Supporting Information

Bren d'Amour et al. 10.1073/pnas.1606036114

Data Inputs and Processing

We base our study on a spatially explicit urban area expansion probability dataset (4), projected in Goode's Homolosine Equal-Area projection. The dataset uses urban extent in 2000 as baseline and forecasts urban area expansion for the year 2030. We use two gridded datasets on global croplands in 2000 and 2005 [from EarthStat (15) and from the International Institute for Applied Systems Analysis and the International Food Policy Research Institute, IIASA–IFPRI (16)]. The EarthStat cropland map by Ramankutty et al. (15) combines agricultural inventory and satellite-derived land cover data in a 5-min grid (~10 km at the equator). We integrate a newly developed high-resolution map of global cropland from IIASA–IFPRI by Fritz et al. (16) (~1 km) into our analysis. Both datasets are in GCS_WGS_1984 projection. We use the EarthStat dataset on gridded global crop yields by Monfreda et al. (17) in 2000 to calculate the productivity of the displaced land. Yields of 16 important food crops (barley, cassava, groundnut, maize, millet, oil palm, potato, rapeseed, rice, rye, sorghum, soybean, sugarbeet, sugarcane, sunflower, and wheat) are converted to calories and aggregated in a single dataset. We supplement this with a disaggregated analysis of four staple crops (maize, rice, soybean, and wheat) and three cash crops (cacao, oil palm, and sugarcane). The dataset uses GCS_WGS_1984 projection with a spatial resolution of 5 min. We reproject the urban expansion dataset to fit GCS_WGS_1984 projection. We aggregate the IIASA–IFPRI map to the same resolution as the initial urban expansion forecast by assigning the mean values of the ~1-km pixels to the resultant ~5-km pixel. We create separate shapefile layers for a selection of megaurban regions (MURs) by creating a 100-km buffer around the geographic centers of the most prominent urban centers of each region. For Java, we take the administrative boundaries of the island. We define MURs as continuous urban regions with multiple urban centers and a combined population greater than 20 million, often expanding over 10,000 km^2 or more (with the exception of Greater Cairo). Our selection is based on our cropland loss findings and mostly entails countries from developing or emerging regions. For comparison, we supplement them with MURs from developed regions (the United States and Japan). Note: this list of MURs is not comprehensive. We further include World Bank data on poverty (58) and FAOSTAT data from the Food and Agriculture Organization of the United Nations (25) to supplement our findings (Table S3).

Analyzing the Cropland and Crop Production Losses

We assess the impact of urban area expansion by intersecting three distinct urbanization projections for the year 2030 with the EarthStat cropland dataset for the year 2000 (at 5-min resolution). The resulting cropland and production loss scenarios are "low" (with a restrictive threshold including only grid cells exceeding 87.5% urbanization probability), "medium" (>75% urbanization probability), and "high" (>50% urbanization probability). As a "best guess," we assume that all grid cells with >75% probability of becoming urbanized (medium scenario) will be affected by urbanization until 2030.

If the urbanization probability of a grid cell exceeds one of the predefined thresholds, it is assumed that it will be urbanized. Loss of cropland due to urban area expansion is only calculated for grid cells with a cropland area fraction >0%. The corresponding cropland areas (and corresponding production metrics) are aggregated and subsequent calculations made at national level (for the MURs at the corresponding regional level). We assume that cropland area is partially maintained within the predominantly urbanized regions to account for the potential of urban agriculture. For each country, we assume that cropland area is only lost to the extent that it exceeds the prevailing fraction of the initial cropland area. This prevailing fraction is estimated for each country by intersecting urban areas around the year 2000 with the cropland map for the year 2000. For example, if croplands cover 25% of urbanized areas in a country in 2000, we assume that 25% of the initial cropland area in the newly urbanized area is maintained, whereas the remaining cropland area is lost.

A similar procedure is applied for calculating the corresponding production losses. We use the aggregate production in urban areas in 2000 to calculate the average productivity in million calories per km^2 of croplands in urban areas in 2000. This average productivity is then used to compute the crop production on the prevailing cropland in competing areas. Loss of production due to urban expansion is the total production in competing areas minus the so-computed production on the remaining croplands. We assume that the production is spread equally over the cropland of a grid cell.

For the disaggregated crop specific analysis, we abstract from calculating actual losses. Instead, we use the amount of crop production [and the average harvested area fraction (HAF) for the MURs] in competing grid cells as an indicator of the relevance of a specific crop in a specific area. We intersected the urban area expansion dataset with the production and HAF datasets of the respective crops. The HAF represents the ratio of area harvested of a specific crop over the total area harvested in a grid cell. We aggregated the production in the grid cells with an urbanization probability >75% (medium scenario) and compare it to the total production of the country/region. For the HAF, we computed the average in all competing pixel per MUR.

We cross-check our cropland loss estimates by intersecting the urban area expansion forecasts with the generated cropland map at ~5-km resolution (Table S5), finding little to no variation on aggregate (both 29.9 Mha of total cropland loss; medium scenario). Some variation was visible in Africa and Asia (6.1 vs. 5.6, and 17 vs. 17.9, Mha, medium scenario, high- to lower-resolution analysis), which can be explained by the differences between the two cropland datasets as discussed in detail by Fritz et al. (16).

Table S1. Disaggregated crop analysis

Region or country	Maize production in competing cells		Rice production in competing cells		Soybean production in competing cells		Wheat production in competing cells	
	Mton·y^{-1}	Share of total production, %	Mton·y^{-1}	Share of total production, %	Mton·y^{-1}	Share of total production, %	Mton·y^{-1}	Share of total production, %
World	25.8	4.3	51.8	9.1	3.3	2.1	39.6	7.1
Asia	15.1	9.6	48.2	9.2	1.7	7.0	31.9	12.9
Africa	5.1	14.1	2.9	18.8	0.1	11.2	4.0	26.0
Europe	1.0	1.5	0.1	2.2	0.1	2.8	2.7	1.6
Americas	4.6	1.4	0.6	2.2	1.5	1.1	0.9	0.9
Australasia	0.0	0.7	0.0	0.0	0.0	0.2	0.0	0.1
Top 10								
China	12.7	10.9	18.7	10.2	1.4	9.0	20.6	20.5
India	0.7	6.5	10.5	8.3	0.1	2.2	5.7	8.2
Nigeria	0.5	11.7	0.5	17.5	0.0	11.6	0.0	10.4
Pakistan	0.2	13.0	0.8	12.2	0.0	13.2	3.1	16.7
United States	2.1	0.9	0.1	0.9	0.6	0.8	0.4	0.6
Brazil	0.7	1.9	0.2	1.8	0.4	1.3	0.1	2.2
Egypt	3.8	63.3	2.3	41.2	0.0	53.3	3.7	59.5
Vietnam	0.3	14.7	7.5	27.1	0.0	24.3	—	—
Mexico	0.9	4.9	0.0	4.3	0.0	0.9	0.2	5.4
Indonesia	0.7	7.3	4.5	9.2	0.1	9.2	—	—

Overview of the disaggregated production analysis for a selection of staple crops. Provided are the production in competing areas (medium scenario, urbanization probability of >75% and cropland area fraction of >0%), both in total (megatons) and as share of total for the year 2000. Note: not all this production is necessarily lost. This is supposed to serve as indication of which crops are grown around urban areas.

Table S2. MURs

MUR	Expected cropland loss, Mha	Productivity relative to regional/domestic average	Crop type	Production in competing cells, $Mton \cdot y^{-1}$	Average HAF in competing cells, %
Bohai Economic Rim	1.2 (1.1–1.4)	1.47	Maize	3.8	22
			Wheat	3.4	19
			Soybean	0.2	3
			Rice	0.7	3
Delhi National Capital Region and Jaipur	0.3 (0.3–0.4)	2.71	Wheat	1.1	38
			Sugarcane	9.5	18
			Rice	0.4	14
			Maize	0.0	2
Expanded Metropolitan Complex of São Paulo	0.1 (0.1–0.1)	1.68	Sugarcane	5.8	7
			Maize	0.1	2
Ganges-Brahmaputra Delta	0.6 (0.5–0.7)	2.34	Rice	3.3	83
			Wheat	0.1	3
Greater Cairo	0.3 (0.3–0.3)	1.12	Maize	1.6	25
			Wheat	1.3	24
			Rice	1.1	14
			Sugarcane	3.0	3
Greater Ibadan Lagos Accra Corridor	0.5 (0.5–0.6)	1.50	Maize	0.2	10
			Cacao	0.0	8
			Oil palm	0.3	5
Java	0.5 (0.4–0.6)	2.05	Rice	4.3	49
			Maize	0.6	11
			Soybean	0.1	4
Northeast Megalopolis	0.2 (0.2–0.2)	0.75	Maize	0.2	2
			Soybean	0.1	1
Pearl River Delta	0.2 (0.2–0.2)	1.05	Rice	0.9	23
			Sugarcane	0.9	2
Tokaido Corridor	0.1 (0.1–0.1)	1.17	Rice	0.6	7
Yangtze River Delta	0.9 (0.8–1)	2.05	Rice	6.4	35
			Wheat	1.6	15
			Soybean	0.2	3
			Maize	0.3	2

Medium-scenario results are reported; ranges indicate low- to high-scenario results. Average productivity reported represents the medium scenario. Crop-specific analysis is conducted with a sample of staple crops (maize, rice, soybean, and wheat) and cash crops (cacao, oil palm, and sugarcane) that are characteristic for specific MUR. Harvested area fraction (HAF) is the fraction of total area harvested used to grow a specific crop. Only crops with a HAF greater than 1% are reported.

Table S3. Cropland and productivity loss estimates for countries

Country	Absolute cropland loss, '000 ha	Relative cropland loss, %	Absolute production loss, Tcal·y^{-1}	Relative production loss, %	Poor population (<$1.90/d), million	CIDR, %	Agricultural employment, %	Rural population, %	Agricultural value added to GDP, %
Angola	1	0.04	5	0.06	7.8	50.5	48	69	18
Argentina	304	0.92	2,678	1.21	0.8	−100	10	25	10
Armenia	9	1.65	21	1.63	0.1	55.7	17	15	5
Azerbaijan	14	0.71	38	0.72	0	37.7	77	73	36
Bangladesh	289	3.43	3,783	3.48	69.4	10.8	63	80	34
Belarus	5	0.08	12	0.06	0	1.4	—	78	54
Benin	39	1.45	0	0.00	5.6	22.2	11	42	5
Bolivia	14	0.44	37	0.35	0.8	18.7	36	82	46
Botswana	5	0.52	0	0.00	0.3	80.8	51	69	18
Brazil	1,004	2.00	9,929	2.39	10	−3	39	49	14
Bulgaria	13	0.36	79	0.40	0.2	−92.2	71	66	32
Burkina Faso	23	0.53	61	0.76	7.8	9.8	79	67	27
Burundi	177	28.07	461	26.93	8.8	21.4	64	84	31
Cambodia	31	0.80	159	1.36	0.9	−1.4	66	63	39
Cameroon	79	1.08	532	4.83	6.3	25.8	70	83	35
Central African Republic	2	0.12	8	0.49	3	21.4	57	82	38
Chad	1	0.03	2	0.05	5.2	9.6	44	63	24
Chile	62	2.65	293	2.88	0.2	38.8	13	39	3
China	7,631	5.39	136,572	8.74	152.5	2.1	31	55	14
Colombia	222	6.16	2,509	6.99	2.9	63.3	5	37	3
Congo	1	0.22	0	0.00	1.3	92.9	70	71	31
Costa Rica	5	1.00	53	1.00	0.1	82.4	54	62	37
Côte d'Ivoire	58	0.86	108	0.87	4.2	52.4	23	29	9
Croatia	2	0.10	14	0.11	0	−12.4	72	85	26
Czech Republic	6	0.18	19	0.08	0	−44	49	69	19
Dominican Republic	81	5.12	204	4.93	0.2	73.9	38	46	7
Ecuador	54	2.05	324	2.15	0.7	36.4	20	55	14
Egypt	774	34.08	24,717	36.53	1.5	44.2	45	58	26
El Salvador	39	4.24	231	5.54	0.2	41.8	36	33	13
Ethiopia	94	0.88	150	0.77	32.5	10.7	—	61	9
Gabon	10	2.11	14	2.07	0.1	81.9	—	89	41
Georgia	21	1.97	53	1.95	0.5	68.6	—	48	23
Ghana	210	3.54	912	4.31	6.7	26.1	—	61	55
Guatemala	41	2.06	269	2.32	1.9	43	12	11	4
Guinea	1	0.09	8	0.09	4.3	13.8	29	37	10
Haiti	5	0.45	10	0.45	5.7	53.9	20	35	12
Honduras	15	0.92	70	1.03	1.5	56.5	48	49	29
Hungary	3	0.05	51	0.12	0	−81.1	34	50	12
India	3,413	2.01	33,966	3.89	275.3	−3.1	—	54	46
Indonesia	556	1.06	9,517	2.29	40.5	12.7	21	29	7
Iran	331	2.34	1,831	3.08	0.1	28.7	61	76	27
Iraq	316	5.50	239	11.39	1.4	56.8	34	65	24
Jamaica	16	5.84	38	5.77	0.1	99.5	18	43	11
Jordan	42	11.17	3	1.12	0	96.2	14	22	3
Kazakhstan	10	0.04	14	0.03	0	−50.6	37	31	17
Kenya	383	7.27	979	7.67	15.1	36.4	41	42	14
Kyrgyzstan	15	1.05	63	0.96	0.2	23.4	—	69	28
Laos	0	0.04	3	0.04	2	−5.1	29	42	19
Latvia	0	0.02	1	0.02	0	−72.2	49	56	28
Lesotho	4	1.24	0	0.00	1.3	78.2	34	55	12
Liberia	6	1.60	39	2.28	3.7	61.1	77	75	34
Madagascar	2	0.06	32	0.34	19.3	8.7	32	82	10
Malawi	59	4.37	390	6.77	11.8	1.6	53	73	24
Malaysia	69	0.93	2,821	0.93	0.5	76	—	64	21
Mali	6	0.13	16	0.24	8.7	4.7	1	9	8
Mauritania	2	0.22	4	0.79	0.8	74	7	27	6
Mexico	683	1.90	4,130	3.73	3.4	30.7	5	31	4
Mongolia	6	0.30	2	0.29	0	35.1	29	46	6
Morocco	198	2.16	512	2.83	2.1	36.4	10	33	4

Table S3. Cont.

Country	Absolute cropland loss, '000 ha	Relative cropland loss, %	Absolute production loss, Tcal·y^{-1}	Relative production loss, %	Poor population (<$1.90/d), million	CIDR, %	Agricultural employment, %	Rural population, %	Agricultural value added to GDP, %
Mozambique	9	0.21	36	0.44	16.5	27.3	28	41	21
Namibia	0	0.04	0	0.03	0.6	55.9	8	26	4
Nepal	68	2.87	591	2.77	4.2	3.9	22	45	10
Nicaragua	16	0.72	62	1.51	0.9	31.5	4	46	4
Niger	31	0.22	22	0.26	9.6	7.3	41	55	10
Nigeria	2,070	5.70	16,016	11.71	110.1	21.7	18	31	9
Pakistan	1,754	7.58	9,296	8.81	15.4	−12.2	10	5	9
Panama	1	0.12	1	0.07	0.1	71.4	—	59	—
Paraguay	10	0.34	114	0.56	0.1	−100	41	37	20
Peru	51	1.19	181	1.30	1.2	48.4	28	44	3
Philippines	252	2.90	2,851	4.84	13	21.9	18	25	7
Poland	13	0.09	81	0.09	0	−2.5	35	36	4
Russian Federation	28	0.02	65	0.03	0.1	−27.5	—	49	23
Rwanda	259	33.47	465	26.18	6.8	23.7	—	23	4
Senegal	40	1.66	97	1.86	5.6	46.9	14	25	7
Sierra Leone	2	0.41	14	0.73	3.3	19.7	54	47	10
Slovakia	7	0.48	84	0.69	0	−27.5	—	47	—
Slovenia	1	0.37	8	0.40	0	36.9	37	48	13
South Africa	265	1.77	1,477	3.21	8.9	2.8	23	31	
Sri Lanka	248	13.00	580	6.95	0.4	25.4	19	46	6
Tajikistan	35	3.38	72	3.42	0.5	43.7	12	75	8
Tanzania	29	0.57	109	0.67	24.2	13.2	47	52	—
Thailand	150	0.90	1,780	1.26	0	−41.6	13	28	10
Togo	25	0.95	166	4.43	3.9	14	—	43	23
Tunisia	73	3.17	126	3.06	0.2	55.3	9	60	4
Turkey	429	1.97	2,597	2.30	0.2	0.8	7	37	10
Uganda	288	3.54	427	3.25	12.6	9.1	27	57	9
Ukraine	22	0.06	64	0.05	0	−60.3	16	35	5
Uruguay	21	1.48	23	0.39	0	−100	9	23	8
Uzbekistan	450	8.76	1,355	8.75	20.9	18.2	40	58	16
Venezuela	116	3.39	412	3.23	5.2	56.6	—	79	7
Vietnam	759	10.34	15,445	15.86	2.9	−11	17	34	9
Yemen	40	2.70	59	2.51	2.6	81.2	9	11	5
Zambia	4	0.07	9	0.18	10.1	−8.2	25	68	10

This table contains estimates of cropland loss for countries with available World Bank data (58) on poverty (medium scenario, estimated cropland loss of >0). The last columns present additional information on the structure of the population and the importance of agriculture for the respective country (25). CIDR refers to the cereal import dependency ratio of countries, which is defined as the ratio of cereal imports over domestic supply of cereals.

Table S4. Governance indicators of selected countries

Country	Control of corruption	Government effectiveness	Regulatory quality	Rule of law
Brazil	47	48	51	53
China	48	63	44	42
Egypt	33	20	27	34
India	40	50	36	55
Indonesia	34	49	48	40
Japan	93	96	84	90
Mexico	30	62	67	37
Nigeria	9	15	24	12
Pakistan	21	25	28	23
United States	88	90	88	90
Vietnam	38	51	31	44

Selection of countries based on Table 1 (of the manuscript) and Table S2. Governance indicators are derived from the World Bank's World Governance Indicators (58). Numbers represent percentile ranks, which indicate the country's rank among all countries covered by the aggregate indicator, with 0 corresponding to lowest rank, and 100 to highest rank. Values represent 3-y averages for the years 2013–2015.

Table S5. Comparison of aggregated cropland losses for different spatial resolution

	Higher resolution, Mha			Lower resolution, Mha		
Region	Low	Medium	High	Low	Medium	High
World	27.3	29.9	35.4	27.3	29.9	35.4
Asia	15.5	17.0	20.0	16.3	17.9	21.0
Africa	5.6	6.1	7.0	5.1	5.6	6.4
Europe	1.6	1.7	2.8	1.5	1.6	2.7
Americas	4.5	4.9	5.4	4.3	4.7	5.3
Australasia	0.0	0.1	0.2	0.0	0.1	0.1

Comparison between cropland loss calculations with the higher [~5 km at the equator (16)] and the lower resolution [~10 km at the equator, used in main analysis (15)] cropland products. Low, medium, and high refer to the urbanization scenarios from the main analysis.