over various research institutions or private industry laboratories.

Policy options to mitigate GHG emissions by grassland and livestock management

Overall, there appears a general lack of understanding among various stakeholders on the nature and extent of livestock's impact on the environment. The broad and complex interactions between the two are not easily segregated and understood adequately. The remoteness of livestock productionin many of the world's marginal areas further reduces the reach of regulatory authorities. Livestock products, especially dairy and beef, continue to be heavily subsidized amounting to almost 32% of total farm income in OECD countries (Steinfeld *et al*., 2006). At the same time, the world's grasslands have higher GHG

Table 6. A list of proposed measures for mitigating GHG emissions by grassland management

Measure	Practices/ Techniques	Mitigative Effects[a]				Confidence[b]	
		CO_2	CH_4	N_2O	T/ha/yr C eq (30 cm soil)	Agree	Evi-dence
Global overall improved arable lands potential		+			0.90	***	**
Conversion of grasslands to bio-fuels crops		+			0.5-0.8	+	*
Global potential by overall improved grasslands management		+			1.7	***	**
Grazing land management/ pasture improvement	Set-aside lands, appro-priateland-use change	+	+	+	0.5	***	**
	grazing intensity	±		±	0.06	*	*
	Increased productivity (e.g. fertilization)	+		±		**	*
	nutrient management	+		±	0.14-0.44	**	**
	Species introduction	+		±		*	**
	Agro-silvo-pastoral				1.8-3.8		
	Fire management	+		±	0.01-1	*	*
	Rotational grazing	+			0.1	*	*
Avoid drainage of organic soils		+	-	±	±	**	**
Desert control measures and soil restoration					0.25-0.35		
Restoration of degraded lands by erosion control, organic amendments, nutrient amendments		+		±	0.19-0.2	***	**
Desertification control-: Full package: measures, restoration of degraded lands, appropriate land use, appropriate crop and grassland management practices		+			1.0	**	**

a ‘+’ denotes sequestration (positive mitigative effect); ‘“’ denotes increased emissions or suppressed removal (negative mitigative effect); ‘±’ denotes uncertain or variable response.

b An* denotes qualitative estimate of the confidence in describing the proposed practice as a measure for reducing *net* emissions of GHGs, expressed as CO_2 eq. ‘Agree’ refers to relative degree of agreement or consensus in the literature; ‘Evidence’ refers to the relative amount of data in support of the proposed effect (the more *s, the greater the amount of evidence in both cases).

emissions than the global road transport sector.With the rise in per capita incomes of the world population, the inverted U shaped relationship between income and environmental degradation, known as “environmental kuznets curve” (Dinda, 2005), gives hope, that willingness to act for environmental protection is going to increase with time.Given the neglect that the sector has received so far, it can only be hoped that even minor changes could bring about a major impact. In general, environmental policy implementation hinges on a combination of regulatory approach and economic instruments. Other additional instruments include technical support and related capacity building, institutional development and infrastructure development. FAO’s recommendations (Steinfeld *et al.*, 2006) for related public policy are summarized below:

1. Limit livestock’s land requirement by enhancing its productivity for reverting it back to woodlots in developing countries and forests in industrialized countries by careful intensification of existing grazing lands, improved livestock, including the use of more efficient breeds, and by increasing feed crop productivity and through land set-aside schemes.

2. Promote research and development in cutting edge technology to build on

Table 7. A list of proposed measures for mitigating GHG emissions by livestock management

Measure	Practices/ Techniques	Mitigative Effects[a]			Confidence[b]	
		CO_2	CH_4	N_2O	agree	Evidence
Livestock management	Improved feeding practices		+		***	***
	Specific agents/dietary additives		+		**	***
	Long term structural &management changes &animal breeding		+		**	*
Manure/ bio-solid management	Improved storage/handling, covered shaded composting		+	±	***	**
	Anaerobic digestion		+	±	***	*
	More efficient use as nutrient source (SOM incorporation& application)	+		+	***	**
Bio-energy: crops, solid, liquid, biogas, residues		+		±	***	**

Note: a, b, +, -, *, ± symbols as explained under table 6.

indigenous knowledge, for example, spiritually protected pastures and woodlots in many South and S-E Asian countries.

3. Reduce overgrazing for halting grassland degradation by grazing fees and removing obstacles to mobility in common property pastures by provision of long term leases or land use rights in government/ community grasslands and land titles where private investment is required.

4. Correct distorting prices, for example, meat and milk subsidies in OECD countries and availing land and water without charges in developing countries that discourage efficient resource use, and foster misallocation and uncontrolled degradation of resources.

5. Incentivise GHG sequestration by pastoralist, herdsmen and land owners and integrate them into environmental management and as protectors of bio-diversity and reserves/protected areas/ national parks.

6. Set standards and targets for improved feed to reduce enteric fermentation in animals, to regulate the use of agro-chemicals, manure's storage and application (incorporation within 24 hours at 3 crop growth stages) | and make provision for fines and charges for non compliancein case of feed and agro-chemicals.

7. As soil organic matter incorporation and its decomposition depends on moisture content of the soils, for reduced water use[6] introduce water pricing, limit inputs, proper equipment, zoning regulations and taxes to discourage large concentrations near cities. Also, secure water rights making it a part of watershed management.

8. Integrate grassland/livestock sector emissions into national GHG reduction targets being provided voluntarily to UNFCCC so that investment can flow to mitigate emissions from grasslands. Make efforts to include GHG sequestration from grasslands a part of Land Use, Land Use Change and Forestry (LULUCF) category so that carbon sequestration from them

[6] 8% of global fresh water used for livestock sector.

can qualify for Clean Development Mechanism (CDM) carbon trading as Certified Emissions Reduction (CERs) or create other markets or ways of compensation.For example, GEF has promoted payments for carbon sequestration and bio-diversity conservation on pasturelands in Costa Rica and Nicaragua (Pagiola et al, 2004).

Conclusion

In general, with improved grassland and livestock resource use practices achieved through appropriate policy measures and technical and operational techniques, the GHG emission can be reduced by up to 1.7 Tons/ha/year in equivalent carbon. This can help curtail global emissions by almost up to 30%. These practices/measures include control of deforestation for grasslands (and other land uses) and desertification, including by setting aside lands, improved silvo-pastoral systems, intensification to reduce pressure on extensive grazing lands, improved breeds and feeds for animals to reduce their enteric fermentation, improved bio-fuel, fertiliser and manure management including its storage, handling and application etc. These are all very well known practices with proven efficacy but often been ignored in the past, especially on extensive pasture lands. Hence, any improvement can have significant impact. In addition, pricing mechanisms (of water, land, waste sink use, removal of perverse subsidies etc) by reckoning full economic and environmental costs can be effective. At the same time, assuring land, water, pasture and forest rights, can reduce environmental damage by livestock production from grasslands. Reducing distorting subsidies, by paying for various environmental services (like watershed management, carbon sequestration) to herders, pastoralists and land owners, specially on extensive pastures and by integrating them into the spiritual and cultural relations with natural resources can go a long way in sequestering GHG in the grasslands, and in improving livestock production for a healthier earth.

For wiser decision making, further data analysis, research and development arerecommended to quantify the GHG sequestration potential of (i) proposed improvements in livestock production cycle, (ii) market based policies, especially in developing countries where extensive grazing is predominant, and (iii) in cutting edge technology to build on indigenous knowledge.

References

Blasing, T. J. 2014. *Recent green house gas concentrations*. CDIAC, US Dept. of Energy, North Ridge National Lab. http://cdiac.ornl.gov/pns/current_ghg.html

CSE (Centre for Science and Env.). 1999. *Milk that ate the grass*. Down to Earth. April 15. pp 1-5.

Dartmouth College. 2014. "Restoring wetlands can lessen soil sinkage, GHG emissions, study finds." *Science Daily*, 30 October. www.sciencedaily.com/releases/2014/10/141030133400.htm.

Dinda, S. 2005. A theoretical basis for the env. Kuznets curve Eco. *Economics* 53, pp 403-413.

FAO. 2006. *World agriculture towards 2030/2050*. Rome.

FAO. 2010. *Forest resources assessment*. https://www.fao.org/forestry/28808/en/

FAO. 2014. *FAO statistical on line data base*. Rome. http://faostat3.fao.org/default.aspx

IPCC. (International Panel on Climate Change). 2000. *Special report on land use, land-use change and forestry*. Cambridge University Press, UK.

IPCC. 2003. *Good practice guidelines for greenhouse gas inventories for land-use, land-use change & forestry*. Institute of Global Environmental Strategies (IGES) Kanagawa, Japan.

IPCC. 2007. *Climate Change. 2007: the physical science basis. Contributions of working group I to the fourth assessment report of the IPCC.* Cambridge University Press, Cambridge, UK.

Lal, R. 2004. Soil carbon sequestration impact on global climate change and food security. *Science*, 304: 1623-1627.

Mittermeier, R. A., P. R-Gil, M. Hoffmann, J. D. Pilgrim, T. B. Brooks, C. G. Mittermeier, J. L. Lamoreux aand G. A. B. Fonseca. 2004. *Hotspots Revised: Earths biologically richest and most endangered eco-regions*, Mexico City, CEME. pp 390

Nair, P.K.R., B. Mohan Kumar and V D Nair. 2009. Agro-forestry as a strategy for carbon sequestration. *Jr. of Plant Nutrition and Soil Science*.172:10-23.

Pagiola, S. K. von Ritter and J. Bishop. 2004. *Assigning the economic value of eco-system conservation*. Environment Departmental Paper No. 101, World Bank, Washington DC.

Panunzi, E. 2008. Are grasslands under threat- brief analysis of FAO-STAT date on pasture and fodder crops. http://www.fao.org/ag/agp/agpc/doc/grass_stats/maps/ map1.htm

Schuman, G. E., J. D. Reeder, J. T. Manley, R. H. Hart and W. A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of mixed-grass range land, *Ecological Applications* 9: pp 65–71. http://dx.doi.org/10.1890/1051-0761(1999)009[0065: IOGMOT]2.0.CO;2

Sinha, R. K., Sonu Bhatia and Ritu Bisnoi. 2000. *Desertification control and rangeland management in the Thar Desert of India.* RALA Report No. 200. IGCHEEPS, Rajasthan University, Jaipur India. pp 115-123.

Soussana, J.F., T. Tallec and V. Blanfort. 2010. Mitigation the green house gas balance of ruminant production systems through carbon sequestration in grasslands. In *Animal*. Chapter 4, Cambridge University Press, Cambridge, UK. pp 334-350.

Steinfeld, H., P. Gerber, T. Wassenaar, V Castel, M. Rosales and C. De Haan. 2006. *Livestock's long shadows-environmental issues and options*. FAO, Rome. p 390.

SWCS (Soil and Water Conservation Society, USA). 2015. Policy thought to be good for environment can have undesired consequences. *Conservation News Brief*, October 8. p1.

UNFCC. 2005. Feeling the heat.http://unfcc.int/esential-_background/feeling_the_heat/items/ 2918.php

US-EPA. 2014. Land use-land use changes and forestry. Chapter 7, *Inventory of Green House Gas Emissions and Sinks*: 1990-2012, EPA-R-14-003, pp. 1-82.