Supplemental Material for Historical And Future Carbon Emissions From Croplands

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1. Region Definitions

The region definitions used in this work, where some ambiguity might exist, are: Western Europe (OECD Europe as of 1990, including Turkey), Eastern Europe (including Albania and the countries of the former Yugoslavia), the Former Soviet Union (including Moldova, Estonia, Latvia, and Lithuania), China (includes Cambodia, Hong Kong, North Korea, Mongolia, and Vietnam), and Korea (South Korea only). Country boundaries over time are fixed. As discussed below, trends in historical production areas are used to scale present-day FAO data to estimate historical values, which eliminates the need to consider changes in country boundaries.

2. Cropland data development

Harvested crop areas for recent decades are obtained from FAO data, adjusted for double cropping using the GCAM data processing methodology (Kyle et al., 2011). For the future, harvested areas were estimated made by scaling FAO 2005 data by the trend in cropland area in the GCAM 4.5 scenario. Harvested area in the past is obtained from the data sources described below. Other arable land is estimated by subtracting the harvested area from the total cropland areas from by Hurtt et al. For other arable land in the future, the 2005 value is adjusted by the trend in other arable land area in the GCAM 4.5 scenario.

For recent years, crop NPP values are calculated from harvest data using the methods of Hicke and Lobell (2004) as implemented in GCAM (Kyle et al., 2011). Regional values were calculated for years centered on 1962, 1970, 1980, 1990, 2000, and 2005, based on harvest data from the Food and Agriculture Organization (FAO) of the United Nations ("FAOSTAT Production," 2012).

Values were also estimated for the years 1950, 1940, 1900, and 1870 (where available) based on harvest data from various data sources (Mitchell, 1975, 1988, 2007a, 2007b, 2007c; Trant 1999; USDA NASS). To create consistent historical trends, values for NPP and area harvested by key crop category are taken from these sources for the largest countries in each region. Trends for individual crops (Wheat, Rye, Barley, Oats, Corn, Buckweat, etc.) were aggregated into 11 general categories used by the GCAM data processing system (Wheat, Corn, Rice, Other Grains, Root&Tubers, Sugar Crops, Fiber Crops, Oil Crops, Miscellaneous Crops, Grass Fodder, and other herbaceous Fodder). The FAO data for each region in each of these categories from 1962 are scaled back in time using these trends, with NPP for grain

crops adjusted between 1940 and 1960 for changes in harvest index. Harvest index between 1940 and 1980 was assumed to increase by a factor of 1.1 for Corn and 1.6 for Rice, with the same values used for all regions. Values for Wheat range from 1.1 to 1.5 depending on the region, and for other grains 1.1 to 1.3. In all cases, the aggregate cropland NPP value is the production-weighted average across crop categories.

As described in the main text, the turnover timescales for the three cropland carbon pools by region are shown below.

Region	Fast	Slow	Passive	MRT
USA	1.5	72	551	59
Canada	1.8	75	580	62
Western Europe	1.8	58	446	48
Japan	1.5	49	376	41
Australia_NZ	1.4	24	186	21
Former Soviet Union	3.9	94	723	79
China	3.6	51	392	44
Middle East	1.6	91	697	74
Africa	1.0	59	450	48
Latin America	0.9	44	339	36
Southeast Asia	1.1	42	326	35
Eastern Europe	2.5	86	660	71
Korea	1.5	34	259	29
India	0.9	41	317	34

Table S1. Carbon pool turnover time (years) by region along with the associated mean-residence time (MRT).

Table S3 shows a comparison between global harvested and total cropland area over time for the historical period considered and under the RCP4.5 future scenario. Global cropland area is relatively stable over time in the RCP4.5 scenario due to agricultural intensification and reduced meat consumption under a carbon policy (Wise et al. 2009). Table S3 below shows harvested area by region, estimated as described in the main text.

Year	Harvested	Total Cropland
2095	9,548	11,040
2080	9,874	11,356
2065	10,241	11,771
2050	10,285	11,942
2035	10,123	12,239
2020	9,970	13,420
2005	10,429	15,594
2000	10,373	15,333
1990	10,265	15,143
1980	9,859	14,482
1970	9,166	14,178
1961	8,711	13,726
1950	7,664	12,141
1940	7,003	11,621
1900	4,218	8,455
1870	2,655	6,420

Table S2. Comparison of global harvested area (Billion m^2), as estimated in this work, with total cropland, from Goldewijk et al. (2011), which is also used in this work.

2.1 US Cropland Area

	US Cropland Detail (1000 Ha)			
	2007	2002	1992	1982
US Census of Ag				
Harvested Cropland	125,347	122,549	119,813	132,108
"Other Aerable"	39,197	53,226	56,449	48,201
Total Cropland	164,544	175,775	176,261	180,309
US Cropland Not Harvested Detail				
Used for Pasture or Grazing	37%	46%	48%	55%
Idle, cover crops, or soil-improvement	39%	28%	29%	16%
Crops failed or abandoned	8%	13%	4%	4%
Cultivated summer fallow	16%	13%	19%	25%
G-Carbon Dataset				
Harvested Cropland	118,516	115,390	111,523	123,105
"Other Aerable"	56,713	62,842	72,330	65,749
Total Cropland	175,229	178,232	183,853	188,854
Difference				
Harvested Cropland	-6,831	-7,160	-8,290	-9,003
"Other Aerable"	17,516	9,616	15,881	17,548
Total Cropland	10,685	2,457	7,592	8,545

Table S3. Comparison of cropland area from the US Census of Agriculture (various years) and the G-Carbon datasets.

Table S3 compares cropland area for the USA in the G-Carbon dataset with data from the United States Census of Agriculture. The US data break out cropland into harvested area and several categories of other uses: pasture or grazing, idle/cover crops/other soil improvement, crop failure, and cultivated summer fallow.

Overall, the US Census data are 1-6% larger than the total cropland areas in G-Carbon, which are ultimately based on HYDE gridded data. The G-Carbon harvested area, which is based on FAO data (adjusted for double cropping), is slightly smaller than the US Census results. G-Carbon "other arable" land is slightly larger than the US data. The reasons for these discrepancies are not known, although some may have to do with different data classifications and also differences that arise from the process of mapping country data to gridded datasets and then re-aggregating to the country level.

3. Additional Results

3.1 Cropland Emissions by Region

Figure S1 shows cropland emissions by region. Historical emissions are dominated by Canada, United States, and the Former Soviet Union. The large emissions for the United States are largely due to conversion of carbon-rich grasslands in the 19th century to cropland, and the subsequent relaxation of carbon values to the lower values typical of croplands of that time period. Productivity increases over recent decades increase carbon flows to croplands resulting in a net uptake in US croplands by the present day. Implementation of no-till practices, which were not included in this central scenario, would increase this uptake level.

A similar dynamic occurs in Canada and the Former Soviet Union (FSU). Native ecosystems in Canada and the FSU were assumed, in aggregate, to have higher soil carbon contents as compared to the United States, which contributes to large carbon releases in these regions. Soil turnover timescales in the FSU are also assumed to be longer as compared to North America (Table S1), which lengthens the decay timescale there.

A more regionally-specific specification of soil properties in croplands, and the associated native ecosystems, would allow refinement of these estimates.

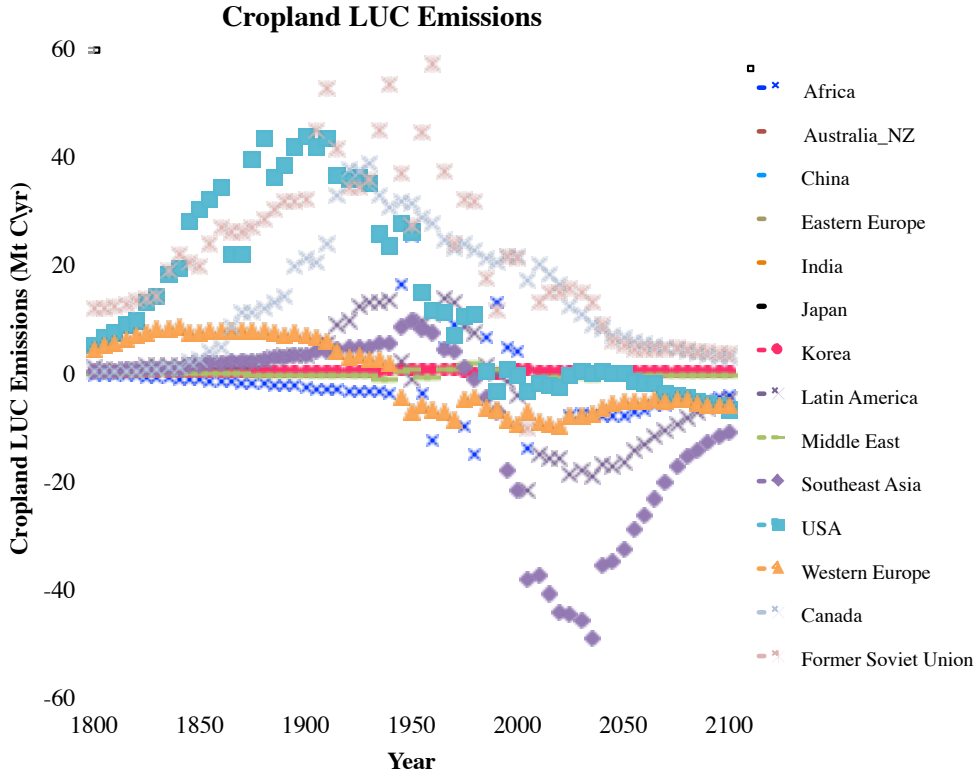

Figure S1. Carbon emissions from cropland by region for the central scenario.

3.2 Carbon density

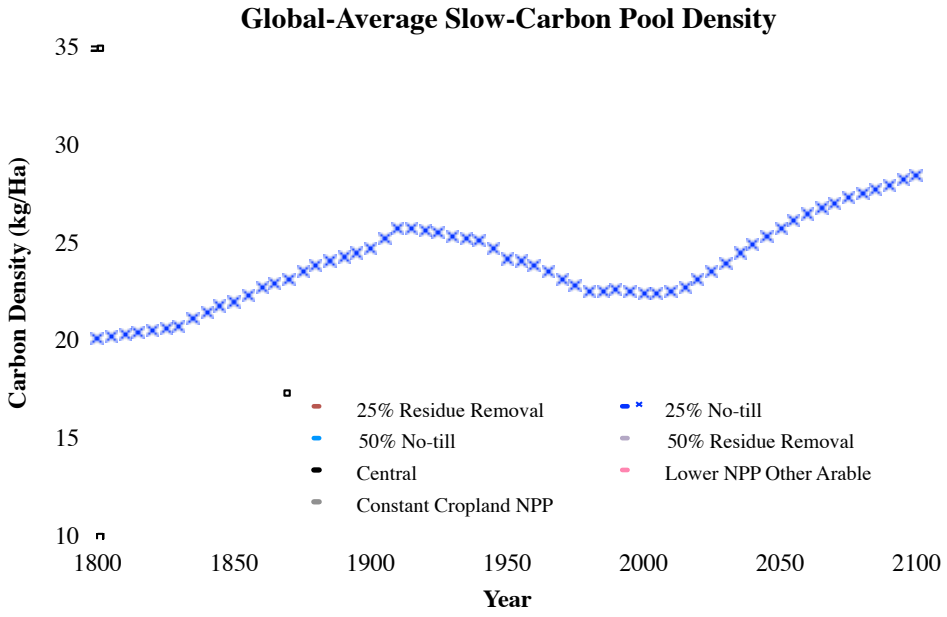

Figure S2. Global-average slow carbon-pool carbon densities under different sensitivity scenarios.

Figure S2 shows how different assumptions impact slow pool carbon densities. Overall, the four classes of assumptions: constant cropland NPP over time, residue removal, no-till application, and NPP for other arable land have impacts of similar magnitude over the 21st century.

3.3 Residue Production

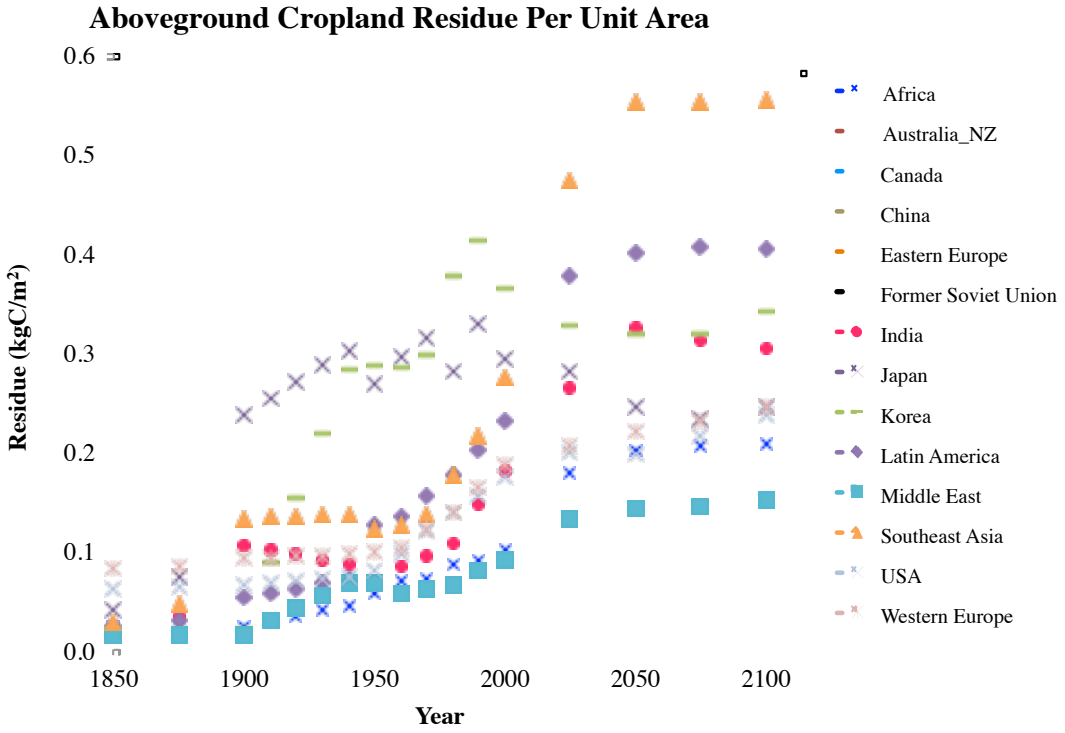

Figure S3. Regional above-ground residue production per unit area of harvested land before any removal.

Above-ground residue production was estimated to be generally below 0.1 kgC/m2 until the 20th century. Improvements in agricultural practices, including increased use of fertilizer, resulted in substantial increases in residue production over the 20th century. The trends shown in the figure are the net result of productivity changes, assumed historical changes in grain harvest index, and changes in regional crop production mix.

SM References

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Harvested Area (billion m^2)

Year	USA	Canada	Western Europe	Japan	Australia_NZ	Former Soviet Union	China	Middle East	Africa	Latin America	Southeast Asia	Eastern Europe	Korea	India	Global
2095	1,240	184	800	42	171	686	1,644	200	1,351	792	785	439	19	1,194	9,548
2080	1,300	193	830	44	177	714	1,726	206	1,388	810	815	454	20	1,198	9,874
2065	1,410	211	877	44	184	759	1,774	214	1,424	824	838	473	20	1,188	10,241
2050	1,457	223	902	41	186	781	1,737	217	1,420	814	837	475	19	1,178	10,285
2035	1,382	235	910	37	178	931	1,541	218	1,381	784	841	445	18	1,223	10,123
2020	1,229	272	911	33	160	1,083	1,310	231	1,346	783	925	402	16	1,270	9,970
2005	1,183	265	882	31	203	1,127	1,317	227	1,728	997	911	372	14	1,172	10,429
2000	1,154	265	904	31	193	1,282	1,271	223	1,623	956	888	393	14	1,179	10,373
1990	1,098	263	945	31	174	1,582	1,181	215	1,419	876	842	433	14	1,192	10,265
1980	1,289	241	891	38	181	1,717	1,093	165	1,120	787	754	431	15	1,136	9,859
1970	1,066	207	827	44	142	1,685	1,055	146	1,142	679	640	450	18	1,066	9,166
1961	1,061	189	817	56	98	1,737	1,072	122	936	570	551	486	15	1,000	8,711
1950	1,141	210	758	54	75	1,349	850	93	911	396	485	471	10	861	7,664
1940	1,061	210	822	50	77	1,586	553	47	590	411	378	470	7	742	7,003
1900	896	59	816	42	31	1,062	182	11	94	62	136	450	1	376	4,218
1870	357	23	583	4	5	906	170	9	77	35	23	291	1	171	2,655

Table S4. Harvested Areas over time as estimated in this work (see text).