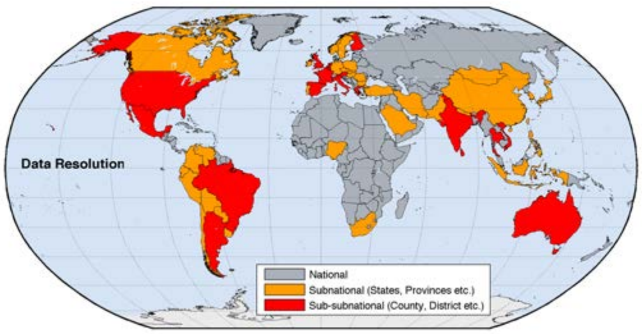
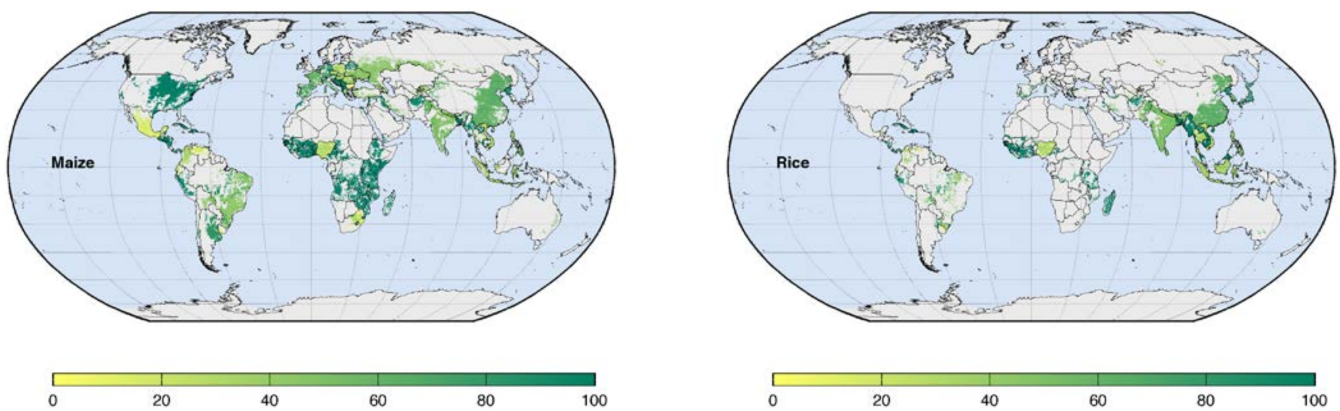
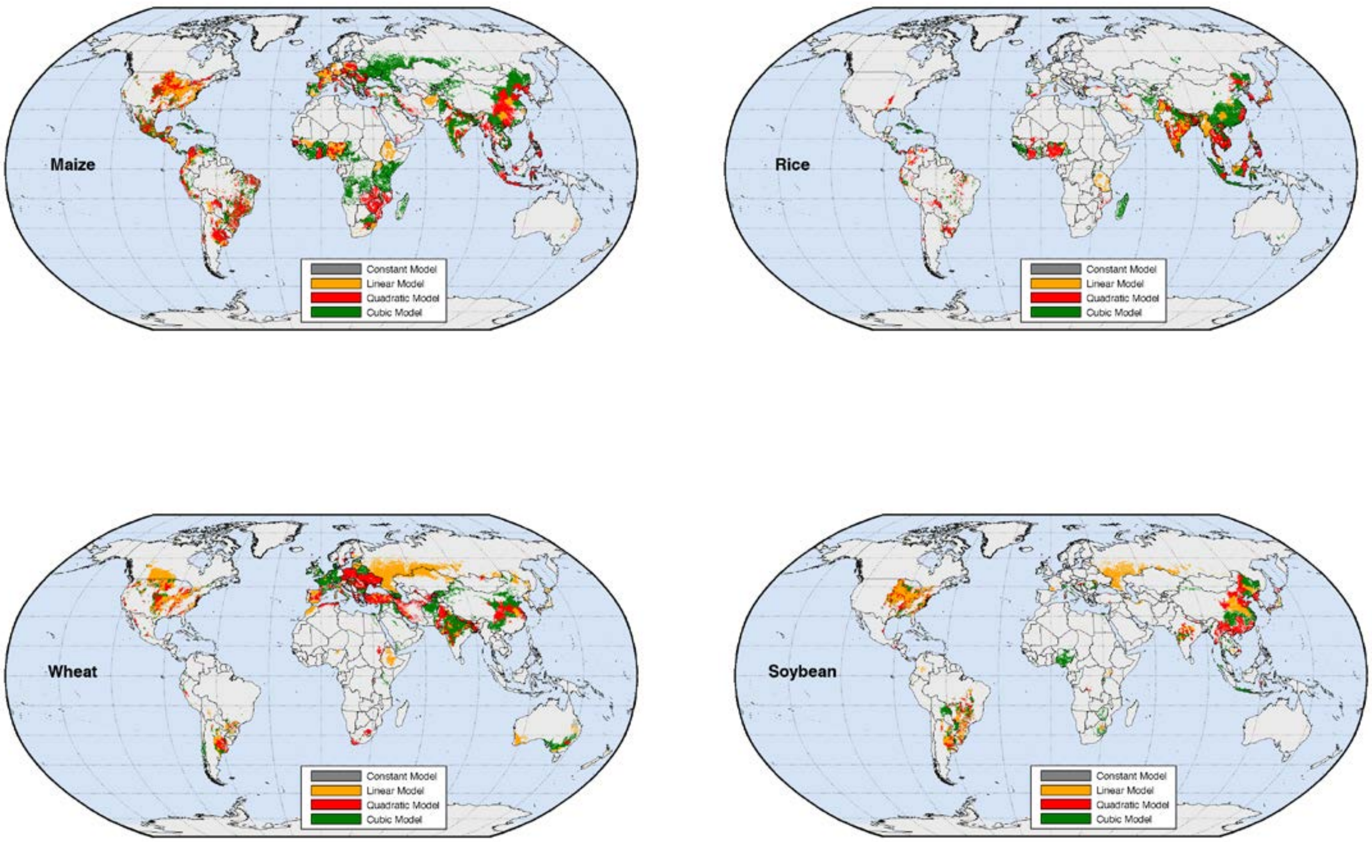


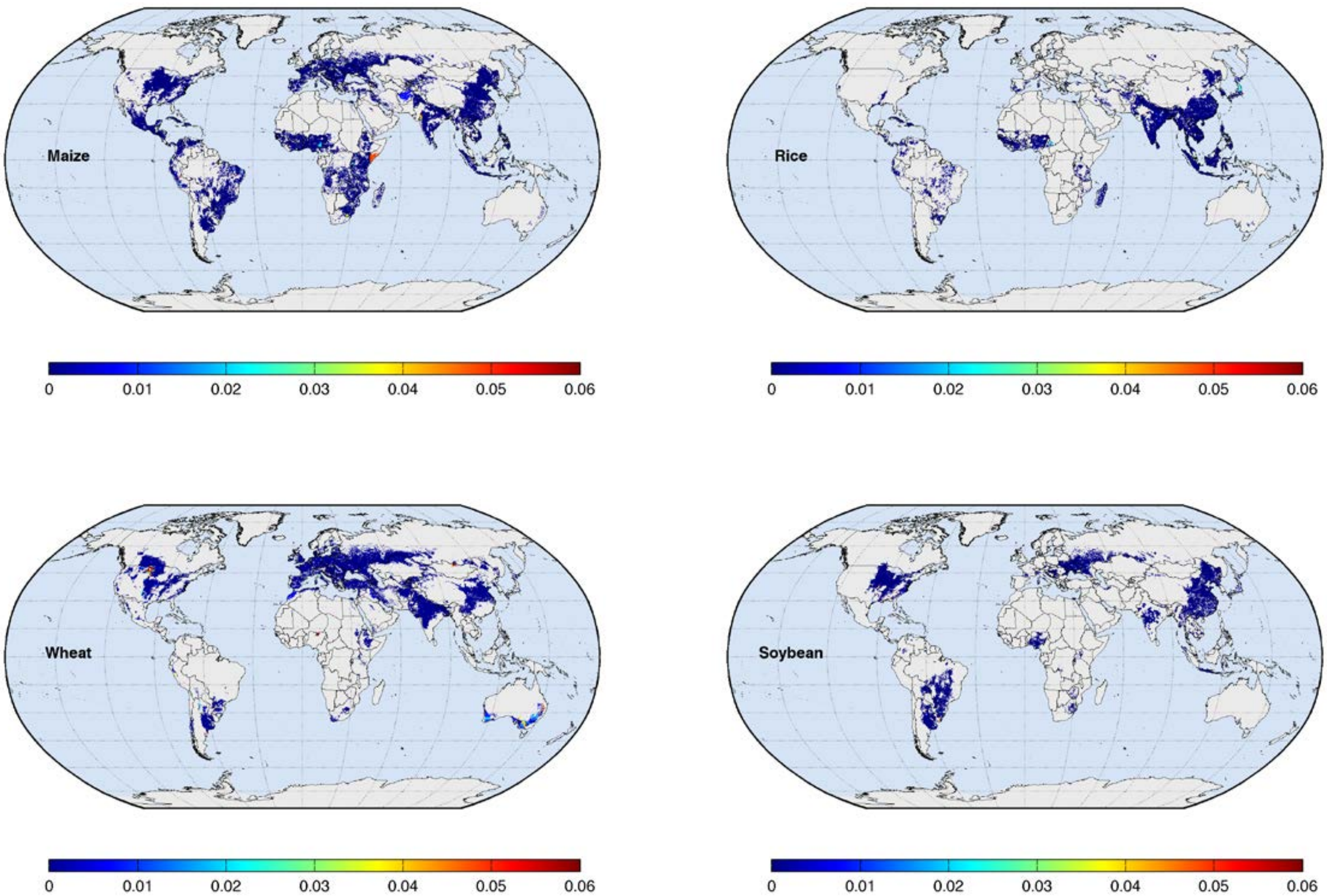
Supplementary Figure S1. Data Resolution. Resolution at which we collected the data



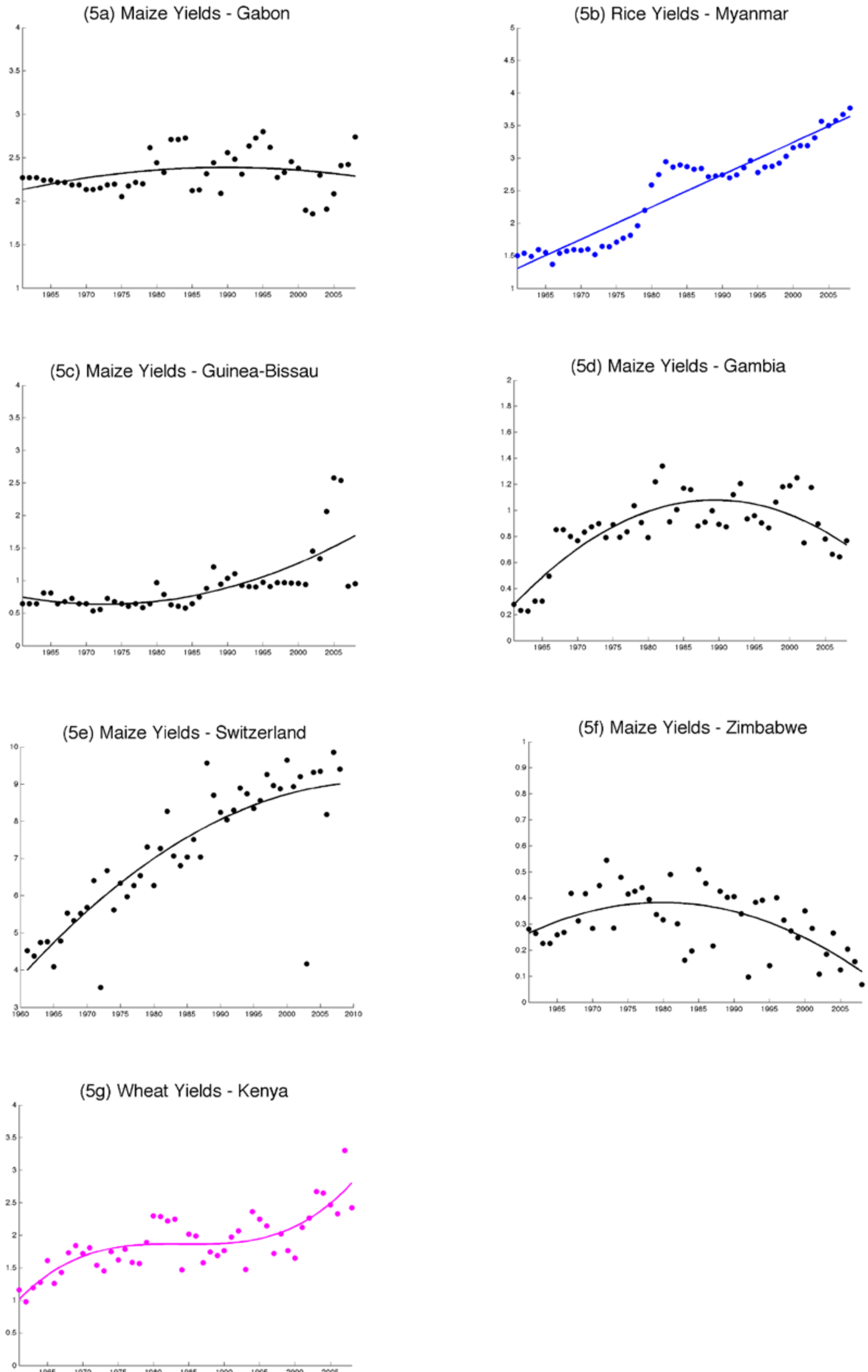
Supplementary Figure S2. Data quality. Data quality related to harvested areas for maize and rice. Wheat and soybean quality are similar in their respective harvested areas.



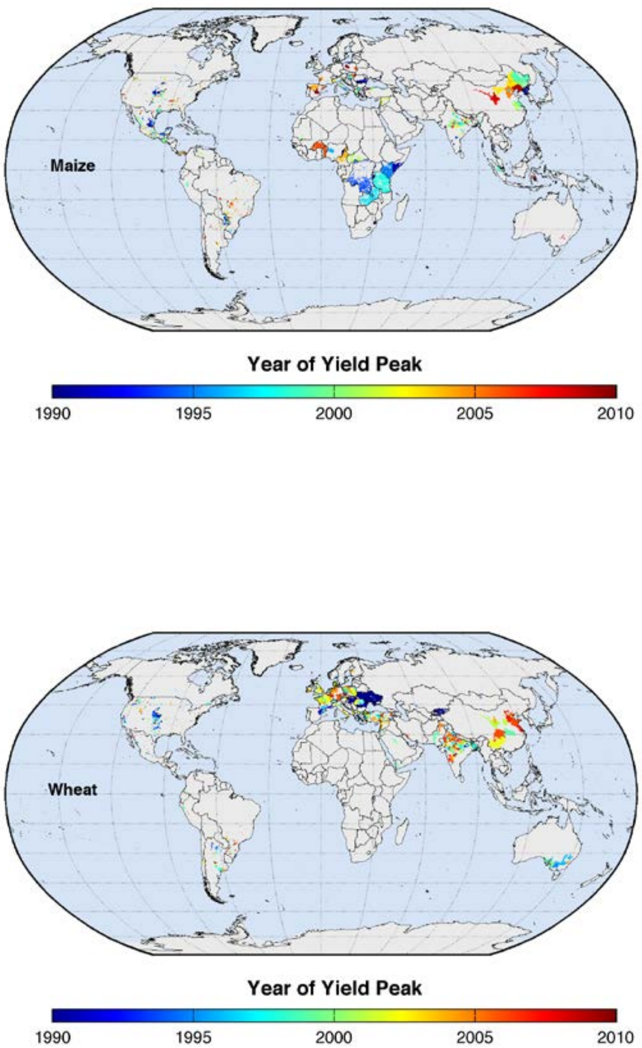
Supplementary Figure S3. Statistical models by location. Global maps of spatial locations of the chosen statistical model based on AIC for maize, rice, wheat, and soybean.



Supplementary Figure S4. Statistical analyses. p-value associated with F tests for maize, rice, wheat, and soybean.



Supplementary Figure S5. Examples of yield trend categories. Examples of how the parameters of the 4 equation types determined the yield trend category. Color scheme is the same as in Figure 1.



Supplementary Figure S6. Year of yield peak in stagnating regions. Year of yield peak in areas classified as yield stagnation for maize, rice, wheat, and soybean.

Supplementary Table S1. Country data source and number of political units analyzed per country					
	Country	Source	Number of political units	Time frame (years)	Number of census reported statistics collected per crop
1	Argentina	(60), (61)	499 municipios + 22 states + 1 national level	39 municipios + 39 states + 48 national	38922 municipios + 1716 states + 96 national
2	Australia	(60), (62), (63), (64)	59 statistical divisions + 9 states + national level	19 statistical divisions + 48 states + 48 national	2242 statistical divisions + 864 states + 96 national
3	Austria	(60), (65)	9 states + 3 regions + national level	34 states + 34 regions + 48 national	612 states + 204 regions + 96 national
4	Belgium	(60), (65)	11 states + national level (prior to 2000 we used Belgium-Luxembourg)	34 states + 48 national	748 states + 96 national
5	Bolivia	(60), (66)	9 regions, + national level	17 regions + 48 national	306 regions + 96 national
6	Brazil	(60), (67), (68)	5510 municipios + 27 states + national level	20 municipios + 48 states + 48 national	220400 municipios + 2592 states + 96 national
7	Bulgaria	(60), (65)	28 provinces + national level	1 provinces + 48 national	56 provinces + 96 national
8	Canada	(60), (69)	13 (provinces & territories) + national	48 (provinces & territories) + 48 national	1248 (provinces & territories) + 96 national
9	Chile	(60), (70)	13 regions + national	29 regions + 48 national	754 regions + 96 national
10	China	(60), (71)	30 provinces/autonomous regions/municipalities + national	29 provinces + 48 national	1740 provinces + 96 national
11	Colombia	(60), (72)	33 departments + national level	14 departments + 48 national	924 departments + 96 national
12	Czech Republic	(60), (65), (73)	8 states + national level	14 states + 35 national	224 states + 70 national
13	Ecuador	(60), (74)	22 states + national level	9 (states) + 48 national	396 states + 96 national
14	Finland	(60), (65)	6 counties + 2 states + national level	17 (counties and states) + 48 national	204 (counties) + 68 (states) + 96 national
15	France	(60), (65)	22 counties + 8 states + national level	33 (counties and states) + 48 national	1452 (counties) + 528 (states) + 96 national
16	Germany	(60), (65)	16 states + national	34 states + 48 national	1088 states + 96 national
17	Greece	(60), (65)	13 counties + 4 states + national	20 (counties and states) + 48 national	520 (counties) + 160 (states) + 96 national
18	Hungary	(60), (65)	7 states + national	14 states + 48 national	196 states + 96 national
19	India	(60), (75), (76), (77)	552 districts + 32 states + national	23 districts + 48 states + 48 national	25392 districts + 3072 states + 96 national
20	Indonesia	(60), (78)	26 states + national level	16 states + 48 national	832 states + 96 national
21	Iran	(60), (79)	24 states + national level	26 states + 48 national	1248 states + 96 national
22	Ireland	(60), (65)	2 states + national level	19 states + 48 national	76 states + 96 national
23	Italy	(60), (65)	20 counties + 12 states + national level	33 (counties and states) + 48 national	1320 counties + 792 states + 96 national
24	Japan	(60), (80)	9 states + national level	48 states + 48 national	864 states + 96 national
25	South Korea	(60), (81)	14 states + national level	28 states + 48 national	784 states + 96 national
26	Mexico	(60), (82)	2402 counties + 32 states + national level	6 counties + 29 states + 48 - national	28824 counties + 1856 states + 96 national
27	Mongolia	(60), (83)	20 states + national level	13 states + 48 national	520 states + 96 national
28	Nepal	(60), (80)	14 states + national level	22 states + 48 national	616 states + 96 national
29	Netherlands	(60), (65)	12 counties + 4 states + national level	34 (counties and states) + 48 national	816 counties + 272 states + 96 national
30	Nigeria	(60), (84)	31 states + national level	12 states + 48 national	744 states + 96 national
31	Norway	(60), (85)	18 states + national level	16 states + 48 national	576 states + 96 national
32	Pakistan	(60), (80)	5 states + national level	19 states + 48 national	190 states + 96 national
33	Paraguay	(60), (86)	19 states + national level	19 states + 48 national	722 states + 96 national
34	Peru	(60), (87)	26 states + national level	48 states + 48 national	2496 states + 96 national
35	Philippines	(60), (80)	11 states + national level	19 states + 48 national	418 states + 96 national
36	Poland	(60), (65)	16 states + national level	13 states + 48 national	416 states + 96 national
37	Portugal	(60), (65)	7 states + national level	28 states + 48 national	392 states + 96 national

38	Romania	(60), (65)	8 states + national level	14 states + 48 national	224 states + 96 national
39	Saudi Arabia	(60), (88)	14 states + national level	30 states + 48 national	840 states + 96 national
40	Slovakia	(60), (65)	4 states + national level	14 states + 48 national	112 states + 96 national
41	South Africa	(60), (89)	11 states + national level	4 states + 48 national	88 states + 96 national
42	Spain	(60), (65)	16 counties + 6 states + national level	32 (counties and states) + 48 national	1024 counties + 384 states + 96 national
43	Sri Lanka	(60), (90)	24 counties + 9 states + national level	30 (counties and states) + 48 national	1440 counties + 540 states + 96 national
44	Sweden	(60), (65)	8 states + national level	23 states + 48 - national	368 states + 96 national
45	Thailand	(60), (91)	72 counties + 5 states + national	14 (counties and states) + 48 - national	2016 counties + 140 states + 96 national
46	Turkey	(60), (92)	73 states + national level	18 states + 48 national	2628 states + 96 national
47	United Kingdom	(60), (65)	12 counties + 4 states + national level	34 (counties + states) + 48 national	816 counties + 272 states + 96 national
48	United States	(60), (93)	3078 counties + 50 states + national level	48 years counties + 48 years states + 48 years national	295488 counties + 4800 states + 96 national
49	Uruguay	(60), (94)	19 states + national level	2 states + 48 national	76 states + 96 national
50	Venezuela	(60), (95)	24 states + national level	3 states + 48 national	144 states + 96 national
51	Vietnam	(60), (96)	61 counties + 8 states + national level	14 (counties and states) + 48 national	1708 counties + 224 states + 96 national
Countries with incomplete national data					
	Former Soviet Republics	(60), (97)	1 national level	22 – national (1986-1990; 1992-2008)	44 national
	Eritrea, Ethiopia	(60)	1 national level	48 national	48 national
Countries with complete National data for all years (1961-2008)					
Afghanistan, Albania, Algeria, American Samoa, Andorra, Angola, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bermuda, Bhutan, Botswana, British Virgin Islands, Brunei Darussalam, Burkina Faso, Burundi, Ivory Coast, Cambodia, Cameroon, Cape Verde, Cayman Islands, Central African Republic, Chad, Republic of Congo, Democratic Republic of Congo, Denmark, Cook Islands, Costa Rica, Cuba, Cyprus, Democratic People's Republic of Korea (North Korea), Djibouti, Dominica, Dominican Republic, Egypt, El Salvador, Equatorial Guinea, Faeroe Islands, Falkland Islands, Fiji Islands, French Guiana, French Polynesia, Gabon, Gambia, Ghana, Gibraltar, Greenland, Grenada, Guadeloupe, Guam, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Iceland, Iraq, Isle of Man, Israel including Palestine, Jamaica, Jordan, Kenya, Kiribati, Kuwait, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libyan Arab Jamahiriya, Liechtenstein, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Islands, Martinique, Mauritania, Mauritius, Mayotte, Micronesia (Federated States of), Monaco, Montserrat, Morocco, Mozambique, Myanmar, Namibia, Nauru, Netherlands Antilles, New Caledonia, New Zealand, Nicaragua, Niger, Niue, Norfolk Island, Northern Mariana Is, Oman, Palau, Panama, Papua New Guinea, Paracel Islands, Pitcairn Islands, Puerto Rico, Qatar, Reunion, Rwanda, Saint Helena, Saint Kitts and Nevis, Saint Lucia, Saint Pierre & Miquelon, Saint Vincent/Grenadines, Samoa, San Marino, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, Spratly Islands, Sudan, Suriname, Swaziland, Switzerland, Syrian Arab Republic, Tanzania, Togo, Tokelau, Tonga, Trinidad and Tobago, Tunisia, Turks and Caicos Is, Tuvalu, Uganda, United Arab Emirates, US Virgin Islands, Vanuatu, Wake Island, Wallis and Futuna Is, Western Sahara, Yemen, Zambia, Zimbabwe.					
Countries not analysed					
Bosnia and Herzegovina, Croatia, Serbia and Montenegro, Slovenia, Taiwan					

Supplementary Table S2. Intercomparison of methods with more limited studies						
	Brisson et al.	Lin and Huybers	Year of yield max from our generalized algorithm	FAO reported year of maximum yield	Both algorithms agree (absolute difference in years Lin and Huybers)	Further notes on our comparison
Austria	NA	1990	2005	2004	Y (15)	This large difference is due to the higher yields of 2004 and 2008 which if removed as outliers gives our modeled maximum year as 1999
Colombia	NA	1995	1999	2005	Y (4)	
Denmark	1995	1995	2002	2009	Y (7)	
Germany	1999**	2010	2008	2004	Y (2)	
Greece	NA	1980	1988	2010	Y (8)	There is an initial yield peak in 1988 after which yields decreased but then there has been a restart in yield increase from 1999 and continuing
India	NA	2001	2009	2009	Y (8)	In the last two years wheat yields are above the linear trend line. Thus both results no longer hold and the subnational map for wheat shows where this may have likely occurred
Ireland	NA	2000	2004	2004	Y (4)	
Netherlands	1993	1995	2004	2009	Y (9)	
Norway	NA	1982	1996	1993	Y (14)	
Romania	NA	1980	1994	1988	Y (14)	
Sweden	NA	1991	2009	1990	Y (18)	
Switzerland	1990	1991	2000	1996	Y (9)	
United Kingdom	1996	1997	2002	2008	Y (5)	
Zambia	NA	2001	2005*	2008	N	*(In 2008 Zambian wheat yields were boosted by 64% over the last 5-year average. If this point is dropped then Zambian yields peaked in 2005 agreeing with the Lin and Huybers[11] method.)
France	1996	1996	2004	1998	Y (8)	
Algeria	NA	-	-	2010	Y	
Argentina	NA	-	-	2010	Y	
Bolivia	NA	-	-	2010	Y	
Brazil	NA	-	-	2010	Y	
Canada	NA	-	-	2008	Y	
Chile	NA	-	-	2010	Y	
Lebanon	NA	-	-	2001	Y	
Nepal	NA	-	-	2008	Y	
New Zealand	NA	-	-	2007	Y	
Peru	NA	-	2007	1993	N	
Saudi Arabia	NA	-	-	2010	Y	
South Africa	NA	-	-	2009	Y	
United States	NA	-	-	2010	Y	
Uruguay	NA	-	-	2009	Y	
Tunisia	NA	-	-	2003	Y	

We did an intercomparison between the results of plateau-only detection algorithm of national wheat yields (Lin and Huybers, 2012)[11] that built upon the Brisson et al. (2010)[10] wheat yield plateau detection algorithm. Note that our algorithm is geared to detecting whether yield maximum has been reached, which by its form leads to a peak later that a linear-plateau change point algorithm. We compare only those countries for which Lin and Huybers (2012)[11] show a 95% confidence (p value < 0.05) in the occurrence of yield plateau. **Brisson et al. (2010)[10] $p > 0.05$, NA = results not available.

Supplementary Table S3. Utility of subnational analysis.

		Maize								Wheat							
		National %				Subnational %				National %				Subnational %			
		a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
1	Argentina	-	-	-	100	0	5	0	95	-	100	-	-	5	34	0	61
2	Australia	-	100	-	-	0	39	0	61	-	100	-	-	4	44	12	40
3	Austria	-	-	-	100	0	12	0	88	-	100	-	-	0	82	0	18
4	Belgium	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
5	Bolivia	-	-	-	100	0	5	0	95	-	-	-	100	0	0	0	100
6	Brazil	-	-	-	100	2	11	6	81	-	-	-	100	0	19	0	81
7	Bulgaria	-	-	-	100	0	0	0	100	-	-	-	100	0	0	0	100
8	Canada	-	-	-	100	0			100	-	-	-	100	0	1	0	99
9	Chile	-	100	-	-	0	57	0	43	-	-	-	100	0	8	0	92
10	China	-	100	-	-	0	52	0	48	-	-	-	100	0	56	0	44
11	Colombia	-	-	-	100	0	0	0	100	-	100	-	-	0	99	0	1
12	Czech Republic	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
13	Ecuador	-	-	-	100	0	2	0	98	-	-	100	-	0	1	94	5
14	Finland	n	n	n	n	n	n	n	n	-	-	-	100	0	20	0	80
15	France	-	-	-	100	0	10	0	90	-	100	-	-	0	79	0	21
16	Germany	-	-	-	100	0	0	0	100	-	100	-	-	0	80	0	20
17	Greece	-	100	-	-	0	100	0	0	-	100	-	-	0	74	0	26
18	Hungary	-	100	-	-	0	70	0	30	-	100	-	-	0	89	0	11
19	India	-	-	-	100	5	31	1	63	-	100	-	-	0	70	0	30
20	Indonesia	-	-	-	100	0	2	0	98	n	n	n	n	n	n	n	n
21	Iran	-	-	-	100	0	0	0	100	-	-	-	100	0	3	0	97
22	Ireland	n	n	n	n	n	n	n	n	-	100	-	-	0	100	0	0
23	Italy	-	-	-	100	0	59	0	41	-	-	-	100	0	24	0	76
24	Japan	-	-	-	100	0	0	0	100	-	-	-	100	4	0	0	96
25	Mexico	-	-	-	100	0	31	0	69	-	-	-	100	0	35	0	65
26	Mongolia	n	n	n	n	n	n	n	n	-	100	-	-	64	14	14	8
27	Nepal	-	-	-	100	0	0	20	80	-	-	-	100	0	2	0	98
28	Netherlands	-	-	-	100	0	0	0	100	-	100	-	-	0	94	0	6
29	Nigeria	-	-	-	100	0	17	0	83	-	-	100	-	100	-	-	-
30	Norway	n	n	n	n	n	n	n	n	-	100	-	-	0	62	0	37
31	Pakistan	-	-	-	100	0	0	0	100	-	-	-	100	0	13	0	87
32	Paraguay	-	-	-	100	0	84	0	16	-	-	-	100	0	0	0	100
33	Peru	-	-	-	100	2	13	1	84	-	100	-	-	10	39	12	38
34	Philippines	-	-	-	100	0	0	0	100	n	n	n	n	n	n	n	n
35	Poland	-	-	-	100	0	22	0	78	-	100	-	-	0	84	0	16
36	Portugal	-	-	-	100	0	35	0	65	-	-	-	100	0	11	0	89
37	Romania	-	-	-	100	0	53	0	47	-	100	-	-	0	100	0	0
38	Saudi Arabia	-	-	-	100	25	0	0	75	-	100	-	-	0	99	0	1
39	Slovakia	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
40	South Korea	-	100	-	-	0	46	0	54	-	-	-	100	2	75	0	24
41	Spain	-	-	-	100	0	52	0	48	-	-	-	100	0	18	0	82
42	Sri Lanka	-	-	-	100	0	3	0	97	n	n	n	n	n	n	n	n
43	Sweden	n	n	n	n	n	n	n	n	-	-	-	100	0	3	0	97
44	Thailand	-	-	-	100	1	0	0	99	n	n	n	n	n	n	n	n
45	Turkey	-	-	-	100	0	26	0	74	-	100	-	-	0	64	0	36
46	United Kingdom	n	n	n	n	n	n	n	n	-	100	-	-	0	99	0	1
47	United States	-	-	-	100	0	8	0	92	-	-	-	100	9	27	0	64
48	Venezuela	-	-	-	100	0	6	0	94	-	-	100	-	0	0	0	100
49	Vietnam	-	-	-	100	0	0	0	100	n	n	n	n	n	n	n	n

Percentage of areas under the 4 yield trend types from just using FAO reported national statistics and the resolution offered via conducting subnational analysis: a=yield never improved, b=yields stagnating, c=yields collapsed, d=yields increasing, n=crop not grown in this country as per FAO, or analysis cannot be performed. Results shown only for maize and wheat for countries without political unit restructuring and numbers are rounded to the nearest integer.

Supplementary Note 1

Comparison of national-level wheat yield stagnation

Two recent studies analysed leveling of wheat yield using new statistical techniques that determine the year when yields changed from linear increases to a plateau. Our method is different as our goal goes beyond just the detection of a yield plateau to the detection of yield maxima and yield declines. Nevertheless, if yields have stagnated then all three studies should detect such a trend. There were two additional complications in a direct comparison: (a) the published studies were at the national level, whereas ours was at the subnational level for the major producers, and (b) results were only available for some countries and only for one crop (wheat). We thus conducted a separate study where we (a) acquired national wheat yield time series from FAO[60] (including the preliminary data from 2009 and 2010) to match up with the time series used in Lin and Huybers (2012)[11]. Next (b) we detected yield trends using the national data using our AIC model selection method and F test. The results were generally comparable, although the exact year when yields started to stagnate differed between this study and the two other studies[10,11] (Supplementary Table S2). This is expected as our algorithm is not only for detecting areas with “yield stagnation” but also areas of “yield collapse,” “never improved,” and “increasing.” Our algorithm finds the year the yield maximum occurred in areas where yields have stagnated, whereas others found the point at which the yields started to stagnate. Regardless of this difference, the studies generally agreed when yield stagnation occurred.

Utility of subnational data

As noted in Supplementary Methods, we collected subnational statistics for the 51 countries that cover 70% to 90% of the harvested areas for our four crops and are responsible for 79% to 99% of total global production of these four crops. So the question arises: how much additional utility does our subnational analysis provide versus an analysis with national-level data? Supplementary Table S3 lists the yield trend condition using only the national yield data versus subnational information, and only for the crops maize and wheat to serve as examples. Results clearly show that subnational analysis provided additional information similar to the finding of Lin and Huybers (2012)[11] for wheat yields in United States and France.

Our maps show where each of the subnational yield trend conditions were found. Also note that even when 100% of the area was under the condition of yield increasing, it does not necessarily imply that all areas are increasing at the same rate, unlike a national-only analysis. The same applies to the other yield condition categories. Future studies should aim to further improve the subnational resolution, enabling an even more precise identification of global yield trends.

Supplementary Methods

Data collection and its importance

We collected maize, rice, wheat, and soybean area harvested and production numbers from ~13,500 fixed political units to build our national and subnational information of crop yields (yield is the ratio of production and harvested area) at each of these political units (Supplementary Table S1). What we describe here is the data used in this specific study, approximately 600,000 census statistics per crop. Out of the 226 political units (nations) for which the Food and Agriculture Organization (FAO)[60] provides national-level data, we collected data at the next administration level for 51 countries, and also at the third administration level for 17 countries (Supplementary Table S1, Supplementary Figure S1). These 51 countries account for ~79% maize, ~80% rice, ~70% wheat, and ~97% soybean harvested areas globally, between 2004-2008[60]. More importantly, these 51 countries account for ~91% maize, ~83% rice, ~78% wheat and ~99% of soybean total global production during the same years[60]. Thus our study's data set of ~13,500 political units provides a much improved picture of crop yield trends globally than was previously available using only national data.

Where sub-national data are available, the frequency of reporting varies among countries. As can be expected, data were more easily available in the recent past (post 1980s) compared to 1961-1980. Supplementary Table S1 provides further details of the length of time for which we were able to collect subnational statistics, and Supplementary Figure S1 provides the locations of national, state and county level data. Our largest gap of missing subnational information is from the former Soviet Republics. Future studies should attempt to include these countries; doing so would particularly improve the understanding of wheat yield trends.

Initial data quality inspection

Wherever possible we collected harvested hectares and production from our source data (see Supplementary Table S1) and derived yield from these two primary quantities. If either of these two primary quantities was absent but the yield information present, we computed the missing production or harvested area statistic using the reported yield. During the process of collecting the data from their original source, we conducted visual inspection followed by deriving yields from the primary data to determine any potential outliers. As an example, we found that the Bali province of Indonesia reported that 839775 tons of rice were harvested from just 14503 ha which gave an unreasonable yield of 57.9 tons/ha in the year 2007. Fortunately, in this case yields were also reported that were reasonable: 5.79 tons/ha. We thus corrected the harvested ha based on this additional information to 145040 ha. We similarly made several corrections elsewhere globally where reasonable, but where such judgments were not possible we removed the data and they did not enter into further analysis.

Handling of missing years and generating a consistent database across all spatial levels

Missing data were of two types: (a) the crop was not grown (this was reported in various forms in the official statistics as "-", "0", etc., or the subnational data was absent for the unit whereas other units reported the statistics); and (b) data for the entire year was absent for all units from the time series, or the time series was not reported any further beyond a specific year. When the case was (a) we simply noted the harvested area and production numbers as 0 for the unit as the statistics collected. When (b) occurred we first had to determine whether the crop was even harvested in the missing years (the next administrative level reported statistics if harvested), and if yes then we interpolated the production and harvested area.

Missing data were interpolated in three progressive steps. First, we determined the earliest or closest five years of data before the data time series was unavailable. We then determined the average five-year harvested area and production amount for each state/region/province. From these numbers we determined the proportion of total harvested area and total production that each state/region/province contributed. Finally, we used these proportions to estimate the individual state/region/province data for the missing period from national harvested and production numbers[60]. In all other years for which data were available, we summed the harvested area and production numbers and then compared the total of the subnational numbers to the FAO reported national totals. If there was a discrepancy between the two numbers, we scaled the subnational numbers proportionately to match the FAO reported numbers. Thus implicit in this step was the assumption that the FAO numbers were accurate; summing the state/region/province data would produce the same results at the national level as using only the FAO reported numbers. In other words, our data is consistent with the FAO, yet enables analysis at finer scales to understand regional variability. If the unit of data collection was the county level then we interpolated in the same three steps for missing county level data, but of course in this case the next higher unit was the state level data.

With the exception of China, missing county-level data (Supplementary Table S1) were interpolated using the same methods. In China, we redistributed state level data with the harvested area and production amount defined by Monfreda et al. (2008)[58].

Often countries reported their agricultural statistics in units other than tons and hectares, and in some cases reporting units varied among years. For consistency, we converted all data to tons and hectares.

Data quality

We generated data quality maps integrating both the length of time as well as the spatial unit of our data from the primary source. For example, a very small area with only 25 years of data has a smaller impact to our overall global analysis than a ten-fold larger area with only 25 years of data. Thus integrating both the time and the spatial unit of analysis into a single data quality metric provides a better measure of data quality. We used the following simple metric:

$$Q(PU) = 100\frac{\sum_t \sum_i A(i,t)t(0,1)}{\sum_t \sum_i A(i,t)}$$

where $Q(PU)$ is the data quality for the political unit (PU), term $A(i,t)$ is the strength of a country, state or county census unit (i) for a given year (t), and $t(0,1)$ denotes the presence (1) or absence (0) of the data. The term $A(i,t)$ is the harvested area or production amount present in the database for the political unit under consideration. If the data was from interpolation at this census unit (i) level then $t(0,1)$ is recorded as 0, else 1. In the ideal cases where county, state, and national data are available for all years, the metric has its highest value, 100. Supplementary Figure S2 provides this metric for maize and rice valid at the spatial resolution given in Supplementary Figure S1. Data quality maps are quite similar for wheat and soybean in their respective harvested areas, since data availability was similar for these crops. Data quality was generally above 50%.

Yield trends

We determined yield trends in three steps. First we parsimoniously determined the statistical model that best fit the observed yield data in every political unit. Next we calculated F tests to determine the goodness of the fit of the chosen model at the five percent confidence level. In the third step the parameters of the parsimoniously chosen model guided the classification of the yield trend into four classes: (a) Yields never improved, (b) Yields stagnating, (c) Yields collapsed, and (d) Yields increasing.

Parsimoniously choosing the statistical model that best represents yield trends

In every political unit across the globe, we analysed four polynomial representations of the yield-time relationship with an increasing number of parameters – an intercept only model (1), linear model (2), quadratic model (3) and cubic model (4) of the form:

$$Y = k \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$
$$Y = at + k \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2)$$
$$Y = at^2 + bt + k \dots\dots\dots\dots\dots\dots\dots.. (3)$$
$$Y = at^3 + bt^2 + ct + k \dots\dots\dots\dots (4)$$

where Y = yield in tons/ha/year and t = year; a, b, and c are the coefficients of regression; and k is the intercept.

We next identified the model that best fit the yield data parsimoniously (utilizing as few parameters as necessary). We utilize the Akaike Information Criterion (AIC) developed by Akaike (1974)[59], and computed AIC for each of the above four models (5):

$$AIC = n\log\left(\frac{SS}{n}\right) + 2p \dots\dots\dots\dots\dots.. (5)$$

where SS is residual sum of squares, n is the sample size (generally 48 corresponding to the 48 years), and p is the number of parameters. Since the objective is to minimize AIC, the metric penalizes for having a larger number of parameters and gives credit for higher explanatory power. The model with the minimum AIC was chosen as the best representation of the yield trend for a given location. Supplementary Figure S3 shows the model chosen based on AIC for each crop spatially.

Goodness of fit of the chosen model

While AIC helps to decide on the model that best represents the yield trend, it does not provide a test on the overall goodness of the fit. If all models fit the data poorly, then the best model chosen on the basis of AIC would still be a poor fit to the observed data. Thus, additional statistics on the goodness of model fit are required before using the chosen model to classify yield trend type. We tested the chosen model's goodness of fit using F statistic against the null hypothesis of a constant model. We failed to reject the null hypothesis only in a very small percentage of global areas (at alpha = 0.05); 0.3%, 0.1%, 0.9%, and 0.5% of global maize, rice, wheat, and soybean areas, respectively and in most areas where we fail to reject the null hypothesis we also have good data coverage. Those areas where we failed to reject the null hypothesis were re-classified using the null hypothesis (the constant model). The degrees of freedom associated with the F-statistic were the number of data points minus the number of coefficient estimates required for the chosen model form chosen through AIC. This F test neglects autocorrelation and could potentially inflate significance[11]. The p-value associated with the F test for each crop is given in Supplementary Figure S4.

Classification of yield trends

Based on the chosen model parameters, yields were classified into four categories: yields never improved, yields stagnating, yields collapsed, and yields still increasing. In the next few paragraphs we show using easily available data (FAO[60]) how yield trend types were classified.

When the AIC criterion suggested a constant model, this implied that the yield-year relationship was a constant or that "yields never improved" (see Figure 1 a for examples). However, in some cases where a model other than the intercept only model was chosen, we found that the F test failed. We reassigned these political units into "yields never improved." Less than a percent of the world for any of the four crops were reassigned. An example of this would be maize yields for Gabon. While the model chosen was quadratic based on AIC, after conducting the F test we reassigned yields for Gabon as "yields never improved" (Supplementary Figure S5 a).

When the model chosen was a linear model, we classified yield trend based on the sign of the slope. If the slope was negative it meant that yields were decreasing always and thus they were classified as "yields collapsed." On the other hand if the slope of the linear equation was positive it meant that yields were increasing and thus we classified such areas as "yields increasing." As an example, consider Myanmar's rice yields where we found that the best fit was a straight line with a positive slope (Supplementary Figure S5 b).

When the chosen model was quadratic we first determined the sign of the quadratic term. When positive it meant that yields were increasing. As an example consider maize yields from Guinea-Bissau (Supplementary Figure S5 c). When the quadratic term was negative it meant that yields had a year of yield peak (Supplementary Figure S5 d – maize yields of Gambia) and were thus classified as "yields stagnating". There are various rates at which yields were declining since the maximum yield/inflection year. However, when the year of yield peak was beyond the year 2010 it only meant that the yield gains were slowing towards a future peak yield. Hence yields were *still* increasing and thus classified as "yields increasing" (Supplementary Figure S5 e – Swiss maize yield). However, if after the year of yield max/maximum inflection point, yields had reached the 1960s level it meant yields had collapsed. We reclassified these areas as "yield collapsed" and tested them by determining whether the average yields in the 2000s had reached below the average yields of 1960s (Supplementary Figure S5 f – maize yields of Zimbabwe). We did this simple test only when we had at least 7 of the 10 years data in each of the two periods.

When the chosen model was cubic we solve for both the year when yield improvement started as well as the year of yield maximum. If the maximum year was reached on or before 2010 we classified those areas as "yield stagnation", and after 2010 we classified them as "yields increasing." In some cases however, yields went through an initial yield maximum followed by a yield minimum in more recent times and then another rise. We detected such cases as well and classified them as "yield increasing" (Supplementary Figure S5 g – wheat yields of Kenya). Also similar to the quadratic case, if the yields for the 2000s had reached the values of 1960s we reclassified the yield trend category into "yield collapsed".

Maps of the year in which “yield stagnation” started are given in Supplementary Figure S6.

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