Supplementary Tables and Figures

Table S1. Estimated total crop input costs and gross economic and yield (per acre) returns per acre, for the major crops of corn, soy, and wheat (A) across the central and western United States for 2019 (University of Minnesota 2019) and (B) in the province of Ontario, Canada for 2020 (OMAFRA 2020). For the US (A), the total number of overall farms in the database cover 9.42 million acres. N = number of farms contributing data per crop. Direct expenses are fully relatable to crop yield, and can be variable by year depending on weather, amount planted, pest infestation, and market factors. Overhead costs are not directly related to production and are generally fixed, in the sense that their value tends to not vary from year to year in response to climate or market conditions. Data for S1A are publicly available from https://finbin.umn.edu/, one of the largest available databases globally on farm costs and production. For Ontario (S1B), data are estimated field budgets describing farm expenditures for corn, soybean, and wheat, expressed in Canadian dollars. (see Methods). All costs for Ontario are estimated from 2020. All prices are based on five-year averages $acre^{-1}$ from 2014-2018, the most recent available data http://www.omafra.gov.on.ca/english/stats/crops/. The Ontario OMFRA data lacked land rental fees and insecticide/fungicide costs for corn and soybean. For the former, we determined mean rental costs across Ontario's thirty counties adjusted for mean percentages of rented land per farmer (53% of total cropped acreage – see Methods). For the latter, we used the FINBIN data from Table S1A as an approximation.

(A)

Factor	Average for all farms

	Corn (n=1573)	*Soybean (n=1539)*	*Spring wheat (n=381)*
Total acres	345.1	348.6	552.8
Yield per acre (bushels)	173.3	44.2	57.1
GROSS RETURN PER ACRE	**$726**	**$454.2**	**$359.57**
Direct Expenses (per acre)			
seed	101.8	57.5	19.3
fertilizer	122	19.2	77.3
Crop chemicals	34.9	38.3	32.3
Crop insurance	18.5	16.9	13.1
Drying	19.5	0.3	1
Storage	2.1	0.7	-
Fuel and oil	24	15.2	13
Repairs	42	26.5	23.7
Labor – custom hire	11.8	7.7	6.7

Labor – hired labor	4.1	2.9	1.8
Land rent	183.6	152.4	77.8
Machinery leases	4.2	3.2	1.2
Utilities	1.3	0.7	-
Hauling	1.9	0.7	-
Marketing	1.5	1.1	0.8
Operating interest	16.4	9.8	6.7
Miscellaneous	2.8	2	2.4
TOTAL DIRECT COSTS	**$592**	**$355.1**	**277**
(DIRECT COSTS) – (GROSS RETURN)	**$134.7**	**$99.1**	**82.6**
Overhead Expenses (per acre)			
Labor – hired labor	11.9	7.4	8.8
Machinery leases	5.5	3	3.1
Building leases	1.7	0.8	0.7

Farm insurance	9.2	6.4	5
Utilities	5.2	3.6	3.6
Dues and professional fees	4.1	2.8	2.2
Interest	6.2	4	3.4
Machinery & building depreciation	46.6	30.7	25.8
TOTAL OVERHEAD COSTS	**$97.61**	**63.8**	**56.4**
NET RETURN (GROSS – [DIRECT + OVERHEAD])	**$37.1**	**35.3**	**26.2**
GOVERNMENT SUBSIDY	+$6.20	+$5.6	+$5.5
Labor and management charges	-$43.89	-$29.5	-25.48
FINAL NET RETURN (for 2019)	**-$0.64**	**+$11.4**	**+$6.2**

(B)

Factor	Estimated cost average ($ acre^{-1})		
	corn	*soy*	*wheat*
seed	108.8	48.8	71.25
insecticide on seed	1.6	13	-
fertilizer (N, P, and/or K)	138.45	45.35	103.7
herbicide	26.4	69.95	11
insecticide/fungicide	51.1	49.6	37.45
machine expenses incld fuel	65.65	55.05	53.7
marketing boarding	1.9	1.9	2.05
insurance	11.6	7.9	8.9
risk management program	8.8	2.3	3.5

custom labor	23	23	23
trucking	39.85	11.5	21.3
drying	92.85	-	-
land rent	95.82	95.82	95.82
operating labor	15.3	12.65	12.65
storage	41.6	12	-
interest on operating	14.25	7.5	14.3
OPERATING			
depreciation costs	41.15	39.05	38.15
interest on investment	13.95	13.85	13.55
other	5.8	6.3	6.2
TOTAL COST ACRE^{-1}	781.7	504.2	516.52
GROSS RETURN ACRE^{-1}	790.6	592.5	548.8
NET RETURN ACRE^{-1}	**$-7.2**	**$+76.9**	**$+32.3**

Table S2. Qualitative definitions of the seven major classes of farm soil, as shown in Figure 2. Note that our assessment of "marginal lands" is largely restricted to classes IV-VII, although Class III, which is heavily farmed in Canada (Fig. 2A), also possesses some level of severe limitation requiring management intervention by farmers.

Land Suitability	Description
1	No significant limitations in use for crops.
2	Moderate limitations that reduce the choice of crops, or require moderate conservation practices.
3	Moderately severe limitations that reduce the choice of crops or require special conservation practices.
4	Severe limitations that restrict the choice of crops, or require special conservation practices and very careful management, or both.
5	Very severe limitations that restrict their capability to producing perennial forage crops, and improvement practices are feasible.
6	Unsuited for cultivation, but are capable of use for unimproved permanent pasture.
7	No capability for arable culture or permanent pasture.

Table S3. List of databases used in this study – note that all data are publicly available.

Area	Data	Table ID	Location	Start	End	Notes
			Inputs			
Canada	Farm Operating Expenses, historic	32-10-0278-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210027801	1926	1972	Pesticide applications in the years 1926-1947 include containers and could not be separated from the sole cost of pesticides
Canada	Farm Operating Expenses, current	32-10-0049-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210004901	1971	1917	NA
Canada	Archived - Fertilizer shipments	32-10-0274-01	https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210027401	1967	2005	NA
Canada	Fertilizer shipments	32-10-0039-01	https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210003901	2006	2018	NA
Canada	Average operating revenues and expenses of farms, by farm type	2-10-0078-01	https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210007801	2001	2014	NA
			Outputs			
Canada	Canadian Yield, Production, Area Seeded	32-10-0359-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210035901	1908	2019	NA
			Market Prices			
Canada	Farm product prices, crops	32-10-0077-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210007701	1980	2019	supplemented by Table 31-10-0359-01
United States	Government subsidies, profits		https://finbin.umn.edu/	1994	2018	
			Population			
Canada	Canadian Population, Historic	17-10-0063-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710006301	1852	1977	NA
Canada	Canadian Population, Current	17-10-0005-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501	1971	2018	NA
World	World Population	NA	https://population.un.org/wpp/DataQuery/	1950	NA	NA
			Inflation Adjustments, CPI			
Canada	Canadian Consumer Price Index	18-10-0005-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000501	1914	2018	NA
Canada	Farm input price index 1986=100	18-10-0110-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810011001	1961	1999	from 1961 to 1970, crop production index is the mean of (fertilizer, seeds)
Canada	Farm input price index (1992=100)	18-10-0123-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810012301	1998	2007	
Canada	Farm input price index, quarterly	18-10-0258-01	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810025801	2002	2018	NA

United States	US CPI		https://download.bls.gov/pub/time.series/cu/	1947	2019	NA
			Other			
United States	CRP Rental Payments, 1986-2017	none	https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index	1986	2017	NA
Canada	Average operating expenses of farms, by farm type	2-10-0078-01	https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210007801	1993	2014	NA
Canada	Net farm income	32-10-0052-01	https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210005201	1926	2017	NA

Figure S1. Changes in input costs (fertilizer, seed and feed and pesticides), cultivated land, and farm labor costs based on USDA data 1947-2018 for the United States (https://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/agricultural-productivity-in-the-us/). Values are calculated relative to 1948, in the identical fashion to how Canadian farm data are displayed in Fig. 1a in the main text. Pesticides (lower panel) are separated because their increase costs dwarf that of the other values. This graph, compared to Fig. 1a, shows the similarities in input trends between Canada and the US, while also showing the large decline in labor costs (data not available for Canada) and the decline of total farmed land in the US. Canada shows a large net increase in farmland since 1926, although Canada only has 190 million acres of farmland, compared to the 900 million acres of the US. Canada also has 10 times fewer farms than the US (205,000 vs 2 million farms, respectively), although the average farm size in Canada is double that of the US (778 scres vs 443 acres). Data are from the USDA 2012 Census of Agriculture (www.agcensus.usda.gov), and do not include recent

cropping trends towards increased use of marginal lands in response to rising global food demands[22,44].

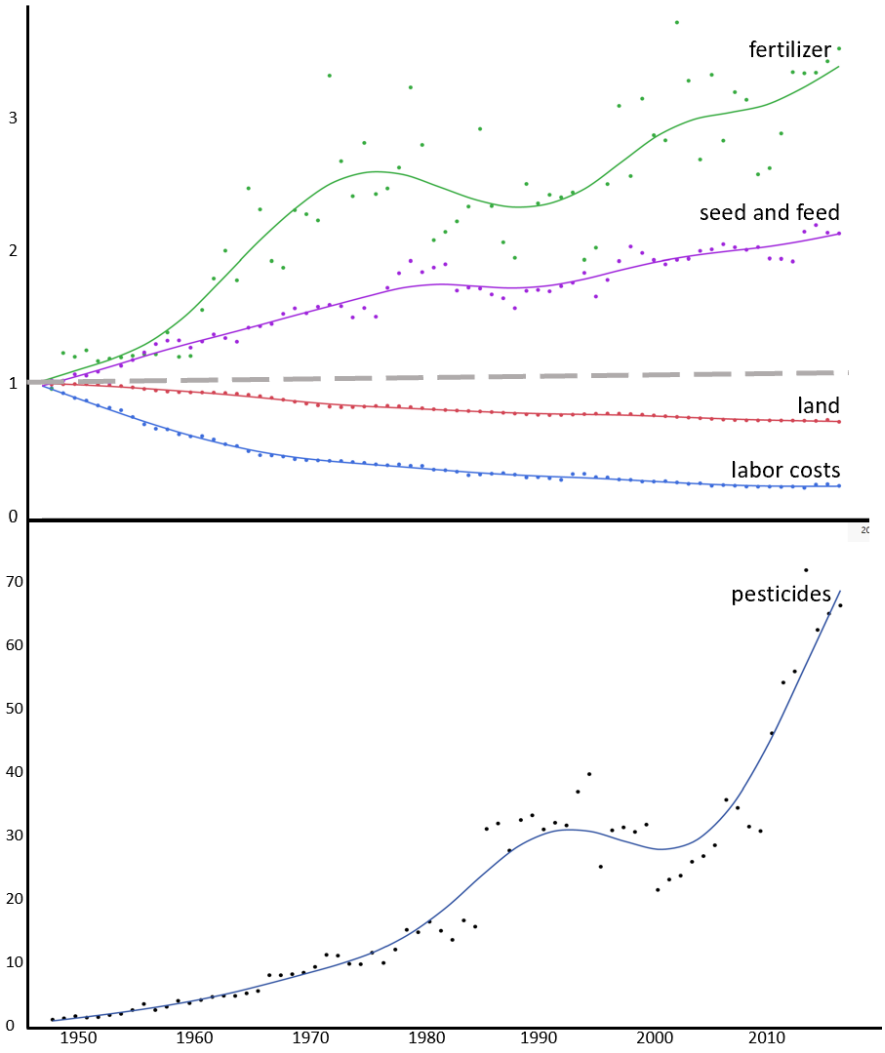


Figure S2. Changes in tonnes of grain harvested per acre in Canada since 1926. The fitted polynomial trend shows a consistent and strong increases over the 93 years ($R^2 = 0.751$; $F_{2,92} = 135.9$, $p<0.0001$), in association with greater fertilizer inputs, pesticide use (herbicide and insecticide), mechanization, and crop breeding.

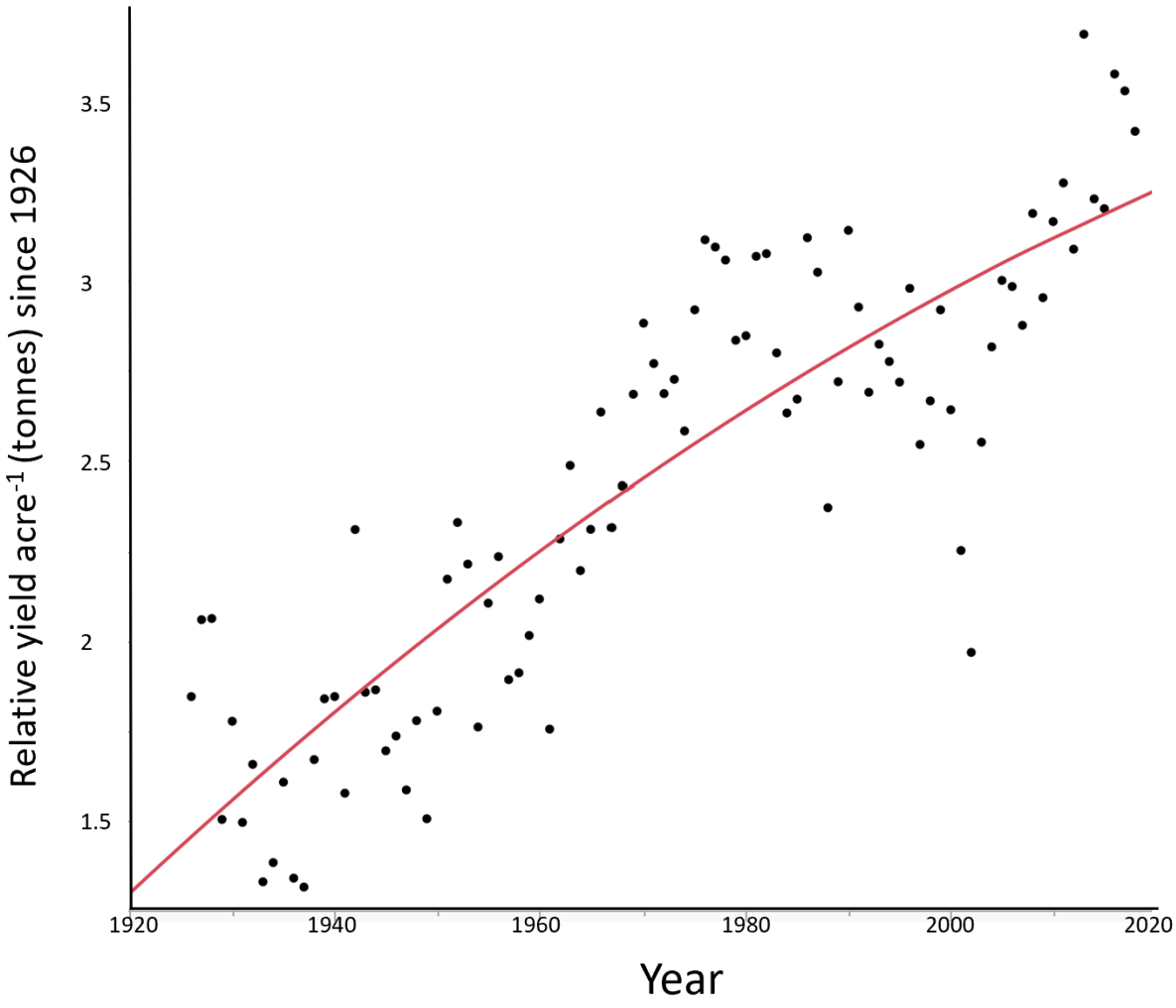

Relative yield acre-1 (tonnes) since 1926
3.5
3
2.5
2
1.5
1920
1940
1960
1980
2000
2020
Year

Figure S3. Changes in the ratio of input costs of fertilizer, insecticide, and seed to farm labor, between the years 1947 and 2017. Data are from the USDA, and for all crops including labor intensive fruits, nuts, and vegetables – our main analysis (e.g., Fig 1a) only targets the nine major grain crops of North American markets, where reductions in labor costs due to mechanization are much higher. Current labor costs for fruits, nuts, and vegetables in the US are estimated at 25-30% of all costs; current farm labor costs for the none major grain crops are ~3% (see Table S1). Data below show that input costs began to exceed labor costs in the early 1980s, and have increased significantly since ($F_{1,68} = 298.7$; $p<0.0001$).

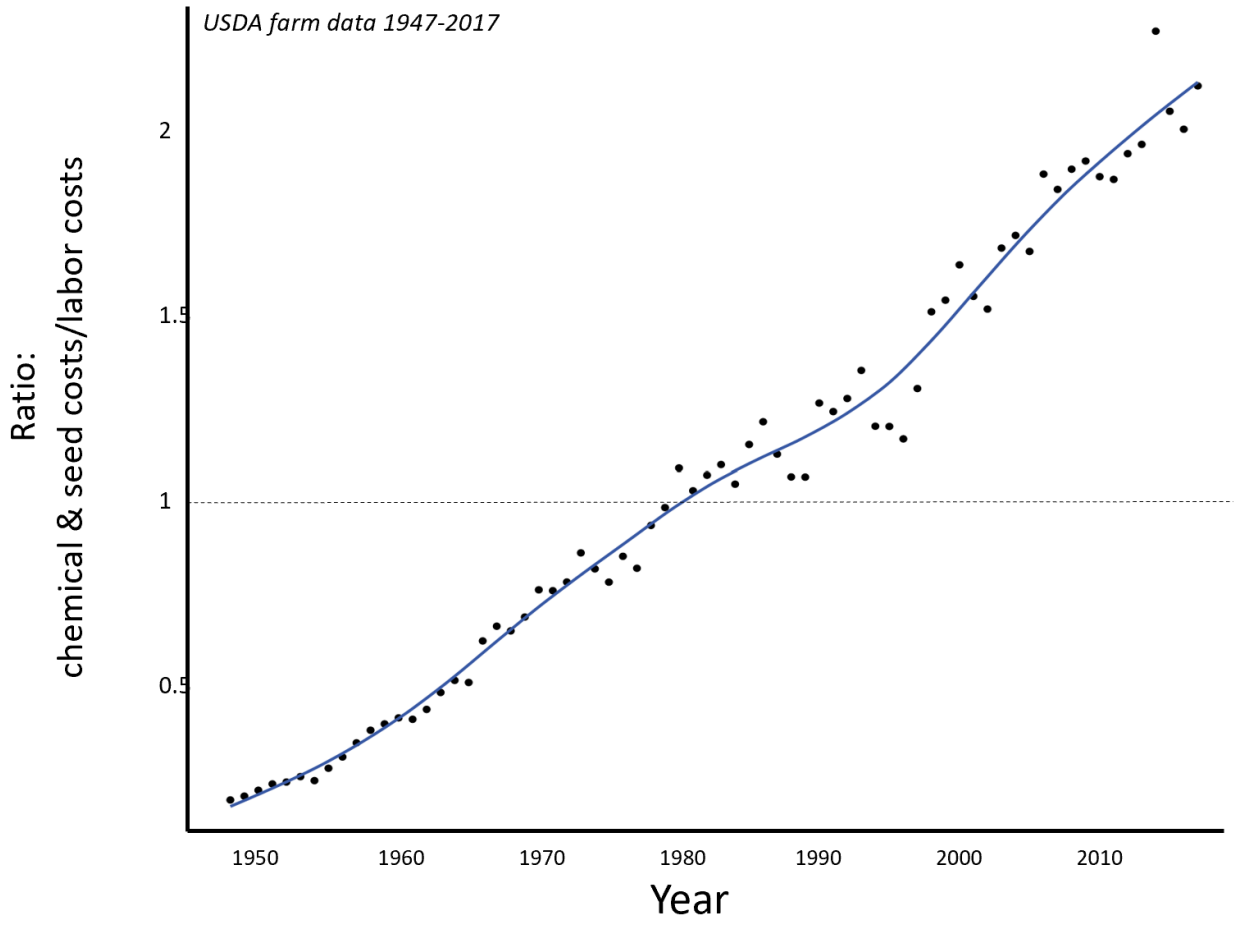


Figure S4. Temporal trends showing a growing gap between agricultural inputs (green) and agricultural productivity (gold) outputs for Canada (**A,** circles) and for the five major world regions (*b*, triangles). The response variable is presented as an index (using a log scale) where 1926 = 1 for Canada (**A**) and 1961=1 for the world (**B**). In **A** inputs are given as inflation-adjusted dollars spent on intensification costs including fertilizers, pesticides, seed technology, and irrigation (circles) whereas **B** uses mass of nitrogenous fertilizers (triangles). Crops included in production vary slightly between Canada and the world (see Methods).

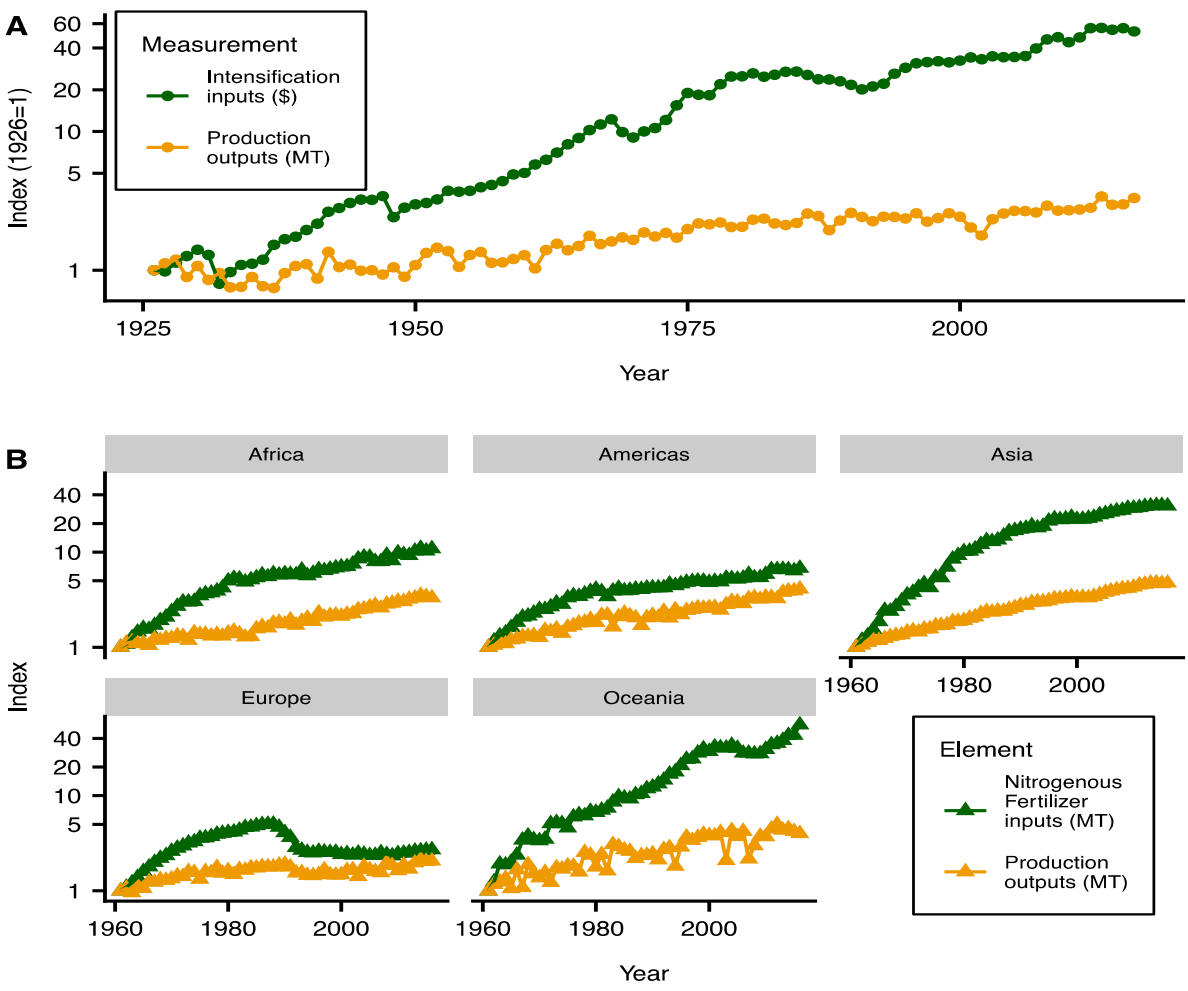


Figure S5. Land conversion into and out of cropland cover. Type of previous land cover for new cropland and current land cover for lost cropland is shown. Most cropland lost is due to conversion into urban settlement.

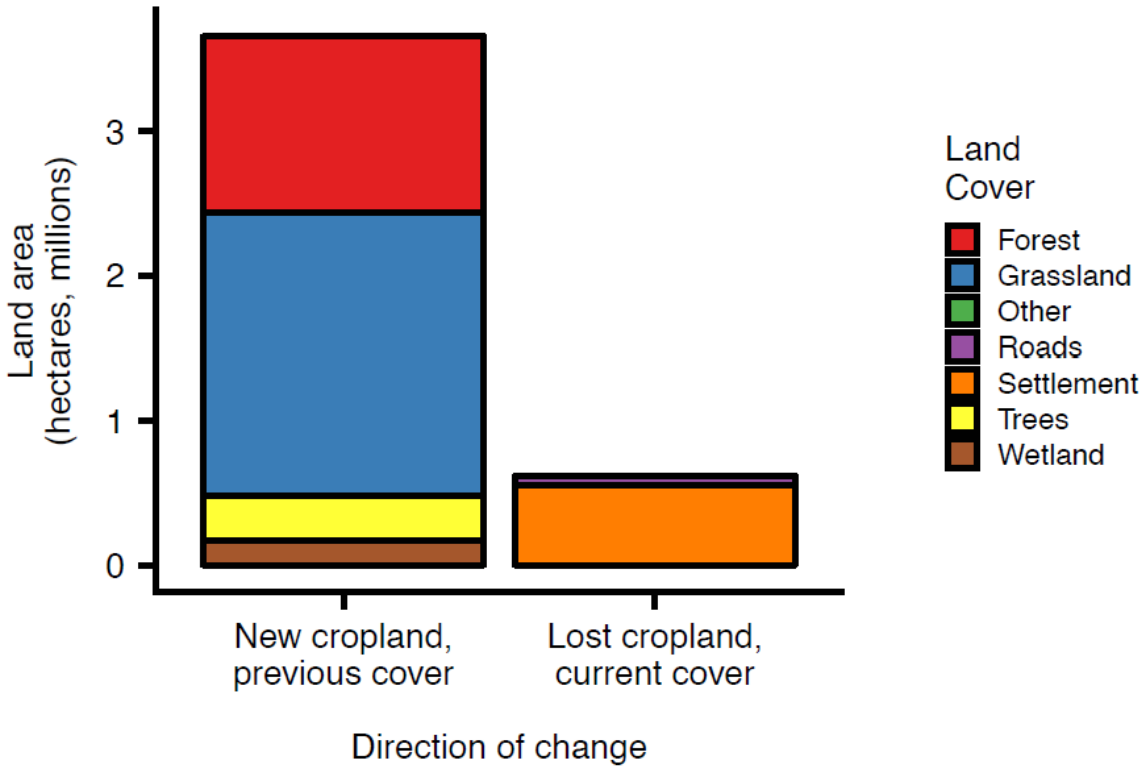
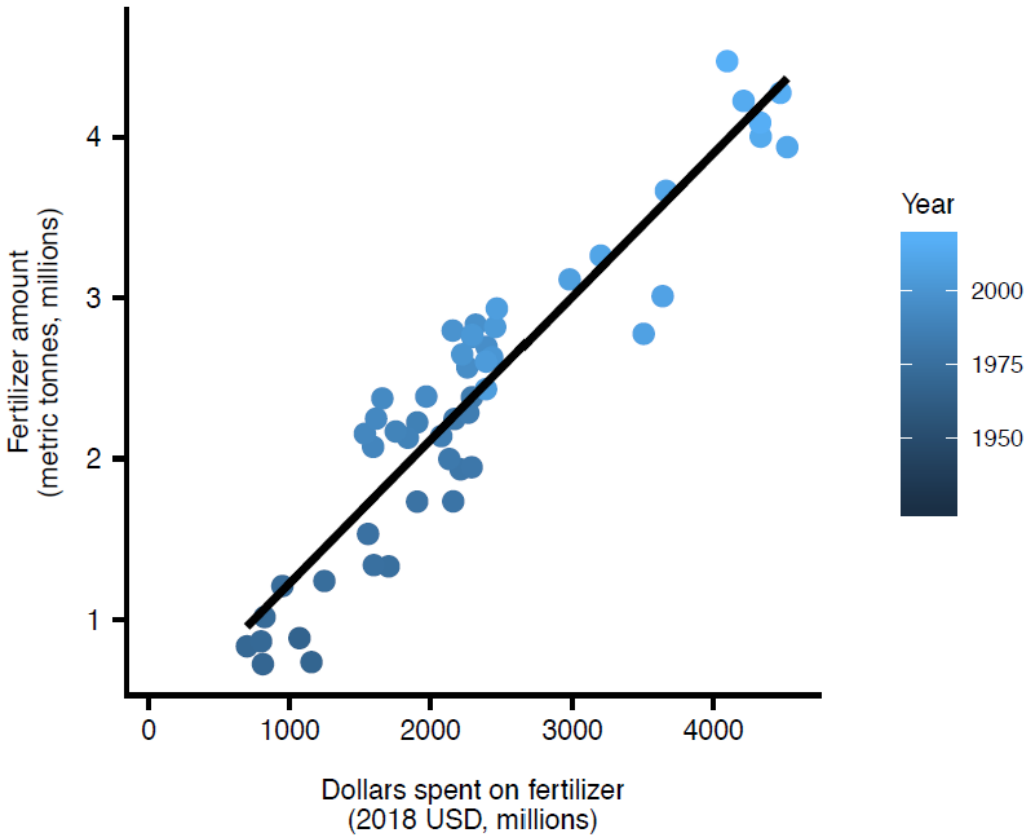


Figure S6. Relationship between dollars spent on fertilizer (before rebates) within Canada and amount of fertilizer shipments to Canadian agricultural markets between the years 1967-2017 (Pearson's correlation r = 0.94).



Supplement Methods: Comparing timeseries trends of Figure 1a, with Input Cost increases since 1926 outpacing all other indices creating increasing "cost gap"

Figure 1a displays strong visual shifts in the relative change since 1926 in major factors of farm costs, yields, and profitability. We used autoregressive timeseries analysis to test the underlying dynamics of these shifts which include the possibility that growing gaps between time series are caused by "noisy" temporal autocorrelation (what happens the year prior is not independent from what happens in the current year). Although seemingly unlikely given the 93-year duration of our time-series, such hidden auto-regressive processes could over-inflate differences among the various trends we examine (i.e., Type I error). Here, we focus on the five indices calculated for Figure 1a, as well as "yield efficiency" (yield per acre) shown in Figure S3.

To test the trends in the time series indices we assumed that the timeseries were autocorrelated with a linear trend (or bias). For example, in the "Input Cost" time series we found a strong fit to an autoregressive model of order 1 (AR(1); coefficient close to 1; 0.94) but with residuals that were still skewed positive implying a trend remained after the AR(1) fit (Hamilton 2020). The AR(1) fit below shows that the real data (black solid curve) is fit well by the AR(1) model but on close examination the AR(1) model frequently underestimates the positive trend up (i.e., positive residuals dominate). Below we follow this up in our analysis of the residuals after differencing (Hamilton 2020).

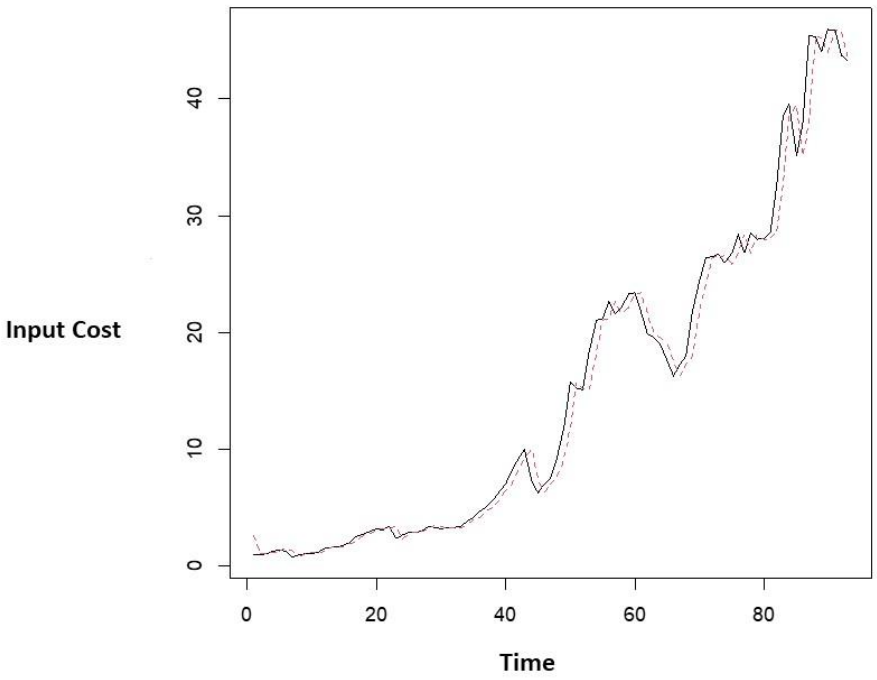


Fig. S7. Time series of "Input Costs" Index (black line) and AR(1) model fit (red dashed curve).

Because of this, we compared trends across time series using the following model:

$$Y_{t+1} = Y_t + \tau_t + \varepsilon_t \qquad (1)$$

where Y_{t+1} is any of the response variables of interest (e.g., input cost), τ is the mean trend increase with any 1 time step after accounting for autocorrelation (i.e., next step depends on last step, Y_t) and, ε_t is the error around this trend at time step, t, assumed to be normal $(0,\sigma^2)$. We can also re-write this by differencing Eq. 1 such that:

$$\Delta Y = Y_{t+1} - Y_t = \tau + \varepsilon_t \qquad (2)$$

Given this, we can calculate ($\tau+\varepsilon_t$) for each time step, t, and determine an overall mean trend, τ, and ask if it significantly different from 0 (i.e., whether there is a trend or not). Further, we can also use ANOVA techniques to compare across time series to ask if there is a difference in means (after differencing these means represents trends if they are non-zero) and whether one time series of responses has a significantly higher trend than another.

The boxplot of the residuals after differencing for all timeseries of the indices is seen below

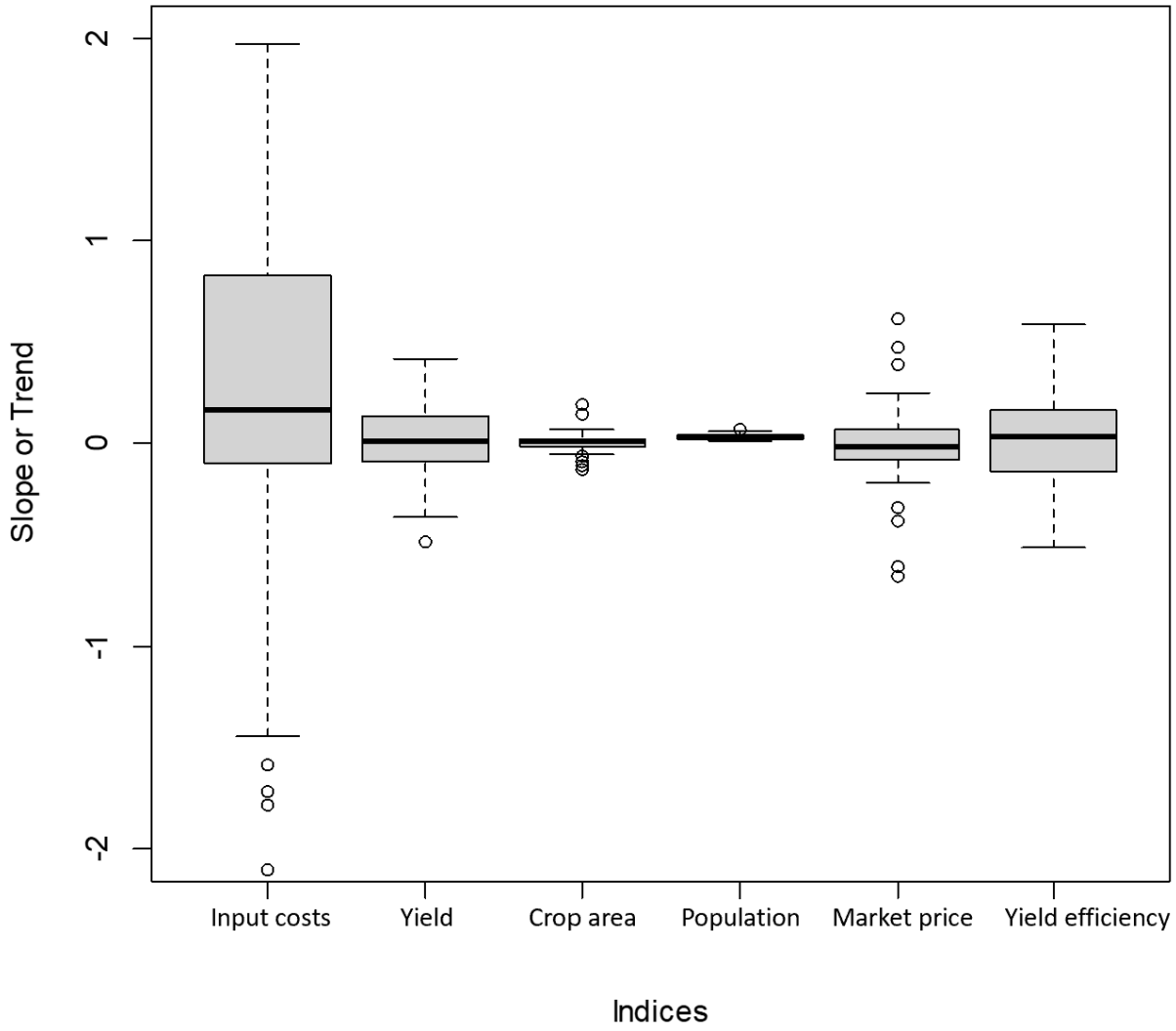


Fig. S8. Boxplot of the indices showing residuals ($\tau + \varepsilon_t$) after differencing. Note, means of zero suggest no trend and therefore are consistent with random walks. Each box plot consists of 93 data points. Whiskers are quartiles, showing the range of distribution

The ANOVA test on residuals looking for a difference in means (i.e, trends) was done in R using aov followed by a Tukey's post hoc test (TukeyHSD). The ANOVA is highly significant across time series of indices suggesting differences exist across time series indices (F=6.704; p=4.48E-6). Additionally, the post hoc Tukey test finds that the Input Cost time series (A-ICI) has significantly higher trends than all other indices while no other indices show significant differences and in fact are highly similar (p>.98 in all cases). The specific p-values for all ICI are:

Total crop yield index-A-ICI -0.441785278; p=0.0001564

Crop area index-A-ICI -0.452349896, p=0.0000972

Canadian Population index-A-ICI -0.428656157, p=0.0002786

Market price index-A-ICI -0.466441051, p=0.0000571

Yield Efficiency index I-A-ICI -0.436276225, p=0.0001997.

Citation

Hamilton, J.D., 2020. *Time series analysis*. Princeton university press.