**Partitioning United States’ Feed Consumption Among Livestock Categories For Improved Environmental Cost Assessments**

**Supporting Information**

Gidon Eshel1\*†, Alon Shepon2†, Tamar Makov3 and Ron Milo2\*

1*Physics and Environmental Sci. Depts., Bard College*

*Annandale-on-Hudson, NY 12504-5000; (845) 758-7232; geshel@bard.edu*

2*Dept. of Plant Sciences, Weizmann Institute of Science, Rehovot, 76100, Israel*

3*Yale School of Forestry & Environmental Studies, New Haven, CT 06511*

*\*Corresponding authors. Email:* [*geshel@bard.edu*](mailto:geshel@bard.edu)*;* [*ron.milo@weizmann.ac.il*](mailto:ron.milo@weizmann.ac.il)

*†These authors contributed equally to this work*

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S-1 More on Key Assumptions

S-1.1 On the Exclusion of Fish

In this analysis, we do not address fish, for two key reasons. First and foremost, in the mean American diet, the caloric fraction due to fish is very small. Since 2000, fish and shellfish have contributed on average 14 kcals person−1 day−1 to the mean American loss-adjusted diet. Over these years, animal-based items have contributed 750 kcals person−1 day−1  to this diet on average, while the diet total ingested energy has been 2,669 kcals person−1 day−1. Fish and shellfish thus amount to roughly 2% of the animal-based energy, and 0.5% of the total (USDA Economic Research Service, 2012a). In addition, data addressing feed use by fisheries and aquaculture (which are dominated by imports) are very limited and incomplete (relative to the five categories considered).

S-1.2 The Uniform Feed Distribution Assumption

Under this assumption, a livestock category’s share of any specific feed type is proportional to the category’s demand of that feed type. That is, e.g., we extend the fact that poultry consume 27% of the concentrates to mean that they also consume 27% of total corn or sorghum. This assumption ignores the possibility of preferential relative consumption of a particular type of grain or a concentrated byproduct by a given livestock category, e.g., hypothetically, that pork feed contains higher corn and lower sorghum proportions than poultry feed. Since all grain types are widely distributed and easily accessible throughout the U.S., and since most grains are nutritionally similar, this assumption—while by no means a fact—makes sense. Future data on the exact composition can be easily incorporated in the currently presented framework.

S-1.3 Defining Edible and Other Livestock Categories

Our analysis considers beef cattle, hogs, dairy cattle, egg layers, meat poultry, sheep and goats. While the latter two (which together with horses are referred to as “others”) are also raised for human consumption, their caloric contributions to the mean American diet are minuscule (USDA Economic Research Service, 2012a). The sole import of “others” in our study is therefore as consumers of small yet non-negligible feed mass for which available feed totals must be corrected in order to better estimate the feed consumed by the 5 major “edible” categories.



**Figure S-1:** A flowchart outlining our partitioning methodology. Each step is indicated by a letter (upper left corner) permitting direct reference in the text. Corresponding cells in the supplementary Excel sheet “Main Feed Needs & Partitioning” tab are specified in the lower left corners (except box F which refers to a different tab, as written). References to the corresponding SI sections (S-x) are indicated in the lower right corners. The “edibles” are beef, poultry, pork, eggs and dairy; “others” are horses, sheep and goats. Boxes corresponding to final partitioning results (derived in the main text's Results section) are highlighted with a dark blue frame.

S-2 Total Categorical Feed Consumption Estimates

Total annual categorical feed consumption estimates presented in table 1 are the product of categories’ total slaughter headcount and kg feed requirement per slaughtered kg (for pork and poultry), or of total live inventory and per head feed requirements (for eggs, meat layers, beef and dairy). These calculations are represented by figure S-1, boxes A-C and detailed separately below.

S-2.1 Pork

Since pork specific feed requirements are given in kg DM per slaughter kg, pork feed needs are

|  |  |
| --- | --- |
|  | (S-1) |
|  |  |

(table 1), where (a,I) ≈ 106 million heads is hogs’ annual slaughter count (USDA Economic Research Service, 2011a) [and where (a,I) is a general (row, column) table 1 cell identifier we employ], (a,II) ≈ 127 kg is pork’s mean slaughter weight (USDA Economic Research Service, 2011a), and (a,III) ≈ 3.16 kg per kg reflects hogs’ mean full life feed conversion. We derive this factor from the NRC pork feeding recommendations [integrating their figure 3-11 equations over 3–127 kg of body weight, where 3 kg is a typical piglet weight when solid feeding commences, and 127 kg ≡ (a,II)], assuming 5% waste products in pigs’ diet and 90% DM content in their non-waste feed (National Research Council, 1998). Note that because pigs’ lifespan typically exceeds 1 year, the above formalism is only valid for an approximately invariant production scope, with pig numbers neither steadily rising nor declining. As this condition is met by the roughly stable current U.S. pork industry, the formalism is valid, yielding (a,V) ≈ 43 yr−1, with corresponding uncertainty—the standard deviation of the mean estimate—of ≈ 17 yr−1 derived in section S-3.3.

S-2.2 Poultry

Poultry’s (except meat layers’) feed needs—like pork’s—are also given as feed conversion rate (kg DM feed per kg slaughter weight). Consequently, most of poultry’s feed demands are derived in a format similar to eq. S-1, kg of animal product produced (slaughtered) annually (USDA Economic Research Service, 2011a), times feed conversion rate ((National Research Council, 1994) table 2-5 for broilers and other chicken, and table 3-2 for turkeys). Those demands are,

|  |  |  |  |
| --- | --- | --- | --- |
|  | | (S-2) | |
|  | |  | |

|  |  |
| --- | --- |
|  | (S-3) |
|  |  |

|  |  |
| --- | --- |
|  | (S-4) |
| for turkeys. |  |

Finally, we estimate meat layers’ annual feed consumption by multiplying meat layers’ live 2002-2011 annual mean headcount (e,I) (USDA Economic Research Service, 2012b), by per bird daily feed demands (e,IV) = 76 g ≈ 0.08 kg ((National Research Council, 1987) table 4-1),

|  |  |
| --- | --- |
|  | (S-5) |
| 58.2 × 0.08 × 365 . |  |

Summing sub-categorical annual feed consumptions (b,V)–(e,V) yields poultry’s overall national feed consumption, (b-e,VI) ≈ 50 DM yr−1 .

We derive the uncertainty estimate (section S-3.4) of the overall poultry consumption mean estimate by combining uncertainty estimates of each of the individual components leading to (b–e,V) using equation S-27, yielding poultry’s estimated national feed consumption uncertainty of ≈ 8 DM yr−1 [also reported in table 1’s (b-e,VI)].

S-2.3 Eggs

Our estimated egg layers’ total annual feed consumption is the egg layers’ 2002-2011 average annual head count (USDA Economic Research Service, 2012b), (f,I), times the per layer feed demands introduced in section S-2.2, (f,IV) ≈ 0.08 kg (laying hen · day)−1 (National Research Council, 1987). This yields,

|  |  |
| --- | --- |
|  | (S-6) |
| , |  |

with associated uncertainty (section S-3.5) of ±3 yr−1.

S-2.4 Dairy

Dairy cattle comprise of cows, their heifer replacements, and required sire bulls, the latter two of which we lump into the “other dairy” subcategory. The feed demands of each subcategory are headcounts times per head feed requirements,

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| --- | --- |
|  | (S-7) |
|  |  |

|  |  |
| --- | --- |
|  | (S-8) |
|  |  |

where inventories (g,I) and (h,I) are data based averages for 2002-2011 ((USDA National Agricultural Statistics Service, 2011a) table 7-2) , and accounts for dairy sire bulls (see below).

Per head daily feed requirements [(g,IV) and (h,IV) above] are characteristic body masses times DM feed consumption as percent of body mass. For mature dairy cows, we take average body mass of (g,II) ≈ 632 kg (which reflects large breed populations outnumbering small ones 9-to-1 (Capper et al., 2009; National Research Council, 2001) and percent of body mass in DM feed consumption of 3.05% (averaging (National Research Council, 2001), table 5-13 and (National Research Council, 1987) Pg. 48). This yields daily feed intake (g,IV) ≈ 19.2 kg DM feed (head · day)−1 used in eq. S-7.

We derive heifers’ characteristic body weight as follows. We assume heifers’ self-weight at breeding is 55% that of a mature dairy cow’s, (h,II) ≈ 632 kg, and that this weight is first attained at age 407 days (National Research Council, 2001); the weight reached at the time of first calving, taken to occur at age 687 days, is 82% of a mature dairy cow (National Research Council, 2001). Assuming a roughly linear first year weight gain from a 34 kg birth weight (which we take for cattle throughout) to (h,II), heifers’ mean first year weight is [34 + 55%· (h,II)]/2 = 191 kg. Subsequently and until first calving (day 687), their average weight is [55%· (h,II)+ 82%· (h,II)]/2 = 442 kg . Heifers’ mean weight till calving is therefore a weighted averaged of both values, i.e. 278 kg. Taking non-lactating (i.e., less productive) heifers’ feed consumption as percent body mass of 2.0% ((National Research Council, 1987), Pg. 48) the above mean weight yields the per head daily DM consumption (h,IV) = 5.5 kg (head · day)−1 used in eq. S-8.

We approximate bulls’ feed needs by assuming 1 bull per 80-85 cows (i.e., a bull population 1.2% that of dairy cows’), with characteristic weight of 827 kg and daily DM feed requirements of 2% of body mass (Capper et al., 2009),

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| --- | --- |
|  | (S-9) |
|  |  |

Adding this result to equation S-8 yields

|  |  |
| --- | --- |
| (h, V) ≈ 9 DM yr−1. | (S-10) |

One might suggest that from (g,V) + (h,V) we should subtract feed consumption by culled dairy cattle that yield beef, not milk. We choose to ignore this issue in our calculation, for the following reasons. A culled cow is typically still lactating (i.e., not dry) when the farmer reaches the culling decision. Once the decision is made, it is typically only a matter of days before the cow departs the herd. It is thus producing milk until its final day, and its feed must therefore be viewed as dairy’s. It is true that the relatively small flux of “free” low grade beef from culled cows that is added to beef produced by the beef herd raises the apparent efficiency of beef (there is more product for the same resource investment), but efficiency is not an issue here. Consequently, we disregard dairy-to-beef flux.

With (g,V) and (h,V) given in equations S-7, and S-10, total dairy cattle DM consumption is

(S-11)

with associated uncertainty of ±9 yr−1 (section S-3.6).

S-2.5 Beef

The beef category comprises beef cows (mothers, row i) and other beef cattle (“non-cows” in USDA nomenclature, mostly steers for slaughter and replacement beef heifers, but also including the small subcategory of beef sires; table 1 row j), with respective feed demands

|  |  |
| --- | --- |
|  | (S-12) |
|  |  |

|  |  |
| --- | --- |
|  | (S-13) |
|  |  |

where and (i,II) and (j,II) are observed live inventories averages for 2002-2011 ((USDA National Agricultural Statistics Service, 2011a), table 7-2). For the less productive, fully mature beef cows, we consider specific DM feed requirements of 2.25% of body mass per day (National Research Council, 1987). Characteristic weight for beef cows, (i,II) ≈ 459 kg, is based on their dressed slaughter weight, 280 kg (USDA Economic Research Service, 2011a), scaled up by the ratio of dressed to live weights, 1.65, derived for the inclusive “Cattle” category. Given this characteristic live weight of 459 kg, this yields the reported requirement of (i,IV) ≈ 10.4 kg DM feed (head · day)−1. For the “other beef” subcategory, we consider an averaged per day DM consumption of (j,IV)=8.9 kg DM (head · day)−1  ((National Research Council, 1987), tables 6-9 and 6-10).

Combining partial beef feed consumption values,

(S-14)

is our estimate of the total national feed consumption by beef cattle, with associated uncertainty of ±24 yr−1 (section S-3.7) .

S-2.6 Total Feed Consumption by Edibles

Summing annual feed consumption by, pork, poultry, egg layers, dairy cattle, and beef cattle [(a,VI), (c-d,VI), (f,VI), (g-h,VI), and (i-j,VI), respectively], and suitably combining all categorical uncertainties, the total feed consumption by the “edibles” (figure S-1, box E) is (k,VI) ≈ 458±32 DM yr−1.

S-2.7 Feed Consumption by “others”

“Others” comprise horses, goats (milk & angora and meat & other) and sheep. The feed needs of “others” grown for breeding or milk purposes are estimated much in the same fashion as those of dairy cows (using live inventory head-count and feed requirements per head).

|  |  |
| --- | --- |
|  | (S-15) |
|  |  |

|  |  |
| --- | --- |
|  | (S-16) |
|  |  |

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| --- | --- |
|  | (S-17) |
|  |  |

Average live inventory head-counts for horses, milk & angora goats, and mature sheep are 3.8, 0.5 and 4.5 million respectively (USDA National Agricultural Statistics Service, 2009, 2011b, 2012).

For horses, we take characteristic body mass of ≈ 500 kg , and percent of body mass in DM feed consumption of 2.0% (Anderson, 2001; National Research Council, 2007), yielding daily feed intake of ≈ 10 kg DM feed (head · day)−1 used in eq. S-15. For milk and angora goats, we take characteristic body weight of ≈ 70 kg , and percent of body mass in DM feed consumption of 4.0% (Rinehart & Baier, 2011), yielding daily feed intake of ≈ 3 kg DM feed (head · day)−1 used in eq. S-16. For mature sheep, we use a body mass of ≈ 70 kg (Faller et al., 1996) , and 3.65% of body mass in DM feed consumption (Rinehart & Baier, 2011), yielding daily feed intake of ≈ 2.5 kg DM feed (head · day)−1 used in eq. S-17.

The feed needs of “others” for meat are calculated like those of poultry (based on slaughter data),

|  |  |
| --- | --- |
|  | (S-18) |
|  |  |

|  |  |
| --- | --- |
|  | (S-19) |
|  |  |

Average slaughter head-counts for meat & other goats and meat sheep & lambs are 0.8 (USDA National Agricultural Statistics Service, 2012) and 2.8 (USDA Economic Research Service, 2011a) million respectively.

For meat & other goats, we derive the average body weight as follows. Assuming linear growth, 3 kg birth weight and 28 kg final weight (USDA National Agricultural Statistics Service, 2012), mean weight is [3 + 28]/2 ≈ 15.5 kg. Taking 3.0% body mass in feed consumption (Rinehart & Baier, 2011), and an average weight gain of 0.11 kg per day (yielding an average life span of 220 days), DM consumption per slaughtered kg is 0.03∙15.5∙220/28≈ 3.7 kg used in eq. S-18.

DM consumption for meat sheep & lambs is estimated much in the same way. Again, assuming linear growth, ≈3.6 kg birth weight and 63 kg final slaughter weight (USDA Economic Research Service, 2011a), mean weight is [3.6 + 63]/2 ≈ 33.3 kg. Taking feed consumption of 3.3% of body mass, and an average daily gain of 0.3 kg (yielding a life span of 200 days on average), DM consumption per slaughtered kg of sheep is 0.033∙33.3∙200/63 ≈ 3.5 kg used in eq. S-19.

Combining partial goat and sheep consumption values, goats total DM consumption (equations S-16 and S-18) = 0.5 + 0.09 sheep total DM consumption (equations S-17 and S-19) = 4 + 0.6

With the above head counts and body masses, our estimate of the total DM feed consumption by “others” is *t*others ≈ 19±3 yr−1 (table S-1’s bottom row).

S-2.8 Dividing Total DM Consumption by Edibles into Feed Classes

Our starting point for the calculation is the estimate of “others”’ total roughage (processed roughage and pasture) consumption (table S-1); however the processed roughage (*r)*: pasture (*p)* split is unknown. With no concrete data source, it is based on recommendation of 80% roughage for horses (with preference towards pasture when available (Anderson, 2001)) and approximately 15% concentrates for sheep and goats on average and the remainder based more on processed roughage (65%) than pasture (20%) (Faller et al., 1996). Therefore, corresponding with figure S-1 boxes D and G,

|  |  |
| --- | --- |
| *c*others = (0.20 × *t*horses)+ (0.15 × *t*sheep & goats) ≈ 4±0.5 DM yr−1 | (S-20) |
| *r*others = (0.35 × *t*horses)+ (0.65 × *t*sheep & goats) ≈ 8±0.9 million metric tonne DM yr−1 | (S-21) |
| *p*others = (0.45 × *t*horses)+ (0.20 × *t*sheep & goats) ≈ 7±1 million metric tonne DM yr−1 | (S-22) |

With this assumption, the concentrates and processed roughage DM mass the “edibles” consume (figure S-1, boxes L and P) is respectively

|  |  |
| --- | --- |
| *c*edib = *c*tot − *c*others ≈ (186 ± 11) − (4 ± 0.5) ≈ 183 ± 11 million metric tonne DM yr−1 , | (S-23) |
| *r*edib = *r*tot − *r*others ≈ (175 ± 5) − (8 ± 0.9) ≈ 166 ± 5 million metric tonne DM yr−1 , | (S-24) |

The “edibles” pasture consumption, *p*edib (figure S-1, box S), is derived as a balance between total feed consumption by edibles and the sum of *c*edib and*r*edib and equals

|  |  |
| --- | --- |
| *p*edib = *t*edib – *c*edib – *r*edib ≈ (458 ± 32) − (183 ± 11) − (166 ± 5) (S-25)  ≈108 ± 34 million metric tonne DM yr−1. |  |

**Table S-1:** Feed consumption by horses, goats and sheep (the “others”), in million metric tonne DM yr−1.

|  |  |  |
| --- | --- | --- |
| Source | symbol | mean±stdev |
| concentrates† | *c*others  *r*others | 4±0.5 |
| Processed roughage‡ | 8±0.9 |
| Pasture | *p*others | 7±1 |
| Total | *t*others | 19±3 |

†Grain plus byproduct.

‡Hay, Haylage, Greenchop and silage.

S-3 Uncertainty Estimates

Most analyzed data are in the form of time series, for which the standard deviation is straightforwardly evaluated, and is our uncertainty measure (see section S-3.1.1). In other cases, especially in needed parameters for which no repeatedly recorded data exist (e.g., the daily feed consumption of livestock types, the age and weight of a dairy heifer), this simple calculation is not possible. In such cases, we average all available published alternative estimates for the most likely value, and the mean absolute deviation of individual estimates from that mean as the uncertainty estimate. We specifically indicate in the text those exceptional cases. Last, when these alternative estimates are nonexistent we use a best estimate uncertainty of 10% (see section S-3.1.2).

However they are obtained, typical uncertainty estimates combine, additively or multiplicatively, several terms. Consequently, full uncertainty estimates typically involve (1) determination of the individual uncertainty characteristic of each participating term; and (2) propagating those individual uncertainties into a single final uncertainty measure.

S-3.1 Individual Uncertainty Estimates

S-3.1.1 Data Based Uncertainty Estimates

Whenever possible (i.e., whenever data are available) we use the standard deviation computed over all observed annual means available as the individual term uncertainty estimate. That is, for a variable whose *i*th annual mean is ,

|  |  |
| --- | --- |
|  | (S-26) |

is the standard deviation used as ’s uncertainty, is the first available annual mean, typically 2001 or 2002, and is the final available annual mean, typically 2010 or 2011. We refer to such estimates as “data based”.

S-3.1.2 Estimated Uncertainty When Data Are Not Available

For the uncertainty of a variable whose annual time series or referenced alternative estimates is not available, we assume a standard deviation of 10% of the mean or the best estimate of the mean. This mostly applies to specific feed demands of livestock types, e.g., for laying hens feed requirements we use a best estimate of 76 g dry matter day−1 (National Research Council, 1987), for which no actual observed time series exist. We therefore assume the uncertainty of the 76 g day−1, best estimate is 10%, or ≈8 g day−1.

S-3.2 Combined Uncertainty Estimates

S-3.2.1 Sums

When a variable is a sum of *I* additive annual means, , the variance of the *i*th of which is , we assume zero covariance, for all, and approximate ’s uncertainty (standard deviation) as

|  |  |
| --- | --- |
|  | (S-27) |

S-3.2.2 Products

When a variable is the product of two or three annual means, or, we assume zero covariance as above, and use

|  |  |
| --- | --- |
| or | (S-28) |

respectively.

S-3.3 Pork Uncertainty

Pork feed intake uncertainty is

|  |  |
| --- | --- |
|  | (S-29) |
| million metric tonne yr−1 |  |

where 3.16 is (a,III), 127 is (a,II), 6.1 is the observed interannual variability about (a,I) ≈ 106 million heads, 0.7 kg is the observed interannual variability about (a,I) ≈127 kg, and 1.2 reflects our assumed variability of the 3.16 DM feed kg per slaughter kg feed conversion efficiency based on several references (Smil, 2001; USDA National Agricultural Statistics Service, 2011a).

S-3.4 Poultry Uncertainty

For, we use ≈ 183.4 million broilers and ≈ 0.05 kg (both estimated from year-to-year variability over 2001–2010), and ≈ 0.35 kg DM (slaughter kg) −1 (assuming a variability of several sources (Smil, 2001; USDA National Agricultural Statistics Service, 2011a)).

For , we use ≈ 12.1 million birds and ≈ 0.05 kg (both estimated from year-to-year variability over 2001–2010), and—as above—≈ 0.35 kg DM (slaughter kg)−1.

For , we use ≈ 11.2 million turkeys and ≈ 0.2 kg (both estimated from year-to-year variability over 2001–2010), and—as above— ≈ 0.35 kg DM (slaughter kg)−1 based on other sources (Smil, 2001; USDA National Agricultural Statistics Service, 2011a).

Finally, for, we use ≈ 1.2 million meat layers (estimated from year-to-year variability over 2002–2011), and use a variability assumption of ≈ 11 kg DM per head per year (Smil, 2001; USDA National Agricultural Statistics Service, 2011a).

S-30 yields poultry’s overall feed requirement uncertainty,

|  |  |
| --- | --- |
| million metric tonne yr−1 | (S-30) |
|  |  |

S-3.5 Egg Layers’ Uncertainty

To derive egg layers’ uncertainty, we again first estimate and (inventory and per bird feed intake). For the egg layer inventory we use ≈ 2.9 million egg layers (estimated from year-to-year variability over 2002–2011). Per bird layer feed intake uncertainty is based on various estimates (Smil, 2001; USDA National Agricultural Statistics Service, 2011a) resulting in ≈ 11 kg DM per head per year. Finally, we use equation S-28 (assuming the inventory variability is independent of per bird feed intake variability) to combine the individual uncertainties, obtaining ≈ 3 million metric tonne yr−1 overall egg layers’ feed consumption standard deviation.

S-3.6 Dairy Uncertainty

For dairy cow inventory we use ≈ 0.1 million cows (estimated from year-to-year variability over 2002–2011). For dairy cow’s 632 kg mean body weight and 3.05% of body mass in daily feed requirements we assume ±10% uncertainty. Since feed consumption for dairy cows (g,V) =365 · (g,I) · (g,IV). Hence,

|  |  |
| --- | --- |
|  | (S-31) |
| million metric tonne DM yr−1. |  |

To estimate feed consumption uncertainty of dairy’s heifers, we need individual uncertainty estimates for its contributing terms. Recall that heifers’ daily feed requirements are (h,IV) = 2% day−1 · 278 kg. Consequently, (h, V) ≈ (h,I) · (0.02 · 278) · 365. For heifers’ 2 % specific feed requirements and 278 kg mean weight, we use the ±10% variability assumption, and for their 4.3 million headcount we use observed interannual variability, ±0.2 million heads. This yields

|  |  |
| --- | --- |
|  | (S-32) |
| million metric tonne DM yr−1. |  |

For dairy bulls, we use the ±10% variability assumption throughout yielding ≈ 0.1 million metric tonne DM yr−1. Combining these three uncertainties yields dairy’s overall feed requirement uncertainty,

|  |  |
| --- | --- |
| million metric tonne yr-1 | (S-33) |

S-3.7 Beef Uncertainty

For cow beef (i,V),

|  |  |  |
| --- | --- | --- |
|  | (S-34) | |
| million metric tonne DM yr−1 | |  | |

in which 32.3 = (i,I) and 0.7 million are beef cows’ mean inventory and its data base uncertainty (estimated from year-to-year variability over 2002–2011), 0.0225 and 0.00225 are beef cows’ feed conversion efficiency mean and uncertainty, and 459 = (i,II) and 46 kg are beef cows’ mean body mass and its data based variability –assuming ±10% variability in both cases.

For non-cow beef (j,V),

|  |  |
| --- | --- |
| million metric tonne DM yr−1 | (S-35) |

where 49.5 = (j,I) and 0.8 million heads are non-cow beef’s mean inventory and its data based uncertainty (estimated from year-to-year variability over 2002–2011), 8.9 and 0.9 kg feed (head ·day)−1 are non-cow’s mean feed per head-day and its uncertainty, again assuming ±10% variability.

Combining these individual uncertainties according to equation S-26 yields

|  |  |
| --- | --- |
| million metric tonne DM yr−1 | (S-36) |

S-4 Corn Fertilizer Use Statistics

S-4.1 Total U.S. Livestock Related Corn Fertilization

Recent years’ (2000–2010) annual fertilizer use for U.S. corn has been (USDA Economic Research Service, 2011b) (45±4)×108 kg nitrogen (mean and interannual standard deviation), 40%±3% of total U.S. N fertilizer consumption; (16±2)×108 kg phosphate, 41%±4% of total U.S. phosphate consumption; and (17±2 )×108 kg potash, 40%±4% of U.S. total potash consumption.

During the same period, domestically used corn feed represented 46%±7% of the total U.S. corn production (USDA Economics Research Service, 2012). Modifying the above fertilizer use data by this fraction yields table S-2’s row a, corn feed fertilizer use.

S-4.2 Corn Fertilizer Energy Use

Global manufacturing energy cost estimate averages are approximately 70, 7 and 7 MJ per kg of N fertilizer, phosphate and potash, respectively (Gellings & Parmenter, 2004), becoming ≈ 79, 19 and 14 MJ kg-1 at the farm gate (Gellings & Parmenter, 2004). Slightly lower farm gate values are also reported specifically for the U.S. corn belt (Kim & Dale, 2003), with the means and variability values from the above sources shown in table S-2’s row b. Multiplying row a’s application rates by row b’s energy costs yields row d’s total national annual corn fertilization related energy costs.

**Table S-2:** Summary of the corn fertilization data and calculations discussed in the text. Values to the right of the “±” signs are standard deviations.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | N | phosphate | potash | sum |
| a: | use [108 kg yr-1] | 20±4 | 7±1 | 8±1 |  |
| — per kg nutrient (N, P2O5 or K2O, respectively) — | | | | |  |
| b: | energy [MJ] | 60±25\* | 18±1\* | 12±3\* |  |
| c: | GHG† [kg CO2eq ] | 2.1±0.6‡ | 1.3±0.2§ | 0.6±0.1§ |  |
| — nationally per year — | | | | |
| d: | energy [1015 J] | 123±55 | 14±2 | 9±3 | 146±56 |
| e: | GHG† [108 kg CO2eq] | 43±14 | 9±2 | 5±1 | 57±15 |

†Emissions: full life, CO2 & non-CO2 greenhouse gasses (GHGs).

\*Derived from the disparity between the sources (Gellings & Parmenter, 2004; Kim & Dale, 2003).

§Upward rounded assumed 10% variance, in the absence of variance data.

‡Somewhat liberally estimated, to reflect byproduct CO2 recapture uncertainty, see text.

S-4.3 Corn Fertilizer GHG Emissions

In the U.S. corn belt, these emissions are approximately 3.3, 1.3 and 0.6 kg CO2 equivalent (hereafter CO2eq) per kg of N, P2O5  and K2O, respectively (Kim & Dale, 2003), with the added complication that for some N fertilizer manufactured in developed nations’ plants in which byproduct CO2 produced in the manufacturing chemical reactions is captured and used, emissions drop to 1 kg CO2eq per kg N. Since we were unable to locate quantitative information about the scope of this practice, we represent its existence by a relatively large assumed uncertainty,±0.6 kg CO2eq (kg N) −1 or almost 30% of the 2.1 kg CO2e (kg N)−1 mean, in table S-2’s row c. Likely more important than the direct emissions—and not addressed here because of their very high uncertainty—are indirect effects on soil C sequestration (Blevins et al., 1977; Gregorich et al., 1996). Multiplying row a’s application rates by row c’s GHG emission costs yields row e’s national total annual corn fertilization related GHG emissions.

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