**TEXT S1. Data Sources, Assumptions, Supporting Calculations, and Structure of the U.S. Foodprint Model**

\*Christian J. Peters1, Jamie Picardy2, Amelia Darrouzet-Nardi3, Jennifer L. Wilkins4, Timothy S. Griffin, and Gary W. Fick5

1Friedman School of Nutrition Science and Policy, Tufts University

2Geography and Regional Planning, Mount Ida College

3Global Health Studies Program, Allegheny College

4Department of Public Health, Food Studies and Nutrition, Syracuse University

5Section of Soil and Crop Sciences (Emeritus), Cornell University

\*Corresponding author: Friedman School of Nutrition Science and Policy, Tufts University, 150 Harrison Ave., Boston, MA, 02111; [Christian.Peters@tufts.edu](mailto:Christian.Peters@tufts.edu)

**DATA SOURCES AND ASSUMPTIONS**

*Characterization of food in the U.S. Foodprint model*

The model includes 186 primary food commodities (items at the first stage of entry into the food supply, such as fresh produce or foods at first stage of processing) from the Loss-Adjusted Food Availability data set (USDA-ERS, 2010) plus two additional foods, soy milk and tofu, needed for examining vegan diets.

Composition

Composition (variable C from Eq. 1) is the proportion of the servings within a food group (or sub-group) that come from an individual food commodity. It was calculated based on the 3-year average of food consumption for individual food commodities as estimated by the loss-adjusted food supply from 2006-2008. Several commodities present in the Loss-Adjusted Food Availability Data were excluded from the model for the following reasons: (a) they are not produced commercially within the continental U.S. (bananas, coconuts, mangoes, pineapples, and other nuts), (b) they are produced on land other than cropland or grazing land (mushrooms and maple syrup), (c) yield data were unavailable (pecans), or (d) they do not compete with crops for land (honey). Note that four commodities in the added fats group (margarine, salad and cooking oils, shortening, and other edible fats and oils) were decomposed into individual plant oils to permit subsequent calculations (see SI section “Supporting Calculations, Disaggregation of fats”).

Losses and waste

Loss adjustment factors (variable L from Eq. 1) convert food intake to the equivalent consumption of primary food commodities, the stage of the food system at which commodities are tabulated in the food supply. Losses and waste in the food system are characterized according to the precedent set by USDA (Kantor, 1998), which estimates loss at three stages: the food service and consumer level, the retail level, and the primary to retail level of the food supply. In addition, USDA accounts for the removal of inedible parts from fresh produce and losses incurred by cooking. The loss adjustment factors were calculated from estimates of food losses and waste used by USDA in the Loss-Adjusted Food Supply Database (USDA-ERS, 2010). The loss adjustment factor is the product of the reciprocals of the percentage of food remaining at each stage in the food system (see SI Dataset).

Processing conversions

As described in the main text, conversion factors to determine the weight of agricultural commodity needed to produce a given weight of food commodity (variable P from Eq. 2) were obtained from Agricultural Handbook 697 (USDA-ERS, 1992) and the Loss-Adjusted Food Supply (USDA- ERS, 2010). However, alternative sources were used in seven cases (canola oil, olive oil, refined cane and beet sugar, rice, rye flour, soy milk, and tofu) where data were not available from these two sources (Table S2).

*Crop and livestock productivity*

Crop yields

For most crops, data were compiled from the QuickStats Database (USDA-NASS, 2014). Various summary reports were used for citrus (USDA-NASS, 2004, 2008a, 2010b), non-citrus fruit and nuts (USDA-NASS, 2008b, 2011),sweet potatoes (USDA-NASS, 2010a), and raisins (USDA-NASS California Field Office, 2011),cases where the QuickStats database lacked the necessary information. Data for certain minor crops were not available for all years in the time series. In such cases, average yields were calculated as the mean of the available years.

Livestock feed requirements

As mentioned in the main text, the U.S. Foodprint model uses data from earlier work (Peters et al., 2014) to characterize the feed needs of livestock. The livestock model represents each livestock category as a steady-state system of stocks and flows, including both production animals (e.g. laying hens or market hogs) and support animals (e.g. dry cows or replacement heifers). For each life stage, the nutritional requirements were estimated using the most recent summaries from the National Research Council, and the ration composition of each life stage was balanced from a simplified set of potential ration ingredients. Estimates of the quantities of feed ingredient per unit of livestock product were taken from the feed requirements model. 34

Feed requirements were converted into crop requirements for certain feeds. Soybean meal was converted to soybean needs based on the yield of meal from whole soybeans (USDA-ERS, 1992). Grass hay and alfalfa silage were converted to equivalent quantities of cut hay and forage to account for storage losses, which are significant for forage crops. Losses were assumed to be 5% of harvested material for hay and 10% of harvested material for silage based on Figure 5-37 of the *National Range and Pasture Handbook* (USDA-NRCS, 2003).

**SUPPORTING CALCULATIONS**

**Disaggregation of fats**

The Loss-adjusted Food Supply Data (USDA-ERS, 2010) distinguish thirteen different commodities within the added fats category. Seven of these commodities are dairy products: butter, cream cheese, eggnog, half and half, heavy cream, light cream, and sour cream. Two of these commodities, lard and tallow, are byproducts of meat production. The remaining four commodities are fats that may be derived from multiple sources, mostly from plant oils: margarine, salad and cooking oils, shortening, and other edible fats and oils. Unlike most other plant-based foods in the model, these commodities do not originate from a single crop. Rather, they represent a general food category which can be filled by oils from multiple crops.

USDA Economic Research Service tracks several of the constituent oils used to make margarine, salad and cooking oils, and shortening. These data are reported in Tables 37, 39, and 41 of the Oil Crops Yearbook (USDA-ERS, 2012). Twelve plant oils are tracked in the Oil Crops Yearbook, but the individual contribution of these oils to different fat categories are only reported for canola oil (edible rapeseed), corn oil, cottonseed oil, olive oil, palm oil, peanut oil, and soybean. Of these, palm oil was excluded from the model because it is a tropical crop not grown in the U.S. Cottonseed oil was removed because it is a byproduct of fiber production. A breakdown of the “Other edible fats and oils” commodity category is not provided in the Oil Crops Yearbook. Thus, all fat in this category was initially assigned to soybean oil, the predominate oil used in the U.S.

Preferences for canola, olive, peanut, and soybean oil were calculated based on the proportion each contributes to the U.S. food supply. Corn oil, lard, and tallow were kept out of initial calculations and added back during the multiuse crop adjustment step. Corn oil was excluded from preliminary calculations because it is a co-product of corn refining for starch and corn sweetener, but would not likely be grown solely for oil. Likewise, lard and tallow were considered co-products of beef and pork production, and were permitted to substitute for a portion of the added fat servings.

**Processing conversions for dairy products**

The dairy industry creates a range of products from a single raw material, fluid milk. This raw material is generally separated into milk fat and non-fat portions and then blended in the proportions needed to make a given product. For example, 2% fat milk is lower in fat than raw fluid milk from cows (about 3.7% milkfat), whereas butter is composed almost entirely from milk fat. Thus, the amount of fluid milk needed to create all dairy products in a diet depends on the balance of the dairy fat portion to the non-fat solids portion of milk needed to manufacture dairy products.

To this end, the model includes a calculation of the aggregate quantities of milk fat and non-fat solids needed to manufacture all dairy foods in the diet (see “Dairy processing conversions” tab in the SI Dataset). The calculation is flexible, recalculating the balance of milk fat to non-fat solids if the intake of dairy products or dairy fats changes. Thirty-six dairy products are included in the model to represent the dairy and added fats food groups. Aggregate needs for milk fat and non-fat solids are determined by taking the sum of the products of the consumption of each dairy commodity by the proportion of milk fat or non-fat solids in each commodity (Eqs. S1a and S1b).

[Eq. S1a] QMF = ∑ (QFj × MFj)

[Eq. S1b] QNFS = ∑ (QFj × NFSj)

As shown above, the quantity (kg) of milk fat (QMF) needed to produce all dairy products in the diet is the sum of the products of the quantity of food commodity (QF) needed to supply each individual food commodity (j) in the diet times the proportion of milk fat (MF) in the product. The quantity of non-fat solids (QNFS) is calculated similarly based on the quantity of food commodity consumed and the proportion of non-fat solids (NFS) in each product. These values are used to calculate the quantity of fluid milk required to produce the foods in the diet (Eqs S2a and S2b).

[Eq. S2a] QFMMF = QMF / MF

[Eq. S2b] QFMNFS = QNFS / NFS

The quantity (kg) of fluid milk required to produce the dairy products in a diet is estimated on both a milk fat basis (Eq. 2a) and a non-fat solids basis (Eq. 2b). In each equation, the quantity of fluid milk (QFM) required to produce all dairy commodities in the diet is the quotient of the quantity of the dairy component required, either milk fat (QMF) or non-fat solids (QNFS) divided by the proportion of that dairy component in fluid milk from U.S. dairy farms. The average milk fat percentage in fluid milk is assumed to be 3.7% and the non-fat solids fraction is assumed to be 8.6% (USDA-ERS, 1992). The method that leads to the larger estimate of fluid milk requirements indicates the dairy fraction that is limiting in the diet scenario and dictates the processing conversions (see P in Eq. 2) used to calculate the quantity of agricultural commodity (QA) required for each dairy food (Eqs. S3a and S3b).

[Eq. S3a] Pj = 1 / (MFj / MF)

[Eq. S3b] Pj = 1 / (NFSj / NFS)

If the quantity of fluid milk required needed to meet the foods in the diet is determined on a milk fat basis, then the processing conversion (P) for each dairy food (j) equals the reciprocal of the ratio of proportion of milk fat in the product (MFj) to the proportion of milk fat in fluid milk on U.S. dairy farms (MF). On the other hand, if the quantity of fluid milk required needed to meet the foods in the diet is determined on a non-fat solids basis, then the processing conversion (P) for each dairy food (j) equals the reciprocal of the ratio of proportion of non-fat solids in the product (NFSj) to the proportion of non-fat solids in fluid milk on U.S. dairy farms (NFS). The calculations from Eq. S3a and Eq. S3b are shown in column H of the “Processing conversions” tab of the SI Dataset.

**Grazing yields**

As described in the main text, the yield of forage on private grazing lands is not tracked by USDA. Thus, grazing yields were estimated through a synthesis of related data. The process is outlined in Table S1 and described below.

The starting point for estimating forage yield on grazing land is an USDA estimate of the feed value livestock obtain from pasture and rangelands. Table 1-77 of *Agricultural Statistics 2010* (USDA-NASS, 2010) reports the amount of feed consumed by livestock and poultry, aggregated into major categories: concentrates, harvested roughage, and pasture. In this context, pasture refers to all forms of grazing land. Table 1-77 reports feed consumption on a corn equivalent basis (feed value of corn). Consumption of pasture was converted from corn equivalents to forage equivalents by converting tons of corn into tons total digestible nutrients and dividing this value by the digestibility of pasture.

The second step in estimating forage yields on grazing land is to estimate the area of land used for grazing. The area of cropland, grassland, and woodland used for grazing is reported in *Major Land Uses* (USDA Economic Research Service, 2011). This data source aggregated both private and public lands. Use of cropland for pasture is tracked separately in our calculations because it is suitable for cropping and is generally of higher productivity than land usable only for grazing. Separate estimates of yield are used in subsequent calculations (see “Grazing land adjustment” section below).

The third step in estimating forage yields is to estimate grazing yields on cropland pasture based on yields of non-alfalfa hay, a proxy variable. Harvested biomass is first converted to an estimate of aboveground biomass by accounting for (a) the amount of biomass left standing after mowing and (b) the loss of cut material in hay curing and harvesting. The grazing yield is then calculated from the estimate of aboveground biomass based on grazing efficiency assumptions suggested in the *National Rangeland and Pasture Handbook, Revision 1* (USDA-NRCS, 2003).

The fourth, and final step, is to estimate grazing yields on land other than cropland pasture. The feed value obtained from other grazing land was estimated as the total feed value minus the amount obtained from cropland pasture (yield times area). The quotient of feed value of other grazing land divided by the area of other grazing land equals the yield. Based on this procedure, the average grazing yield of cropland pasture was estimated at 1995 lbs per acre and the average grazing yield of other land was estimated at 458 lbs per acre.

**Land use adjustments**

As described in the Methods, two types of adjustments were made to the simple sums of land requirements for all individual products.

*Multi-use crop adjustment*

The multi-use crop adjustment (MUCA) determines the extent to which a simple sum of the land requirements for individual foods overestimates aggregate needs for cultivated cropland. It prevents double-counting (or triple-counting) of crops for which multiple co-products are manufactured from the same feedstock. Soybean (*Glycine max*), for example, is used to make vegetable oil and concentrated protein feed for livestock. The MUCA is derived by a series of steps that account for the coproduction of starch, sweeteners, oil, and high-protein livestock feed from corn refining, the co-production of plant oil and high-protein livestock feed from oilseeds, and the co-production of animal fats (lard and tallow) from beef and pork production. Byproduct feeds, such as wheat middlings or pulp from sugar beets, are not included in this adjustment. A step-by-step description of the MUCA is provided below, and calculations are shown in the Supplementary Information dataset.

The MUCA is performed in six steps (see “Multiuse crop adjustment” tab in the SI Dataset).

* First, the quantities of corn oil and corn gluten meal (feed) co-produced in the wet milling of corn for starch and corn sweeteners are tabulated. The quantity of each co-product is estimated based on the yield of product from whole corn and the quantity of whole corn required to manufacture corn starch and corn sweeteners (high fructose corn syrup, glucose, and dextrose) in the diet. The total protein content of the corn gluten meal and feed was also calculated.
* Second, the quantity of high-protein livestock feed co-produced in the manufacture of plant oils is tabulated. The quantity of feed produced from each oilseed (canola, peanut, and soybean) is calculated based on the yield of meal or cake from the whole seed and the quantity of seed required to supply the plant oils in the diet. The total protein content of all oilseed meals was also calculated.
* Third, the quantity of plant oil co-produced in the manufacture of soybean meal for use in feeding livestock was tabulated. The quantity of oil was determined based on the yield of oil from soybeans and the quantity of whole soybean needed to meet the feed needs of all livestock-based foods in the model. The quantity of protein in the livestock feeds was also estimated.
* Fourth, the area of oilseed land displaced by the substitution of corn oil for other plant oils is determined. Corn oil is assumed to replace other oils on a 1:1 basis. Therefore, the area of land displaced is proportional to the amount of oil substituted. The area of oilseed land displaced by corn oil equals the percent of oil displaced times the initial estimated area of land needed to produce plant oils.
* Fifth, the potential land savings of lard and tallow are tabulated. As animal fats, lard and tallow are considered products to avoid according to the Dietary Guidelines for Americans (USDA and HHS, 2010). Thus, the user can set the amount of tallow and lard permitted in the diet. Lard and tallow replace a portion of the plant oils in the diet, further reducing the land area required from step four. The amount of protein concentrate is recalculated based on the revised estimate of land in plant oils.
* Sixth, the MUCA is determined. If the production of protein meal from corn milling and oilseed production meets or exceeds the amount required by livestock, then the MUCA equals the area of soybeans needed to meet livestock feed requirements plus the area of oilseeds offset by corn oil, lard, and tallow. Alternatively, if the co-production of protein meal from plant oils cannot offset the livestock feed needs, then the MUCA equals the area of oilseed land spared by the co-production of plant oils in making soybean meal for livestock feed plus the area offset by corn oil and tallow.

*Grazing land adjustment*

Preliminary estimates of land requirements for individual ration ingredients used to produce animal-based foods assume that all grazed forage needs are met from grazing land. Depending on the land requirements for the entire diet, this assumption could cause subsequent calculations of carrying capacity to be limited by the available area of grazing land while not making full use of cropland. Since cropland can be used to graze livestock, such a result is nonsensical. Therefore, the estimates of aggregate dietary needs for grazing land are adjusted to permit substitution of cropland for grazing land.

The grazing adjustment (GA in Eqs. 4b and 4c) assumes that all grazing will occur on the land with the lowest use value (i.e. permanent pasture and range) until the supply of available grazing land is exhausted, at which point cropland will be used for grazing. The GA for each land type is calculated by solving two simultaneous equations, one that requires the ratio of the dietary requirements for cropland to grazing land to match the availability of cropland to grazing land and a second that requires the substitution of cropland to be inversely proportional to the forage yield of cropland to grazing land. These equations result in estimates of the area of cropland needed (ha person-1 year-1) to supplement the supply of grazing land available and the amount of grazing land spared (ha person-1 year-1) by spreading grazing needs across two land pools. A step-by-step description of the GA is located in the Supplementary Information text, and calculations are shown in the Supplementary Information dataset.

If the ratio of grazing land requirements to cropland requirements is less than or equal to the ratio of grazing land availability to cropland availability, then all needs for grazed forage can be met by land limited to grazing. In such instances, the calculation of carrying capacity will be limited by the area of available cropland, not all grazing land will be used, and the GA equals zero. However, if the ratio of grazing land requirements to cropland requirements is greater than the ratio of grazing land availability to cropland availability, the calculation of carrying capacity will be limited by the total available area of agricultural land (cropland plus grazing land). In such instances, cropland is implicitly substituted for grazing land, but at the wrong rate. Grazing land, on the average, has a lower productivity than cropland, and therefore the rate of substitution must be a function of yield. Thus, the grazing adjustment is calculated by solving the following set of simultaneous equations [Eq. S4a and S4b]:

[Eq. S4a] ALRgrazing / (ALRcultivated cropland + ALRperennial cropland) = Agrazing/Acropland

[Eq. S4b]GAgrazing land = GAperennial cropland \* (Ycropland / Ygrazing)

The terms used in Eqs. S4a and S4b are identical to those used above in Eqs. 4a through 4c. Equations S4a and S4b can be rewritten as follows:

[Eq. S5]GAperennial cropland = (LRgrazing – ((Agrazing/Acropland) \* (Ycropland/Ygrazing))) / ((Agrazing/Acropland) + (Ycropland/Ygrazing))

The term LRgrazing is the preliminary estimate of grazing land needs determined by taking the sum of grazing land needs for all individual foods that include grazed forage as a portion of the ration for meeting livestock feed needs. It is equivalent to Eq. S4c above, omitting the grazing adjustment. Solving Eq. S5 provides the grazing adjustment for cropland (GAperennial cropland), the area of cropland (per capita) that must be shifted to grazing. The adjustment to grazing land is determined by plugging the value obtained from Eq. S5 into Eq. S4b.

**Land availability**

Agriculture occurs across a wide range of land types. A typical U.S. farm, for example, includes crop fields, pasture, woodlots, farm buildings, roads, plus a mixture of odd features that are unsuitable for any productive purpose (e.g. rock outcrops, waterways, wetlands). For the purposes of estimating land availability for food production, only the potentially productive portion of this land is relevant.

The starting points for defining agricultural lands are the 2007 Census of Agriculture (USDA-NASS, 2009) and the Major Land Uses data (USDA-ERS, 2011). Food production is assumed to occur solely on farms and public grazing lands. The USDA defines a farm as an entity that makes, or is capable of making, at least $1,000 in annual gross sales. This expansive definition includes almost all agricultural activity, but excludes non-commercial activities such as gardening, hunting, and recreational fishing.

Two categories of land are enumerated for the purposes of estimating land availability for food production, cropland and grazing land. By definition, cropland is arable land, meaning it is capable of being used for cultivation. The determination of whether or not land is arable is made by the farm operators who complete U.S. Census of Agriculture surveys. Thus, the definition used by USDA is empirical rather than biophysical. Grazing land, for the purposes of this paper, includes those resources capable only of supporting grazing. The methods for enumerating each are outlined below. All calculations are shown in the “Land availability” tab of the SI Dataset.

*Cropland*

Not all cropland is considered available for production. For a variety of reasons, a portion of U.S. cropland is neither harvested nor used as pasture in any given year. The first step in determining land availability is to account for unproductive uses of cropland (Eq. 6a).

[Eq. S6a] A productive cropland = A total cropland – A other cropland

The area (A) of productive cropland in the U.S. equals the area of total cropland *minus* the area of other cropland. According to USDA-NASS (2009), other cropland includes land on which crops failed, cultivated fallow, and idle land. Idle land accounts for the largest share and includes land enrolled in the Cropland Reserve Program that may not be cultivated according to lease agreements with USDA.

Land available for food production is further constrained based on its suitability of production. Economic suitability of land for different crops constantly changes in response to prices, technological and management innovations, and over long periods of time, to soil degradation. A major distinction can be made between perennial forage crops, which provide year-round cover for soils, and cultivated crops, which often expose soils to erosion for certain periods of the year. We assume that not all cropland could be used for cultivated crops in a given year. Rather, we expect that some portion of cropland is sufficiently steep, wet, erosive, or rocky that it is either suitable only for hay crops or requires the presence of perennial crops in order to create sustainable cropping rotations. Thus, cropland is divided into two pools: cropland in cultivated crops and cropland in perennial forages. The maximum footprint of land in cultivated crop production is calculated based on the areas of land in cultivated crop types from the Census of Agriculture (Eq. 6b).

[Eq. S6b] A cultivated cropland = ∑ A cultivated crop i

The maximum area (A) of cultivated cropland is estimated as the sum of all cultivated crop groups (i). Six aggregated groups tracked by the USDA are considered “cultivated crops”: total berries, harvested acres; total citrus fruit, bearing age acres; total non-citrus fruit, bearing age acres; total nuts, bearing age acres; land in vegetables; and nursery crops, in the open. A seventh, and final, group of cultivated crops are the annual field crops. The land footprint of annual field crops is not calculated by USDA and therefore was estimated as a residual. The area in annual field crops equals the area of productive cropland (Eq. S6a) *minus* the area of the six cultivated crop groups and four perennial crop groups: field and grass seed crops, forage – land used for all hay and all haylage, grass silage, and greenchop, cut Christmas trees, and short rotation woody crops.

Land in cultivated crop production can, under certain conditions, be used to harvest more than one crop per year. Research from USDA suggests that the prevalence of multi-cropping in the U.S. is low, occurring on just 1-2% of all cropland (Borchers et al., 2014). Nonetheless, an estimate of cropping intensity is calculated from USDA Census of Agriculture data (Eq. S6c).

[Eq. S6c] CI = (∑ A field crop i + A vegetable crop i + A cultivated crop i ) /A cultivated cropland

Cropping intensity (CI) is defined as the ratio of area of land harvested to the actual footprint of land in production. It equals the sum of the area (A) harvested for all individual field crops (i) and all individual vegetable crops plus the sum of the areas of the remaining cultivated crop groups that represent fruit, nuts, or nursery groups divided by the area of cultivated cropland.

A final consideration in determining the area of land available for food production is the area of land used for non-food crops. The model assumes that some area of land must be reserved for the production of fiber crops, ornamentals, and other crops not used for food, feed, or forage (Eqs. S6d and S6e).

[Eq. S6d] A non-food, cultivated crops = ∑ A non-food cultivated crop i

[Eq. S6e] A non-food,perennial crops = ∑ A non-food perennial crop i

The area of land (A) in cultivated non-food crops equals the sum of the individual (i) non-food crops or crop groups that are considered cultivated. This includes cotton, tobacco, and nursery crops. The area of land (A) in non-food perennial crops equals the sum of the individual (i) perennial non-food crops or crop groups: field and grass seeds, cut Christmas trees, and short rotation woody crops. This step does not account for the use of commodity crops for biofuel or other industrial use. The utilization of corn and soybean for production of ethanol and biodiesel is not a separate land use but rather an industrial process that co-produces fuel, food products (e.g. corn oil), and feed products (e.g. soybean meal) from a single raw material. Use of land for biofuels has been considered beyond the scope of the scenarios examined in the model. Were these uses to be included, they would need to be accounted in the Multiuse Crop Adjustment step.

The final step in the determination of cropland availability is to determine the effective area of cultivated cropland available to the model (Eq. 6f). The effective area (EA) of cultivated cropland equals the area (A) available for cultivated crop production minus the area (A) in non-food cultivated crops times the cropping intensity (CI).

[Eq. S6f] EA = (A cultivated cropland- A non-food, cultivated crops) × CI

*Grazing land*

Grazing of livestock occurs on a wide variety of land types. In this analysis, “grazing land” includes categories of land suitable only for grazing. It does not include cropland pasture or the use of crop stubble as a feed source. While the model permits cropland to be used for grazing, it is considered part of the cropland pool. The area of land available for grazing was estimated based on data from Major Land Uses (Eq. S7)

[Eq. S7] A grazing land = A grassland + A woodland

In this analysis, grazing land equals the sum of the area of grassland pasture and rangeland (A grassland) and the area of forest-use land that is grazed (Awoodland). The Major Land Uses data cover all land in the U.S. Thus, the estimates of grazing land used in the model include both public and private lands.

**MODEL STRUCTURE**

A copy of the spreadsheet model accompanies this article (SI dataset). The dataset is a Microsoft Excel workbook with 16 worksheets. A key to the tabs of the spreadsheet is shown below.

* “README”: States the purpose of the workbook, directing the user to the paper and the supporting information text for a complete description of the model. Contains a list of all worksheets included in the workbook with brief descriptions of each sheet.
* “Users diet”: Starting point for using the model. Assumptions about dietary intake (variable *I* from Eq. 1) are entered here by food group, food subgroup, or food item as shown in the shaded cells in the range E23 to E49.
* “Dietary recommendations”: Reports the dietary recommendations (USDA and HHS, 2010) specific to each age-gender cohort used to calculate weighted average food group and nutrient requirements for the U.S. population. Calculation of weighted averages is also shown.
* “Food preferences”: Reports assumptions made about the percent composition (variable *C* from Eq. S1) of each food group by individual food commodities. Derivation of estimates is described in the Methods.
* “Nutrient composition”: The weight of a serving of a food commodity (variable *W* from Eq. S1) is reported in this worksheet along with estimates of the content of water, energy, protein, lipid, carbohydrate, sugars, saturated fats, and cholesterol.
* “Losses and waste”: Reports the loss adjustment factors (variable *L* in Eq. S1) used to account for losses and waste that occur across the distribution system. Includes estimates of losses and waste at three distinct points in the supply chain (primary to consumer, retail, and food service/consumer) that are used by USDA-ERS in creating loss-adjusted food availability data (USDA-ERS, 2010).
* “Processing conversions”: Reports estimates of conversion factors used to account for processing (variable *P* in Eq. S2) in determining the weights of agricultural commodities (variable *QA* from Eq. S2) required to provide the food commodities (variable QF from Eqs. S1 and S2) required to supply human dietary needs.
* Dairy processing conversions”: Reports the assumptions used in determining the processing conversions for dairy products as described in Eqs. S6a through S8b
* “Fats and oils”: Shows assumptions made about the percent composition and processing conversions for individual plant oils and animals fats included in certain aggregated food commodities, such as “salad and cooking oils.”
* “Food requirements”: Calculates the intake (*I*), quantity of food commodities (*QF*), and quantity of agricultural commodities (*QA*) for each food included in the model.
* “Livestock feed requirements”: Reports the ration ingredients (variable *R* from Eq. S3b) needed to provide livestock feed for animal-based foods. Also includes the determination of the percentage of beef from dairy and beef breeds.
* “Crop and grazing yields”: Reports estimates of yields (variable *Y* from Eqs. S3a and S3b) used in the model to estimate land requirements for individual food commodities or feed ingredients to livestock production.
* “Land requirements”: Calculates the raw estimates of land requirements (variable *LR* from Eqs. S3a and S3b) for each food commodity or feed ingredient to livestock production.
* “Multiuse crop adjustment” Shows the derivation of the multi-use crop adjustment (MUCA) used to calculate the adjusted land requirements for cultivated cropland (variable *ALR* from Eq. S4a).
* “Grazing land adjustment”: Shows the derivation of the grazing land adjustments (variable *GA* from Eqs. S4b and S4c) used for calculate the adjusted land requirements for perennial cropland and grazing land. Steps are outlined above in Eqs. S9a, S9b, and S10.
* “Land availability”: Shows the calculation of available land in the three pools used in the analysis: cultivated cropland, perennial cropland, and grazing land. Includes the derivation of land availability estimates used in the calculation of carrying capacity in Eq. S5. Steps outlined in Eqs. S11a-f and S12 are included here.

**Using the spreadsheet model**

The foodprint model was designed to enable a user to readily change assumptions regarding food intake. All scenarios described in the main text can be re-run by entering the assumptions made regarding food intake into the Users diet worksheet in the spreadsheet model (see SI Dataset). To explore alternative scenarios, a user may enter new values into the cells shaded in blue in the cell range E23:E49. Changes may only be made to these shaded cells. Changing other cells may influence the structure of the model or the summary results.

Recommended values for food intake are shown in column D of the Users diet worksheet, where appropriate. Note that the user is free to enter any value he or she chooses; the model will not prevent the user from analyzing a poorly balanced diet. A summary of the total energy and macronutrient profile is shown in cells A14:C18.

Summary results for per capita land requirements of diet are reported in rows 54 and 55. The potential carrying capacity and associated aggregate land use are shown at the top of the worksheet in cell ranges A6:C7 and A9:C12.

**REFERENCES**

Borchers, A., Truex-Powell, E., Wallander, S., and Nickerson, C. 2014. Multi-Cropping Practices: Recent Trends in Double Cropping. Economic Information Bulletin No. 125, USDA Economic Research Service, Washington, D.C. Available at Web site: <http://www.ers.usda.gov/media/1437476/eib125.pdf> (verified 14 March 2015).

International Rice Research Institute (IRRI). undated. Rice Milling. Agricultural Engineering Unit, IRRI. Available at Web site: <http://www.knowledgebank.irri.org/postproductioncourse/factsheetsNRefences/Milling/Teaching%20Manual%20Rice%20Milling.doc> (verified 13 February 2015).

Mag, T. undated. Canola seed and oil processing. Canola Council of Canada. Available at Web site: <http://canola.okstate.edu/canola-info/canolaoilmeal/oilprocessing.pdf> (verified 28 March 2015).

Peters, C.J., Picardy, J.A., Darrouzet-Nardi, A., Griffin, T.S. 2014. Feed conversions, ration compositions, and land use efficiencies of major livestock products in U.S. agricultural systems. *Agricultural Systems* **130**: 35-43.

U.S. Department of Agriculture and U.S. Department of Health and Human Services (USDA and HHS). 2010. Dietary Guidelines for Americans, 2010. 7th Edition, Washington, DC: U.S. Government Printing Office, December 2010. Available at Web site: <http://www.cnpp.usda.gov/sites/default/files/dietary_guidelines_for_americans/PolicyDoc.pdf> (verified 14 November 2014).

USDA Economic Research Service (ERS). 1992. Weights, measures, and conversion factors for agricultural commodities and their products. Agric. Handb. 697. USDA Economic Research Service, Washington, D.C.

USDA, Economic Research Service (ERS). 2010. Loss Adjusted Food Availability Data [on-line]. Accessed October 2010, Available at Web site: <http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system/.aspx> (verified 14 November 2014)

USDA, Economic Research Service (ERS). 2011. Major Land Uses, Summary table 4: Total grazing land, by region, State, and United States, 2007. Available at Web site: <http://www.ers.usda.gov/data-products/major-land-uses.aspx> (verified 16 November 2014).

USDA, Economic Research Service (ERS). 2012. Oil Crops Yearbook [On-line]. Accessed March 2012. Available at Web site: http://www.ers.usda.gov/data-products/oil-crops-yearbook.aspx (verified 14 March 2015).

USDA, National Agricultural Statistics Service (NASS). 2004. Citrus Fruit Final Estimates, 1997-2002. Statistical Bulletin No. 997 (04). Available at Web site: <http://usda.mannlib.cornell.edu/usda/nass/SB997/sb997.pdf> (verified 14 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2008a. Citrus Fruit Final Estimates, 2003-2007. Statistical Bulletin No. 1009. Available at Web site: <http://usda.mannlib.cornell.edu/usda/nass/SB997/sb1009.pdf> (verified 14 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2008b. Noncitrus Fruit and Nuts, Final Estimates 2002-2007. Statistical Bulletin No. 1011. Available at Web site: <http://usda.mannlib.cornell.edu/usda/nass/SB985/sb1011.pdf> (verified 16 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2009. 2007 Census of Agriculture, Desktop Data Query Tool 1.02. Available at Web site: <http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Desktop_Application/> (verified 16 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2010a. Agricultural Statistics 2010. Government Printing Office, Washington, D.C. Available at Web site: <http://www.nass.usda.gov/Publications/Ag_Statistics/2010/2010.pdf> (verified 16 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2010b. Citrus Fruit 2010 Summary. Available at Web site: [http://usda.mannlib.cornell.edu/usda/nass/CitrFrui//2010s/2010/CitrFrui-09-23-2010.pdf](http://usda.mannlib.cornell.edu/usda/nass/CitrFrui/2010s/2010/CitrFrui-09-23-2010.pdf) (verified 14 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2011. Noncitrus Fruit and Nuts, 2010 Summary. Available at Web site: [http://usda.mannlib.cornell.edu/usda/nass/NoncFruiNu//2010s/2011/NoncFruiNu-07-07-2011.pdf](http://usda.mannlib.cornell.edu/usda/nass/NoncFruiNu/2010s/2011/NoncFruiNu-07-07-2011.pdf) (verified 16 November 2014).

USDA, National Agricultural Statistics Service (NASS). 2014. Quick Stats database [on-line]. Accessed September 2011. Available at Web site: <http://quickstats.nass.usda.gov/> (verified 14 November 2014).

USDA National Agricultural Statistics Service, California Field Office (NASS-CA), 2011. California Agricultural Statistics, 2010 Crop Year. Sacramento, California. Available at Web site: <http://www.nass.usda.gov/Statistics_by_State/California/Publications/California_Ag_Statistics/Reports/2010cas-all.pdf> (verified 16 November 2014).

USDA Natural Resource Conservation Service (NRCS). 2003. National Range and Pasture Handbook, Revision 1. Available at Web site: <http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/rangepasture/?cid=stelprdb1043084> (verified 28 March 2015).

Vossen, P. undated. Understanding olive oil yield. University of California, Cooperative Extension Service, Sonoma County. Available at Web site: <http://cenapa.ucdavis.edu/files/52581.pdf> (verified 28 March 2015).

Table S1: Grazed forage yields on cropland pasture and other grazing lands

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Step | Calculation | Units | Value | Notes |
| Feed value obtained from grazing lands | Feed consumed as pasture, corn basis | Million tons | 158 | 1 |
| Conversion, corn to pasture | Tons forage DM ton corn-1 | 1.30 | 2 |
| Feed consumed as pasture, forage basis | Million tons forage DM | 205 | 3 |
| Land used for grazing | All land | Million acres | 775 | 4 |
| Cropland pasture | Million acres | 36 | 5 |
| Other grazing land | Million acres | 739 | 6 |
| Grazing yields, cropland pasture | Hay yields, cropland pasture | Pounds forage acre-1 | 3876 | 7 |
| Forage equivalents | DM grazed DM harvested as hay-1 | 0.51 | 8 |
| Grazing yield, cropland pasture | Pounds forage acre-1 | 1995 | 9 |
| Grazing yields, grazing land | Feed value of cropland pasture | Billion lbs forage DM | 72 | 10 |
| Feed value of other grazing land | Billion lbs forage DM | 339 | 11 |
| Grazing yield, other grazing land | Pounds forage DM acre-1 | 458 | 12 |

1Value shown for pasture from Table 1-77: Feed consumed by livestock and poultry, by type of feed, with quantity expressed in feeding value of corn, 2000-2009 of *Agricultural Statistics* (USDA-NASS, 2010). Note that pasture includes all grazing lands.

2Feed value of corn converted to feed value of pasture assuming a dry matter content of 89.4% and digestibility of 88.2% (TDN basis) for corn. Feed value of pasture biomass assumed for be 60.8% (TDN basis). Conversion factor equals (0.894\*0.882)/0.608.

3Equals product of feed consumed on corn basis and conversion factor.

4From *Major Land Uses* (USDA-ERS, 2011)

5From *Major Land Uses* (USDA-ERS, 2011)

6Calculated by difference.

7Ten-year average. Calculated from yields of Hay, excluding alfalfa from USDA-NASS (2014).

8Yield of forage under grazing calculated by using hay yields to estimate aboveground biomass and a grazing efficiency factor to determine the amount harvested by grazing livestock. Assumes that the stubble remaining after mowing is 15% of the aboveground biomass and that 20% of cut biomass is lost in hay harvest. Grazing efficiency on cropland pasture is assumed to be 35% of total aboveground biomass under continuous grazing (see glossary of USDA-NRCS, 2003).

9Equals product of hay yield and conversion factor.

10Equals yield times area.

11Calculated by difference (Total feed value minus feed value of cropland pasture).

12Equals feed value divided by area of other grazing land.

Table S2. Processing conversion parameter estimates obtained from non-standard sources

|  |  |  |  |
| --- | --- | --- | --- |
| Commodity | Units | Value | Notes |
| Canola oil | Kg oil kg canola seed-1 | 0.40 | 1 |
| Olive oil | Kg oil kg olives-1 | 0.15 | 2 |
| Refined cane and beet sugar | Kg sugar kg raw material-1 | 0.14 | 3 |
| Rice | Kg polished rice kg paddy rice-1 | 0.71 | 4 |
| Rice | Kg brown rice kg paddy rice-1 | 0.80 | 4 |
| Rye | Kg flour kg rye grain-1 | 0.87 | 5 |
| Soy milk | Kg soy milk kg soybean-1 | 6.0 | 6 |
| Tofu | Kg tofu kg soybean-1 | 2.5 | 7 |

1Authors’ calculations using oil content of canola from Mag 47 and yield of refined oil from crude oil from Agricultural Handbook No. 697 . 46

2 Authors’ calculations using oil yield (volume per acre) from Vossen 48 and oil density from Agricultural Handbook No. 697. 46

3 Personal communication with Stephen Haley, USDA Economic Research Service, March 2012.

4 From International Rice Research Institute. 49

5 Personal communication with Colleen Zammer, Bay State Milling, 04 January 2012

6 Personal communication with Melinda Anderson, University of Illinois Soybean Research Laboratory, 25 September 2012.

7 Personal communication with Karl Weingartner, University of Illinois Soybean Research Laboratory, 30 October 2012.