Supporting Information

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SI Materials and Methods

Modeling Framework. We use the Global Trade Analysis Project Agro-Ecological Zone (GTAP-AEZ) model, a modified version of the standard GTAP model that incorporates different types of land. The GTAP model is a multicommodity, multiregional computable general equilibrium model. Detailed discussion on theory and derivation of the behavioral equations involved in the model can be found in the volume edited by Hertel (1). In GTAP, the world economy is divided in regions. Depending on the availability of national input–output data, these regions can be countries (e.g., Brazil) or aggregations of countries (e.g., Rest of North Africa).

In each region a representative "regional household (e.g. the EU) collects all the income in its region and spends it over three expenditure types: private household (consumer), government, and savings, as governed by a Cobb-Douglas utility function. A representative firm maximizes profits subject to a nested Constant Elasticity of Substitution (CES) production function which combines primary factors and intermediates inputs to produce a final good. Firms pay wages/rental rates to the regional household in return for the employment of land, labor, capital, and natural resources. Firms sell their output to other firms (intermediate inputs), to private households, government, and investment. Since this is a global model, firms also export the tradable commodities and import the intermediate inputs from other regions. These goods are assumed to be differentiated by region, following the Armington assumption, and so the model can track bilateral trade flows." (ref. 2, p. 583).

The model used in this article incorporates different types of lands in the GTAP standard model. The foundation of these data is global datasets for agricultural productivity (3) and forests (4), which have been used to develop a land use and land cover database (5) that offers a consistent global characterization of land in crops, livestock, and forestry, taking into account biophysical growing conditions. We use the version of this database compatible with the GTAP Database V7, which defines 18 global AEZs and identifies crop and forest extent and production for each region by AEZ for specific crop and forest types in year 2004 (6). The AEZs represent six different lengths of growing periods (6×60-d intervals) spread over three different climatic zones (tropical, temperate, and boreal). Following the work of the International Institute for Applied Systems Analysis and the United Nations Food and Agriculture Organization, the length of the growing period depends on temperature, precipitation, soil characteristics, and topography.

Modeling the Derived Demand for Land. The basic production function in the GTAP-AEZ framework is given in Fig. S1, where we see that output is a function of all intermediate inputs and a value-added composite. These factors of production substitute for one another with the ease of substitution governed by the parameter δ_T. As with the standard GTAP model, value added is a composite of skilled and unskilled labor, capital, land, and natural resources (in the case of the extractive sectors). The ease with which these factors substitute for each other is governed by δ_{VA}, and this determines the demand for land. The substitutability of the value-added components in the production of crops implies that producers can substitute capital and labor for land to increase output. Thus it is possible to increase production using the same amount of land by using more of the nonland factors, or in other words, the yields are endogenous.

The land input is an aggregation of the diverse AEZs. For this we assume that the same products produced in the same region must share a common price because they are perfect substitutes in use. If, as we assume, production functions for each crop and within a given region are similar across AEZs, and the firms face the same prices for nonland factors, then land rents in comparable activities must move together (even if they do not share the same initial level). In this case, from the point of view of land markets, the returns to land on different AEZs used in the production of the same product must move together. This suggests a very high elasticity of substitution, δ_{AEZ}, between AEZs in the crop-specific national production function specification.

Modeling Land Supply. This section draws heavily on the model descriptions in other sources (7, 8) and is included here for convenience.

The GTAP-AEZ framework used for this work introduces land competition directly into land supply via a two-tiered structure, such as that used by Keeney and Hertel (9), shown in Fig. S2. In the upper tier, crops compete with each other for land within a given AEZ. In the lower tier, crops as a whole compete with grazing and forestry for land within a given AEZ. In addition, different AEZs can be substituted in the production for any single agricultural or forest product.

Calibration of the constant elasticity of transformation of land supply functions in the model is based on the available econometric evidence as discussed by Hertel et al. (7). These authors set the constant elasticity of transformation (CET) parameter at the bottom of this supply tree equal to −0.25, thus placing the maximum forest land supply elasticity at 0.25, and at the top of the supply tree where land is supplied to individual crops, they use the elasticity from the standard GTAP model (which suggests an upper bound of 1 on this elasticity).

Methodological Limitations. The introduction of land heterogeneity in CGE models is a relatively new enterprise, and much validation with respect to observed data is still needed. In particular, the assumption of a unique crop-specific national production function requires further assumptions (ref. 7, pp. 128–131), such as identical products across AEZs, common nonland input prices prevail across AEZs, and the nonland input–output ratios are the same across AEZs. Under cost minimization and zero profits, these assumptions mean that land rents must vary in direct proportion to yields (see also ref. 10). Hertel et al. (8) emphasize the need for testing the existence of a national production function using observed data. Of particular interest is the extent to which nonland input–output ratios vary systematically with AEZ either owing to different techniques across AEZs or because of differing input prices.

A special challenge for modeling land use is the issue of the homogeneity of land and its potential mobility across uses. As mentioned above, the GTAP model deals with land heterogeneity by using a simple CET function by which an aggregate endowment of land is transformed across alternative uses, subject to some transformation parameter that governs the responsiveness of land supply to changes in relative yields. A more explicit approach to handling land heterogeneity would be desirable (8).

A last caveat is that we do not model access to new land in this study. By "new land" we mean land that is not economically accessible given current market conditions and thus does not produce land rents. The issue of inaccessibility has been explored in considerable detail using a dynamic recursive version of the

GTAP model (11). By formulating land use decisions in an investment framework, one can model access costs explicitly, and thus the access to new land requires real resources. Given the difficulties of modeling the long-run accessibility of new land in a static model, we maintain the CET formulation discussed above in which the total land endowment is fixed and composed of accessible forests, pastures, and cropland.

Design of Simulations to Estimate Impact of Crop Germplasm Improvement. We focus on the impacts of crop germplasm improvement (CGI) contributions attributable to national agricultural research systems (NARS) and international agricultural research centers (IARCS) (11) and labeled 1965 CGI. The estimates are presented in terms of total factor productivity (TFP), which is defined as the additional agricultural output produced by the same set of inputs, given an improvement in crop germplasm. Besides CGI, there are other sources of TFP growth, such as extension programs and agronomic research. In turn, these sources of TFP can interact with CGI, a fact that is difficult to disentangle using the qualitative and regression methods used by Evenson (see ref. 13). Thus, he offers low and high TFP estimates: the former assumes that TFP growth comes only from CGI, whereas the latter assumes that CGI was complementary to other sources of productivity growth, thus yielding higher changes in TFP. These scenarios are used by Evenson and Rosegrant (12) (hereafter E&R) to simulate how agricultural prices, production, consumption, and trade would have differed in the year 2000 if the developing world had been constrained to have no CGI after 1965. These scenarios assumed historically observed TFP growth via CGI in the developed world and thus aimed to isolate the combined effects of developing countries' NARS and IARCs on the world food system.

Evenson (ref. 13, table 22.9, p. 466) provides the basis for the shocks we replicated in our model. For convenience, Table S1 reproduces the figures relevant for this study. Table S1 shows the annual TFP growth contributions from the adoption of improved crop germplasm averaged over 1960–1998. Thus, on average for 1960–1998, CGI contributions to TFP growth in "All crops" and "All regions" from both NARS and IARCS was 0.72% per annum. Taking these annual shocks and compounding them over the period 1965–2004 suggests a compounded contribution of crop germplasm improvement to TFP growth of 32.2% over the period.

In a static model like GTAP, these are one-time shocks; that is, the assumption is that the economy moves from an initial equilibrium (characterized in the baseline year of 2004) to a counterfactual equilibrium in one step. This contrasts with the solution of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model that recursively applies annual shocks for as many periods as needed. Another difference between E&R and this work is the baseline years. As mentioned, E&R used the year 2000 for the IMPACT modeling, whereas we use the year 2004. In practical terms, this means that we will be using slightly larger shocks (equivalent to the difference in TFP growth between 2000 and 2004). However, to the extent that the TFP growth between 2000 and 2004 is properly reflected in our baseline, this difference is of limited importance.

Another slight issue is that the commodity aggregations of the IMPACT and GTAP model are different. In particular, barley, maize, millets, and sorghum are all embedded within the coarse grains ("Cereal grains nec") sector, whereas cassava, lentils, beans, and potatoes are aggregated within the vegetable and fruits ("Vegetable, fruit, nuts") sectors.

To translate shocks from ref. 13 to the GTAP model, we weight the shocks using production value-shares derived from Food and Agriculture Organization data. The value-share weighted shocks are shown in Table S2. As can be seen, the shocks in the vegetable and fruits sectors are quite low because cassava, lentils, and potatoes have both low CGI gains (Table S1) and low value shares. On the other hand, the coarse grains sector shows large shocks due to the significant CGI gains in maize, millets, and sorghum, and the large value shares of these products in the coarse grains aggregate. The values for sub-Saharan Africa are relatively low owing to the low CGI gains for this region.

The shocks in Tables S1 and S2 are implemented by using the factor neutral (i.e., TFP), technological change variable attached to the production functions of each crop and region (see ref. 14 for derivations). This is an analogous procedure to that of E&R, who applied their shocks to a "non-price total factor productivity term" embedded in the IMPACT's yield functions (ref. 12, p. 478). We use the standard GTAP model closure, which imposes equilibrium in all of the markets, where firms earn zero profits, the regional household is on its budget constraint, and global investment equals global savings.

Full Set of Simulation Results. Our objective is to understand the changes in global land use associated with the productivity gains in crop germplasm improvement. To initiate this investigation, we begin with a focus on developing countries, where the initial impact of productivity shocks arises. The first row in the upper half of Table S3 show the impacts on agricultural output for the lower and upper ends of the 1965 CGI counterfactuals in developing countries discussed above. Unless otherwise indicated, the results are the percentage differences between the base year (2004) and the counterfactual. Thus, in the absence of CGI, wheat production in the developing world in 2004 would have been 43–60% lower than it actually was. The decrease in production can be observed in wheat, rice, grains, and vegetables and fruits. These are the crops affected by the productivity shocks, so this decline across the board is not surprising. Table S3 shows two additional commodity categories—"oilseeds" and "other agricultural products"—that, although not directly affected by the shocks, are important for the aggregated changes in land use discussed below. As can be seen in Table S3, these crops also show declines in production as a result of the reallocation of production factors (such as land) to those crops for which prices have increased.

The contribution of each crop to total agricultural output varies by region. Thus, we weight the percentage changes by production values to get a sense of the overall output results. The column "All E&R crops" shows the weighted average only for the crops subjected to productivity shocks. Thus, on average, the combined output of these crops in the developing world would have been 10–15% lower than actually observed. When all of the crops are included (column "All crops") production-value-weighted output would have declined by 8–12% in the developing countries.

The output reductions in the developing world are ultimately reflected in increased world prices. Table S4 shows equilibrium prices for our simulations in GTAP-AEZ and compares these results (where relevant) with the estimates made by E&R. We find that wheat prices would have been 29–59% higher than they actually were in 2004. For rice, 2004 prices would have been 68–135% higher. As noticed by E&R, price increases from CGI reductions in developing countries depend on both actual CGI gains, which vary by crop, and on the proportion of the crop produced in developing countries. Because rice is mostly produced in developing countries, price effects in the rice sector are more pronounced than in other crops. The coarse grains also show significant price increases (20–42%), whereas prices in the vegetable and fruit categories are more moderate (6–10%), reflecting both lower CGI gains in cassava and the fact that potatoes and cassava represent relatively low shares of the production value of vegetables and fruits. For the crops subjected to shocks, "All E&R crops" shows that prices would have been 13–26% higher.

The crops not subjected to shocks (oilseeds and the rest of the agricultural sector) also experience price increases as a consequence of the decline in production associated with the migration of production factors to the sectors with direct productivity loses (three right-most columns in Table S4). Thus, for all crops (column "All crops"), price increases would have been between 10% and 19%; these figures are slightly lower than those for the crops affected by productivity shocks, because oilseeds and other agricultural products represent large shares of global exports.

The lower half of Table S4 shows the main results obtained by E&R. Their price increases are remarkably similar to ours. They found that wheat prices would have increased by 29–61%, rice by 80–124%, maize by 23–45%, and other grains by 21–50%. Although not shown in Table S4, E&R also reported price increases for potatoes (13–31%) and other root crops (28–52%). In GTAP, these products are in the vegetable and fruit categories, which show a moderate range of price increase (6–10%), reflecting both lower CGI gains in cassava and the fact that potatoes and root crops have relatively low production values.

For all crops, E&R estimated price increases of 35–66%, twice as high as our estimates. This reflects differences in trade assumptions and weighting schemes. The trade assumptions are important because they determine the international patterns of agricultural production. Although IMPACT assumes that there is an integrated world market with one global market clearing equation for agricultural commodities, GTAP uses the Armington assumption that assumes that products are differentiated by virtue of their national origin (15). In the first case there is a prevailing world price, whereas in the latter there are as many prices as trading partners. In general, the integrated world market tends to give a higher supply response in larger countries, thus reducing trade relative to the Armington assumption.

Price effects are the consequence of reduced productivity, but at the same time, higher prices make production more profitable, thus attracting production factors (land, labor, capital) that are withdrawn from other activities. In the case of land, the increase in supply prices translates into higher land rents, thus attracting more land into the sectors where productivity was negatively affected. As mentioned above, these higher land rents in the affected sectors are responsible for the output contraction and price increases of the nonaffected crops, oilseeds, and rest of the agricultural sector. Referring to Table S3, we can see that the harvested area of rice and coarse grains increase considerably (19–25% and 15–25%, respectively). The expansion of lands in these sectors is partly sustained by reductions of land in wheat, vegetable and fruit, oilseed, and other agricultural sectors, which also experience a reduction of their outputs. Overall, harvested areas in the developing world increased by 1%.

Together, the figures in Table S3 indicate that the expansion of areas experienced by the developing countries would not have offset the decline in yields, leading to a decline in overall production. This decline in overall production is reflected in reduced exports from developing countries. The exception is rice, a crop for which exports increased by 19–240%. The wide range of these changes in exports is consistent with the wide range of rice price increases shown in Table S4. To get a more realistic measure of export decline, we weight the changes in exports by their export values. These weighted averages show overall export reductions of 7–11%. To compensate for the losses in domestic production, developing countries would have imported more of their food from abroad. For the crops affected by productivity shocks, imports would have increased by 54–99%. For the agricultural sector as a whole, imports would have increased by 6–8%.

The price increases caused by declining production in developing countries would have stimulated expansion of the crop sector in developed countries. In Table S3, we can see that for all of the crops subject to shocks ("All E&R crops"), the increase in production in developing countries in the counterfactual scenario would have been 16–27%. When oilseeds and other agricultural sectors are included, the increase is 12–20% (column "All Crops"). The output expansion in the developed countries is explained by modest increases in area (1–2%) and sizable increases in yields of 11–19%. Finally, exports from the developed to the developing countries would have increased by 25–43%, which is consistent with the trade changes for developing countries discussed above.

Table S4 combines the changes in developing and developed countries, showing that production in the crops receiving the productivity shocks declined by approximately 1%. When all crops are included, production declines were slightly higher (2%). This finding is in line with those of E&R, who found that the impacts of CGI were sizable and important for prices but much more reduced in terms of production and area than what can be expected at first sight by seeing the important contributions of CGI to agricultural growth.

In terms of the area devoted to the crops subjected to the productivity shocks, we find an increase of 6–8%. As with prices, these results are quite close to those of E&R, who found aggregate area changes of 2.8–4.6%. However, when the area contraction in the rest of the agricultural sector (oilseeds and others) is considered, the expansion reduces to 1–2%. In addition to the differences between the trade assumptions in IMPACT and GTAP, another cause of the divergence in E&R and the GTAP results is that GTAP includes factor markets that are linked to product markets. In the case of land, the endowment is fixed, and thus expansion possibilities are constrained. Much of the expansion in the affected crops comes from reductions in the area of other crops, forest, and pastures.

As noted in the previous section, the CET functional form optimizes land allocations according to their productivity. As a consequence, land allocation in the CET is constrained by the productivity-weighted value of the land endowment rather than by total area. Because not all of the hectares are equally productive, CET effective area and physical area generally differ considerably. An ad hoc mechanism to translate the CET changes to physical changes is to adjust the CET outcomes by a productivity differential. This productivity adjustment equalizes the productivity-weighted sum of changes in effective hectares of different crops (such as those reported in Table S3) or land cover (shown in Table 4) with the area-weighted sum of changes in physical hectares. The intersection of the right-most two rows in Table S4 and the right-most column in Table S5 shows that globally, the productivity shock counterfactual would imply an expansion in cropland of between 17.99 and 26.83 million ha, of which 11.98–17.7 million ha are in developing countries. These results are in line with those obtained by E&R, who estimated an expansion of 24–32 million ha (15–20 million ha in developing countries). Table S5 also shows that the contributions of regions such as sub-Saharan Africa and the Middle East and North Africa are quite modest because the CGI contributions in these regions were low. The bulk of the area comes from the developed countries and the Rest of Asia (which includes large countries such as China and India).

Additional Simulations Holding Consumption Constant. A plausible hypothesis is that in the absence of technological change, governments across the world would have implemented a set of alternative policies (such as allowing increased deforestation) to ensure food security. We offer an exploration of upper bound land use/land cover and greenhouse gas (GHG) emission effects by simulating an scenario in which consumption of staples in the developing countries is held constant so it does not decrease as a consequence of higher food prices. Detailed results from this simulation are reported in Table S6 (percentage changes in price, production, and harvested areas) and Table S7 (physical hectares by crop).

GHG Emissions. GHG emissions are calculated by applying CO_2 (16) and non-CO_2 (17) emission factors to the different changes in both consumption and production. We pay particular attention to the emissions derived by changes in fertilizer production (as a response of both increased demand from domestic producers and from abroad); nitrous oxide (N_2O) from agricultural soils; methane (CH_4) from changes in rice cultivation; and emissions from changes in land cover.

Sensitivity Analysis. We explore the sensitivity of our results (hectares of agricultural and GHG emissions) to some of the key parameters regulating them in the GTAP model, namely (*i*) the elasticity of crop yields to crop prices; (*ii*) the elasticity of land transformation across uses; and (*iii*) the elasticity of effective croplands with respected to harvested area. We follow closely the procedures described in ref. 16 in the context of analyzing the indirect land use effects of biofuel policies. The elasticity of crop yields to prices is related to the ease with which land can be substituted by intermediate inputs to boost yields. The GTAP-AEZ model uses a value of 0.25, which represents recent evidence for the United States (7). This elasticity varies across crop and regions and test sensitivity results for a range of 0–0.5 (16). The elasticity of land transformation across cropland, pasture, and forestry captures the empirical fact that land does not move freely across use. The maximum value this elasticity can attain in the GTAP-AEZ model is 0.2. Unfortunately, there is limited evidence on the size of this elasticity, which makes the parameter inherently uncertain for most regions and crops. Following ref. 16, we capture uncertainty by varying this parameter by 80%. Finally, the GTAP-AEZ model assumes that pasture and forest lands converted to agriculture are less productive than lands currently under production. The parameter value used is 0.66, implying that forests and pastures brought into production are only two thirds as productive as the existing cropland. Again following ref. 16, we examine the sensitivity of our results by letting it vary from 0.32 to 1.0.

Note on Grainger (2009) and Rudel et al. (2009). We use the term "land saving" to describe our estimates of the extent to which the adoption of agricultural technologies in developing countries has prevented agricultural expansion, relative to a simulated counterfactual scenario in which these agricultural technologies had not been adopted. Two alternative terms, "sparing land" and "spared land," introduced by Grainger (18) and based on the article by Rudel et al. (19), are both subtly different from our intended meaning.

For Grainger, "sparing land" occurs when, as a result of agricultural intensification, agricultural area increases more slowly than population *and* deforestation falls. "Spared land" is when particular areas of agricultural land actually contract as a result of agricultural intensification, with the land reverting to an alternative use.

The "sparing land" concept implicitly suggests that agricultural expansion and deforestation are primarily driven by population growth. This may have been the case until the 1980s, but there is now a broad consensus that economic growth in an increasingly interconnected world, and the increase in demand for livestock and oil crops that comes with increasing wealth, is a much more important driver of land-use/land-cover change. We think that the sparing land concept has the wrong counterfactual check built into it—demand for agricultural land is only very weakly linked to population growth.

The "spared land" concept is even stronger and is not actually concerned with the nuances of a counterfactual analysis—did agricultural area (for a given country or region) shrink or not? Working back from specific instances where land has been taken out of production, and trying to understand the driving forces behind the retirement, would be the only approach to understanding this phenomenon.

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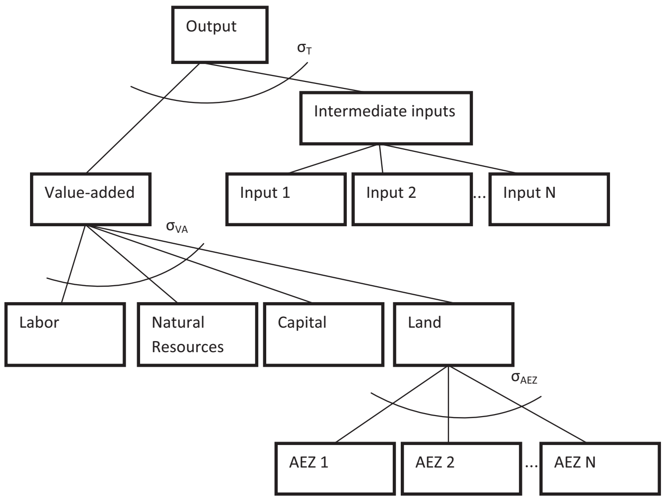

Fig. S1. Land demand in GTAP-AEZ.

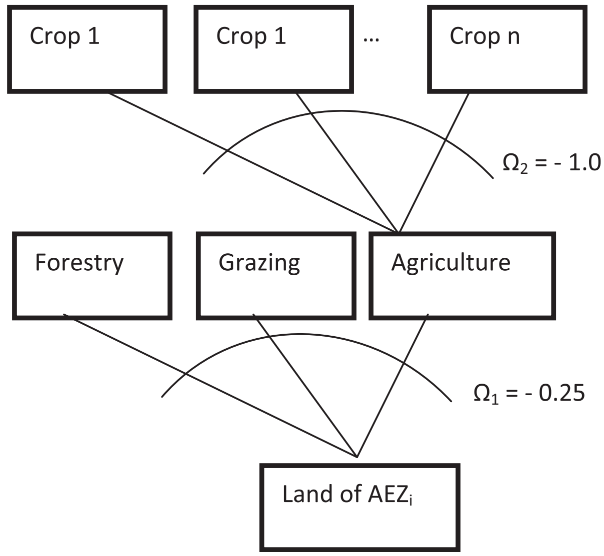

Fig. S2. Land supply in GTAP-AEZ.

Table S1. Crop germplasm improvement contributions to TFP growth compounded over 1965–2004 using the annual contributions estimated from Evenson

Crop	Regions	Annual % contribution of crop germplasm improvement to growth in TFP*	Compounded % contribution of crop germplasm improvement to TFP growth (1965–2004)
All crops	All regions	0.72	32.18
	Asia	0.88	40.95
	Latin America	0.66	29.15
	MENA	0.69	30.66
	SS Africa	0.28	11.52
Barley	MENA	0.49	21.00
Beans	All regions	0.21	8.44
	Latin America	0.22	9.03
	SS Africa	0.18	7.27
Cassava	All regions	0.22	9.03
	Asia	0.17	7.02
	Latin America	0.10	3.98
	SS Africa	0.25	10.18
Lentils	MENA	0.28	11.65
Maize	All regions	0.66	29.50
	Asia	0.96	45.10
	Latin America	0.62	27.51
	SS Africa	0.22	9.12
Millets	All regions	0.56	24.57
	Asia	1.04	49.88
	SS Africa	0.74	7.43
Potatoes	All regions	0.81	36.82
	Asia	0.82	37.77
	Latin America	0.75	33.93
	SS Africa	0.74	33.26
Rice	All regions	0.79	36.13
	Asia	0.87	40.08
	Latin America	0.82	37.40
	SS Africa	0.54	23.61
Sorghum	All regions	0.50	21.66
	Asia	0.85	38.95
	SS Africa	0.30	12.57
Wheat	All regions	0.96	45.15
	Asia	1.01	47.75
	Latin America	1.06	50.81
	MENA	0.83	37.99
	SS Africa	0.53	22.94

MENA, Middle East, North Africa; SS, Sub-Saharan.
*From Evenson (ref. 13, table 22.9, pp. 466–467).

Table S2. E&R shocks aggregated to GTAP categories

Category	Region	TFP shock (%)
Vegetables and fruits	Asia	−2.30
	Latin America	−2.74
	Middle East, North Africa	−0.13
	Sub-Saharan Africa	−3.01
Coarse grains	Asia	−43.34
	Latin America	−23.44
	Middle East, North Africa	−11.41
	Sub-Saharan Africa	−9.23

These shocks come from adjusting the shocks for cassava, potatoes, and lentils from 1.1 by their value shares in the aggregated GTAP category vegetables and fruits (top four rows); likewise, sorghum, barley, and maize are adjusted by their value shares on the GTAP category "Coarse grains." E&R, Evenson and Rosegrant (12).

Table S3. Decomposition of production changes in yield and area changes: developing and developed countries

Region	Variable	Wheat	Rice	Coarse grains	Vegetables and fruits	All E&R crops	Oilseeds	Other agriculture	All crops
Developing	Production	−43, −60	−14, −22	−6, −6	−4, −7	−10, −15	−7, −11	−3, −5	−8, −12
	Harvested area	−5, −11	19, 25	15, 25	−11, −15	5, 7	−12, −16	−11, −14	1, 1
	Yield	−38, −49	−33, −48	−21, −31	7, 8	−15, −22	4, 5	8, 10	−9, −13
	Exports	−85, −93	19, 240	−34, −38	−2, −1	−11, −7	3, 6	1, 6	−5, 0
	Imports	111, 191	228, 560	23, 50	6, 11	54, 99	−1, −2	6, 13	30, 56
Developed	Production	46, 76	53, 90	9, 15	1, 1	16, 27	−1, −2	1, 1	12, 20
	Harvested area	21, 30	24, 40	−6, −8	−12, −18	5, 8	−12, −18	−13, −20	1, 2
	Yield	25, 46	29, 50	14, 23	13, 20	11, 19	11, 16	14, 21	11, 19
	Exports	104, 177	297, 572	27, 49	4, 6	38, 65	−4, −7	4, 5	25, 43
	Imports	−2, 0	−6, −3	−1, −1	0, 0	0, 0	0, 0	0, 1	0, 1

Results reported here are percentage changes relative to the baseline year (2004) in production, harvested area, yields, exports, and imports. The values are weighted averages using the following as weights: physical output in tons for production; hectares for area; and export and import values. For each scenario, lower and upper bounds are separated by a comma. Lower bounds are estimates for crop germplasm improvement impacts only. Upper bound estimates are simulations of a synergy between crop germplasm improvement with other yield changing factors, modeled as a 30% increase in the productivity impact of crop germplasm improvement alone. E&R, Evenson and Rosegrant (12).

Table S4. Comparison of our results with those of E&R

Source	Variable	Wheat	Rice	Coarse grains	Vegetables and fruits	All E&R crops	Oilseeds	Other agriculture	All crops
Present article	Price	28.9, 59.3	68.3, 135.1	20.2, 41.7	5.7, 9.8	13.4, 26.3	4.9, 8.5	5.22, 9.3	10.0, 19.3
	Production	6, 15	−10.6, −17.3	2.8, 6.6	−3.0, −5	−1.4, −1.1	−4.7, −7.2	−2.5, −3.8	−1.9, −2.3
	Harvested area	9.4, 12.2	20.1, 26.8	8.0, 13.6	−10.6, −15.2	5.7, 8.3	−11.2, −16.1	−10.9, −15.0	1.5, 2.2
E&R	Price	29, 61	80, 124	23, 45		35, 66			
	Production	−9, −14	−11, −14	−9, −12		−8, −12			
	Harvested area	3.5, 5.6	7.5, 9.4	1.1, 1.9		2.8, 4.6			

Results are percentage changes relative to the baseline year (2004) in prices, production, and harvested area aggregated using as weights: output values for prices, and physical output for production and area. For each scenario, the values for the lower and upper bounds are separated by a comma. The lower part of the table shows some of the results obtained by Evenson and Rosegrant (E&R, ref. 12, table 23.3, p. 484). Omitted are changes for other grains, potatoes, and root crops. Their results for maize are under the column "Coarse grains."

Table S5. Change in agricultural area by crop and region (in millions of hectares) under the counterfactual of no crop germplasm improvement since 1965

Region	Wheat	Rice	Coarse grains	Vegetables and fruits	E&R all	Oilseeds	Other agriculture	All crops
Latin America	−4.7, −6.9	1.6, 2.3	4.8, 7.0	−0.5, −0.7	1.3, 1.7	0.5, 0.9	−0.6, −0.8	1.2, 1.8
SE Asia	−0.1, −0.1	7.0, 8.5	1.6, 2.5	−2.3, −2.9	6.3, 8.1	−3.3, −4.4	−1.9, −2.4	1.1, 1.4
Rest of Asia	5.2, 5.0	19.1, 25.1	19.6, 33.8	−17.0, −24.9	26.9, 39.0	−12.9, −18.7	−6.3, −9.0	7.7, 11.4
Sub-Saharan Africa	−0.4, −0.4	1.3, 1.8	2.5, 3.1	−1.0, −1.2	2.4, 3.2	−0.7, −0.9	0.1, 0.4	1.9, 2.7
Middle East, North Africa	−4.6, −8.0	0.4, 1.3	2.4, 3.8	1, 1.7	−0.8, −1.2	0.6, 1.0	0.4, 0.6	0.1, 0.4
Developed countries	24.9, 36.7	1.0, 1.6	−6.1, −8.1	−4.0, −6.3	15.7, 23.9	−7.6, −11.6	−2.2, −3.2	6.0, 9.1
All regions	20.5, 26.3	30.4, 40.5	24.8, 42.2	−23.8, −34.3	51.9, 74.8	−23.4, −33.6	−10.5, −14.4	17.9, 26.7

Lower and upper estimates are separated by a comma. E&R, Evenson and Rosegrant (12).

Table S6. Price, production, and area effects: alternative counterfactual scenario holding constant the consumption of staples in the developing countries

Variable	Wheat	Rice	Coarse grains	Vegetables and fruits	E&R all	Oilseeds	Other agriculture	All crops
Price	37.2, 201.6	94.2, 315.0	24.2, 91.3	8.1, 25.5	17.5, 74.2	6.10, 15.4	7.7, 22.6	13.3, 52.2
Production	7.2, 74.7	−9.6, −17.7	4, 8.5	−1.1, −1.6	0.1, 9.6	−5.6, −11.7	−3.5, −4.4	−1.3, 4.2
Harvested area	13.3, 41.6	19.4, 19.7	9.6, 12.3	−11.2, −18.7	6.9, 12.8	−13.2, −25.2	−14.0, −21.1	1.8, 3.6

Results are percentage changes relative to the baseline year (2004) in prices, production, and harvested area aggregated using as weights: output values (for prices), and physical output and area. The values for the lower and upper ends are separated by a comma. E&R, Evenson and Rosegrant (12).

Table S7. New hectares by crop and region (million ha): alternative counterfactual scenario holding constant the consumption of staples in the developing countries

Region	Wheat	Rice	Coarse grains	Vegetables and fruits	E&R all	Oilseeds	Other agriculture	All crops
Latin America	−3.8, −3.7	1.6, 2.6	4.6, 5.8	−0.64, −1.0	1.8, 3.6	0.2, −0.5	−0.7, −0.5	1.3, 2.7
SE Asia	−0.0, 0.0	6.4, 6.8	2.7, 5.0	−1.9, −2.0	7.1, 9.7	−3.7, −5.3	−2.1, −2.5	1.3, 1.9
Rest of Asia	8.2, 17.6	17.5, 13.4	25.3, 47.8	−15.9, −23.3	35.1, 55.5	−16.6, −27.2	−8.7, −14.3	9.8, 14.0
Sub-Saharan Africa	1.2, 3.4	2.6, 4.0	2.2, 1.5	−1.9, −2.0	4.0, 6.9	−1.0, −1.7	−0.0, 1.9	3.0, 7.1
Middle East, North Africa	2.3, 5.6	0.1, 1.4	0.3, −0.7	−1.2, −2.9	1.5, 3.5	−0.4, −0.9	−0.2, −0.3	0.9, 2.3
Developed countries	21.0, 67.2	1.1, 1.6	−5.3, −21.2	−3.5, −10.9	13.1, 36.7	−6.1, −17.0	−1.7, −4.6	5.4, 15.0
All regions	28.8, 90.1	29.2, 29.6	29.8, 38.2	−25.2, −42.1	62.6, 115.9	−27.5, −52.6	−13.4, −20.3	21.7, 43.0

Lower and upper estimates are separated by a comma. E&R, Evenson and Rosegrant (12).