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Contact the authors for collaboration and data access while the submission is under review. All data and code will be in a repository immediately on acceptance.

Only half of the calories produced on croplands are available for human consumption

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Only half of the calories produced on croplands are available for human consumption

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Abstract

Managing limited agricultural land to feed a growing population with changing diets requires understanding and managing tradeoffs associated with how crops are utilized. Here, we quantify the impact of how 50 crops are used for food, livestock feed, biofuels, and other non-food uses on available calories from 2010 to 2020. We find that, although total calorie production increased by 23.9% from 2010 to 2020, the available calories in the food system increased by only 16.6%. This decrease in efficiency was driven by increases in the changes in calories used for livestock feed (31.2%) and non-food uses (36.2%). Calories used for biofuel production, a subset of non-food uses, increased 27.9% and accounted for 5.3% of all calorie production in 2020. In comparison, crops consumed directly as food increased by only 14.9%. In 2020, half (50.1%) of calories produced on croplands were available for people to eat. The calories 'lost' to inefficiency of the food system (49.9%) is equivalent to 7.22 x 10^{15} calories per year, enough to support 7.2 billion people. 39.7% of the lost calories are from beef production, which requires 33 calories of feed for every calorie of boneless meat. If excess beef consumption were reduced to healthy quantities, as defined by the EAT Lancet diet, and substituted with chicken in forty-eight higher income countries, the number lost calories avoided would be enough to meet the caloric needs of 850 million people. The results presented here demonstrate that a few commodities, particularly beef and pork, are primarily responsible for the current inefficiencies in how croplands are used to produce food for people. Further, these inefficiencies are concentrated in a small set of countries. Targeting actions and policies for these commodities and countries can have an outsized impact on improving food security, health, and the environment.

keywords: food security, diet, agriculture, biofuels

1. Introduction

How we manage the world's limited arable land is critical for increasing food security and protecting nature. Agriculture is the largest land use on Earth [1–3], the largest consumer of water [4], a primary source of water pollution [5], and the primary driver of deforestation and species extinction [5]. Cropland area expanded into natural ecosystems between 2003 and 2019 [6], and is on track to continue expanding to fulfill growing demands for food, biofuels, and other commodities. Demand for crop production is projected to increase by 60-110% relative to 2005 during the first half of this century [7,8].

Given agriculture's large environmental footprint, production increases should come from the sustainable intensification of existing agricultural lands [9]. Although global crop production continues to increase, the rate of yield increase is insufficient to meet this demand [10]. Closing yield gaps could produce an additional 5×10^{15} calories, which is enough to provide calories for 5 billion people [2]. Increasing low-yield areas to the 50th percentile of attainable yields could provide enough calories for ~850 million people [11]. Unfortunately, yield gaps are widening in many of these lowest-yielding areas [12].

If the projected demand cannot be met through sustainable intensification alone, reducing demand is critical. Pressure for more crop production is driven more by changes in diets than population growth [13]. In general, consumption of meat, dairy, and eggs tends to increase as income rises [13,14]. Animal products require more feed than calories contributed to the food system [15,16], creating competition for how crop production is utilized. As a result, fewer calories are available for consumption as more crop production is used for feed. Using crops for biofuels is even less efficient.

Cassidy and colleagues (2013) previously assessed the impact of using crop production for food, feed, and fuel on global calorie availability in the year 2000. They reported that

36% of total calorie production on croplands was used for feed, and only 12% of that was available in the food system as livestock products [17]. As a result, 24% of calories were “lost” to the inefficiencies of using crops to support meat, dairy, and egg consumption in 2000 [17].

To improve food security and decrease agriculture’s environmental impact, the food system will need to be more efficient. But recent research suggests the trend is toward less efficiency. Ray et al. (2022) reported an increase in the fraction of crop production used for feed and other non-food uses between 2000 and 2010 [18]. However, quantifying what the feed is used to produce is required to estimate the calories available in the food system. Further, since 2010, the consumption of calories from meat, dairy, and eggs has increased by 22% (8% per capita, 13% increase per capita) [1]. During that same period, ethanol and biodiesel production also increased [19]. Understanding how these changes affect food availability is crucial for identifying leverage points to improve the efficiency of the global food system.

Here, we quantify the impact of how croplands are used for food, livestock feed, biofuels, and other non-food uses from 2010 to 2020. First, we allocate crop production to its various uses, including food, feed, biofuels, and other non-food purposes. Second, we calculate the number of calories available in the food system based on feed-to-food conversion ratios for meat, dairy, and eggs. Third, we quantify the changes in crop usage and the changes in available calories between 2010 and 2020. Finally, we identify places with the greatest inefficiencies and what is driving them. The results presented in the main text focus on the comparison between 2010 and 2020. The Supporting Material also includes results for 2015.

2. Methods

2.1. Scope of the analysis

The analysis described below was conducted for the top 50 crops in terms of calorie production (Table 1), which account for 97.6% of all calories produced. The analysis was done for each year and then averaged across three years to create data sets representing the years 2010, 2015, and 2020. This averaging approach reduces the impact of short-term large changes in production resulting from weather or price shocks, as well as potential reporting errors in FAOSTAT. The average representing 2010 data was calculated from a linear trend fit to the years 2010-2012.

Table 1. 50 crops included in this analysis. The percentages are based on the average production from 2019 to 2021. *Note: 'nes' (not elsewhere specified) is used by FAO to track the production of crops when countries don't report a specific crop name.*

Crop Group	Percent global calorie production	Crops in this group
Cereals	62.6%	maize (26.2%), wheat (16.5%), rice (13.5%), barley (2.9%), sorghum (1.3%), millet (0.7%), oats (0.5%), triticale (0.3%), rye (0.3%), cerealsnes (0.2%)
Oil Crops	19.2%	soybean (9.4%), oilpalm (4.3%), rapeseed (1.6%), sunflower (1.5%), groundnut (1.5%), coconut (0.3%), sesame (0.3%), olive (0.2%), linseed (0.1%)
Roots & Tubers	5.2%	cassava (2.5%, potato (1.6%), sweet potato (0.6%), yam (0.5%), taro (0.1%)
Sugar Crops	5.0%	Sugarcane (4.0%), sugarbeet (0.9%)
Fruits	2.1%	banana (0.5%), grape (0.3%), apple (0.3%), plantain (0.2%), orange (0.2%), mango (0.2%), date (0.1%), fruitnes (0.1%), tangerine (0.1%)
Pulses & Legumes	1.9%	Bean (0.6%), chickpea (0.3%), cowpea (0.2%), lentil (0.1%), broadbean (0.1%), pigeonpea (0.1%)
Vegetables & Melons	1.5%	Vegetablesnes (0.5%), onion (0.3%), tomato (0.2%), garlic (0.2%), watermelon (0.1%), cabbage (0.1%)
Other	0.2%	Cocoa (0.2%)
Rest of the crops	2.5%	103 additional crops tracked by FAO

2.2. Crop Production and Utilization

We used the Food and Agriculture Supply Utilization Accounts (SUA) [20] to allocate crop production within each country to food, feed, and non-food categories. Although previous analyses [17] used FAO's Food Balance Sheets (FBS) [21], we used the SUA as it provides a more detailed breakdown of commodities associated with each crop [22]. This additional detail allowed us to avoid making assumptions about how to allocate the FBS "Processed" category across food, feed, and non-food uses. Also, it is important to note that FAO's current accounting methodology for both the Food Balance Sheets and Supply Utilization Accounts started in 2010. Previous efforts that compared the Food Balance Sheet data for 2010-2013 using the old and new databases found large discrepancies [23]. As such, we could not credibly assess longer term trends or compare the results presented here to similar work by Cassidy and colleagues [17] for the year 2000.

First, each crop was broken up into its constituent commodities within each country. For example, linseed is broken up into linseed, cake of linseed, and oil of linseed. The complete list of crop-specific commodities, along with their corresponding calorie content per gram, is in Table S1. To standardize the assessment of impact on the food system, the volume (in tons) of each commodity was converted to calories. *See Supplemental Material for further details.*

Second, we calculated the total calories allocated as Food, Feed, and Other (non-food) for each crop (and its constituent commodities). We calculated 'Food' as the sum of the 'Food supply quantity (tonnes)' and 'Tourist consumption' elements in the SUA database. For 'Feed' and 'Other (non-food),' we used elements in the Supply Utilization Accounts with those same names.

Third, we calculated the allocation of calories as described above for every country and the globe as a whole. For each country-crop combination, we assume that exported calories are allocated according to the global pattern and that domestic and exported calorie utilization is weighted appropriately. These steps were repeated for each year for each country where the crop was produced. *See Supplemental Material for further details.*

2.3. Feed calories utilized for livestock commodities

We used feed-to-food conversion rates to estimate what percentage of total feed calories were returned to the food system for human consumption. We refer to this quantity for consumption as 'Indirect Food.' The following livestock commodities were included to calculate Indirect Food calories: cattle meat, pig/swine meat, chicken meat, dairy, and eggs. Consistent with [17], goats, sheep, water buffalo, camels, and horses were excluded from the analysis as these livestock are primarily produced on rangelands. Indirect Food was calculated using a weighted average of domestic livestock production [1], animal-specific feed-to-food calorie conversion rates, and supplemental feeding rates (Table S2, Equations S1-S5). The feed-to-food calorie conversion rates vary across livestock commodities. Dairy is the most efficient (2.5:1); beef is the least efficient (33:1). *See Supplemental Material for further details.*

2.4. Calories utilized for biofuel production

We estimate the calories allocated to biofuel production from OECD-FAO Data Explorer [19], which reports the quantity of the domestic output of crops and commodities used to produce ethanol and biodiesel. Our analysis accounts for 93.6% of the bioethanol and 99.2% of the biodiesel produced globally between 2021 and 2023 [19]. We assumed that quantities reported were categorized as 'non-food' in the SUA data. We accounted for the calories in the distiller grains byproduct of producing ethanol from maize. Estimates of feed production calculated above were not adjusted, as the SUA data reported the amounts of byproducts used as feed. *See the Supplemental Material text and Table S3 for additional details*.

2.5. Available and Lost calories

We use the term ‘available calories’ to represent the sum of crop calories available as food for people, either by eating crops (‘direct calories’) or from livestock commodities after accounting for feed-to-food efficiency factors (‘indirect calories’). ‘Lost calories’ as the sum of calories unavailable because of the inefficiency of feed-to-food conversion and the calories allocated to non-food uses, such as biofuels. We then estimated the number of people that could have their caloric needs met from the total calorie production and the available calorie production. Consistent with Cassidy and colleagues [17], we assumed a 2700 kcal/person/day diet. We do not address food loss and waste here. While there is a ‘loss’ category in the Supply Utilization Accounts, we allocate those calories proportionately to ‘food,’ ‘feed,’ and ‘non-food’ since the database did not have commodity-level values. The reported loss accounts for 5% of all production. We do not include the Supply Utilization Account elements of ‘*seed’* in our results, as this ensures they remain relevant for policy on crop utilization; we do not propose reallocating seed to any other purpose.

2.6. The influence of diet on available calories

To quantify the impact of diet choice on the number of available and lost calories, we calculated the amount of beef consumption in excess of a healthy quantity defined by the EAT Lancet Diet [24]. More specifically, we calculated the difference between per capita beef consumption [21] and 7.16 kg/cap/year. This difference was multiplied by population size to estimate total excess. Next, we calculated the number of lost calories avoided if the excess beef were substituted with chicken or lentils. The analysis was completed for all countries, excluding countries that had a lower per capita beef consumption 7.16kg/person/year and Low Income Food Deficit Countries as defined by FAO [21]. Those criteria limited the scenario or forty-eight countries.

2.7. Geographic patterns

To visualize spatial patterns, we distributed the results using crop-specific sub-national data for 50 crops. These maps were created by combining data on sub-national production [25], national production [1], and sub-national crop distribution (CROPGRIDS) [26]. Specifically, we reconstructed the Monfreda et al. [25] geodatabase, perturbed the data by adjusting it annually based on national production data in FAOSTAT, and then distributed the data within administrative units using the CROPGRIDS data set [26]. Each step normalized the data to align with FAOSTAT's annual production data and distributed it among administrative units in GADM v4.1 ((OECD and Food and Agriculture Organization of the United Nations 2024)) (see supplemental material). Direct, Indirect, and Non-food calories data were then distributed across these production maps for three-year periods circa 2010, 2015, and 2020. *See Supplemental Material for additional details on data construction, testing, and the raster products for 50 crops.*

3. Results

3.1. Crop Production and Utilization

Global crop production increased by 2.80 x 10^{14} calories/year (23.9%) between 2010 and 2020. This increase is attributed to increased calorie production used for (direct) food (14.9%), feed (31.2%), and non-food uses (36.3%) (Figure 1). The biggest increases in food calories were from wheat (14.9% of the total food calorie increase), rice (13.9%), and maize (7.2%). *See Table S1 for crop-specific calorie totals and allocation breakdown.*

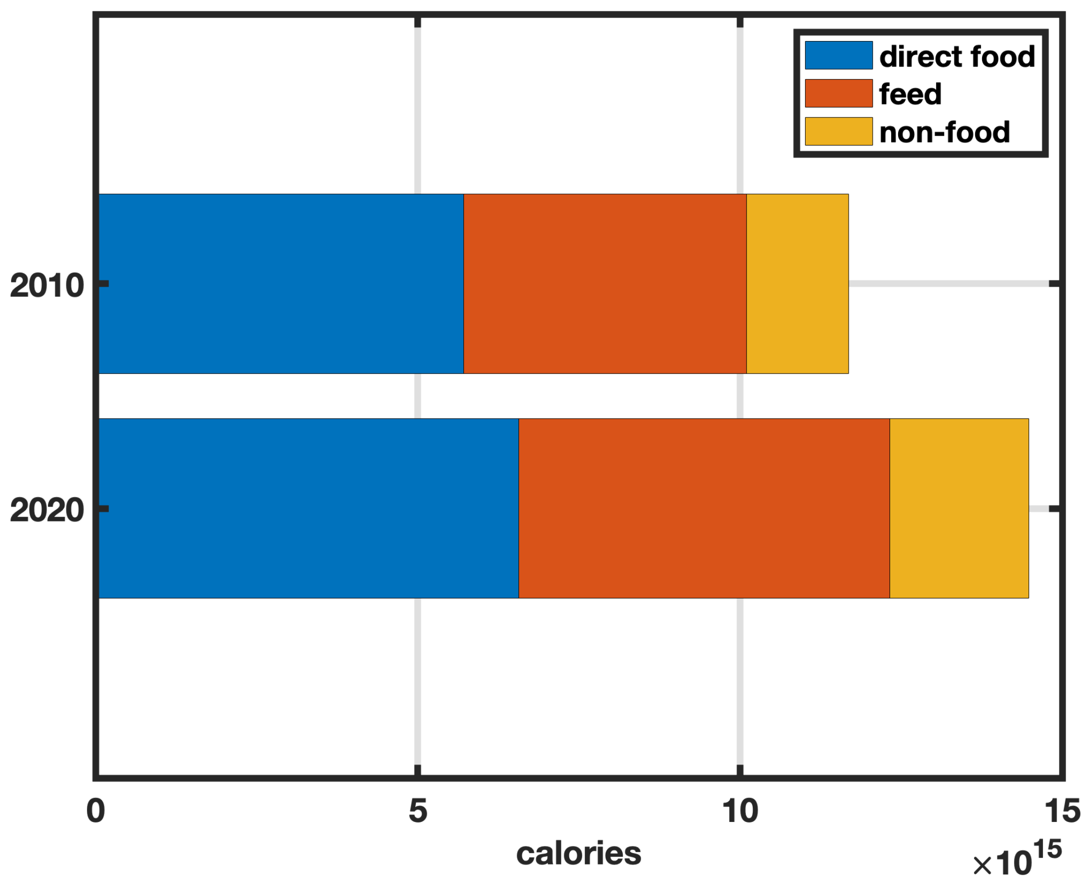

Figure 1. Crop production utilized as food, feed, and non-food uses. Total calorie production on croplands increased 23.9% between 2010 and 2020. This increase was primarily due to calories used for feed and non-food purposes. For context, 1 x 10^{15} calories are enough to meet the annual caloric needs of 1 billion people eating 2,700 kilocalories per day.

3.2. Feed calories utilized for livestock commodities and non-food uses

Feed production increased 31.2% from 2010 to 2020. The increased production was not evenly distributed across livestock commodities, indicating changes in diet. The largest increases in commodities used for feed were maize (59.6%) and soybeans (21.1%). The largest increases in feed allocation were for beef and pork, garnering 31 and 25% of the total increase in feed share, respectively. These represent a slight decrease in total fraction of feed going to beef and pork, at (4 and 6% decrease respectively.) *See Table S4a for country-specific calorie totals and allocation breakdown.*

The fraction of crop calories used for non-food uses increased from 2010 to 2020. Biodiesel and bioethanol production, a subset of non-food uses, increased 226% and 19.8%, respectively, accounting for 1.4% and 4.0% of global calorie production in 2020. Oil palm and maize had the largest increases in non-food calorie production, at 33.7% and 29.1%, respectively. The percentage of domestic calories used for ethanol feedstocks was highest in the United States (16%) and Brazil (13%). For biodiesel, the highest percentages of domestic production used for biodiesel were Colombia (9%), Indonesia (8%), Thailand (8%), and Malaysia (7%). These estimates for calories used for biofuels are conservative—we only estimated calories for biofuels from domestic production, excluding biofuels produced using imported feedstocks. For example, biodiesel produced in Germany using oil palm feedstock from Indonesia is excluded from estimates for both countries. *See Table S3c for crop-specific calorie totals and allocation breakdown.*

3.3. Available and Lost calories

Total calorie production increased 23.9% between 2010 and 2020, yet available calories per person only increased by 9%. Several key factors contribute to this decline in efficiency (Figure 3). First, although production of crops consumed directly as food (direct calories) increased 14.9%, direct calories were a smaller fraction of total calories in 2020 than in 2010 (Figure 1). A larger fraction of total calories was also utilized as non-food commodities.

Second, the use of feed became less efficient during that time (Figure 2). As a result, a smaller fraction of the feed calories was available as calories from livestock commodities (indirect food). Only 10.8% of calories from feed were available as food from livestock commodities in 2020. Increased feed calories for beef and pork were the largest source of the lost calories (Figure 2).

3.4. Effects of diet choice on available and lost calories

If beef consumption in the 48 countries included in this analysis (Table S5) was reduced to healthy quantities, as defined by the EAT Lancet diet, 1.23 x 10^{15} calories currently lost in the food system could become available. That is enough calories to support 1.23 billion people. For a more conservative estimate, 8.51 x 10^{15} calories lost in the food system could be avoided if the chicken replaced the same amount reduced beef consumption. Those quantities are enough to meet the caloric needs of 1.23 billion and 851 million people, respectively. More than half of the global potential to increase available calories is in the United States (37%) and Brazil (21%). As mentioned in the Methods, Low Income Food Deficit Countries and countries consuming less than 7.16 kg/person/year were excluded from the analysis. *See Table S5 for results for all 48 countries.*

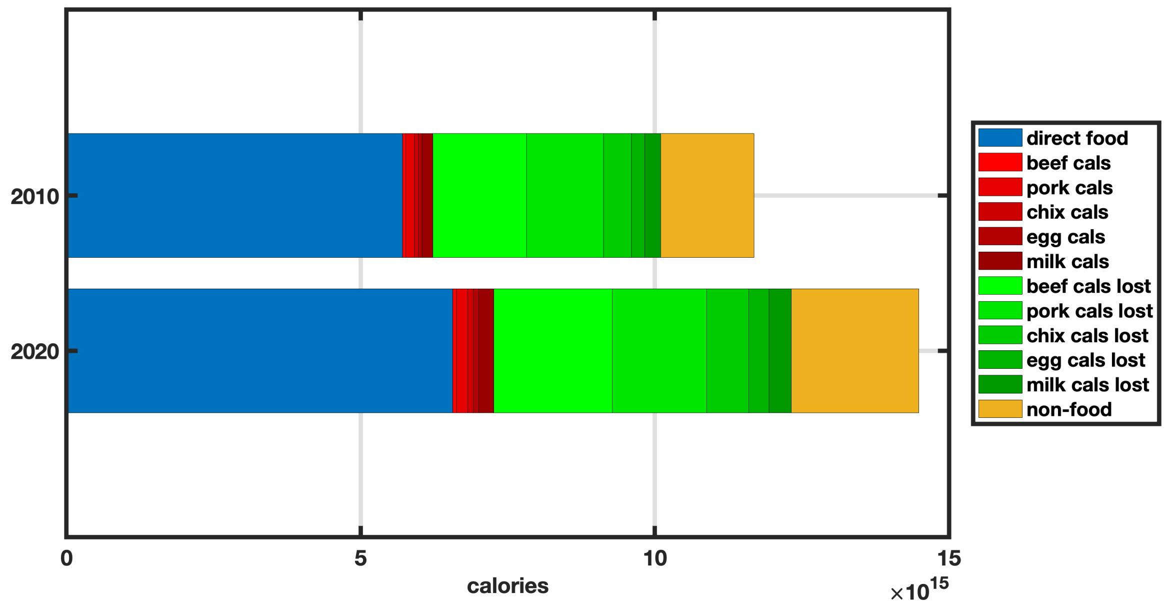

Figure 2. Available and lost calories from croplands. 'Available' calories are the sum of calories of crops consumed directly as food (blue) and indirect calories from livestock commodities like beef and eggs that were produced using feed calories (red). 'Lost' calories are the sum of feed calories used to produce livestock commodities that do not end up as feed calories (green) and calories lost for non-food uses like biofuels and shampoo (yellow).

3.4. Geographic patterns

The four countries, the EU27, Rest of World, and Global, illustrate a wide range of how crops are used and the changes between 2010 and 2020 (Table 2, Figure 3). Calorie production on global croplands increased 23.9% between 2010 and 2020. Combined, the four countries and the EU27 produced 47% of global calories, with country-scale increases ranging from +15% in the USA to +46% in Brazil. These gains were outweighed by the "Rest of World," whose share of global calorie production increased from 41% to 43%.

However, these gains do not necessarily translate to an increase in available food. In 2020, only 17% and 24% of calories produced on croplands were used directly for food in the USA and Brazil, respectively. After accounting for the indirect food calories from using feed to produce livestock commodities, the available food in the USA was 23% and in Brazil, 29% of total calorie production. In contrast, India consumed 79% of calories produced on croplands directly as food in 2020, a decrease from 82% in 2010. While India's allocation of calories to feed increased since 2010, it was still far lower (19% of total calories) than any of the four countries or regions. In 2020, 84% of total calorie production in India was available, after accounting for the indirect food calories contributed by livestock commodities. The difference in the percentage of direct and available food is much higher in India (from 79% to 84%) than in all countries and regions listed in the table. This difference is because most feed calories are used to produce milk, which has a more efficient feed-to-food conversion factor (Table S2). Although calorie production is much lower, the percentage of calories available as food is similar across much of sub-Saharan Africa.

The number of people fed per hectare integrates the production and the allocation data. On average, croplands produce enough calories to meet the needs of 12 people per hectare, but only 6 after accounting for lost calories (Table 2). The geographic patterns vary widely. For example, while the production in the United States feed 22.1 people per hectare of cropland, but the available calories are only sufficient to meet the needs of 5.0 people per hectare. The efficiency of croplands for food production has decreased, potentially supporting 2.3 more people per hectare, yet only 0.3 more based on available calories. Although the differences are not as stark, Brazil and the EU27 also have a wide gap between calorie production and calories available for people. In contrast, India produces 40% few calories per hectare of cropland than in the United States yet could feed 2.3 more people. China uses a high fraction of crop production for feed but could support more people per hectare because only a small fraction is for non-food uses. *See TableS4. Country-specific calorie totals and allocation breakdown*

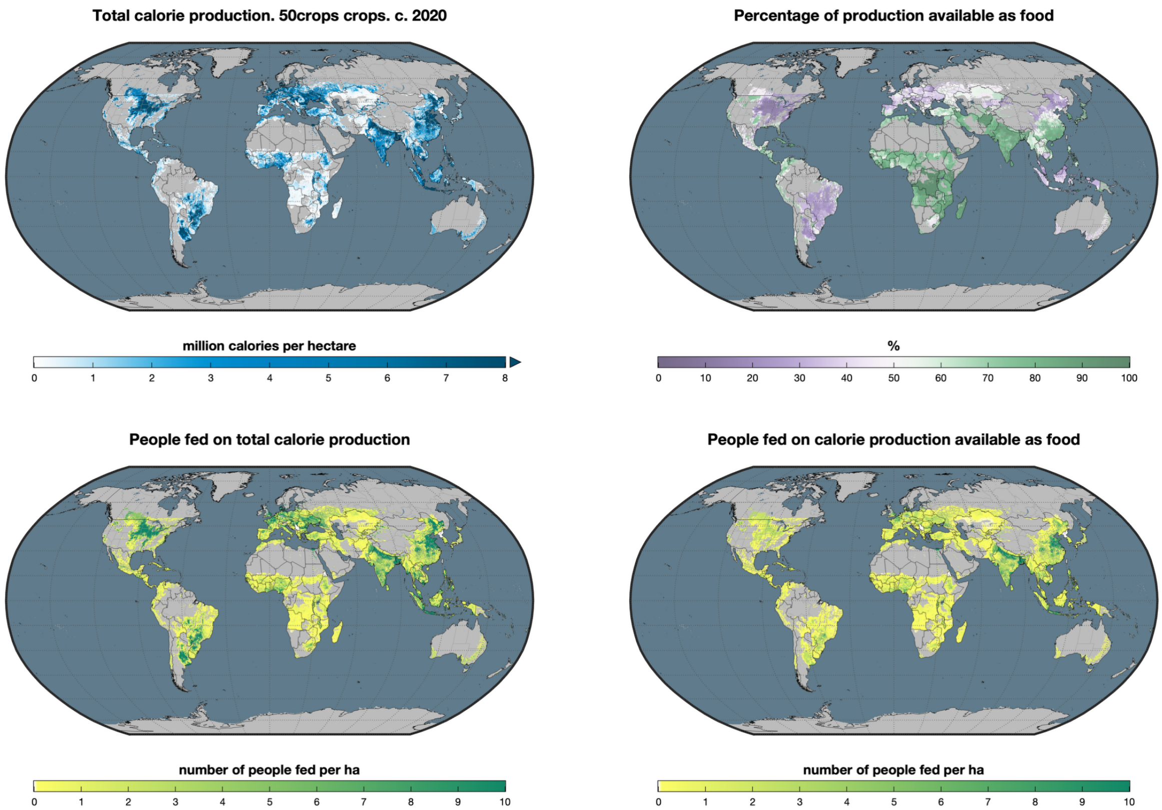

Figure 4. Geographic patterns of calories produced and available for human consumption in 2020. The above maps show (a) total calorie production, (b) the ratio of calories consumed directly as food vs. feed and non-food, (c) the fraction of total calorie production available for human consumption, and (d) the number of people potentially fed per hectare of available calories. Available calories are the sum of direct and indirect (livestock commodities via feed) calories. The number of people fed per hectare assumes 2700 kcal/day for a year. *Maps for the years 2010 and 2015 are in Figures S1-S4 in the Supplemental Material.*

Table 2. Changes in crop production and allocation from 2010 to 2020

Table 2. Changes in crop production and allocation from 2010 to 2020

	Production in 2010						Production in 2020					
Geography	Production calories	Direct Food	Feed	Non-food	People fed per ha, total calories	People fed per ha, available calories	Production Calories	Direct Food	Feed	Non-food	People fed per ha, total calories	People fed per ha, available calories
USA	1.74×10^{15}	0.20	0.50	0.30	18.8	4.7	2.00×10^{15}	0.17	0.56	0.28	22.1	5.0
China	2.06×10^{15}	0.55	0.37	0.08	14.8	8.7	2.51×10^{15}	0.48	0.42	0.11	18.1	9.5
India	1.16×10^{15}	0.82	0.15	0.02	7.1	6.2	1.46×10^{15}	0.79	0.19	0.02	8.6	7.3
Brazil	8.14×10^{14}	0.29	0.45	0.26	13.6	4.5	1.19×10^{15}	0.24	0.50	0.26	16.2	4.7
EU27	1.08×10^{15}	0.36	0.56	0.07	14.3	6.2	1.14×10^{15}	0.36	0.54	0.10	15.7	6.7
Rest of World	4.82×10^{15}	0.55	0.33	0.12	8.3	4.9	$6.19 \text{ X } 10^{15}$	0.52	0.34	0.14	9.4	5.2
Global	1.17×10^{16}	0.49	0.38	0.14	10.5	5.6	1.45×10^{16}	0.45	0.40	0.15	12.1	6.0

4. Discussion

Calorie production on global croplands increased by 23.9% from 2010 to 2020 while cropland area only increased by 3.2% [1]. However, croplands were less efficient at delivering available calories to the food system in 2020 than in 2010. The decreased efficiency is primarily due to a greater fraction of calories being used for feed and non-food uses. Feed and non-food calories increased by 31.2% and 36.3%, respectively, while calories consumed directly as food only increased by 14.9%. While consumption of meat, dairy, and eggs all increased globally, the increase in beef consumption was the biggest driver of increased feed use. From 2010 to 2020, feed calories for beef production increased by 25.8%.

The inefficiencies highlighted here occur in the context of several additional factors that increase the risk to food security. Yield trends of major crops have stagnated in many regions and are not on track to meet projected demand by 2050 [10,27]. Further, the gaps between current and attainable yields are widening in many areas where a high fraction of crop production is consumed directly as food [12]. Climate change has already affected crop yields [28–30], and they are projected to decrease across most of today's croplands [31,32].

Although this study emphasized the impact of crop use on the competition for limited cropland, the findings' relevance is much broader. Croplands produced enough calories to support 14.5 billion people in 2020 (this research), yet 733 million people faced chronic hunger in 2023, while 2.3 billion were moderately to severely food insecure [33]. Another 2.11 billion adults over 25 years old were overweight or obese in 2021 [34]. The current food system is clearly not meeting the nutritional needs of half of the global population.

These choices of how crop production is utilized for food, feed, and non-food uses also directly influence agriculture's environmental impact. Agriculture accounts for 22% of global greenhouse gas emissions [35,36], 92% of consumptive water use [4], is a primary source of water pollution [5,37], and is the leading cause of deforestation [38,39]. In most cases, the environmental impact aligns with how calories are utilized. For example, beef production is the least efficient use of crops analyzed here, and it has the highest greenhouse gas emissions per kilogram [40]. In contrast, crop calories consumed directly as food generally have much lower greenhouse gas intensities [40,41]. Our findings complement related studies that show how shifting to healthier diets, even just shifting some beef consumption to chicken, would greatly reduce diet-related emissions [42,43]. These climate impacts from agriculture can create a downward spiral, where a warmer climate exacerbates the environmental impacts of agriculture [44] and increases deforestation to mitigate climate-induced production declines [30].

There are several caveats to this analysis. First, food availability is not the same as food security. Additional factors such as accessibility, affordability, and nutrition would be required to have a more holistic view of food security. Second, the analysis included 50 crops that comprise 97.5% of calories produced on croplands. The remaining 103 crops tracked by FAO are primarily fruits and vegetables. Third, there are no sub-national data for all countries included in this analysis. However, that limitation would only affect how the results are presented on the maps. The analysis presented here only required national data from the FAO. Further, restricting the crop-specific raster data sets to only administrative units where data are available enables other studies that can use climate, soil, market access, and other socio-environmental characteristics as independent variables. Fourth, the analysis does not include the source countries for feed used for the domestic production of livestock commodities. However, using the global average of crop utilization for feed commodities is likely to have a minimal impact on the results, as our analysis is limited to calories and domestic livestock production. This assumption would be less credible if the analysis included where livestock were consumed or assessed other embodied resources, such as greenhouse gases, water, land, or fertilizer. Fifth, food waste is not included in our analysis and falls beyond its scope. If included, the results would illustrate that while all food waste impacts the food system, the impact is not evenly distributed. Wasting livestock commodities, particularly beef, has a disproportionately large impact due to the significant amount of feed calories required to produce the commodity. Despite these limitations, the analyses and underlying data sets developed here have the potential for use in related analyses to assess opportunities and tradeoffs for improving global food security while reducing agriculture's environmental impact. We caution that the approximations we made to update the data to 2020 are uncontrolled in the sense that there is no estimate of the error. We provide high-resolution, high-quality data in the same format from the agricultural statistics agencies of Brazil and the USA to facilitate application-specific validation studies.

This analysis highlights several key leverage points for targeting action to enhance the efficiency of the global food system. First, a few commodities drive most of the inefficiency. More than half (54.7%) of calories produced on croplands in 2020 were utilized as feed (39.7%), and other non-food uses, including biofuels (14.9%). Shifting these calories to be directly consumed as food would be enough calories to feed an additional 7.9 billion people. We are not naïve enough to think that people would be healthy if they only ate the crops currently used for animal feed, biofuels, and other non-food uses. However, the land currently used to produce livestock feed and feedstock for biofuels could be used to grow different crops that meet caloric and nutritional requirements. Due to the significant differences in feed-to-food efficiencies, even reallocating some of the calories used for beef production to feed for pigs or chickens would increase the calories available for people. The calories lost from biofuels and other non-food uses have limited benefits, as feedstocks for biofuels compete for land that could be used to grow food.

Second, these challenges are concentrated in a small set of countries. Biofuel production is tightly concentrated—72% of bioethanol production is in only two countries, the US (47%) and Brazil (25%). The European Union produces 31% of the world's biodiesel, and three countries – Indonesia (19%), the US (19%), and Brazil (12%) – account for another 50%. Feed production and beef consumption are also tightly concentrated. 47.9% of feed production is concentrated in the USA (19.3%), China (18.2%), and Brazil (10.4%). Reducing beef consumption to healthy levels in 48 higher-income countries and replacing that protein with lentils or chicken reduce the number of lost calories equivalent to meeting the caloric needs of 1.2 billion or 850 million people, respectively. More than half of that opportunity is from substituting excess beef for chicken in the United States (37%) and Brazil (21%).

5. Conclusion

How we use croplands to produce food for people has become less efficient from 2010 to 2020. The results presented here illustrate that a few commodities, particularly beef and biofuels, account for most of the current inefficiencies. Further, these inefficiencies are concentrated in a small set of countries. Shifting to healthier diets in the United States and Brazil, and reducing biofuel production in the United States, Brazil, European Union, and Indonesia are leverage points for increasing the number of available calories from croplands. Targeting actions and policies for these commodities and countries can have an outsized impact on improving food security, health, and the environment.

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Supporting Material

Crop-specific utilization

Table S1. Primary crops and their constituent commodities

This table is at the end of the Supporting Material. It is also available as *TableS1_commoditiesandcaloriesfromSUA.csv*

Converting tons to calories

Where possible, the relationship between tons of commodity and calories was inferred from the SUA data. For consistency across the analysis, we use the ratio of the global totals of 'Food Supply quantity (tonnes)' to 'Calories/Year' to infer the number of kilocalories per ton of commodity. This value was used to convert tons to kilocalories for each crop and commodity in each country. We note the data sources and assumptions in cases where it was not possible to infer the ratio of production weight to calories (Table S1). Table S1 also includes the values from the Nutrient Conversion Table spreadsheet, which was made available by FAO. These results broadly agree with the values inferred from the SUA data, although there are some discrepancies (e.g., cocoa paste, cocoa powder).

Accounting for total available calories produced

Total calories available for each crop and all commodities derived from it are calculated as calories produced – calories for seed. We use the data from the Supply Utilization Accounts as described below to derive fractions of those calories allocated to 'direct food', 'feed', and 'non-food', where those fractions are country- and year-specific.

This approach has the following implicit properties: calories ascribed to the 'loss' category from Supply Utilization Accounts are proportionally allocated to 'direct food' 'feed' and 'non-food'; Stock Variation and Residuals are ignored; Crop production data is used to assess the total number of calories available; Any commodities which are not fully accounted for in the Supply Utilization Accounts are assumed to be allocated to ‘direct food’, ‘feed’ and ‘non-food’ proportionately to all accounted calories.

Allocating calories to Food, Feed, and Other Uses (non-food)

Our calculations of crop calorie allocations to food and feed are conceptually similar to those of Cassidy et al., with some changes motivated mainly by the FAO's revised accounting for Supply Utilization and Food Balances.   Here, we describe the methods as implemented:

Each crop is first broken down into its constituent commodities. The table of crops and constituent commodities is given in Table *SupplementalTable1_commoditiesandcaloriesfromSUA.csv.* Where possible, the relationship between tons of commodity and calories was inferred from the SUA accounts. We use the ratio of ‘Food supply quantity (tonnes)’ to ‘Calories/Year’ for the globe to infer a ratio between tons of food and calories. Our method of inferring calorie density reproduces the values in a table available at www.fao.org/3/CC9678EN/Nutrient_conversion_table_for_SUA_2024.xlsx, covering a broader set of commodities, and assuring consistency with FAO when weighting across commodities. We have noted sources and assumptions for cases where it was not possible to infer a ratio of production weight to calories.

For each commodity, we calculate a domestic food utilization vector Udom with the following elements.

```
'Food - direct'
'Food - indirect'
'Feed'
'Other uses (non-food)'
'Loss'
'Seed'
```

Udom has the following properties:

Eq S1	$U_{dom}(1) + U_{dom}(3) + U_{dom}(4) = 1$	Calories allocated to direct food, feed, or non-food
Eq S2	$U_{dom}(2) = U_{dom}(3) * ICF$	"Indirect Calorie Factor" relates feed calories to calories from livestock products.

A global food utilization vector U_{world} is created with the same properties based on utilization for the World.

Accounting for imports and exports

We assumed that each country's exports are utilized according to the global average utilization for that crop, thus for each commodity. This assumption and method are consistent with Cassidy et al. [17]. To assess the utilization of calories for each crop produced within a country, we calculate a normalized utilization vector by averaging Udom and Uworld according to the ratios of calories consumed domestically and exported:

Eq S3

$$U_{tot} = U_{dom}\frac{Prod + Imp - Exp}{Prod + Imp} + U_{world}\frac{Exp}{Prod + Imp}$$

Feed-to-food conversion factors for livestock commodities ("ICF")

We determine the Indirect Food Calories element of Udom by multiplying the 'Feed' element by a country-specific factor ICF (Indirect Calorie Factor). We calculate ICF as a weighted average of the calorie conversion factors CC_i describing the conversion of feed to human-edible calories reported in Cassidy et al. 2013 for several livestock products i. The weights w_i represent the relative caloric requirements required to produce the livestock production reported in FAO data (Table S2), and are the product of the livestock production P_i (in tons) multiplied by the ratio F_i of tons of feed per ton of produced livestock.

We assume that Feed crops are allocated among Cattle, Swine, and Chicken based on the production of Cattle Meat, Pig/Swine Meat, Chicken Meat, Eggs, and Dairy Products. Since cattle also consume pasture forage, we assume supplementation of cattle feed with pasture. Therefore, in this study we assumed beef cattle feeds have a 15% grassy fodder component (as reported by the USDA) (Johnson 2010) and dairy cow feeds have a 60% grassy fodder component (NRC 2001). These assumptions are consistent with Cassidy et al. 2013.

Eq S4 $$ICF = \frac{\sum_i w_i CC_i}{\sum_i w_i}$$

Where CC_i = Calorie conversion ratio

Eq S5 $$w_i = P_i F_i (1 - \eta_i)$$

Where
P_i = Production of Livestock product i
F_i = ton of feed to produce a ton of Livestock product *i*
η_i = Supplemental feed factor

Table S2. Livestock Conversion Factors

	Item in FAO Crop and Livestock Production Data	Item_Code	F_i = ton of feed to produce a ton of Livestock product	CC_i = Calorie conversion ratio	η_i = Supplemental feed factor
Beef	Meat of cattle with the bone	867	21.17	0.0308	0.15
Pork	Meat of pig with the bone	1035	9.29	0.1043	0
Chicken	Meat, Poultry	1808	3.33	0.1178	0
Eggs	Eggs Primary	1783	2.5	0.2207	0
Dairy	Raw milk of cattle	882	1.1	0.4025	0.60

Biofuels
We estimated the number of calories used for biofuel production based on the quantity of domestic crop production used for ethanol and biodiesel, as reported by the OECD-FAO [45] (Table S3a). As such, this approach does not account for all biodiesel production, as cases like Indonesian-sourced palm oil used to produce biodiesel in Germany. Tons of crop and vegetable oil were converted to calories using the ton:calorie ratios described in the 'Converting tons to calories' section above.

We adjusted the tons of maize feedstock reported by OECD-FAO to correct for the calories in in the byproduct distiller grains. We assumed that the fraction of calories in feed byproducts was 34% for maize [46]. As such, the reported percentage of calories used to produce ethanol from maize in the OECD-FAO database was 66%. We also calculated the distiller grain fraction from the 'Biofuel Use' and 'Distiller Grains' in the OECD-FAO database. Our calculation also showed a 34% of distiller grains from maize quantities per tons of 'biofuel use' for maize.

We assumed no feed byproducts for "vegetable oil" since it was reported as a processed commodity in the Supply Utilization Accounts [20]. The OECD-FAO data reports "vegetable oil" as a feedstock. For this analysis, we assumed that the main crop used as feedstock for biodiesel in the country or region was the sole source of "vegetable oil" (Table S3a). Where possible, we adjusted the fraction of total feedstocks (Table S3b).

Table S4a. Country- and region-specific domestic crops used as feedstocks for biofuels.

Country or Region	Main feedstocks for ethanol	Main feedstocks for biodiesel *
Argentina	maize, sugarcane, molasses	Soybean oil
Brazil	sugarcane, maize, molasses	Soybean oil
Canada	Maize, wheat	Rapeseed oil, soybean oil
China	Maize, cassava	
Colombia	Sugarcane	Palm oil
European Union	sugar beet, maize, wheat	Rapeseed oil, palm oil
India	Sugarcane, molasses, maize, wheat, rice	
Indonesia	molasses	Palm oil

Malaysia	NA	Palm oil
Thailand	Molasses, cassava, sugarcane	Palm oil
United States	Maize	Soybean oil

Modified version of Table 9.1 in OECD/FAO (2024) OECD-FAO Agricultural Outlook 2024-2033

Notes:

1. The countries account for 93.6% of global ethanol production and 99.2% of global biodiesel production.

2. * The OECD-FAO database only reported data for "vegetable oil" as biodiesel feedstocks. In the absence of a feedstock-specific breakdown, we assumed that the first source listed is the only source. These first sources are the dominant oil crops produced domestically in the country.

Table S3b. Adjustment factors for domestic crop feedstocks for biodiesel production. The adjustment factors account for the fraction of biodiesel that is produced from domestic crop production. These factors exclude several sources of feedstock: used cooking oil, animal fat, and crops not produced domestically. For example, palm oil feedstock in the EU is excluded

Country or Region	Adjustment factors
Argentina	1
Brazil	0.7
Canada	0.9
China	0
Colombia	1
European Union	0.4
India	0
Indonesia	1
Malaysia	1
Thailand	1
United States	0.64

Argentina: no commercial operations using waste or used cooking oil as feedstock https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Buenos%20Aires_Argentina_AR2024-0011.pdf
Brazil: Soybean oil is 70% of the feedstock https://www.spglobal.com/commodity-insights/en/news-research/latest-news/agriculture/010225-commodities-2025-brazil-boosts-biodiesel-production-eyes-market-growth#:~:text=Soybean%20oil%20remains%20the%20dominant,to%20ANP%20data%20for%202024.
Canada: https://www.ccarbon.info/article/comparing-biofuel-feedstocks-across-north-america/#:~:text=In%20Canada%2C%20as%20well%20as,the%20production%20of%20Renewable%20Diesel.
European Biodiesel Board. 2024. Statistical Report: 2023. https://ebb-eu.org/wp-content/uploads/2024/03/EBB_Statistical_Report2023-Final.pdf
India and China: 0 Estimated 100% from used cooking oils (OECD-FAO Report)
USA: https://www.eia.gov/energyexplained/biofuels/biodiesel-rd-other-basics.php
Colombia, Thailand, Malaysia, Indonesia: no resources found suggesting any other feedstock than oil palm

Table S3c. Domestic calorie production used for bioethanol and biodiesel production and their percentage of total domestic calorie production.

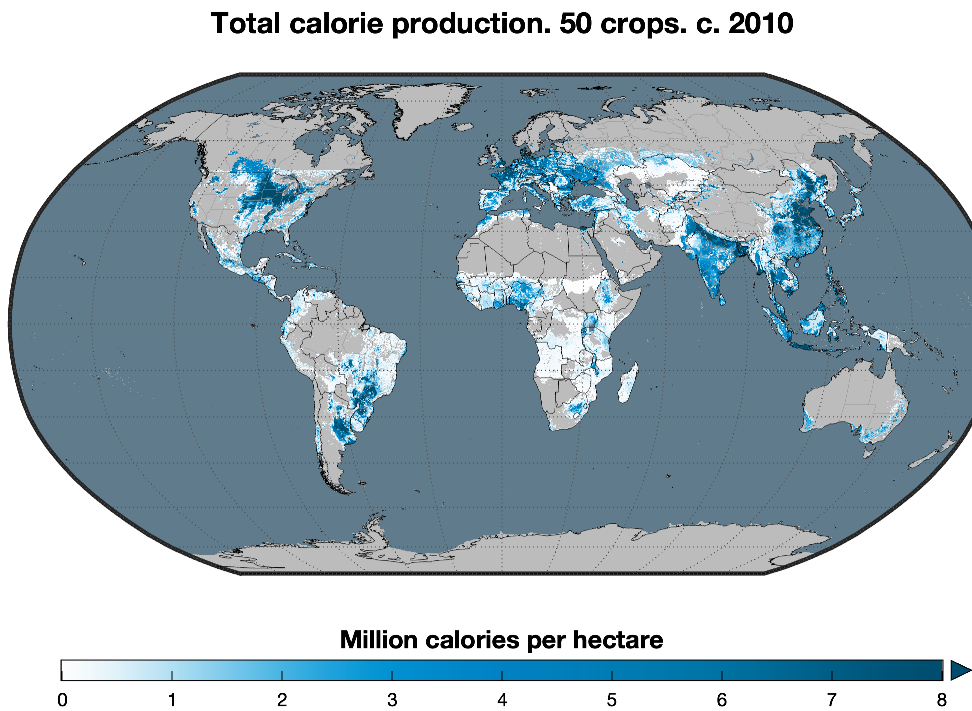
	Bioethanol				Biodiesel			
Country or Region	2010 (cal)	2010 (%)	2020 (cal)	2020 (%)	2010 (cal)	2010 (%)	2020 (cal)	2020 (%)
Argentina	1.9 E+12	1%	6.1 E+12	1%	1.6 E+13	5%	1.7 E+13	4%
Brazil	1.3 E+14	16%	1.5 E+14	13%	9.9 E+12	1%	2.7 E+13	2%
Canada	9.4 E+12	4%	1.2 E+13	4%	4.3 E+10	0%	1.2 E+12	0%
China	4.5 E+13	2%	1.4 E+12	0%	0	0%	0	0%
Colombia	1.4 E+12	4%	2.1 E+12	5%	2.5 E+12	6%	4.0 E+12	9%
European Union	3.3 E+13	3%	3.5 E+13	3%	3.3 E+13	3%	3.9 E+13	3%
India	1.8 E+13	2%	1.8 E+13	1%	0	0%	0	0%
Indonesia	2.1 E+12	0%	1.8 E+12	0%	7.0 E+12	1%	5.8 E+13	8%
Malaysia	0	0%	0	0%	1.5 E+12	1%	1.1 E+13	7%
Thailand	5.9 E+12	3%	1.5 E+13	7%	5.4 E+12	3%	1.6 E+13	8%
United States	2.7 E+14	16%	3.3 E+14	16%	6.7 E+12	0%	2.2 E+13	1%

Table S4a. Crop-specific calorie totals and allocation breakdown.
See TableS4a_ Crop-specific-calorie-totals-and-allocation-breakdown.csv

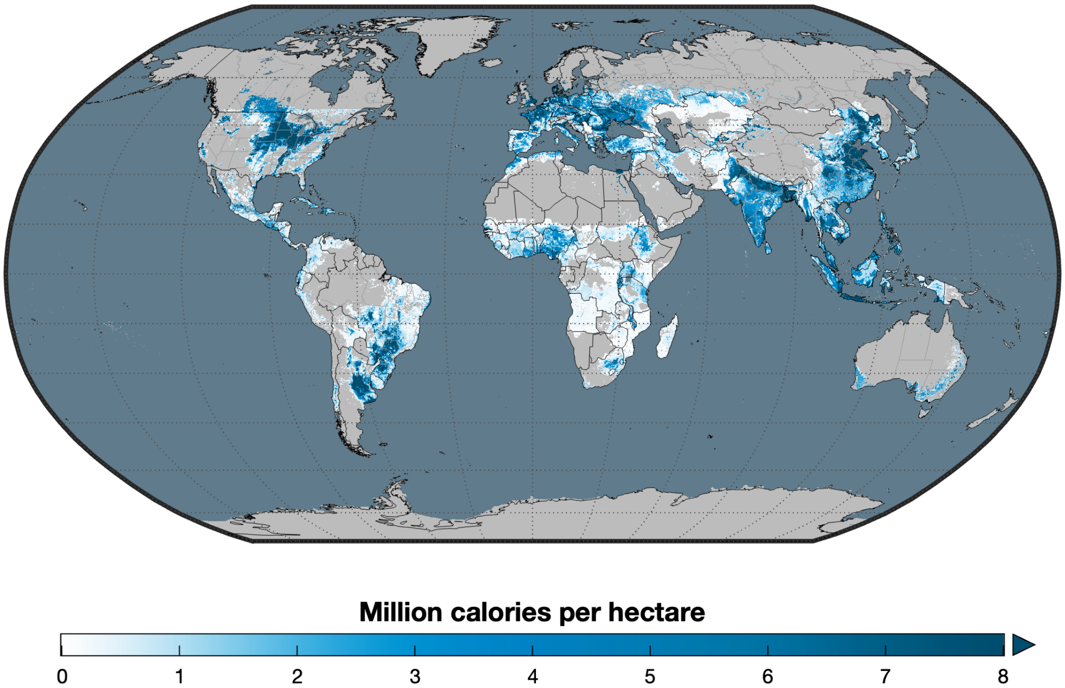
Table S4b. Country-specific calorie totals and allocation breakdown.
See TableS4b_ Country-specific-calorie-totals-and-allocation-breakdown.csv

Table S4b. Country-specific potential calorie savings from reducing excess beef consumption.
See TableS5_Country-specific-potential-calorie-savings-from-reducing-excess-beef-consumption.csv

Figure S1. Total calorie production on croplands in 2010, 2015, and 2020.



Total calorie production. 50 crops. c. 2015



Total calorie production. 50 crops. c. 2020

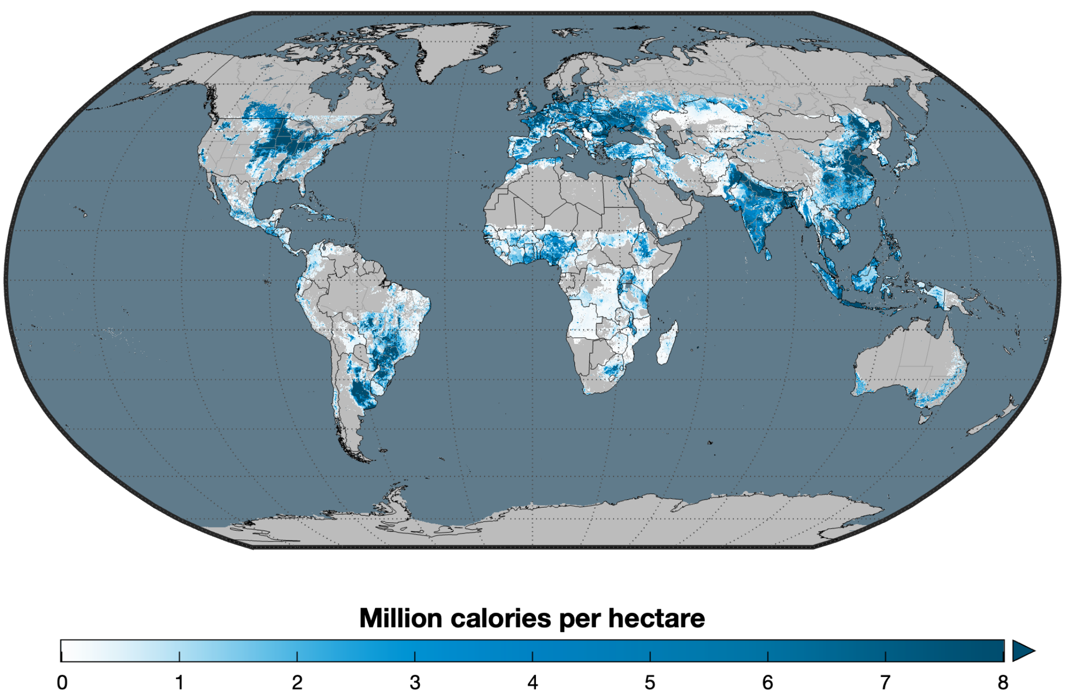
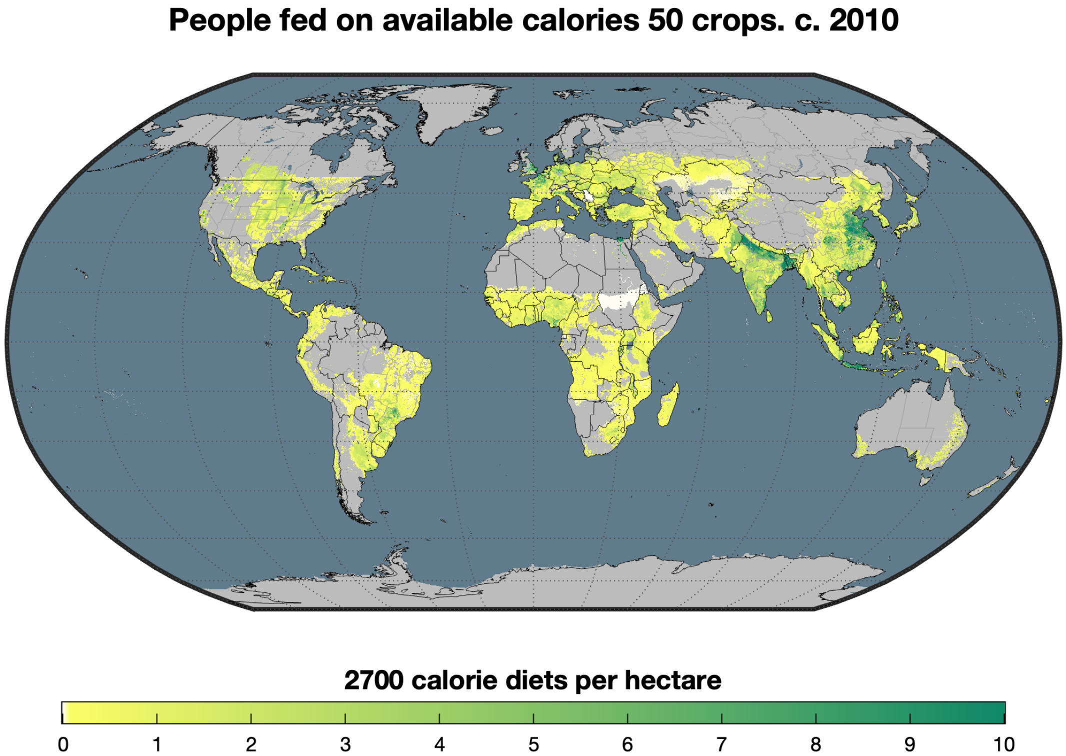
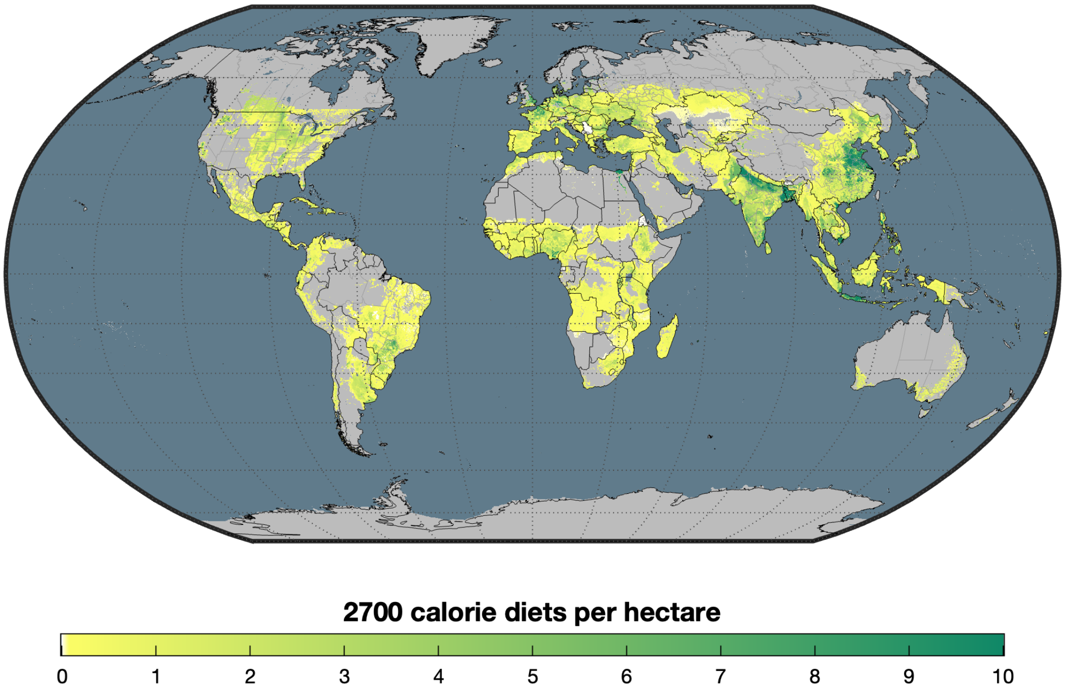


Figure S2. People fed on available calories in 2010, 2015, and 2020.



People fed on available calories 50 crops. c. 2015



People fed on available calories 50 crops. c. 2020

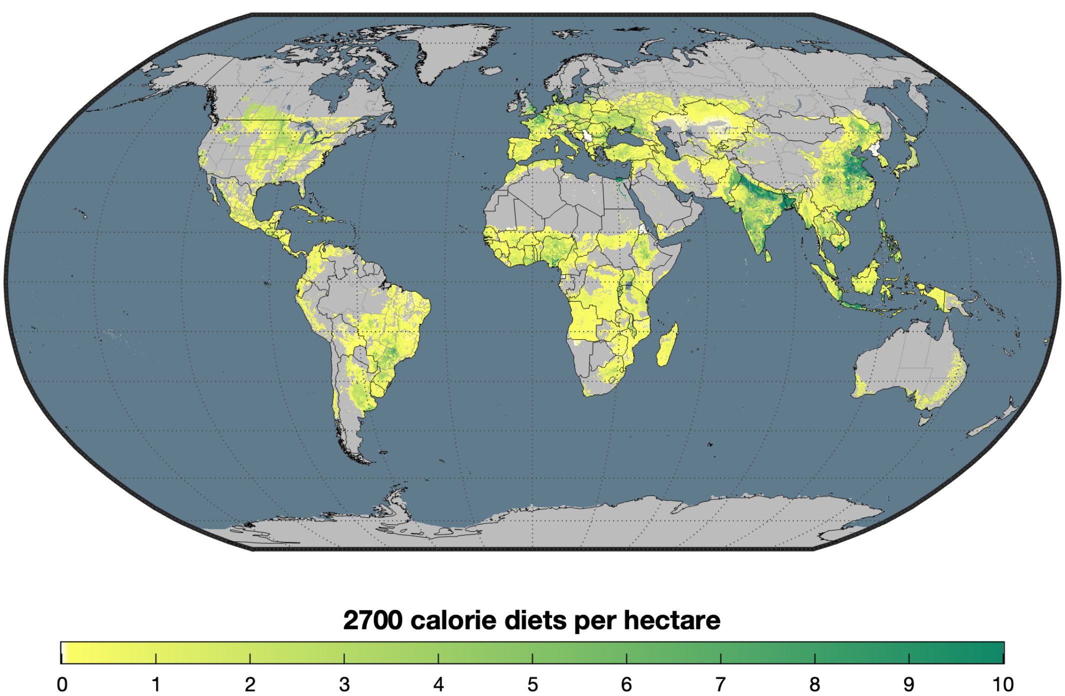
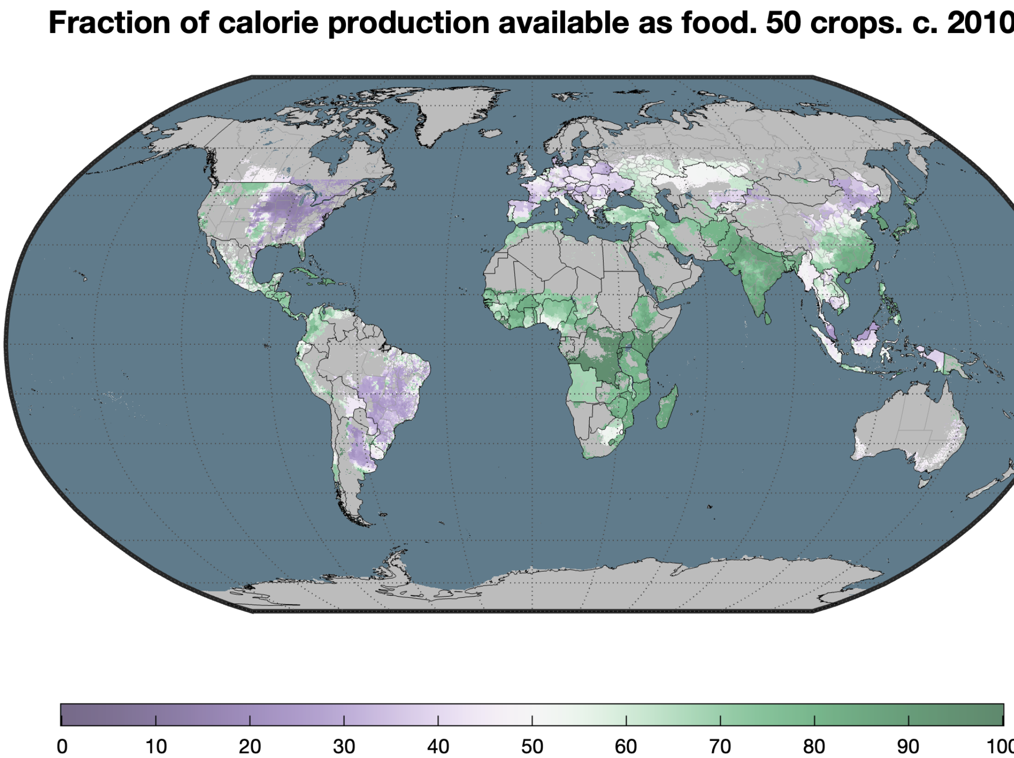
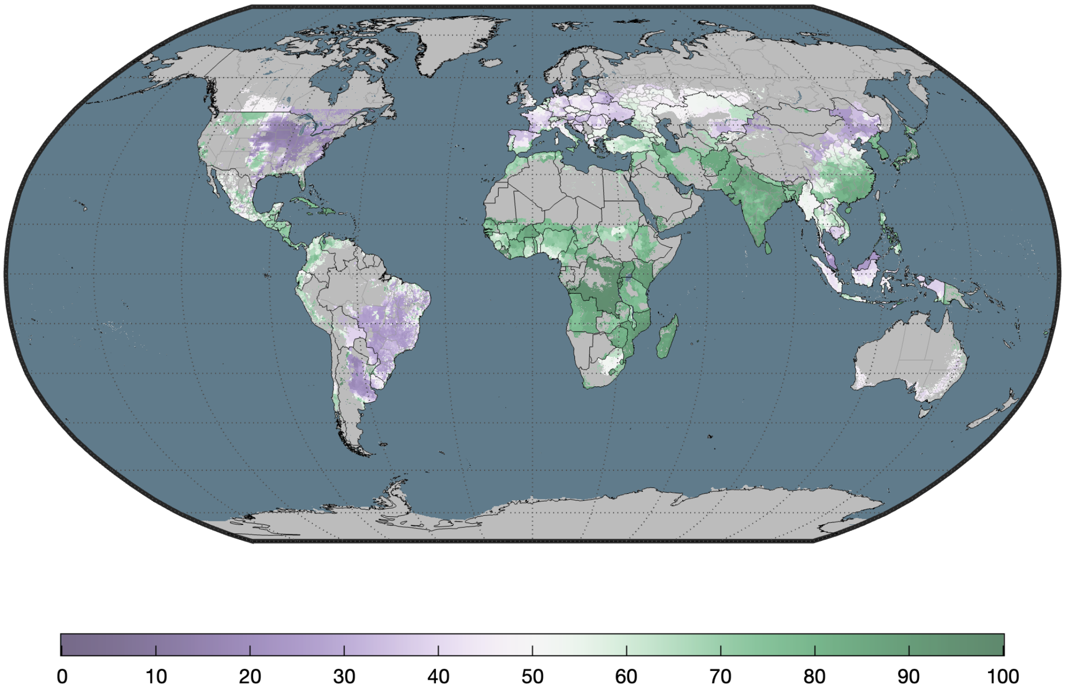


Figure S3. The fraction of total calorie production available for human consumption in 2010, 2015, and 2020.



Fraction of calorie production available as food. 50 crops. c. 2015



Fraction of calorie production available as food. 50 crops. c. 2020

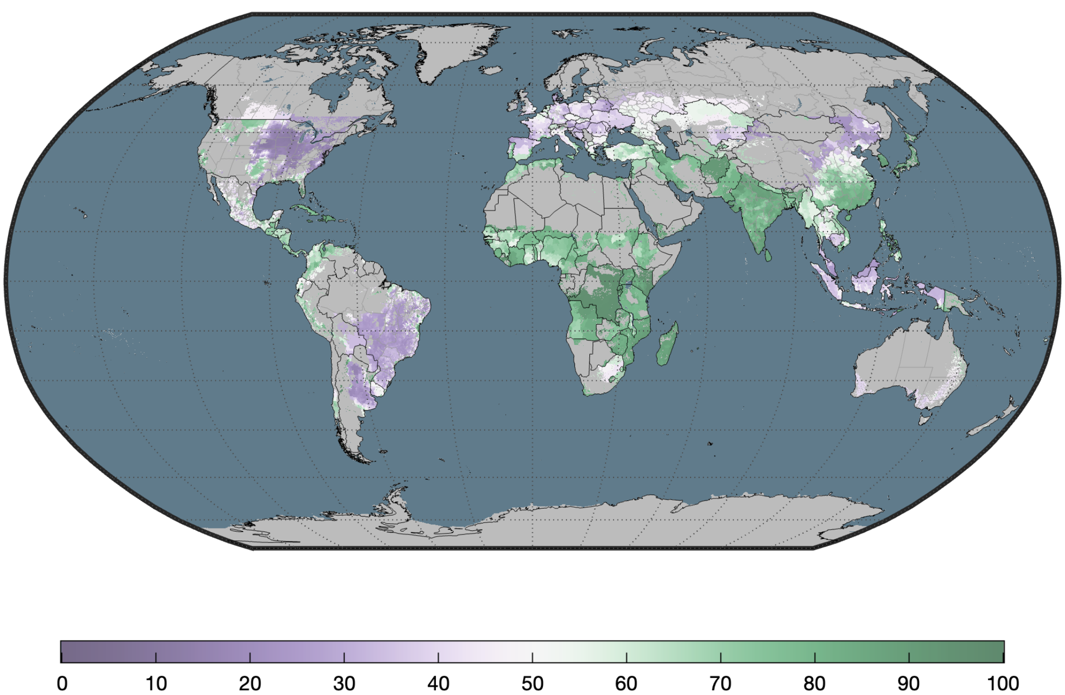
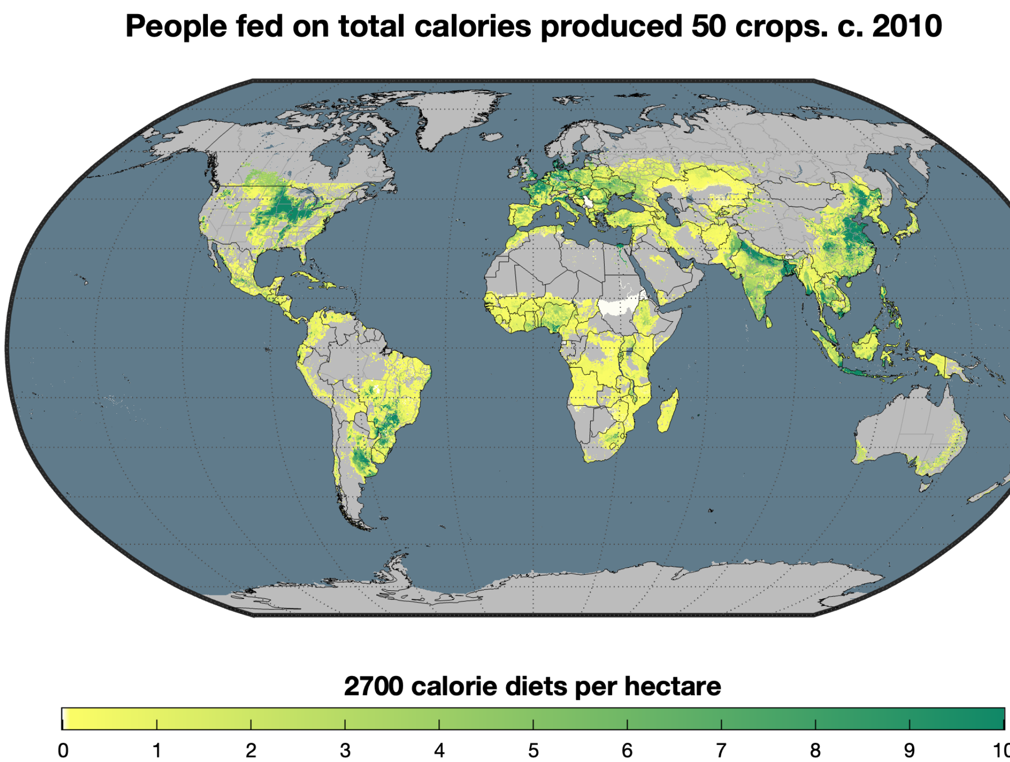
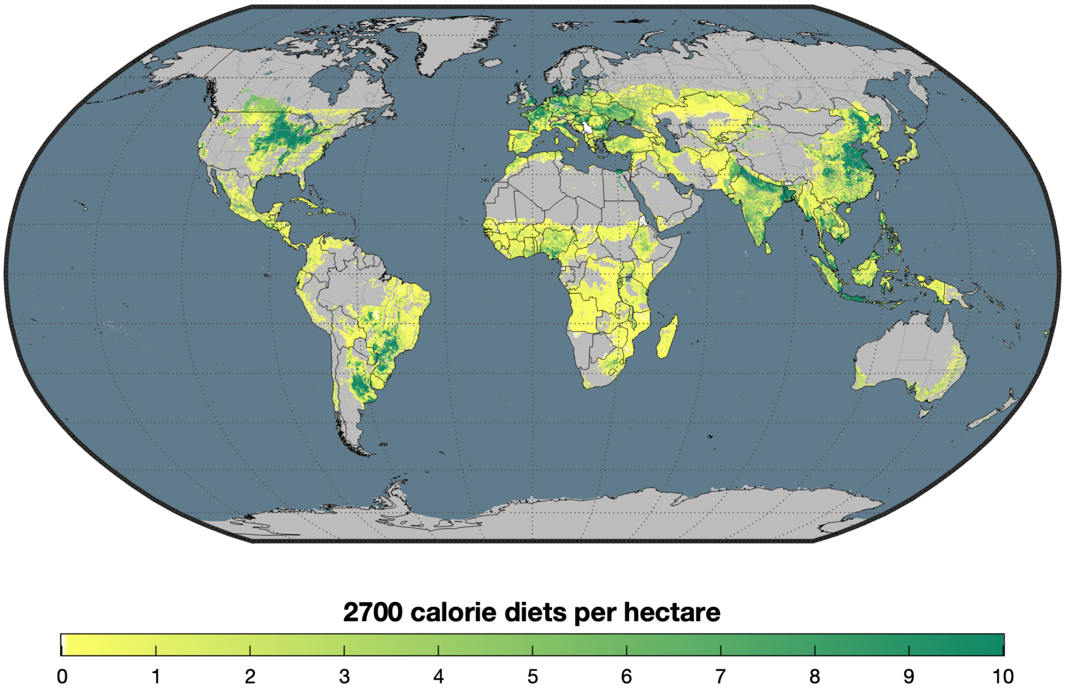


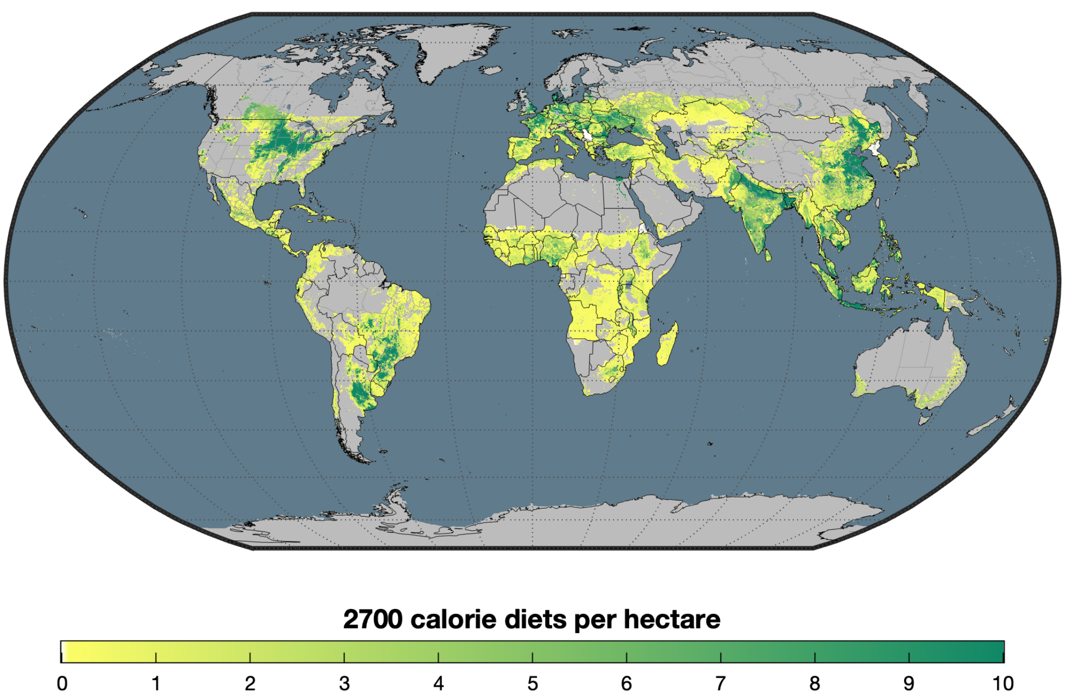
Figure S4. The number of people potentially fed per hectare of available calories in 2010, 2015, and 2020. Available calories are the sum of direct and indirect (livestock commodities via feed) calories. The number of people fed per hectare assumes 2700 kcal/day for a year.



People fed on total calories produced 50 crops. c. 2015



People fed on total calories produced 50 crops. c. 2020



Constructing spatialized maps of crop area and yield
To facilitate the visualization of spatial patterns in crop calorie allocation, we constructed datasets of crop yield and area as an update to the "Earthstat" datasets of Monfreda et al. [25], which included 170 crops, of which 50 were used for the maps presented here. We utilized the CROPGRIDS product [26] for area estimates and employed a perturbation method to scale yields at the national level, using reported FAO yields.

There are several steps involved in producing these updated maps, described below:

1. **Construction of a geodatabase of the Monfreda et al. (2008) original data**. We obtained the original database used in the creation of Monfreda et al. and created a geodatabase for each crop with the following properties: Within political units, the harvested area and yield of each crop correspond to the published Monfreda datasets. The political units align with GADM4.1 (www.gadm.org). There were instances where the political units used for the Monfreda data did not align with the GADM4.1 units. In this case, we introduced GADM4.1 administrative units at a finer level (e.g., counties instead of states). We aligned the yield and area from the Monfreda rasters to the finer-level GADM4.1 units. We made some minor additions to the GADM4.1 dataset (e.g., adding fields to address inconsistencies in naming conventions) as documented in the code. This step is encoded in the matlab files "MakeCDS_Raw.m and makeCDS.m"

2. **Correct geographic inconsistencies and align with FAO.** We correct some geographic discrepancies (e.g., splitting the unit "SMN" into Serbia, Kosovo, and Montenegro). Then, for every country, we read in the geodatabase (referred to as "CDS or Crop Data Structure in the accompanying codes), calculate current total area and total yield, then compare to FAO total area and total yield centered around year 2000, with a moving window of plus/minus N years, then proportionally allocate changes in total area / total yield so that resulting CDS match up with FAO. We do this for a variety of values of N, encoding N in the

output filename. We used the value N=2 for the results presented in the manuscript, and the value N=0 for testing.

3. **Create extrapolated geodatabase versions.** We used a perturbation method to extrapolate the year 2000 databases to 2010, 2015, and 2020. We calculate this for each crop-country combination by multiplying the area of every administrative unit in the geodatabase by the ratio of harvested area from 2000 to 20XX, as determined from FAO area data. We stress that the resulting geodatabases are suitable for visualization but cannot be considered suitable for modeling and building until they have been validated for such purposes, which we do not attempt here.

4. **Create hybridized geodatabase versions leveraging the CROPGRIDS product for 2020.** We create a version of the geodatabase using the CROPGRIDS area for 2020, along with a modified version of the extrapolated yields from Monfreda et al. for 2020. The modification to the extrapolated Monfreda et al. yields involves a scaling factor for each country-crop combination, ensuring that the resulting crop production aligns with FAO data. In other words, sum(Extrapolated Monfreda Area * Extrapolated Monfreda Yield) = FAO Production, and sum(CROPGRIDS Area * Extrapolated Monfreda Yield =/= FAO Production), so we create a CropGridHybridCorrectedYield = Extrapolated Monfreda Yield * sum(Extrapolated Monfreda Area * Extrapolated Monfreda Yield)/sum(CROPGRIDS Area * Extrapolated Monfreda Yield).

5. **Create hybridized geodatabase versions leveraging the CROPGRIDS product for 2010 and 2015.** We then carry out analogous procedures for 2010 and 2015, using an area product that we construct as a linear mix between the 2000 area from Monfreda et al. and the 2020 area from CROPGRIDS.

6. **Spatialize resulting layers:** We spatialized the geodatabases in analogy to the method used to construct the Monfreda et al. layers. Area rasters are constructed by disaggregating the database-reported harvested area onto the points within each administrative unit, assuming that the relative crop mix within each pixel is constant throughout the administrative unit. Whereas the Monfreda et al. layers were based on the Ramankutty et al. satellite-based physical cropland area product, we used the Mehrabi et al. update to that data here.

Assessing the validity of resulting layers for visualization purposes

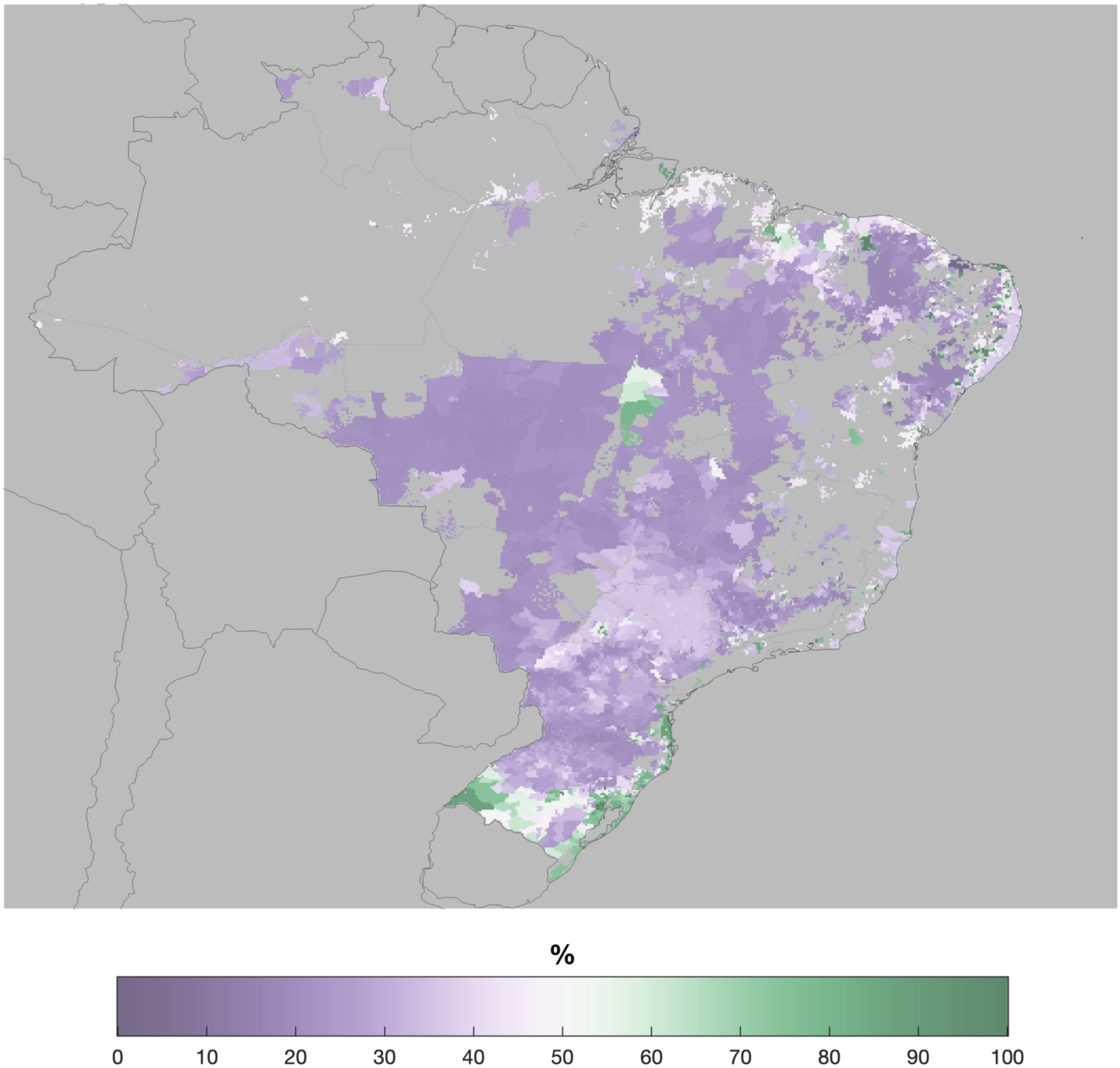
To validate the layers created with the perturbation method, we compare to maps constructed from IBGE crop statistics for Brazil and NASS crop statistics for the USA. We choose these countries because the crop statistics are available at an extremely high resolution (Admin 2; county in the US, municipio in Brazil.). We downloaded the data from the respective websites http://www.nass.usda.gov (downloaded Jan 13 2024) and https://www.ibge.gov.br (Downloaded Dec 15 17 2023). The NASS data required access through an API; we provide the codes we used for accessing the API and constructing a geodatabase. The IGBE data is available as Excel spreadsheets. We provide the code we used to parse the spreadsheets and construct a geodatabase. We did not undertake any gap filling of this data.

The crops for which we have data from NASS include `{'maize', 'wheat', 'soybean', 'rice', 'barley', 'oats', 'cotton', 'groundnut', 'sorghum', 'rapeseed', 'potato', 'rye', 'sugarcane','sweetpotato'};`

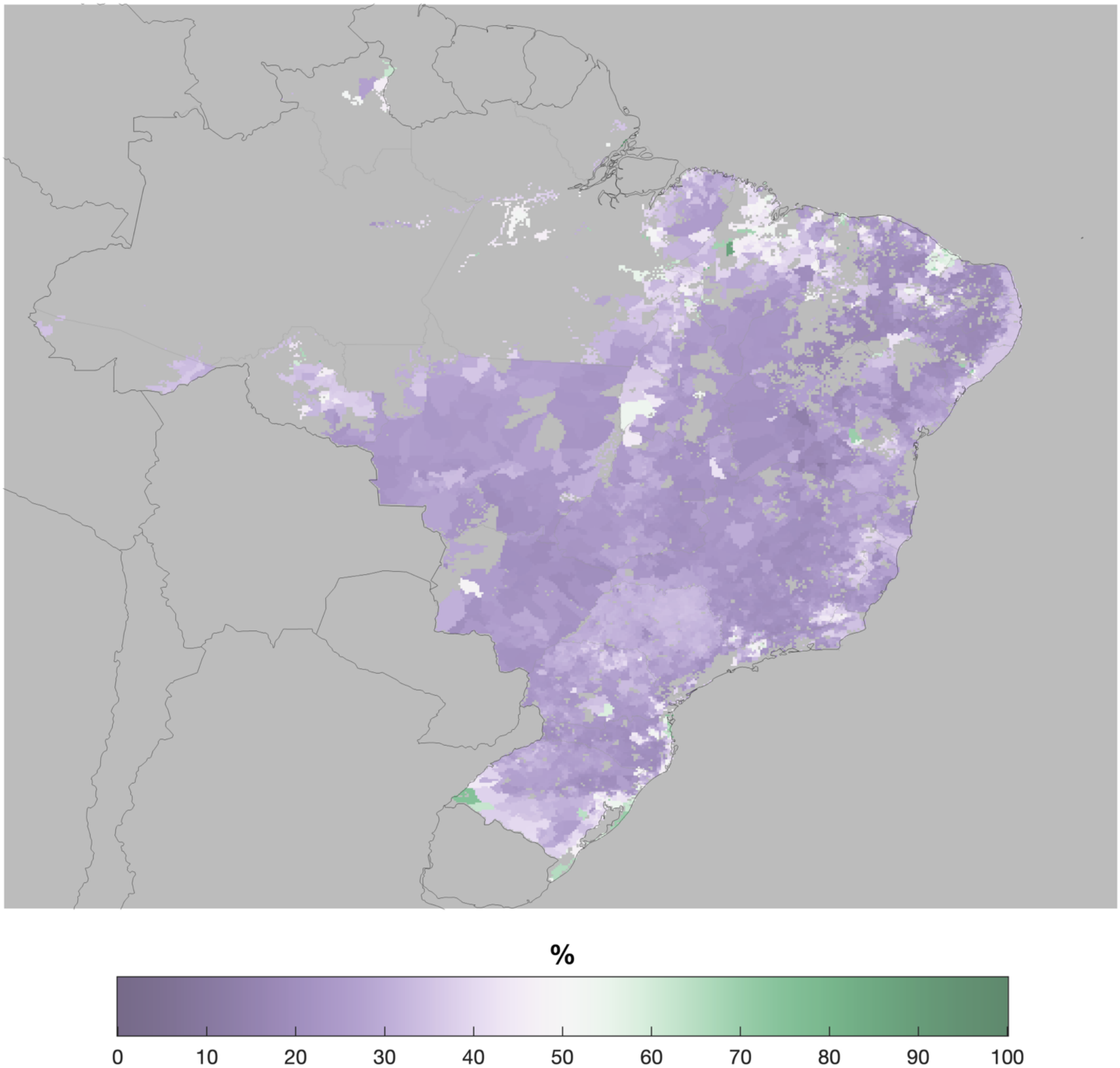
The IBGE crops are `{'cotton', 'rice', 'oats', 'sweetpotato', 'potato', 'sugarcane', 'rye','barley', 'pea', 'cassava', 'watermelon', 'maize', 'soybean', 'sorghum', 'tomato', 'wheat', 'triticale'};`

Comparison of total calorie production for crops which are updated in Brazil. Comparison of map of fraction of calories available as food spatialized with the monfreda/cropgrids hybrid approach described in the manuscript ('Present Method') and year 2020 statistics from Brazil's IBGE crop statistics

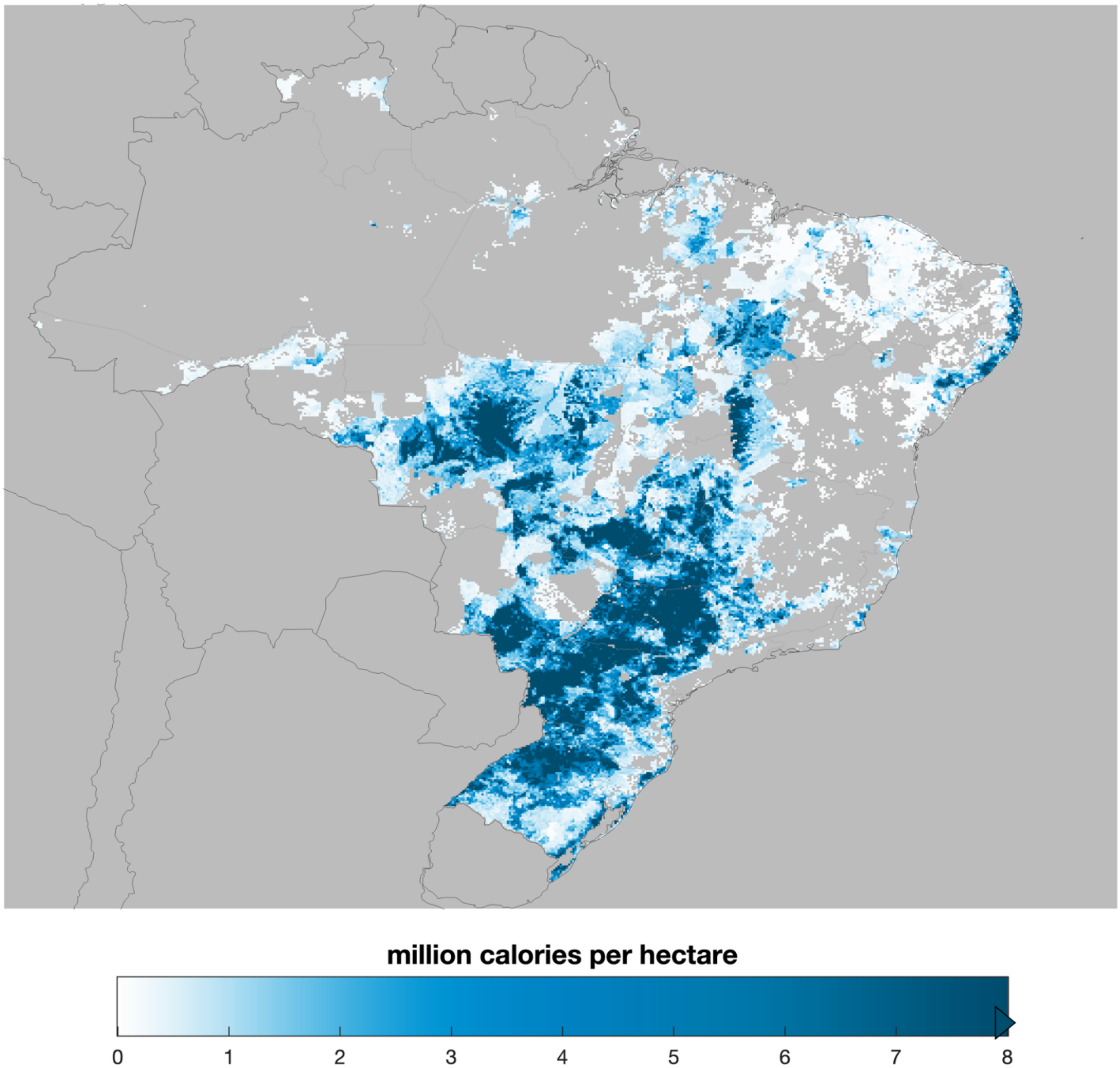
Percentage of production available as food.
Validation (IBGE), 16 crops 2020



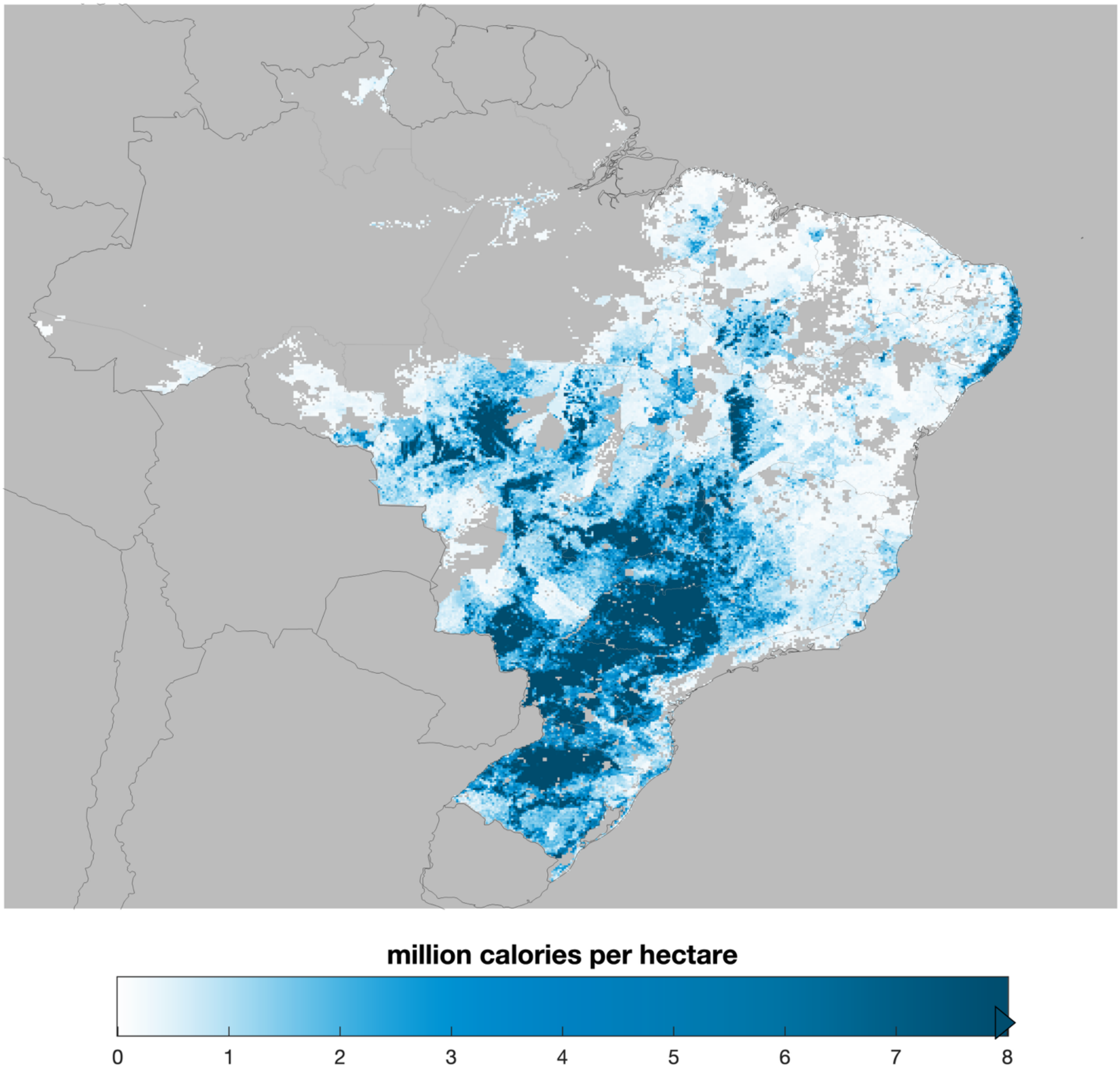
Percentage of production available as food.
Comparison (Present method), 16 crops 2020



Total calorie production
Validation (IBGE), 16 crops 2020

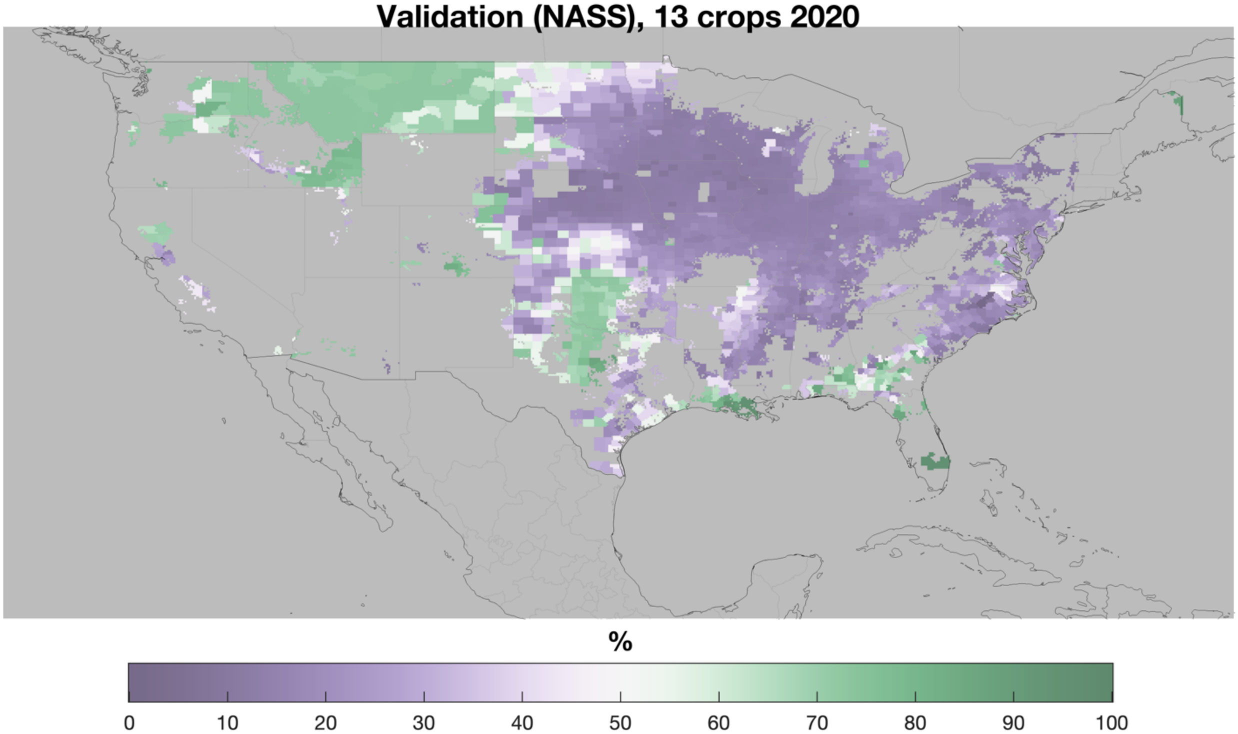


Total calorie production
Comparison (Present method), 16 crops 2020

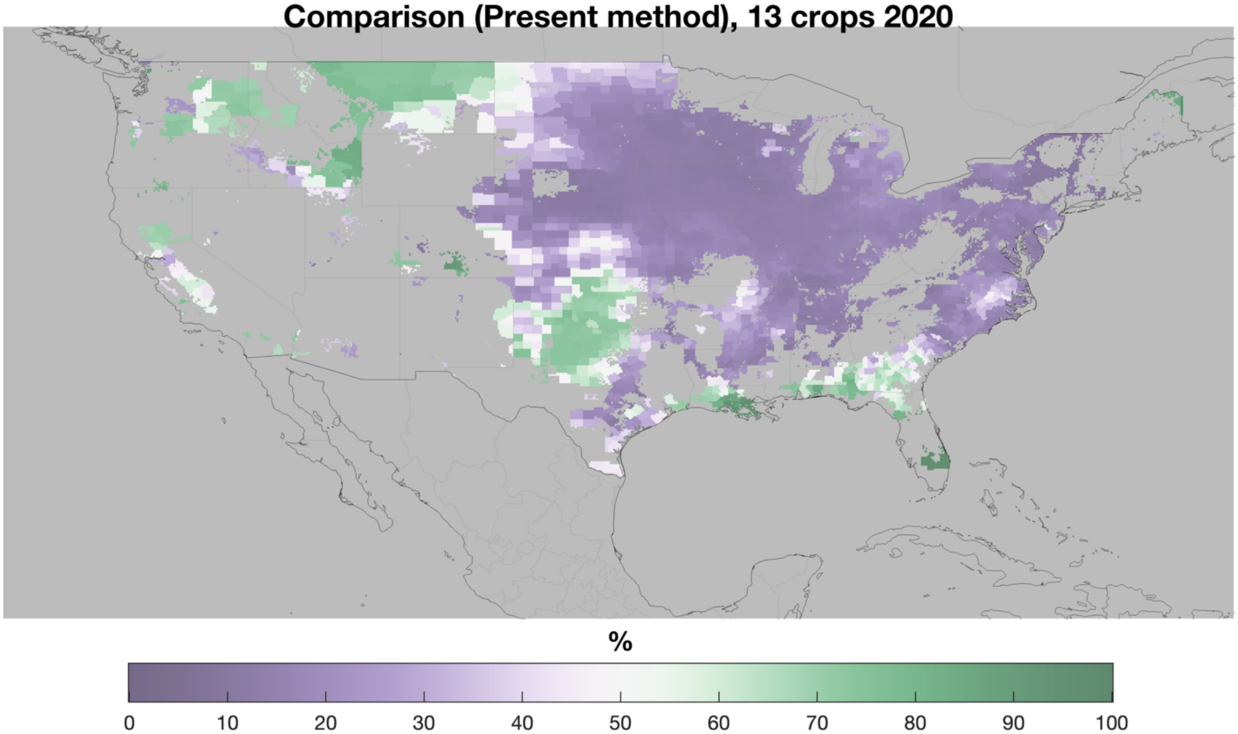


Comparison of total calorie production for crops which are updated in the US
Comparison of map of fraction of calories available as food spatialized with the monfreda/cropgrids hybrid approach described in the manuscript ('Present Method') and year 2020 statistics from USDA's NASS (National Agricultural Statistics Service)

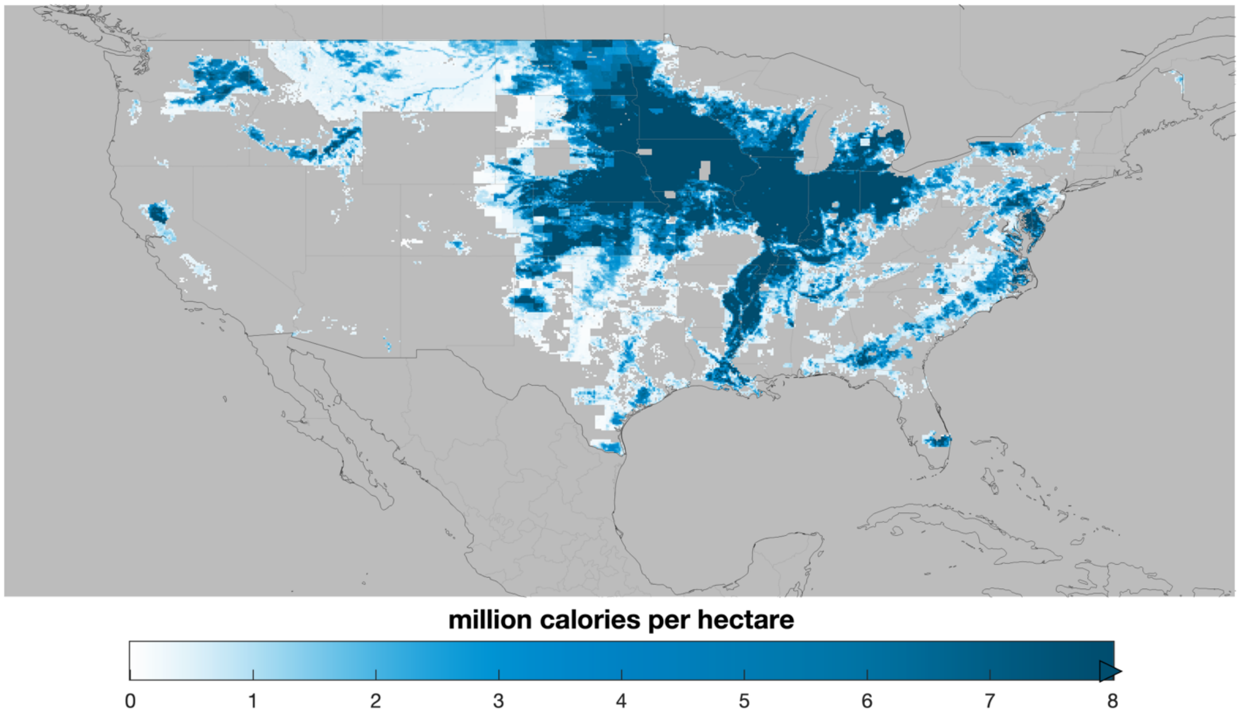
Percentage of production available as food.
Validation (NASS), 13 crops 2020



Percentage of production available as food.
Comparison (Present method), 13 crops 2020



Total calorie production
Validation (NASS), 13 crops 2020



Total calorie production
Comparison (Present method), 13 crops 2020

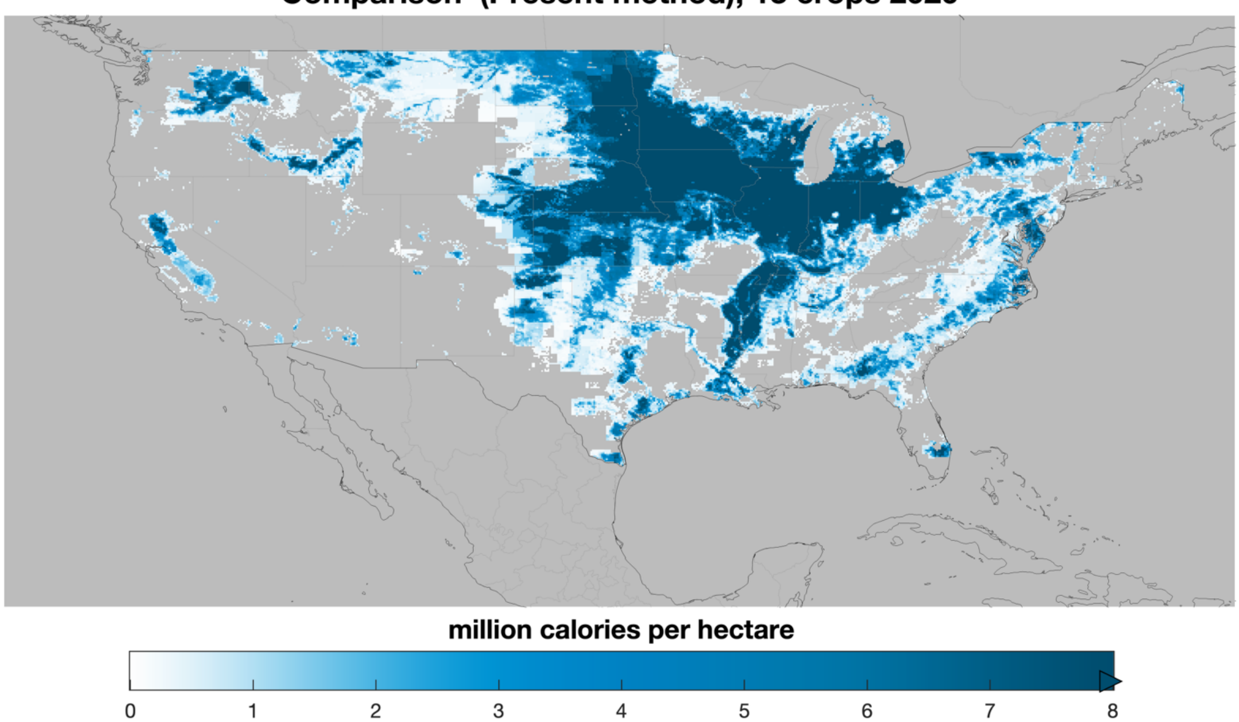


Table S1. Primary crops, their associated commodities, and calorie densities. All 50 crops were broken down to their associated commodities. FAO's Supply Utilization Accounts (SUA) groups these commodities into food, feed, other (non-food). 'Crop Name' is the name used in this study when we when we refer to specific crops. The names are consistent with Monfreda et al. 2008. Some of the crop names are inconsistent across years in the FAOSTAT database so 2016 and 2024 names are shown here as examples. FAOSTAT data were cleaned so that they were consistent for each year of analysis. Calories were derived from the SUA database. In cases where we could not estimate the calorie density using SUA, such as 'cake of groundnut', we used values from feedipedia.org and labeled as "f" with further documentation the code. *This table is also available as SupplementalTable1_commoditiesandcaloriesfromSUA.csv*

Crop name	FAO Crop Name circa year 2016	FAO Crop Name circa year 2024	Commodity Name	Is Primary	kcals per gram	source for kcals per gram
apple	Apples	Apples	Apples	1	0.5278	SUA
			Apple juice	0	0.46	SUA
			Apple juice, concentrated	0	1.65	SUA
banana	Bananas	Bananas	Bananas	1	0.6592	SUA
barley	Barley	Barley	Barley	1	2.8294	SUA
			Barley flour and grits	0	3.36	SUA
			Barley, pearled	0	3.3	SUA
			Beer of barley, malted	0	0.44	SUA
			Bran of barley	0	4.617376	SUA
			Pot barley	0	3.29	SUA
bean	Beans, dry	Beans, dry	Beans, dry	1	3.16	SUA
broadbean	Broad beans, horse beans, dry	Broad beans and horse beans, dry	Broad beans and horse beans, dry	1	3.15	SUA
			Broad beans and horse beans, green	0	0.57	SUA
cabbage	Cabbages and other brassicas	Cabbages	Cabbages	1	0.215	SUA
cassava	Cassava	Cassava, fresh	Cassava, fresh	1	1.222388	SUA
			Cassava leaves	0	0.6006	SUA
			Cassava, dry	0	3.46	SUA
			Flour of cassava	0	3.44	SUA
			Starch of cassava	0	3.36	SUA
			Tapioca of cassava	0	3.52	SUA
cerealnes	Cereals nes	Cereals n.e.c.	Cereals n.e.c.	1	3.57	SUA
			Bran of cereals n.e.c.	0	3.921965	SUA
			Flour of cereals n.e.c.	0	3.59	SUA
chickpea	Chick peas	Chick peas, dry	Chick peas, dry	1	3.43	SUA
cocoa	Cocoa, beans	Cocoa beans	Cocoa beans	1	4.872	SUA

			Cocoa butter, fat and oil	0	8.99	SUA
			Cocoa paste not defatted	0	6.09	SUA
			Cocoa powder and cake	0	3.74	SUA
coconut	Coconuts	Coconuts, in shell	Coconuts, in shell	1	0.848	SUA
			Coconuts, desiccated	0	6.53	SUA
			Coconut oil	0	8.98	SUA
cowpea	Cow peas, dry	Cow peas, dry	Cow peas, dry	1	3.24	SUA
date	Dates	Dates	Dates	1	2.0124	SUA
fruitnes	Fruit, fresh nes	Other fruits, n.e.c.	Other fruits, n.e.c.	1	0.4292	SUA
			Other fruit n.e.c., dried	0	2.3254	SUA
garlic	Garlic	Green garlic	Green garlic	1	1.1256	SUA
grape	Grapes	Grapes	Grapes	1	0.6532	SUA
			Must of grape	0	0.59	SUA
			Grape juice	0	0.59	SUA
			Vermouth and other wine of fresh grapes flavoured with plats or aromatic substances	0	1.35	SUA
groundnut	Groundnuts, excluding shelled	Groundnuts, excluding shelled	Groundnuts, shelled	1	5.87	SUA
			Groundnut oil	0	8.99	SUA
			Cake of groundnuts	0	3.75325	f
			Groundnuts, excluding shelled	0	4.1677	SUA
			Prepared groundnuts	0	6.16	SUA
lentil	Lentils	Lentils, dry	Lentils, dry	1	3.28	SUA
linseed	Linseed	Linseed	Linseed	1	4.93	SUA
			Cake of linseed	0	4.482361	f
			Oil of linseed	0	9	SUA
maize	Maize	Maize (corn)	Maize (corn)	1	3.48	SUA
			Beer of maize, malted	0	0.33	SUA
			Bran of maize	0	3.921965	SUA
			Cake of maize	0	3.921965	f
			Flour of maize	0	3.53	SUA
			Germ of maize	0	3.79	SUA
			Green corn (maize)	0	0.4558	SUA
			Maize gluten	0	4.968929	f
			Oil of maize	0	9	SUA
			Starch of maize	0	3.57	SUA
mango	Mangoes, mangosteens, guavas	Mangoes, guavas and mangosteens	Mangoes, guavas and mangosteens	1	0.435	SUA
			Juice of mango	0	0.53	SUA

			Mango pulp	0	0.66	SUA
millet	Millet	Millet	Millet	1	3.49	SUA
			Beer of millet, malted	0	0.43	SUA
			Bran of millet	0	4.617376	SUA
			Flour of millet	0	3.52	SUA
oats	Oats	Oats	Oats	1	3.162	SUA
			Bran of oats	0	3.971128	f
			Oats, rolled	0	3.72	SUA
oilpalm	Oil palm fruit	Oil palm fruit	Oil palm fruit	1	1.58	f
			Cake of palm kernel	0	4.381262	f
			Oil of palm kernel	0	9	SUA
			Palm kernels	0	6.231166	f
			Palm oil	0	8.98	SUA
olive	Olives	Olives	Olives	1	1.35	SUA
			Oil of olive residues	0	8.99	SUA
			Olive oil	0	9	SUA
			Olives preserved	0	1.3515	SUA
onion	Onions, dry	Onions and shallots, dry (excluding dehydrated)	Onions and shallots, green	0	0.2838	SUA
			Onions and shallots, dry (excluding dehydrated)	1	0.391	SUA
orange	Oranges	Oranges	Oranges	1	0.3384	SUA
			Orange juice	0	0.38	SUA
			Orange juice, concentrated	0	1.59	SUA
pea	Peas, dry	Peas, dry	Peas, dry	1	3.23	SUA
pigeonpea	Pigeon peas	Pigeon peas, dry	Pigeon peas, dry	1	3.06	SUA
plantain	Plantains and others	Plantains and cooking bananas	Plantains and cooking bananas	1	0.7434	SUA
potato	Potatoes	Potatoes	Potatoes	1	0.647061	SUA
			Flour, meal, powder, flakes, granules and pellets of potatoes	0	3.51	SUA
			Potatoes, frozen	0	1.05	SUA
			Starch of potatoes	0	3.28	SUA
			Sweet potatoes	0	0.9794	SUA
			Tapioca of potatoes	0	3.54	SUA
			Vegetables, pulses and potatoes, preserved by vinegar or acetic acid	0	0.5978	SUA
pulsenes	Pulses nes	Other pulses n.e.c.	Other pulses n.e.c.	1	3.36	SUA
			Flour of pulses	0	3.59	SUA
			Bran of pulses	0	3.952055	f

rapeseed	Rapeseed	Rape or colza seed	Rape or colza seed	1	3.4162	SUA
			Rapeseed or canola oil, crude	0	8.99	SUA
			Cake of rapeseed	0	4.105402	f
rice	Rice, paddy	Rice	Rice	1	2.679601	SUA
			Bran of rice	0	3.93	SUA
			Cake of rice bran	0	4.409656	f
			Communion wafers, empty cachets of a kind suitable for pharmaceutical use, sealing wafers, rice paper and similar products.	0	3.59	SUA
			Flour of rice	0	3.52	SUA
			Husked rice	0	3.51	SUA
			Oil of rice bran	0	9	SUA
			Rice, broken	0	3.48	SUA
			Rice, gluten	0	4.968929	f
			Rice, milled	0	3.499359	SUA
			Rice, milled (husked)	0	3.49	SUA
			Rice-fermented beverages	0	1.1	SUA
			Starch of rice	0	3.55	SUA
rye	Rye	Rye	Rye	1	3.309999	SUA
			Flour of rye	0	3.29	SUA
			Bran of rye	0	2.81	SUA
sesame	Sesame seed	Sesame seed	Sesame seed	1	5.85	SUA
			Oil of sesame seed	0	9	SUA
			Cake of sesame seed	0	4.105402	f
sorghum	Sorghum	Sorghum	Sorghum	1	3.44	SUA
			Beer of sorghum, malted	0	0.27	SUA
			Bran of sorghum	0	2.809997	SUA
			Flour of sorghum	0	3.48	SUA
soybean	Soybeans	Soya beans	Soya beans	1	4.06	SUA
			Soya bean oil	0	9	SUA
			Soya curd	0	0.91	SUA
			Soya paste	0	1.96	SUA
			Soya sauce	0	0.67	SUA
			Cake of soya beans	0	4.143403	f
sugarbeet	Sugar beet	Sugar beet	Sugar beet	1	0.5586	SUA
			Refined sugar	0	3.99	SUA
			Raw cane or beet sugar (centrifugal only)	0	3.7506	SUA
sugarcane	Sugar cane	Sugar cane	Sugar cane	1	0.33	SUA

			Cane sugar, non-centrifugal	0	3.82	SUA
			Raw cane or beet sugar (centrifugal only)	0	3.7506	SUA
			Refined sugar	0	3.99	SUA
			Sugar and syrups n.e.c.	0	3.11	SUA
			Sugar confectionery	0	4.11	SUA
sunflower	Sunflower seed	Sunflower seed	Sunflower seed	1	4.62	SUA
			Cake of sunflower seed	0	4.126673	f
			Sunflower-seed oil, crude	0	9	SUA
sweetpotato	Sweet potatoes	Sweet potatoes	Sweet potatoes	1	0.9794	SUA
tangetc	Tangerines, mandarins, clementines, satsumas	Tangerines, mandarins, clementines	Tangerines, mandarins, clementines	1	0.3626	SUA
			Juice of tangerine	0	0.42	SUA
taro	Taro (cocoyam)	Taro	Taro	1	0.8484	SUA
tomato	Tomatoes	Tomatoes	Tomatoes	1	0.2037	SUA
			Tomato juice	0	0.19	SUA
			Paste of tomatoes	0	0.82	SUA
			Tomatoes, peeled (o/t vinegar)	0	0.27	SUA
triticale	Triticale	Triticale	Triticale	1	3.330002	SUA
			Flour of triticale	0	3.32	SUA
			Bran of triticale	0	3.921965	SUA
vegetablenes	Vegetables, fresh nes	Other vegetables, fresh n.e.c.	Other vegetables, fresh n.e.c.	1	0.2607	SUA
watermelon	Watermelons	Watermelons	Watermelons	1	0.2046	SUA
wheat	Wheat	Wheat	Wheat	1	3.336	SUA
			Bran of wheat	0	2.81	SUA
			Germ of wheat	0	3.79	SUA
			Starch of wheat	0	3.49	SUA
			Wheat and meslin flour	0	3.45213	SUA
			Wheat gluten	0	2.09	SUA
			Wheat-fermented beverages	0	0.391156	SUA
yam	Yams	Yams	Yams	1	0.8904	SUA