Supplemental Material Concerning "Deforestation Associated with Pasture or Livestock Feed Crop Expansion", Presented in Appendix B of *Cumulative Global Surface Temperature Change Values Associated With Global CH_4, CO_2, and N_2O Emissions And Livestock-Related GHG Emissions, 1950 -2016. By Todd Shuman, Senior Analyst, WUMU-WURU, 06/30/2017.*

1. [Average of carbon dioxide sequestered by Amazonian primary rainforest]

"*Environmental change and the carbon balance of Amazonian forests"*
Luiz E. O. C. Aragao, Benjamin Poulter, Jos B. Barlow, Liana O. Anderson, Yadvinder Malhi, Sassan Saatchi, Oliver L. Phillips, and Emanuel Gloors 8 Biol. Rev. (2014), **89**, pp. 913–931, doi: 10.1111/brv.12088

"One of the key components of the global carbon cycle is net primary productivity (NPP), defined as the difference between photosynthesis (gross primary productivity, GPP) and autotrophic respiration (R_a)." Page 915

"NPP of Amazonian forests tends to be higher in the western than in the eastern portion of the basin (Malhi *et al.*, 2004, 2009*a*; Aragao *et al.*, 2009). This variation is related to higher soil fertility in the younger alluvial soil of western Amazonia in comparison the highly weathered 'nutrient-poor' soils in eastern Amazonia (Quesada *et al.*, 2010). In Amazonia, NPP pattern is strongly related to soil P availability and soil texture, and varies between +9.3±1.3 Mg C ha^{-1} $year^{-1}$, at a white sand plot, and +17.0±1.4 Mg C ha^{-1} $year^{-1}$ at very fertile anthropogenic 'dark-earth' sites, with an overall average of +12.8±0.9 Mg C ha^{-1} $year^{-1}$ (Aragao et al., 2009; Mercado et al., 2011)." Page 916

Aragao, L. E. O. C., Malhi, Y., Metcalfe, D. B., Silva-Espejo, J. E., Jimenez, Navarrete, D., Almeida, S., Costa, A. C. L., Salinas, N., Phillips, O. L., Anderson, L. O., Alvarez, E., Baker, T. R., Goncalvez, P. H., Huaman-Ovalle, J., Mamani-Solorzano, M., Meir, P., Monteagudo, A.,Patino, S., Penuela, M. C., Prieto, A., Quesada, C. A., Rozas-Davila, A., Rudas, A., Silva, J. A. Jr. & Vasquez, R. (2009). "Above- and below-ground net primary productivity across ten Amazonian forests on contrasting soils." *Biogeosciences* **6**, 2759–2778.

Mercado, L. M., Patino, S., Domingues, T. F., Fyllas, N. M., Weedon, G. P., Sitch, S. Quesada, C. A., Phillips, O. L., Aragao, L. E., Malhi, Y., Dolman, A. J., Restrepo-Coupe, N., Saleska, S. R., Baker, T. R., Almeida, S., et al. (2011). "Variations in Amazon forest productivity correlated with foliar nutrients and modelled rates of photosynthetic carbon supply." *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences* **366**(1582), 3316–3329.

Overall annual average of carbon dioxide sequestered by Amazonian primary rainforest: +12.8±0.9 Mg C ha^{-1} $year^{-1}$

2. [1960-1973]

Forest to Pasture: development or destruction? James J. Parsons, Rev. Biol. Trop., 24 (Supl.l) : 121-138, 1976

"Statistics on the area in planted pasture in Central America and Panama are incomplete and unreliable. Probably better than two-thirds of the agriculturally productive land is devoted to livestock, and the share is increasing (Fig. 2). In Panama the area in planted pasture increased 43 percent between the 1960 and 1970 agricultural censuses, to 965,000 ha; in Nicaragua it increased by 48 percent, to 1.7 million ha, between 1963 and 1971; in Costa Rica a startling 62 percent to 1 .5 million ha, in the 10 years 1963-1973. On the Pacific coastal plains of Guatemala, and on the north coast of Honduras potreros have been expanding at comparable rates." (page 124)

3. [1965-1975]

Conversion of Tropical Moist Forests, Myers, N. (1980), Pages 44-45 http://www.nap.edu/catalog.php?record_id=19767 [Myers, Norman; Committee on Research Priorities in Tropical Biology; National Research Council]

"Other figures suggest that only half as much forest has been eliminated -- at any rate, during the recent past. For example, the main forestry agency, IBDF, asserts (according to several officials consulted in February 1979) that during the period 1966-1977 a total of 114,697 km^2 of forest were eliminated…The agency charged with responsibility for Amazonia, SUDAM, states (according to several authorities consulted in February 1979) that during the period 1965-1975, a total of 115,000 km^2 were accounted for (45,000 through cattle raising, 35,000 through smallholder settlement and other agricultural colonization, 30,000 through highway construction, and 5,000 through timber harvesting); this makes an average of 12,777 km^2 per year."

TABLE 5 Central America and Brazil: Beef Production and Exports (Area-km^2)

Country	Pasture 1961	1975	Forests/Woodlands 1961	1975
Brazil	1,318,800	1,700,000	5,268,000	5,100,000

SOURCE: U.S. Department of Agriculture. 1978 [Page 46]

381,200 km^2 = 38,120,000 ha pasture increase;
168,000 km^2 = 16,800,000 ha forest/woodland decrease

4. [1980-1989]

Livestock & the Environment, FINDING A BALANCE Cees de Haan, Henning Steinfeld, and Harvey Blackburn, 1997, Study Sponsors: Commission of the European Communities, Food and Agriculture Organization of the United Nations, World Bank

Chapter 2: *Livestock grazing systems & the environment - Grazing systems and tropical rainforests*

*Plant and animal biodiversity***.** "For the rainforests, data on biodiversity losses are dramatic. Since 1950, about 200 million hectares of tropical forest have been lost, with the result that of some unique plant and animal species, in one of the world's richest sources of biodiversity have become extinct. Forest areas of Central America have declined from 29 to 19 million hectares, since 1950, although, since 1990, the rate of deforestation in this region has fallen. In Central America in the 1980s rainforests disappeared at the rate of 430 thousand hectares per year but this declined to 320 thousand hectares over the period 1990 to 1994.

In South America, the deforestation rate in the 1980s was about 750 thousand hectares per year. It is not known, whether this rate has declined over the last years. *Table 2.2* gives quantitative information on the rate of degradation, and the current area of remaining tropical rainforest.

Much of the deforested areas in Latin America went into ranching, sometimes after initially being cropped. In Central America, pasture areas have increased from 3.5 million to 9.5 million hectares, and cattle populations have more than doubled, from 4.2 million head in 1950 to 9.6 million in 1992 (Kaimonitz, 1995).

In Brazil, about 70 percent of the deforested areas are converted into ranching. In Asia and sub-Saharan Africa, the decline in the forest area is mainly the result of crop expansion and not livestock related....

Relative importance of different pressure factors in deforestation. As in the case of desertification, there have been several quantitative estimates on the individual importance of these factors. However, unlike in the case of desertification, the direct cause is easier to ascertain, making these estimates more relevant.

Nevertheless, there are some overlaps, especially as logging is often a precursor for cropping, which in turn often precedes ranching. This means that even in tropical rainforests the cause of environmental damage is hard to apportion. For the record, *Table 2.3* provides some estimates. Overall, 'slash and burn' agriculture is said to cause 60 percent of the deforestation (Bruening, 1991)."

Table2.3 Some estimates of the main causes of deforestation (percent of total deforestation).

Region	Crops	Livestock	Forest exploitation
South America	25	44 (70 in Brazil)	10
Asia	50-60	Negligible (Philippines & Indonesia to some extent)	20
Africa	70	Negligible	20

Source: Bruenig, 1991.

[Reference: Bruenig, J. (1991). Tropical Forest Report. Government of the Federal Republic. Bonn, Germany, 118 pp.]

5. [1980-1990]

FAO Livestock Sector Brief – Brazil; July 2005, page 8

Brazil: 1980-1990 Livestock Feed Area – Pasture/Maize

1980 Pasture 1990 Pasture
1,714,140 km^2 1,842,000 km^2

1980 Maize 1990 Maize
15,946,400 tonnes 16,970,700 tonnes

[Supplemental Information – Livestock Feed Crop Area and Tonnage - Brazil: 1980-1990, Pasture/Maize
1980 Pasture: 1,714,140 km^2 1990 Pasture: 1,842,000 km^2
Pasture expansion in Brazil: 1980-1990: 127,860 km^2, or 12,786,000 ha increase
1980 Maize: 15,946,400 tonnes 1990 Maize 16,970,700 tonnes
Maize tonnage expansion in Brazil: 1980-1990: 1,024,300 tonne increase
(Source: FAO Livestock Sector Brief – Brazil; July 2005, page 8)]

[Note: Foregone forest-related CO_2 sequestration that may have resulted from forest conversion into maize-related livestock feed production in Brazil was not analyzed in the primary document.]

6. [1990-2006]

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B. & Steinfeld, H. 2013. *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment.* Food and Agriculture Organization of the United Nations (FAO), Rome.

"In Argentina, the annual increase of area dedicated to soybean is much larger than the increase of total arable land (Table C2), indicating that there has been a shift in land use from other crops to soybean. According to FAOSTAT statistics, 44 percent of the new soybean area was gained against other crops, while the rest was gained against forest (22 percent) and other land (31 percent). The latter category covers natural vegetation that does not include forest and grazed natural grasslands.

The reported annual increase of soybean area in Brazil is 534,000 ha (Table C2). We assumed a simplified pattern of deforestation in the Amazon, in which cleared land is first used as pasture and/or crop land, and then left as fallow land. The latter, classified as 'other land' in FAOSTAT, is occupied by weeds, grasses, shrubs and, partly, by secondary forest. Under this assumption, every year roughly 2.9 million ha are converted to arable land and grassland. At the same time, agricultural land is abandoned at a rate of 1.6 million ha per year. The annual net increase of arable land and grassland is 0.53 and 0.75 million ha, respectively. We thus assume that all incremental soybean area is gained at the expense of forest area." pp. 135-136

Table C2. Average annual land-use change rates in Argentina and Brazil (1990-2006)

	Argentina	*Brazil (1000 ha)*
Agricultural area	+351	+1,288
Grasslands	-7	+753
Arable land & permanent crops	+358	+535
Soybean area	+648	+534
Forest area	-149	-2,855
Other land	-201	+1 567

Source: FAOSTAT (2009). Page 135

Argentina Soya Brazil Soya A+B Soya/yr A+B Soya [Total 1990-2006]
0.22 · 648 = 143/yr; 1 · 534 = 534/yr; 143+534=**677/yr**; 677,000/yr · 17 yr = **11.51 million ha**

"Table C4 presents the countries in which the increase in pasture area was largely facilitated by a decrease in forest area, and our estimates show that about 13 million hectares were deforested for pasture establishment." Page 137

Table C4. Pasture expansion against forestland in Latin America (1990-2006)

Country	Pasture change area (1000 ha)	%
Brazil	10,212.3	77.2
Chile	1,150	8.7
Paraguay	1,040	7.9
Nicaragua	454.3	3.4
Other*	365	2.8
Total	**13,221.6**	**100.0**

* 'Other' category includes: Honduras, Ecuador, Panama, El Salvador and Belize.
Source: Authors' calculations based on FAOSTAT data. Page 137

[Note: Foregone forest-related CO_2 sequestration that may have resulted from forest conversion into maize (corn) production in Brazil was not analyzed in the primary document. Maize is listed as the primary livestock feed crop in Brazil (with production rising from just under 17 million metric tonnes in 1990 to just over 28 million metric tonnes by 2002 – see FAO Livestock Sector Brief – Brazil, July 2005, page 8 above.) The primary document also does not include any analysis of foregone forest-related CO_2 sequestration that may have occurred as a result of forest conversion into sorghum, bran, and other oil-crop-livestock feed-related production in Brazil and other Latin American countries.]

7. [2000-2013]

The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013, Potapov et al. Sci. Adv. 2017; 3: e1600821 13 January 2017

Pages 2,6,7

“From 2000 to 2013, the global IFL area decreased by 7.2%, a reduction of 919,000 km^2 (Table 1). Tropical regions are responsible for 60% of the total reduction of IFL area. In particular, tropical South America lost 322,000 km^2 of IFL area, whereas Africa lost 101,000 km^2 … Three countries comprise 52% of the total reduction of IFL area: Russia (179,000 km^2 of IFL area lost), Brazil (157,000 km^2), and Canada (142,000 km^2). Proportional to the year 2000 IFL area, the highest percentages of IFL area reduction were found in Romania, which lost all IFLs, and Paraguay, where 79% of IFL area was lost; Laos, Equatorial Guinea, Cambodia, and Nicaragua each lost more than 35% of their IFL area (Fig. 3 and Table 2) ... In tropical South America, expansion of agriculture overall and of pastures in particular contributed 65 and 53% of the overall IFL area loss, respectively. Expansion of industrial crops (for example, soybean) was not detected as a cause of IFL area reduction using our sample-based analysis. IFLs were not directly affected by industrial crop expansion in South America because it mainly occurred in areas previously converted to pastures (27).”

8. [2014-2016]

Recent information concerning *Latin American* LSSC-related tropical forest destruction in relation to LFC-related soybean production *over the 2014-2016 period* have been provided by Tabuchi, Rigby, and White (2017) and Bellantonio et al. (2017).

[Tabuchi et al.: “In the Brazilian Amazon, the world’s largest rain forest, deforestation rose in 2015 for the first time in nearly a decade, to nearly two million acres from August 2015 to July 2016. That is a jump from about 1.5 million acres a year earlier and just over 1.2 million acres the year before that, according to estimates by Brazil’s National Institute for Space Research…Here across the border in Bolivia, where there are fewer restrictions on land clearance, deforestation appears to be accelerating as well…About 865,000 acres of land have been deforested, on average, annually for agriculture since 2011, according to estimates from the nongovernmental Bolivia Documentation and Information Center, an area nearly the equivalent of Rhode Island in size. That figure has risen from about 366,000 acres a year, on average, in the 1990s and 667,000 acres a year in the 2000s... A major culprit is the cultivation of soy, which has jumped more than 500 percent in Bolivia since 1991, to 3.8 million hectares in 2013, according to the most recent agricultural censuses. Little of that soy is consumed domestically. The vast

majority is processed and exported as animal feed in a commodities trade that serves a global appetite for hamburgers, chicken and pork."

(2/24/2017, New York Times, *Amazon Deforestation, Once Tamed, Comes Roaring Back*, https://www.nytimes.com/2017/02/24/business/energy-environment/deforestation-brazil-bolivia-south-america.html?smid=fb-share&_r=0

"Approximately three quarters of the world's soy goes to animal feed…This soy production has left an enormous scar on the Earth's surface. More than one million square kilometers of our planet - equivalent to the total combined area of France, Germany, Belgium and the Netherlands - are dedicated to growing soy… In South America, soy and cattle interests have converted vast areas of the Amazon rain forest, Brazil's Cerrado, the Argentine Chaco, Bolivian lowland forests and the Atlantic Forest in Paraguay from diverse native ecosystems into soy monocultures. From 2001-2010, an average of approximately four million hectares of forests were destroyed each year, mostly for soy and cattle."

http://www.mightyearth.org/mysterymeat/ March 3, 2017, Report by Marisa Bellantonio, Glenn Hurowitz, Anne Leifsdatter Grønlund and Anahita Yousefi, RFN and Mighty Earth; The Ultimate Mystery Meat, Exposing the Secrets Behind Burger King and Global Meat Production.

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Opio, C., P. Gerber, A. Mottet, A. Falcucci, G. Tempio, M. MacLeod, T. Vellinga, B. Henderson, and H. Steinfeld. 2013. *Greenhouse Gas Emissions from Ruminant Supply Chains—A Global Life Cycle Assessment*. Food and Agriculture Organization of the United Nations (FAO), Rome.

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Supplement to the Supplement

[1950-1975]

A. Conversion of Tropical Moist Forests, Myers, N. (1980), Pages 44-45 http://www.nap.edu/catalog.php?record_id=19767 [Myers, Norman; Committee on Research Priorities in Tropical Biology; National Research Council]

"Between 1950 and 1975, the area of man-established pasture in Central America more than doubled, almost entirely at the expense of primary moist forests. The numbers of beef cattle also more than doubled, though the average beef consumption on the part of Central American citizens actually declined, the surplus meat being exported to North America among other developed-world markets."

[1965-1990s-2005]

B. FAO Livestock Policy Brief 03, Cattle Ranching and Deforestation, 2005, Pages 1 and 2

“Over the past quarter century, forests have been cleared from an area the size of India. Particularly in Central and South America, expansion of pastures for livestock production has been one of the driving forces behind this wholesale destruction.”

“During the 1990s, the portion of the globe covered by forests shrank by an estimated 94000 square kilometres a year, an area roughly the size of Portugal. Most of the land that was cleared and burned was converted to growing crops and grazing livestock (*graph 1*). In Latin America, in particular, most of the deforested land ended up as pasture used to raise cattle in extensive grazing systems.”

“The link between deforestation and cattle ranching is strongest in Latin America. In Central America, forest area has been reduced by almost 40 percent over the past 40 years. Over the same period, pasture areas and the cattle population increased rapidly (*graph 2*).”

[1994-2004-2010 Projection]

FAO Livestock Policy Brief 03, Cattle Ranching and Deforestation, 2005, Page 2

“The Livestock Environment and Development Initiative (LEAD - www.lead.virtualcentre.org) recently used a sophisticated system for modeling land use change to predict the scale and location of deforestation and pasture expansion for the year 2010. The results confirm that extensive grazing of cattle will continue to expand, mostly at the expense of forest cover. If the projections are accurate, by the year 2010 cattle will be grazing on more than 24 million hectares of land that had been forest a decade earlier. Nearly two-thirds of the deforested land will be converted to pasture. The study produced a map highlighting ‘hotspots’ of forest clearing and pastures expansion that can be used to focus the agenda for policies and research (*see map, facing page*). A substantial and increasing share of deforested cropland is also dedicated to expanding livestock production through intensive, large-scale production of soybeans and other feed crops. Between 1994 and 2004, land area devoted to growing soybeans in Latin America more than doubled to 39 million ha, making it the largest area for a single crop, far above maize, which ranks second at 28 million ha. This trend has been driven mainly by

the sharp increase in demand for livestock products, which led to a tripling of global meat production between 1980 and 2002. Most of this increased production came from large-scale, intensive livestock operations in China and other East Asian countries, where land scarcity has led producers to rely increasingly on imported feed. This demand for feed, combined with other factors, has triggered increased production and exports of feed from countries like Brazil where land is relatively abundant, partly as a result of deforestation."