

Global crop production increase by soil organic carbon

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The SI file includes:

Supplementary Text (1-4)

Figs. S1 to S2

Tables S1 to S6

References

Supplementary Text

Text 1: Causal Forest vs. Random Forest to quantify the causal effect of SOC on crop yield

Effect size estimates from the RF yield model were compared to those from a Causal Forest (CF) model to test for any bias due to heterogeneity in treatment effects between sub populations (see methods; the causal effect of SOC on crop yield). Effect size of SOC on crop yield from RF was estimated by using predicted maximum SOC divided by the 95% confidence intervals of optimum SOC for each crop from partial dependence in Fig. 1. Effect size in CF was estimated using the “average_treatment_effect” function from the R package “grf”. Overall, the effect sizes estimated by CF were in a similar range to those from RF (Table S1), supporting the view that the RF estimates are unbiased by heterogeneous effect sizes.

Text 2: Interactive effects of soil organic carbon and nitrogen fertilization rate on crop yield

Even though addition of higher nitrogen input always contributes to higher crop production (up to optimum levels), crop productivity also increased with soil organic carbon (SOC) increase under any nitrogen input rate (Extended Data Fig. 3). Generally, predicted maximum SOC yield gaps for the combination of the three crops decreased as nitrogen additions increased, with largest normalized SOC yield gaps decreasing from 0.07 in the unamended controls to 0.02 at the optimum rate of nitrogen application. The predicted maximum SOC yield gaps decreased for maize as nitrogen application increased, from 503 kg ha⁻¹ in the control to 153 kg ha⁻¹ at the optimum nitrogen application rate. For rice, SOC yield gaps decreased from 255 kg ha⁻¹ in the control to 74 kg ha⁻¹ at the optimum nitrogen application rate. Surprisingly, for wheat, predicted maximum SOC yield gaps increased from 220 kg ha⁻¹ in the control to 308 kg ha⁻¹ at optimum nitrogen application (Extended Data Fig. 3), indicating that wheat productivity is more dependent on SOC conditions than maize and rice.

Text 3: Estimation of the effects of soil organic carbon on crop yield under global climate zones

Agricultural regions in China cover multiple climate zones where cereal crops are cultivated across the country from cold to subtropical and from arid to semi-arid and humid regions. Field trials were grouped based on IPCC climate zones (methods; the causal effect of SOC on crop yield under climate zones). In total, the field trial data are distributed across seven of the eight tropical and

temperate climatic zones (Extended Data Fig. 1). Few or no maize, wheat and rice are cultivated in polar and boreal climate zones (Extended Data Fig. 7). Maize field trials were distributed across 6 climate zones ($N_{\text{treat}}=10,890$ in the cool temperate dry zone; $N_{\text{treat}}=145$ in the cool temperate moist zone; $N_{\text{treat}}=10$ in the tropical dry zone; $N_{\text{treat}}=236$ in the tropical moist zone; $N_{\text{treat}}=8049$ in the warm temperate dry zone; $N_{\text{treat}}=4777$ in the warm temperate moist zone). Wheat field trials were distributed across 4 climate zones ($N_{\text{treat}}=949$ in the cool temperate dry zone; $N_{\text{treat}}=40$ in the tropical moist zone; $N_{\text{treat}}=17,292$ in the warm temperate dry zone; $N_{\text{treat}}=3273$ in the warm temperate moist zone). Rice field trials were distributed across 6 climate zones ($N_{\text{treat}}=15$ in the cool temperate dry zone; $N_{\text{treat}}=15$ in the tropical dry zone; $N_{\text{treat}}=2649$ in the tropical moist zone; $N_{\text{treat}}=63$ in the tropical wet zone; $N_{\text{treat}}=1559$ in the warm temperate dry zone; $N_{\text{treat}}=16,631$ in the warm temperate moist zone).

The effect of SOC on crop yield was assessed by Random Forest (RF) regression models for 11 out of 16 climate zones (Climate zones with only a few numbers of field trials were excluded from analysis). Normalized predicted yield was calculated as the ratio of predicted yield from partial dependence to the predicted minimum yield for each crop under each climate zone (Extended Data Fig. 4). Normalized predicted maximum SOC yield gap is the difference between normalized predicted yield under optimum SOC and normalized predicted minimum yield for each crop under each climate zone (Extended Data Fig. 4).

For maize, the normalized predicted maximum SOC yield gap is 0.06 in cool temperate dry climate zones, 0.08 in warm temperate dry climate zones, not significantly different from zero in cool temperate moist climate zones, 0.02 in warm temperate moist climate zones, and not significantly different from zero in tropical moist climate zones. For wheat, the normalized predicted maximum SOC yield gap is not significantly different from zero in cool temperate dry climate zones, 0.06 in warm temperate dry climate zones, not significantly different from zero in warm temperate moist climate zone. For rice, the normalized predicted maximum SOC yield gap is 0.02 in warm temperate dry climate zone, 0.04 in warm temperate moist climate zone, 0.02 in tropical moist climate zone (Extended Data Fig. 4).

To conclude, for maize and wheat, normalized predicted maximum SOC yield gaps were higher in dry climate zones than moist climate zones. Surprisingly, the normalized predicted maximum SOC yield gap for wheat was not significantly different from zero in cool temperate dry climates. This is possibly due to the fact that potential evapotranspiration in this zone was the lowest among climate zones (the mean evapotranspiration is 815 mm yr⁻¹ compared with 846-1434 mm yr⁻¹ in other climate zones). As for rice, there is less of a difference for the normalized predicted maximum mean SOC yield gaps between dry and moist climate zones compared to those in maize and wheat systems. This might be attributed to alleviating water constraints via frequent flooded irrigation. Therefore, the aridity index and the difference between optimum and current SOC may be major drivers to jointly control SOC yield gap.

Text 4: Crop production increase by SOC in food-deficit countries

Enhanced crop production due to higher SOC was aggregated to the country level, and benchmarked against both country-level food deficits and current crop yields to provide reference points against which to compare the predicted SOC yield impacts (see methods; benchmarking of yield potential against current food deficits and global extrapolation of SOC yield gap). It is important to note that although we provide comparisons of the modeled yield impacts relative to current yields, this only provides context and does not imply that current yields without improving management would be increased by this much solely by the increasing SOC. In fact, most of the potential to increase yields in food-insecure countries derives from implementing best management practices to eliminate crop production constraints from inadequate nutrition, hydration, or pest, weed and disease pressure. Since the SOC impacts on yield that we report below are based on optimum managements when other production constraints have also been addressed, the amount by which yield may be improved in food-insecure countries through SOC sequestration alone without improving management remains an open question for further research.

Although crop yields under best management only increase by a global average of 41 kg ha⁻¹ yr⁻¹ when SOC is raised to its technical potential, within countries that have a weak or moderate food security (see materials and methods; alleviation of food deficits) the mean impact is somewhat higher (e.g., 71 kg ha⁻¹ in Sub-Saharan Africa, 106 kg ha⁻¹ in Central America, 89 kg ha⁻¹ in the Caribbean and 72 kg ha⁻¹ in South America) (Extended Data Fig. 8c). Overall, there is a technical

potential for SOC to increase crop production by over 1% in forty-five countries, located mainly in South America, Central America and Sub-Saharan Africa, but by over 2% in only seven countries (Extended Data Fig. 8e and Table S5). However, when we benchmark against current yields, the technical potential for SOC to increase yield under best management is equivalent to over 5% of current crop production in 24% of global food-insecure countries (Extended Data Fig. 8a). The SOC-derived yield increase of the three crops in these countries under technical potential is in the range of 69-208 kg ha⁻¹ (Table S5 and Extended Data Fig. 8c), with Central African Republic and Botswana, at the high end, having crop production increases equivalent to 16% and 26% of current production, respectively (Table S5). Moreover, increasing SOC to the technical potential, once other production constraints have also been addressed, could provide calories equivalent to 26% of the total food deficit in food-insecure countries and equivalent to over 100% of food deficits in 24% of food-insecure countries. Togo and Cote d'Ivoire (which have the greatest prevalence of undernourishment) are providing food calories from SOC equivalent to 180% and 150% of their food deficits, respectively (Table S6).

Unconstrained increases in SOC, if they were to become possible, would provide crop production increases, after alleviating other production constraints, equivalent to over 5% of current yields in over half of global countries (Table S5 and Extended Data Fig. 8b). Relevant impacts also occur in food-insecure countries, where the unconstrained increase in SOC would increase crop production under best management by an amount equivalent to over 5% of current production in about 72% of these countries. The additional calories delivered by an unconstrained SOC increase under best management are equivalent to 86% of the food deficits in global food-insecure countries, and over 100% of the food deficit in nearly half of these countries (Extended Data Fig. 9 and Table S6). In the densely populated countries India and Nigeria, the additional calories would be equivalent to 260% and 250% of current food deficits (Table S6). Unconstrained increases in SOC could even contribute to crop production increases in developed countries. For example, unconstrained SOC increases could enhance crop production by 18% and 8% in Australia and Portugal, respectively (Table S6). Specific information regarding crop production increases, yield increase per unit harvested area and the proportion of food deficit addressed in each country are provided in Tables S5 and S6.

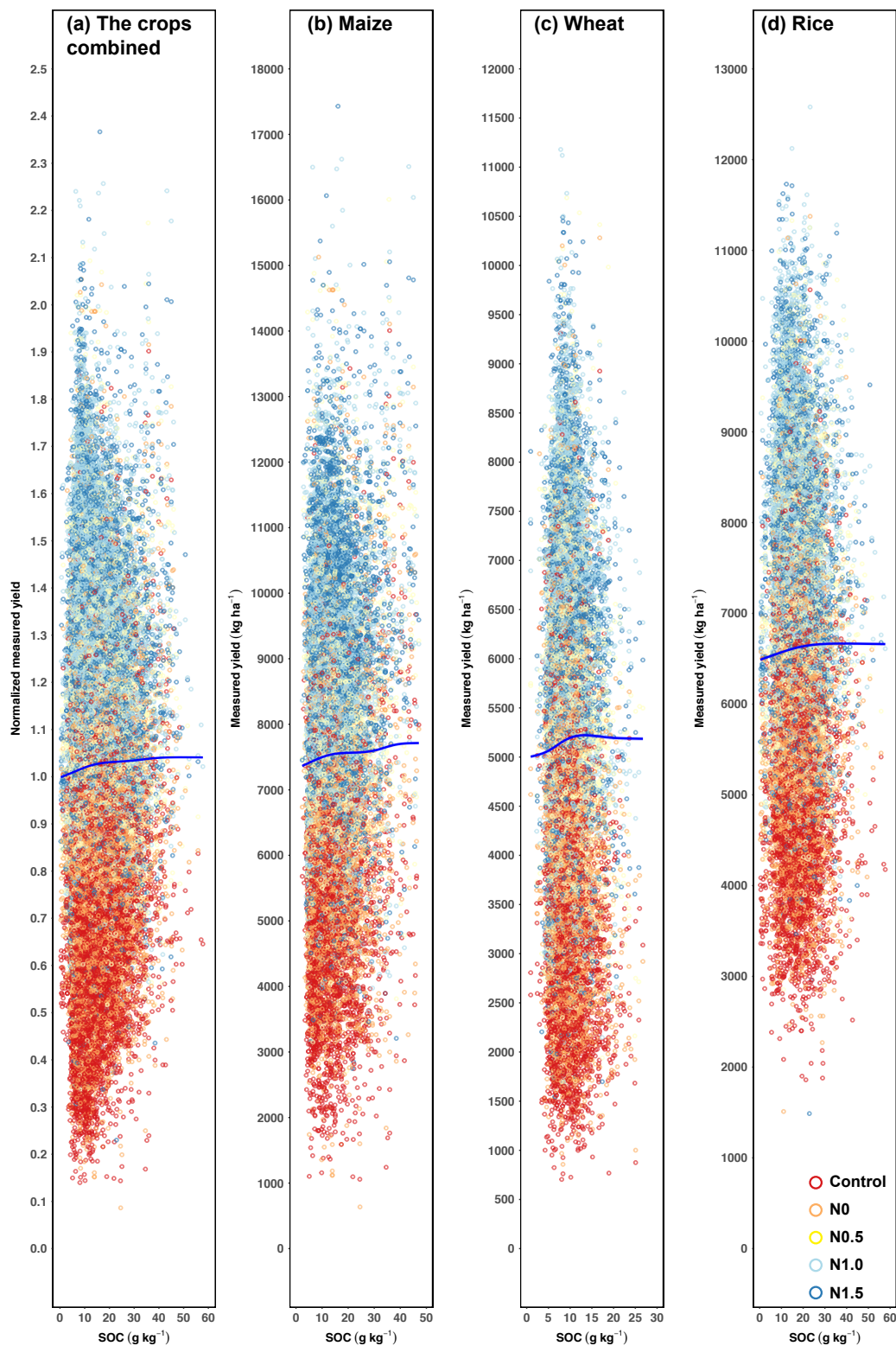


Fig. S1. Individual measured data of soil organic carbon (SOC) and crop yield from field trials for maize, wheat, rice and the three crops combined. N0, N0.5, N1.0 and N1.5 indicate 0, 50%, 100% and 150% of optimum nitrogen input rates, respectively, with optimum phosphorus and potassium input rates. Control means no fertilizer inputs.

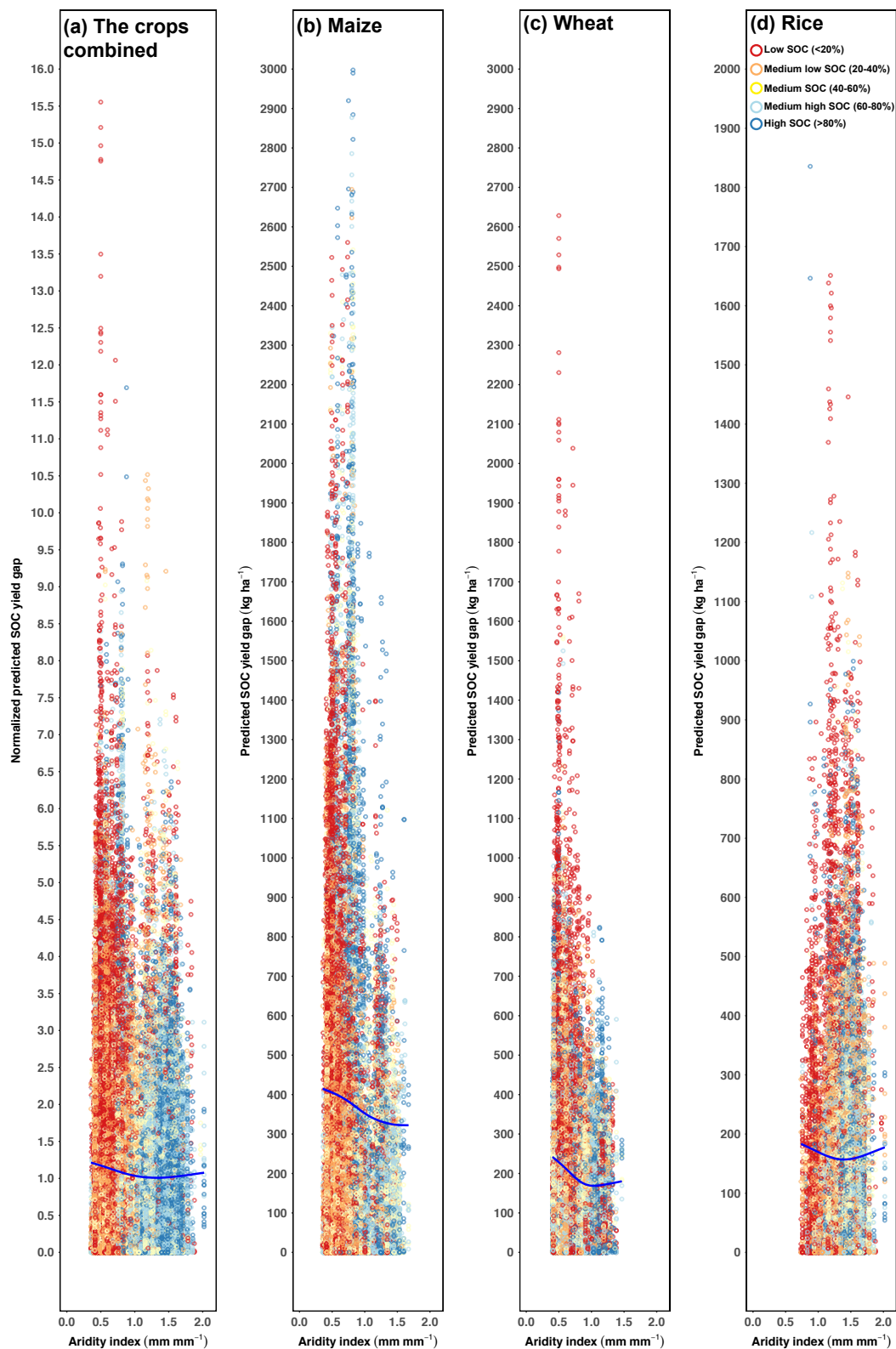


Fig. S2. Individual measured data of the aridity index and the predicted soil organic carbon (SOC) yield gap from field trials for maize, wheat, rice and the three crops combined. Color coding refers to the quintiles (in %) of SOC contents.

Table S1. Comparisons of average treatment effect of soil organic carbon (SOC) on crop yield from Random Forest (RF) and Causal Forest (CF) model for maize, wheat and rice. The RF-based average treatment effect size of SOC on crop yield was estimated by using predicted maximum SOC divided by the 95% confidence intervals of optimum SOC for each crop from partial dependence in Fig. 1.

Crop type	Average treatment effect of SOC on crop yield (kg ha ⁻¹ per unit SOC)	
	RF-based estimate	CF-based estimate
Maize	8	8
Wheat	15-17	22
Rice	5-6	4

Table S2. Predicted average weighted soil organic carbon (SOC) yield gaps in different climates for maize, wheat and rice under the technical potential and unconstrained increase in SOC. Technical potential represents yield gains when SOC increased to levels that are achieved using a combination of high organic matter inputs and zero tillage; an unconstrained increase in SOC represents yield gains when SOC increased to optimum levels.

Crop type	Moisture (& elevation)	Temperature	Average weighted SOC yield gap for the technical potential to increase SOC (kg ha ⁻¹)	Average weighted SOC yield gap for the technical potential to increase SOC under different humidity (kg ha ⁻¹)	Average weighted SOC yield gap for unconstrained increase in SOC (kg ha ⁻¹)	Average weighted SOC yield gap for unconstrained increase in SOC under different humidity (kg ha ⁻¹)
Maize	Dry	(1) Cool temperate	57		519	
		(2) Warm temperate	47	45	501	488
		(3) Tropical	14		383	
	Moist	(4) Cool temperate	52		128	
		(5) Warm temperate	77	110	203	271
		(6) Tropical moist	148		369	
		(7) Tropical wet	76		135	
	Montane	(8) Tropical	100	100	190	190
Wheat	Dry	(1) Cool temperate	26		77	
		(2) Warm temperate	35	17	383	253
		(3) Tropical	8		447	
	Moist	(4) Cool temperate	74		115	
		(5) Warm temperate	59	54	171	197
		(6) Tropical moist	22		297	
		(7) Tropical wet	127		350	
	Montane	(8) Tropical	95	95	179	179
Rice	Dry	(1) Cool temperate	19		42	
		(2) Warm temperate	79	33	209	134
		(3) Tropical	22		126	
	Moist	(4) Cool temperate	40		54	
		(5) Warm temperate	67	24	139	60
		(6) Tropical moist	18		60	
		(7) Tropical wet	10		17	
	Montane	(8) Tropical	35	35	79	79

Table. S3. Demonstration of soil organic carbon (SOC) yield gaps for the regions with the 25% highest yield increase potentials (Extended Data Fig. 5) for maize, wheat and rice under the technical potential and unconstrained increase in SOC. Technical potential represents yield gains when SOC increased to levels that are achieved using a combination of high organic matter inputs and zero tillage; an unconstrained increase in SOC represents yield gains when SOC increased to optimum levels.

Scenario	Crop type	Regions with the 25% highest SOC yield gaps	Average weighted SOC yield gap (kg ha ⁻¹)
Technical potential	Maize	(1) Western US, Mexico, Central America and Caribbean area	190
		(2) Maize producing regions in South America	208
		(3) Maize producing regions in Europe	189
		(4) South and Southeast Asia	191
		(5) Eastern Asia	185
		(6) Maize producing regions in Sub-Saharan Africa	231
	Wheat	(1) US and Mexico	144
		(2) Wheat producing regions in South America	113
		(3) Wheat producing regions in Europe	137
		(4) Wheat producing regions in Sub-Saharan Africa	112
		(5) Central and Southeast Asia	108
		(6) Eastern Asia	127
		(7) Southeast Australia	105
	Rice	(1) Rice producing regions in South America	101
		(2) North Mediterranean Basin	105
		(3) Rice producing regions in Sub-Saharan Africa	76
		(4) Central, West and Southeast Asia	73
		(5) Eastern Asia	98
		(6) Rice producing regions in Australia	103
Unconstrained	Maize	(1) US maize belt and maize producing regions in Canada	679
		(2) Maize producing regions in South America	600
		(3) Maize producing regions in Europe	634
		(4) Maize producing regions in Russia	1,016
		(5) Maize producing regions in Sub-Saharan Africa	549
		(6) Central, South and Southeast Asia	582
		(7) Eastern Asia	812
	Wheat	(1) Southwestern US and Northern Mexico	464
		(2) Wheat producing regions in South America	465
		(3) Wheat producing regions in Sub-Saharan Africa	466
		(4) North Mediterranean Basin	535
		(5) Wheat producing regions in Central, South and Southeast Asia	485
		(6) North China Plain	898
		(7) Wheat producing regions in Australia	407
	Rice	(1) Southern and Eastern South America	242
		(2) Rice producing regions in Sub-Saharan Africa	194
		(3) Central, West and South Asia	192
		(4) Eastern Asia	291
		(5) Rice producing regions in Australia	208

Table S4. Model performances. Determination of coefficient (R^2) for each Random Forest (RF) model was investigated by using out of bag (OOB) (see materials and methods; the causal effect of SOC on crop yield). The index of agreement (d) is a standardized measure of the degree of model prediction error, with value varies between 0 and 1, where a value of 1 indicates a perfect match and a value of 0 indicates no agreement at all⁵¹. NPK = nitrogen, phosphorus and potassium fertilizer rate; PET = potential evapotranspiration; GDD, RAD, PRE, Tmax and Tmin = growing degree days, radiation, precipitation, maximum mean temperature and minimum mean temperature during the growing days; AP = plant-available phosphorus, AK = plant-available potassium. AWC = available water capacity.

No	Dependent variable	Specific type	Independent Variables	Model function	R ² (%) (out of bag)	Index of agreement (d)
Part 1	Crop yield	Maize	N fertilization, Aridity index,	The Random Forest (RF) yield model was used to demonstrate the relative importance of variables to crop yield for Fig. 2 and the causal effect of SOC on crop yield for Fig 1.	76	0.89
		Wheat	RAD, Tmin, Growing days,		81	0.90
		Rice	Tmin, Rotational systems,		77	0.89
		Three crops combined	Previous crop type, GDD, PET, Soil type, PRE, Irrigation, AP, SOC, pH, PK fertilization, Crop variety, AK, Slope, Cropping frequency, Silt, Sand, Clay, Bulk density, AWC		77	0.89
Part 2	SOC yield gap	Maize	Aridity index, Growing days,	The RF SOC yield gap model was used to investigate the major drivers for SOC yield gap in Fig 3	82	0.87
		Wheat	pH, AK, Soil type, AP,		79	0.84
		Rice	Rotational systems, Silt, Sand, Clay, Crop variety, Bulk density, Irrigation, Cropping frequency, Slope, AWC, N fertilization, Previous crop type		73	0.84
		Three crops combined			79	0.86
Part 3	Crop yield	Maize	Tmax, Tmin, PRE, SOC, pH, N fertilization, PK fertilization, Sand, Silt, Clay, AWC, Bulk density, Aridity index, PET	The RF yield model was used to predict global crop production increases for maize, wheat and rice under either technical potential or unconstrained increase in SOC in Fig 4. Uncertainty from this RF extrapolation model was analyzed based on jackknife method in Extended Data Fig. 6 (see methods; Uncertainty analysis of global extrapolations).	68	0.86
		Wheat			75	0.87
		Rice			69	0.86

Table S5. Yield increase of maize, wheat and rice by increasing soil organic carbon (SOC) in each country under technical potential and unconstrained SOC increases as a proportion of either annual production of the three crops, or annual production of the three crops at best management, or total harvested areas of the three crops. Absolute yield increase was calculated by using yield increase of the three crops from SOC under technical potential and unconstrained SOC increases divided by the total harvested area of the three crops in each country.

Country	Current mean crop production for maize, wheat and rice (kg ha ⁻¹)	Total harvested area for maize, wheat and rice (ha)	Technical potential						Unconstrained					
			Annual maize yield increase from SOC (tons country ⁻¹ yr ⁻¹)	Annual wheat yield increase from SOC (tons country ⁻¹ yr ⁻¹)	Annual rice yield increase from SOC (tons country ⁻¹ yr ⁻¹)	Yield increase from SOC as a proportion of current crop production of the three crops (%)	Yield increase from SOC as a proportion of crop production of the three crops at best management (%)	Absolute yield increase of the three crops from SOC (kg ha ⁻¹)	Annual maize yield increase from SOC (tons country ⁻¹ yr ⁻¹)	Annual wheat yield increase from SOC (tons country ⁻¹ yr ⁻¹)	Annual rice yield increase from SOC (tons country ⁻¹ yr ⁻¹)	Yield increase from SOC as a proportion of current crop production of the three crops (%)	Yield increase from SOC as a proportion of crop production of the three crops at best management (%)	Absolute yield increase of the three crops from SOC (kg ha ⁻¹)
Afghanistan	2,123	2,261,175	9,235	91,833	10,522	2.3	0.8	49	34,051	542,232	17,580	12.4	4.1	263
Albania	5,030	161,901	4,578	5,846	0	1.3	1.0	64	18,325	22,782	0	5.0	3.8	254
Algeria	1,896	1,468,392	29	18,097	17	0.7	0.2	12	94	643,777	43	23.1	6.7	439
Angola	1,065	731,050	80,980	258	156	10.5	1.4	111	180,579	693	353	23.3	3.1	248
Antigua and Barbuda	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Argentina	4,450	8,922,569	130,432	151,921	5,615	0.7	0.5	32	1,516,081	1,858,765	8,563	8.5	5.6	379
Armenia	2,391	115,573	104	2153	0	0.8	0.4	20	1062	4264	0	1.9	0.9	46
Australia	1,814	11,949,573	2,284	304,628	5,368	1.4	0.4	26	23,675	3,795,868	20,585	17.7	4.9	321
Austria	7,501	452,636	12,500	12,549	0	0.7	0.8	55	34,979	45,767	0	2.4	2.7	178
Azerbaijan	3,292	577,920	1,973	29,749	284	1.7	1.0	55	10,679	178,090	553	10.0	5.6	328
Bahamas	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Bangladesh	4,645	11,106,027	451	59,726	75,087	0.3	0.2	12	741	265,951	179,820	0.9	0.6	40
Barbados	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Belarus	3,388	381,027	391	29,125	0	2.3	1.3	77	1,721	33,701	0	2.7	1.6	93
Belgium	8,750	137,649	2,785	12,063	0	1.2	1.9	108	4,540	38,997	0	3.6	5.6	316
Belize	3,900	19,009	2,361	0	48	3.2	1.9	127	4,365	0	67	6.0	3.4	233
Benin	1,330	438,563	28,122	0	292	4.9	0.9	65	205737	0	1,736	35.6	6.3	473
Bhutan	3,422	67,684	885	542	1,771	1.4	0.7	47	965	1,098	2,046	1.8	0.8	61
Bolivia	2,310	571,887	32,166	6,996	4,447	3.3	1.1	76	120,629	37,339	10,727	12.8	4.1	295
Bosnia and Herzegovina	5,919	299,983	14,692	2,778	0	1.0	0.8	58	36,484	5,941	0	2.4	2.0	141
Botswana	402	44,014	4,602	32	0	26.2	1.3	105	10,977	86	0	62.6	3.2	251
Brazil	5,377	15,810,433	1,353,516	55,416	94,932	1.8	1.4	95	3,488,858	454,231	324,857	5.0	4.0	270
Brunei	2,296	407	0	0	7	0.7	0.3	17	0	0	17	1.8	0.7	42
Darussalam	5,292	1,520,338	16,949	12,035	130	0.4	0.3	19	239,172	71,729	247	3.9	3.3	205
Bulgaria	1,746	259,717	8,756	4,483	983	0.5	0.6	36	109,107	0	4,579	25.1	5.8	438
Burkina Faso	1,417	138,032	12,805	1,431	926	7.8	1.5	110	34,928	2,906	1,823	20.3	3.9	287
Burundi	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Cabo Verde	3,718	2,049,484	8,801	0	22,003	0.4	0.2	15	24,863	0	107,705	1.7	1.0	65
Cambodia	1,740	331,699	23,721	11	430	4.2	1.0	73	72,903	84	1,684	12.9	3.2	225
Cameroon	4,001	11,579,745	36,185	209,475	0	0.5	0.4	21	68,226	718,256	0	1.7	1.3	68
Canada	870	106,755	14,916	0	154	16.2	2.0	141	41,380	0	1,318	46.0	5.6	400
Central African Republic	1,306	122,854	3,907	18	641	2.8	0.5	37	33,497	783	3,075	23.3	4.1	304
Chad	7,390	381,877	8,358	4,483	983	0.5	0.6	36	30,532	12,796	1,308	1.6	1.9	117
Chile	6,323	80,019,464	1,883,870	1,562,705	1,795,289	1.0	0.9	66	12,071,544	13,676,339	4,702,093	6.0	5.3	381
China	4,609	961,847	42,875	1,261	14,607	1.3	0.9	61	95,733	2520	30,956	2.9	1.9	134
Colombia	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Comoros	916	9,595	501	0	166	7.6	1.1	70	1,049	0	180	14.0	1.9	128
Congo	807	1,881,033	139,458	493	11,682	10.0	1.1	81	437,653	2,158	31,278	31.0	3.6	250
Congo DRC	3,901	66,462	1,532	0	980	1.0	0.6	38	2,083	0	2,123	1.6	0.9	63
Costa Rica	2,373	1,233,679	125,330	0	4,228	4.4	1.5	105	342,335	0	29,542	12.7	8.2	301
Cote d'Ivoire	7,693	601,231	38,877	6,129	0	1.0	1.1	75	100,406	12,550	0	2.4	1.3	188
Croatia	2,974	322,719	25,256	0	3,608	3.0	1.3	89	47,676	0	9,236	5.9	1.4	176
Cuba	5,874	764,387	4,080	22,437	0	0.6	0.6	35	20,117	47,308	0	1.5	3.0	88
Czech Republic	7,452	619,905	0	55,636	0	1.2	1.6	90	0	86,447	0	1.9	2.5	139
Denmark	1,464	2	0	0	0	0.0	0.0	0	0	0	0	11.7	2.9	221
Djibouti	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Dominica	4,515	148,963	2,459	0	2,089	0.7	0.4	31	10,028	0	5,573	2.3	1.5	105
Dominican Republic														

Ecuador	4,086	782,098	27,499	2,034	8,576	1.2	0.7	49	50,467	4,383	15,773	2.2	1.3	90
Egypt	6,844	2,404,563	1,073	3,476	38,578	0.3	0.3	18	202,413	369,830	111,733	4.2	4.1	284
El Salvador	2,960	282,066	58,589	0	65	7.0	2.9	208	95,225	0	332	11.4	4.8	339
Eritrea	1,000	41,232	596	2,238	0	6.9	1.0	69	2,145	8,573	0	26.0	3.7	260
Estonia	4,328	61,808	0	1,935	0	0.7	0.6	31	0	1,999	0	0.7	0.6	32
Eswatini	1,273	71,836	2,813	3	2	3.1	0.5	39	28,305	72	6	31.0	5.1	395
Ethiopia	3,708	1,933,340	53,064	59,606	111	1.6	0.8	58	193,751	127,215	223	4.5	2.3	166
Fiji	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Finland	3,634	144,888	0	33	0	0.0	0.0	0	0	33	0	0.0	0.0	0
France	7,421	6,611,065	108,265	197,981	2,065	0.6	0.8	47	792,637	1,195,663	3,175	4.1	4.9	301
Gabon	1,620	17,303	1,009	0	17	3.7	0.9	59	1,403	0	23	5.1	1.2	82
Gambia	571	23,436	1,451	0	173	12.1	0.9	69	5,934	0	346	46.9	3.7	268
Georgia	2,687	317,474	13,764	2,527	0	1.9	0.7	51	70,309	6,117	0	9.0	3.2	241
Germany	7,488	2,803,731	274,41	121,166	0	0.7	0.9	53	79,687	287,050	0	1.7	2.2	131
Ghana	2,081	809,772	123,933	0	1,034	7.4	2.1	154	357,368	0	6,973	21.6	6.1	450
Greece	4,471	1,001,034	13,709	24,060	1,992	0.9	0.7	40	110,875	214,380	3,224	7.3	5.4	328
Grenada	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Guatemala	2,188	618,948	33,780	760	191	2.6	0.8	56	45,758	1,696	510	3.5	1.1	77
Guinea	1,368	528,550	12,803	0	4,597	2.4	0.5	33	34,760	0	20,183	7.6	1.5	104
Guinea-Bissau	1,446	63,415	4,050	0	907	5.4	1.1	78	6,849	0	3,582	11.4	2.3	164
Guyana	4,380	128,042	266	0	537	0.1	0.1	6	517	0	857	0.2	0.2	11
Haiti	1,208	324,890	36,393	0	858	9.5	1.6	115	118,426	0	2,655	30.9	5.2	373
Honduras	1,865	371,476	50,799	125	157	7.4	1.9	138	90,534	525	341	13.2	3.4	246
Hungary	6,849	2,149,726	34,669	11,990	119	0.3	0.3	22	674,026	150,506	202	5.6	5.8	384
India	3,718	75,036,836	345,323	317,989	681,291	0.5	0.3	18	2,813,333	10,754,424	2,972,661	5.9	3.4	220
Indonesia	5,224	13,564,218	283,916	0	175,913	0.6	0.5	34	622,825	0	332,060	1.3	1.1	70
Iran	2,318	6,237,730	10,662	208,436	33,984	1.8	0.6	41	65,448	1,671,547	76,523	12.5	4.5	291
Iraq	3,701	252,514	728	2,995	1,739	0.6	0.3	22	12,608	56,539	12,031	8.7	4.6	321
Ireland	8,506	85,898	0	658	0	0.1	0.1	8	0	715	0	0.1	0.2	8
Israel	3,893	31,789	1	22	0	0.0	0.0	1	486	15,703	0	13.1	8.0	509
Italy	6,433	2,951,426	39,229	70,809	9,289	0.6	0.6	40	250,273	763,410	21,407	5.5	5.1	351
Jamaica	1,128	1,696	223	0	0	11.6	1.9	131	439	0	0	22.9	3.8	259
Japan	6,743	1,782,600	2	4,172	120,235	1.0	0.9	70	3	9,947	135,527	1.2	1.0	82
Jordan	3,541	14,932	0	32	0	0.1	0.0	2	73	8,951	0	17.1	9.5	604
Kazakhstan	1,212	9,378,949	4,285	30,319	9,547	0.4	0.1	5	37,909	742,715	10,787	7.0	1.8	84
Kenya	1,799	1,704,665	46,364	6,571	332	1.7	0.4	31	374,453	42,563	1,418	13.6	3.2	245
Kuwait	7,567	227	0	0	0	0.0	0.0	0	5	106	0	6.4	7.7	487
Kyrgyzstan	2,951	518,427	3,164	9,987	117	0.9	0.5	26	33,083	26,180	180	3.9	2.2	115
Laos	4,441	740,092	5542	0	9,418	0.5	0.3	20	12,065	0	41,835	1.6	1.1	73
Latvia	4,527	155,380	0	13,785	0	2.0	1.6	89	0	13,791	0	2.0	1.6	89
Lebanon	3,357	39,794	32	1,256	0	1.0	0.5	32	377	16,456	0	12.6	6.5	423
Lesotho	840	133,391	4,286	745	0	4.5	0.5	38	58,429	4,420	0	56.1	5.9	471
Liberia	1,102	111,110	0	2,977	0	2.4	0.4	27	0	0	2,986	2.4	0.4	27
Libya	780	147,553	0	104	0	0.1	0.0	1	196	73,552	0	64.1	8.1	500
Lithuania	4,452	352,064	0	61,589	0	3.9	3.1	175	0	62,787	0	4.0	3.2	178
Luxembourg	6,107	6,370	11	466	0	1.2	1.4	75	12	1,406	0	3.6	4.1	223
Madagascar	2,537	1,146,824	14,566	160	20,611	1.2	0.4	31	37,190	1,296	72,910	3.8	1.4	97
Malawi	1,883	671,014	72,830	194	377	5.8	1.5	109	212,428	528	2,347	17.0	4.3	321
Malaysia	3,762	674,238	693	0	8,871	0.4	0.2	14	2,504	0	19,290	0.9	0.5	32
Mali	3,173	447,150	8,300	0	3,356	0.8	0.4	26	83,580	435	47,844	9.3	4.1	295
Mauritania	3,645	28,624	0	0	112	0.1	0.1	4	2,958	142	3,463	6.3	3.2	229
Mauritius	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Mexico	4,050	7,922,672	742,378	18,579	1,144	2.4	1.3	96	1,974,979	224,631	2,959	6.9	3.6	278
Moldova	3,155	824,366	18,357	11,651	0	1.2	0.5	36	152,479	61,462	0	8.2	3.9	260
Mongolia	1,311	238,319	0	8,460	0	2.7	0.7	35	0	16,201	0	5.2	1.4	68
Montenegro	3,911	189,923	3,208	2,176	0	0.7	0.4	28	3,535	3,009	0	0.9	0.5	34
Morocco	1,609	2,792,199	1,236	18,261	253	0.4	0.1	7	60,563	1,154,397	1,202	27.1	6.7	436
Mozambique	801	977,435	87,809	44	1,042	11.4	1.2	91	391,535	596	7,538	51.1	5.4	409
Myanmar	3,782	6,336,530	24,689	8,138	50,754	0.3	0.2	13	54,077	29,718	130,406	0.9	0.5	34
Namibia	1,934	29,630	1313	137	0	2.5	0.6	49	3,444	284	0	6.5	1.6	126
Nepal	3,288	2,906,442	86,623	17,999	92,079	2.1	1.0	68	175,267	123,357	145,161	4.6	2.2	153
Netherlands	8,668	125,785	1,351	8,359	0	0.9	1.3	77	3,033	26,644	0	2.7	4.1	236
New Caledonia	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
New Zealand	9,876	61,137	572	2,758	0	0.6	0.9	54	1,583	3,658	0	0.9	1.4	86
Nicaragua	2,496	257,545	29,268	0	840	4.7	1.7	117	47,164	0	3,000	7.8	2.8	195
Niger	3,573	24,945	0	0	154	0.2	0.1	6	1,420	1,159	3,713	7.1	3.6	252
Nigeria	1,576	5,753,099	309,345	139	42,782	3.9	0.9	61	1,363,706	13,312	166,700	17.0	3.8	268
North Korea	4,348	1,168,989	37,568	1,381	25,839	1.3	0.7	55	66,077	3,095	38,418	2.1	1.1	92
North Macedonia	3,807	147,619	2,823	2,392	181	1.0	0.6	37	17,238	14,740	234	5.7	3.7	218
Norway	3,958	35,809	0	45	0	0.0	0.0	1	0	45	0	0.0	0.0	1

Oman	3,408	412	0	2	0	0.1	0.1	4	0	151	0	10.8	6.0	367
Pakistan	2,995	11,341,153	41,979	33,850	64,682	0.4	0.2	12	352,031	3,839,976	389,711	13.5	6.3	404
Palestinian Territory	2,017	21,703	1	2	0	0.0	0.0	0	306	11,577	0	27.1	8.7	548
Panama	3,274	146,988	5,850	0	991	1.4	0.7	47	11,069	0	1,565	2.6	1.3	86
Papua New Guinea	4,676	1,599	97	0	5	1.4	0.9	64	192	0	11	2.7	1.8	127
Paraguay	4,331	568,044	40,320	3,123	668	1.8	1.3	78	126,083	58,496	3,357	7.6	5.4	331
Peru	4,672	863,974	37,849	6,435	6,450	1.3	0.7	59	127,355	20,670	17,290	4.1	2.4	191
Philippines	3,688	5,978,446	178,078	0	30,371	0.9	0.5	35	351,991	0	61,358	1.9	1.0	69
Poland	4,621	2,657,209	7,142	62,033	0	0.6	0.4	26	59,221	170,663	0	1.9	1.4	87
Portugal	5,479	382,237	7,005	832	1,789	0.5	0.4	25	81,573	86,216	4,923	8.2	6.3	452
Puerto Rico	2,800	345	52	0	0	5.4	2.2	151	68	0	0	7.1	2.9	198
Romania	5,311	4,943,506	128,924	25,203	98	0.6	0.4	31	1,427,935	219,342	114	6.3	4.7	333
Russian Federation	2,895	20,045,040	29,353	456,143	6,729	0.8	0.5	25	408,132	1,733,384	7,525	3.7	2.0	107
Rwanda	1,553	85,678	9,243	1,004	139	7.8	1.7	121	19,112	1,485	281	15.7	3.3	244
Saint Vincent and the Grenadines	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
San Marino	NA	719	1	4	1	NA	0.1	9	47	256	1	0.0	6.1	422
Sao Tome and Principe	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Saudi Arabia	6,042	452,067	22	1,415	0	0.1	0.1	3	914	202,026	0	7.4	7.3	449
Senegal	2,823	140,637	7,798	0	662	2.1	0.8	60	34,038	0	7,626	10.5	4.1	296
Serbia	6,647	1,771,883	62,850	9,983	0	0.6	0.6	41	536,484	71,791	0	5.2	4.7	343
Sierra Leone	1,410	187,697	980	0	2,022	1.1	0.2	16	1,758	0	2,234	1.5	0.3	21
Slovakia	5,815	518,395	4,599	7,486	0	0.4	0.4	23	76,536	33,984	0	3.7	3.4	213
Slovenia	7,768	82,010	4933	1390	0	1.0	1.1	77	8,512	4,166	0	2.0	2.3	155
Solomon Islands	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Somalia	802	179,966	96	4	27	0.1	0.0	1	37,351	1,139	222	26.8	2.8	215
South Africa	4,977	3,898,272	152,176	29,840	40	0.9	0.6	47	1,171,004	204,619	191	7.1	4.6	353
South Korea	6,773	1,028,425	1,290	45	79,537	1.2	1.0	79	1,774	116	136,366	2.0	1.7	134
South Sudan	464	41,092	3,471	326	31	20.1	1.3	93	9,544	6,442	178	84.8	5.6	393
Spain	5,298	2,793,627	34,437	62,383	12,283	0.7	0.6	39	232,984	854,444	25,085	7.5	6.2	398
Sri Lanka	4,440	814,831	3,269	0	5,952	0.3	0.2	11	8,367	0	38,113	1.3	0.8	57
Sudan	1,995	148,705	260	164	39	0.2	0.0	3	14,322	47,020	583	20.9	6.2	416
Suriname	4,687	44,876	3	0	126	0.1	0.0	3	8	0	193	0.1	0.1	4
Sweden	6,304	314,082	0	32,113	0	1.6	1.8	102	0	42,664	0	2.2	2.4	136
Switzerland	6,795	111,269	874	4,324	0	0.7	0.8	47	959	6,974	0	1.0	1.3	71
Syria	1,916	1,711,337	228	6,015	0	0.2	0.1	4	14,329	883,205	0	27.4	8.2	524
Tajikistan	3,642	356,480	487	16,115	939	1.4	0.8	49	4,340	99,585	1,651	8.1	4.8	296
Tanzania	1,907	1,735,472	142,732	4,942	4,411	4.6	1.2	88	338,867	11,850	14,324	11.0	2.8	210
Thailand	3,114	11,004,955	222,382	58	148,358	1.1	0.5	34	552,440	327	615,778	3.4	1.5	106
Timor-Leste	2,673	65,558	10,468	0	215	6.1	2.2	163	20,372	0	915	12.1	4.4	325
Togo	1,274	415,509	75,132	0	275	14.3	2.4	181	193,954	0	2,526	37.1	6.3	473
Trinidad and Tobago	923	2,737	200	0	36	9.3	1.3	86	403	0	68	18.6	2.5	172
Tunisia	1,906	581,282	0	2,413	0	0.2	0.1	4	0	300,440	0	27.1	8.1	517
Turkey	3,222	9,372,301	38,233	350,964	6,507	1.3	0.7	42	250,833	2,388,424	8,074	8.8	4.9	282
Turkmenistan	1,529	712,141	452	3117	2,849	0.6	0.1	9	3,284	296,372	7,509	28.2	6.6	431
Uganda	2,726	668,567	67,970	638	1,935	3.9	1.4	106	119,632	1,481	3,368	6.8	2.5	186
Ukraine	4,446	6,826,031	74,034	144,541	437	0.7	0.5	32	435,639	336,766	1,219	2.5	1.9	113
United Arab Emirates	NA	NA	0	0	0	NA	0	NA	0	12	0	0.0	6.2	0
United Kingdom	7,884	1,799,261	0	140,882	0	1.0	1.5	78	0	349,252	0	2.5	3.6	194
United States	7,588	52,450,267	1,181,729	789,147	36,268	0.5	0.5	38	10,885,668	3,837,591	158,729	3.7	3.9	284
Uruguay	5,617	367,671	3,176	3,360	12,873	0.9	0.8	53	26,392	19,380	20,200	3.2	2.8	179
Uzbekistan	4,672	1,540,219	1,506	17,468	12,321	0.4	0.3	20	16,329	457,814	24,929	6.9	5.0	324
Vanuatu	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0
Venezuela	3,612	594,533	82,457	52	2,938	4.0	2.0	144	192,586	331	7,012	9.3	4.6	336
Vietnam	5,762	7,171,024	110,129	0	61,113	0.4	0.4	24	169,316	0	100,089	0.7	0.6	38
Yemen	1,519	129,014	825	5,694	0	3.3	0.8	51	6,583	36,635	0	22.1	5.0	335
Zambia	2,434	541,760	96,052	1,563	143	7.4	2.4	180	187,262	3,882	460	14.5	4.7	354
Zimbabwe	1,243	1,095,946	125,778	6,355	4	9.7	1.6	121	360,400	15,466	19	27.6	4.4	343

NA: data not available

Table S6. Proportion of food deficit addressed for the countries with weak, moderate, good and very good global food security index (GFSI) under technical potential and unconstrained increase in SOC.

Global food security index (GFSI)	Country	Depth of food deficit (kcal undernourished person ⁻¹ day ⁻¹)	Prevalence of undernourishment (%)	Technical potential		Unconstrained	
				Daily calorie supply per capita (kcal undernourished person ⁻¹ day ⁻¹)	Percentage of food deficit addressed (%)	Daily calorie supply per capita (kcal undernourished person ⁻¹ day ⁻¹)	Percentage of food deficit addressed (%)
Weak food security environment	Afghanistan	480	25.6	108	22.4	570	118.7
	Burundi	410	NA	NA	NA	NA	NA
	Central African Republic	310	48.2	66	21.2	187	60.2
	Congo	290	37.7	3	1.1	6	2.1
	Congo DRC	380	41.7	42	11.0	130	34.2
	Djibouti	NA	16.2	0	NA	0	NA
	Ethiopia	340	16.2	60	17.6	172	50.6
	Haiti	460	46.8	71	15.4	230	49.9
	Iraq	210	37.5	4	1.7	52	24.9
	Lesotho	280	23.5	100	35.6	1252	447.2
	Liberia	390	38.9	15	3.9	15	3.9
	Malawi	310	17.3	228	73.4	668	215.4
	Mozambique	420	31.2	94	22.3	422	100.4
	Namibia	260	19.8	29	11.2	75	28.9
	North Korea	340	42.4	59	17.4	98	28.9
	Papua New Guinea	260	24.6	0	0.2	1	0.4
	Sierra Leone	380	26.2	15	3.8	19	5.1
	Solomon Islands	NA	16.5	0	NA	0	NA
	Somalia	490	59.5	0	0.0	42	8.6
	Sudan	240	12.3	1	0.4	111	46.3
	Syria	160	NA	NA	NA	NA	NA
	Timor-Leste	NA	22.6	365	NA	728	NA
	Venezuela	210	27.4	109	51.9	255	121.4
	Yemen	290	45.4	5	1.6	31	10.6
	Zambia	340	NA	NA	NA	NA	NA
Moderate food security environment	Angola	320	17.3	148	46.2	330	103.0
	Bangladesh	340	9.7	82	24.2	269	79.1
	Benin	220	7.6	317	144.0	2,313	1,051.2
	Bolivia	230	12.6	297	129.0	1,144	497.2
	Botswana	240	29.3	69	28.6	164	68.3
	Burkina Faso	290	14.4	32	10.9	388	133.9
	Cabo Verde	NA	15.4	0	NA	0	NA
	Cambodia	270	6.2	298	110.5	1,283	475.0
	Cameroon	260	5.3	176	67.7	544	209.3
	Chad	330	31.7	9	2.7	74	22.3
	Cote d'Ivoire	230	14.9	338	146.9	969	421.4
	Ecuador	160	12.4	176	109.8	325	203.4
	El Salvador	200	8.5	1,069	534.6	1,742	870.9
	Eswatini	210	11.6	212	100.7	2,131	1,014.7
	Gabon	160	15.7	30	18.8	42	26.1
	Gambia	240	13.6	51	21.2	196	81.9
	Georgia	210	8.7	463	220.7	2,186	1,040.8
	Ghana	210	6.1	673	320.7	1,963	934.8
	Guatemala	250	16.8	117	47.0	162	64.8
	Guinea	320	NA	NA	NA	NA	NA
	Honduras	270	13.5	388	143.8	694	257.2
	India	290	15.3	63	21.7	753	259.5
	Indonesia	200	6.5	260	130.0	540	270.1
	Jamaica	200	7.7	10	4.9	19	9.7
	Kenya	290	24.8	40	14.0	319	109.8
	Kyrgyzstan	230	7.2	272	118.2	1,247	542.0
	Laos	280	5.3	390	139.4	1,404	501.3
	Lebanon	160	9.3	19	11.8	246	153.7
	Madagascar	310	43.2	30	9.7	95	30.5
	Mali	290	10.4	57	19.6	641	221.2
	Mauritania	240	9.1	3	1.1	158	65.8
	Myanmar	200	7.6	200	100.2	512	256.0
	Nepal	260	4.8	1,414	543.7	3,153	1,212.6
	Nicaragua	300	19.3	238	79.4	397	132.3
	Niger	350	NA	NA	NA	NA	NA
	Nigeria	210	14.6	120	57.1	525	250.0
	Pakistan	270	12.9	49	18.2	1,540	570.5
	Rwanda	330	35.2	23	7.0	47	14.2
	Sao Tome and Principe	NA	11.9	0	NA	0	NA
	Senegal	240	7.5	69	28.8	340	141.7
	South Africa	160	6.5	473	295.5	3,577	2,235.4
	Sri Lanka	260	6.8	63	24.2	317	121.9
	Suriname	190	8.7	25	13.2	39	20.6
	Tajikistan	250	NA	NA	NA	NA	NA
	Tanzania	300	25.1	104	34.7	250	83.3
	Togo	260	20.4	457	175.9	1,191	458.2
	Uganda	280	NA	NA	NA	NA	NA

	Uzbekistan	180	<2.5	362	201.4	5654	3,141.2
	Vanuatu	NA	9.3	0	NA	0	NA
Good food security envi- ronment	Algeria	190	<2.5	157	82.4	5,558	2,925.1
	Argentina	140	3.9	1,587	1,133.2	18,615	13,296.3
	Australia	130	<2.5	4,611	3,547.1	56,657	43,582.5
	Azerbaijan	240	<2.5	1,190	495.8	7,033	2,930.4
	Barbados	NA	4.1	0	NA	0	NA
	Belarus	130	<2.5	1,161	893.4	1,398	1,075.0
	Belgium	130	<2.5	485	373.1	1,413	1,087.1
	Belize	NA	5.9	1,046	NA	1,924	NA
	Brazil	250	<2.5	2,841	1,136.3	8,020	3,208.1
	Bulgaria	220	3	1,345	611.6	14,573	6,624.1
	Canada	130	<2.5	2,467	1,897.8	7,862	6,048.0
	Chile	150	3.4	210	139.7	679	452.7
	China	250	<2.5	1,425	569.9	8,206	3,282.6
	Colombia	220	8.8	132	60.0	291	132.1
	Costa Rica	160	3.1	160	99.8	267	166.9
	Czech Republic	130	<2.5	933	717.4	2,397	1,844.1
	Denmark	130	<2.5	3,581	2,754.6	5,564	4,280.1
	Dominica	NA	5.6	0	NA	0	NA
	Dominican Repub- lic	250	8.3	51	20.3	174	69.7
	Egypt	190	5.4	78	41.1	1,210	637.0
	Fiji	NA	5.6	0	NA	0	NA
	France	130	<2.5	1,807	1,389.8	11,707	9,005.5
	Germany	130	<2.5	671	516.0	1,659	12,76.4
	Greece	140	<2.5	1,452	1,037.3	11,961	85,43.7
	Guyana	230	5.2	195	84.9	335	145.5
	Hungary	140	<2.5	1,897	1,354.8	33,622	24,015.6
	Iran	190	5.5	521	274.5	3,714	1,954.7
	Israel	120	<2.5	1	0.8	708	589.7
	Italy	140	<2.5	754	538.7	6,477	4,626.5
	Japan	130	<2.5	386	297.1	451	346.7
	Jordan	170	9.5	0	0.2	87	51.5
	Kazakhstan	160	<2.5	903	564.2	15,922	9,951.3
	Kuwait	180	<2.5	0	0.0	10	5.5
	Malaysia	140	3.2	92	66.0	211	150.4
	Mauritius	180	6.2	0	0.0	0	0.0
	Mexico	210	7.2	828	394.4	2,381	1,133.6
	Mongolia	310	4.3	567	182.8	1,085	350.1
	Morocco	210	4.2	120	57.3	7,403	3,525.1
	Netherlands	140	<2.5	213	152.3	650	464.2
	New Caledonia	NA	6.9	0	NA	0	NA
	New Zealand	130	<2.5	262	201.6	416	320.4
	Norway	130	<2.5	3	2.4	3	2.4
	Oman	NA	8.2	0	NA	3	NA
	Panama	230	7.5	214	93.2	396	172.2
	Paraguay	220	9.2	677	307.7	2,835	1,288.5
	Peru	240	8.7	178	74.0	579	241.2
	Philippines	270	9.4	205	75.8	406	150.3
	Poland	130	<2.5	684	525.9	2,299	1,768.3
	Portugal	110	<2.5	373	339.3	6,513	5,920.7
	Romania	130	<2.5	3,148	2,421.4	33,697	25,921.0
	Russian Federation	170	<2.5	1,261	741.5	5,555	3,267.7
	Saint Vincent and the Grenadines	NA	5.6	0	NA	0	NA
	Saudi Arabia	150	3.9	10	6.7	1,411	940.7
	Serbia	NA	3.9	2,108	NA	17,633	NA
	Slovakia	160	4	529	330.8	4,953	3,095.4
	South Korea	130	<2.5	623	479.2	1,065	819.2
	Spain	130	<2.5	894	688.0	8,999	6,922.5
	Sweden	150	<2.5	1,189	792.5	1,579	1,052.9
	Thailand	260	8.2	646	248.4	2,032	781.6
	Trinidad and To- bago	230	6.7	25	11.0	50	21.8
	Tunisia	130	3	64	49.1	7,955	6,118.9
	Turkey	170	<2.5	1,778	1,046.0	11,885	6,991.1
	Turkmenistan	190	4.1	253	133.1	11,739	6,178.3
	Ukraine	160	<2.5	1,898	1,186.1	6,816	4,260.0
	United Arab Emir- ates	140	3.7	0	0.0	0	0.2
	United States	140	<2.5	2,371	1,693.5	17,756	12,682.6
	Uruguay	150	<2.5	2,195	1,463.1	7,432	4,954.4
	Vietnam	280	6.7	264	94.2	415	148.1
Very good food security environment	Albania	150	3.9	891	593.9	3515	2,343.0
	Armenia	210	3.4	209	99.6	499	237.8
	Austria	130	<2.5	1,079	830.4	3463	2,663.7
	Bosnia and Herze- govina	190	<2.5	2,092	1,101.2	5088	2,677.9
	Brunei Darussalam	NA	<2.5	6	NA	16	NA
	Croatia	180	<2.5	4,316	2,397.9	10853	6,029.2
	Cuba	210	<2.5	1,017	484.3	2004	954.4
	Estonia	180	<2.5	542	301.3	560	311.3
	Finland	140	<2.5	2	1.6	2	1.6
	Ireland	130	<2.5	50	38.6	54	41.9
	Latvia	150	<2.5	2,685	1,790.3	2687	1,791.1

	Lithuania	140	<2.5	8,287	5,919.3	8448	6,034.5
	Luxembourg	130	<2.5	289	222.0	857	658.8
	Montenegro	NA	<2.5	3,331	NA	4032	NA
	North Macedonia	170	2.7	929	546.2	5540	3,259.0
	Slovenia	150	<2.5	1,198	798.4	2383	1,588.4
	Switzerland	140	<2.5	228	162.6	346	247.3
	United Kingdom	120	<2.5	775	646.0	1922	1,601.4
NA	Antigua and Barbuda	NA	NA	NA	NA	NA	NA
	Bahamas	NA	NA	NA	NA	NA	NA
	Bhutan	NA	NA	NA	NA	NA	NA
	Comoros	NA	NA	NA	NA	NA	NA
	Eritrea	370	NA	NA	NA	NA	NA
	Grenada	NA	NA	NA	NA	NA	NA
	Guinea-Bissau	NA	NA	NA	NA	NA	NA
	Libya	130	NA	NA	NA	NA	NA
	Moldova	210	NA	NA	NA	NA	NA
	Palestinian Territory	NA	NA	NA	NA	NA	NA
	Puerto Rico	NA	NA	NA	NA	NA	NA
	San Marino	NA	NA	NA	NA	NA	NA
	South Sudan	NA	NA	NA	NA	NA	NA
	Zimbabwe	340	NA	NA	NA	NA	NA

NA: data not available

Reference

51. Willmott, C.J. On the validation of models. *Phys. Geogr.* 2, 184-194 (1981).