Supplementary Materials

Title: The nitrogen footprint of organic food in the United States

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SM Introduction

Agricultural production methods vary in terms of their Nr efficiency and therefore are key determinants of Nr losses to the environment. Conventional crop agriculture is typically characterized by intensive, monoculture production that requires high inputs (of synthetic fertilizer, pesticides, irrigation etc.), but produces high yields (USDA 2012). In contrast, organic production prohibits the use of synthetic fertilizers and other chemicals. Conventional animal production relies heavily on confined animal feed operations and processed feed consumption (USDA 2012). In contrast organic guidelines require that animals raised on organic farms have access to certified organic pasture for the entire grazing season, have diets that contain at least 30% dry matter intake from certified organic pasture, and that supplemental feed outside of grazing be certified organic (USDA 2000).

SM Methods

We have focused our description of methods mostly on those sections where modifications were made to the original N footprint calculation factors to represent organic food production (labeled 1 – 3 in Fig. 1). The N footprint of conventional food production was recently updated and calculated as described by Leach *et al* (submitted). The Nr loss associated with energy consumption during food production was not included here because of its very small contribution to a food N footprint (Leach *et al* 2012). The calculation of most Nr losses (with the exception of those described below) were assumed to be the same as conventional and are thus the same as described in the supplementary materials of Leach *et al* (2012, submitted).

N Loss C1 (crop production)

Organic yields from different studies were first used to estimate the total biomass of the plant (based on information on harvest index as well as moisture content for different crop groups; see Table S3 for parameters), and then the Nr in the whole plant (*Crop N Uptake*, Fig. 1; based on information on typical Nr contents of different crop products; see Table S3 for parameters) for each study. The proportion of Nr applied to the field that was not taken up by the whole crop plant then represents the Nr loss at this stage (i.e., N Loss C1).

Due to the limited availability of data on organic production, these data included both studies from within and outside the US but was limited to middle income (12% of studies) and high-income (88% of studies) countries. Studies that did not quantify all of the Nr inputs to the system (i.e. Nr in green manure) were excluded. Most studies include data from more than one year and some studies include data from many years. For the conventional VNFs, data is from state extension agencies on recommended Nr fertilizer application rates and reported annual yields in the USDA Census of Agriculture (Leach *et al* submitted, SM Methods).

Note that equations and some conversion factors used to calculate ‘N loss C1’ do not differ between organic and conventional VNFs; only the yield and Nr application observations and data sources differ (see SM Methods). In both cases, Nr loss was capped at 1 (i.e., 100% N uptake), since the VNF approach is a loss-based metric that tracks the loss of Nr inputs to the environment.

The following calculations were carried out for each observation from each study where data on yields (kg ha^{-1}) and Nr application rates (kg N ha^{-1}) was available (see Table S2 for sources). Nr inputs (kg N ha^{-1}) for each crop included green manures, biological nitrogen fixation (BNF), compost, animal manures and a few other minor sources. N inputs were averaged over the entire crop rotation. Average effects across the four different crop groups were then summarized using a random-effects model with study as the random factor (to control for non-independence between observations from the same study), and uncertainty around the average effect was calculated as 95% confidence intervals (CIs).

Step 1: Calculation of crop residue biomass

$$Crop\ Residue\ = Yield\ *\ Residue\!:\!Yield\ Ratio \qquad \textbf{Eq. 1}$$

with *Crop Residue* as crop residue biomass (kg ha^{-1}), *Yield* as harvested biomass (kg ha^{-1}) data from literature review (see Table S1 for sources and Table S2 for observations), and *Residue: Yield Ratio* (kg yield/kg plant) from Table S3 (Smil 1999). Note that Residue: Yield Ratios including fresh yield data (wet) to dry residue. Therefore, *Yield* is wet and *Crop Residue* is dry.

Step 2: Calculation of crop residue and yield N content

$$Yield\ N\ = Yield\ N\ Content\ * Yield \qquad \textbf{Eq. 2}$$

with *Yield N* as total Nr in yield (kg N ha^{-1}), *Yield N Content* (%) from Table S3, and *Yield* as defined above. Note that *Yield* and *Yield N Content* are both for fresh (wet) weights.

Eq. 3

$$Residue\ N\ = Residue\ N\ Content\ * Crop\ Residue$$

with *Residue N* as total Nr in crop residues (kg N ha^{-1}), *Residue N Content* (%) from Table S3, and *Crop Residue* as defined above. Note that *Crop Residue* and *Residue N Content* are both on a dry weight basis.

Step 3: Calculation of N in whole plant

$$Crop\ N\ = Yield\ N\ + Residue\ N \quad \textbf{Eq. 4}$$

with *Crop N* as total Nr in whole plant (kg N ha^{-1}), *Yield N* and *Residue N*, as defined above.

Step 4: Calculation of proportion of N applied not taken up by the plant (**N loss C1**)

$$Crop\ N\ Uptake = \frac{Crop\ N}{N\ Applied} \quad \textbf{Eq. 5}$$

with *Crop N Uptake* as the proportion of Nr applied that is taken up by the plant (kg N in whole plant/kg N applied), *N Applied* (kg ha^{-1}) as Nr application rates averaged over crop rotation from literature review (see Table S1 for sources and Table S2 for observations) and *Crop N* (kg N ha^{-1}) as defined above. *Crop N Uptake* is a key parameter in the N footprint model (see Figure S1 for *Crop N Uptake* for organic and conventional crop products).

N loss C1 (i.e. the proportion of Nr applied not taken up by the plant, see Table 1, main text) then represents the inverse of *Crop N Uptake*, i.e.:

$$N\ Loss\ C1 = 1 - \ Crop\ N\ Uptake \quad \textbf{Eq. 6}$$

Because the virtual N factor is a loss-based metric, we assume here that soil organic Nr is at a steady state and does not change over time; it is possible that a full accounting of soil

N storage would lower the N footprint of organically produced foods (see Cattell Noll et al 2019 for a full discussion).

<u>N Loss C2 (crop production)</u>

The *Edible Crop N Uptake* (Fig. 1) was calculated for each observation from each study. Because *Residue: Yield Ratios* and Nr contents were assumed to be the same for organic and conventional production, each observation from the same crop type had the same *Edible Crop N Uptake*. When organic crops were grouped into group products (e.g. organic wheat and organic corn were combined into organic grains), the lowest and the highest values for *Edible Crop N Uptake* were used as the high and low inputs for the calculation of the VNF confidence intervals.

Step 1: Calculation of proportion of Nr in whole plant that is harvested

$$Edible\ Crop\ N\ Uptake = \frac{Yield\ N}{Crop\ N} \qquad \textbf{Eq. 7}$$

with *Edible Crop N Uptake* as proportion of Nr in whole plant that is harvested (kg N in yield/kg N in whole plant), *Yield N* (kg ha^{-1}) and *Crop N* (kg N ha^{-1}) as defined above. Note that what we call *Edible Crop N Uptake* is often referred to as a N Harvest Index (kg N in yield/kg N in the whole plant) and represents the ratio of Nr in the yield to Nr in the whole plant (Smil 1999). This is in contrast to a Harvest Index, which is on a mass basis (kg in yield/kg in the whole plant). The proportion of Nr in whole plant that is not harvested (i.e. crop residue N) then represents the inverse of *Edible Crop N*.

Step 2: Calculation of the portion of Nr in residue that is recycled

Recycling of Nr in crop residues during organic and conventional crop production was estimated based on literature sources (see Table S4 for sources and recycling rates).

Eq. 8

Estimates of Nr crop residue recycling were used for crop residue recycling of feed products as well as crop products (see Table S4).

$$Recycled\ N\ = (1 - Edible\ Crop\ Uptake) * Recycling\ Rate$$

with *Recycled N* (kg N ha^{-1}) added back into the *Applied N* in the VNF calculation (and therefore, not considered to be a loss), *Recycling Rate* (%) as the portion of Nr that is in crop residue that later becomes plant available and *Edible Crop Uptake* as previously defined.

Again, only the data for residue recycling rate parameters (see Table 1) differed between organic and conventional VNFs, while equations used did not.

N loss C2 (i.e. the proportion of crop residue Nr that is not recycled) is then determined by the recycling rate (see Table 1, main text and Table S4), which determines how much of the proportion of Nr in whole plant that is not harvested is recycled versus lost from the system (e.g. through residue burning).

$$N\ Loss\ C2 = (1 - \ Edible\ Crop\ Uptake) - Recycled\ N \qquad \textbf{Eq. 9}$$

Legume N uptake

Legume calculations for the whole plant Nr uptake were adapted to reflect biological N fixation (BNF). Literature sources suggest that typical legumes (like soybeans) receive approximately 60% of their Nr from BNF, while 40% of their N uptake derives from soil Nr (Salvagiotti *et al* 2008). For both organic and conventional legumes, we used these estimates to calculate Nr derived from BNF versus Nr derived from soil uptake, based on the Nr in the whole legume plant.

Total Nr applied then equals these inputs plus any additional external Nr applied during legume growth (which is typically negligible, as farmers typically do not fertilize legumes). This approach assumes that during legume growth there occurs a net loss of Nr in the soil (that can be counterbalanced by Nr application) and that the Nr benefits of legumes only occur for the crop following the legume after part of the legume biomass (i.e. crop residues) has been re-incorporated into the soil.

Step 1: Calculation of proportion of Nr in legume derived from BNF versus soil

$$Legume\ N\ Fixation\ = Crop\ N * 0.6 \quad \textbf{Eq. 10}$$

$$Legume\ N\ from\ Soil\ = Crop\ N * 0.4 \quad \textbf{Eq. 11}$$

with *Legume N Fixation* (kg N ha-1) as the estimated amount of Nr fixed by the legume, *Legume N from Soil* (kg N ha-1) as the estimated amount of Nr taken up from the soil by the legume, and *Crop N* (kg N ha-1) as defined above (see Table S1 for sources).

Step 2: Calculation of proportion of Nr applied taken up by the legume plant

$$Legume\ N\ Uptake = \frac{Crop\ N}{N\ Applied + Legume\ N\ Fixation + Legume\ N\ from\ Soil} \quad \textbf{Eq. 12}$$

with *Legume N Uptake* as the proportion of Nr applied that is taken up by the legume plant (%), *Crop N* (kg N ha-1) as defined above, *N Applied* (kg ha-1) as Nr application rates averaged over crop rotation from literature review (as defined above) and *Legume N Fixation* (kg N ha-1) and *Legume N from Soil* (kg N ha-1) as defined above (see Table S1 for sources and Table S2 for observations).

N loss A1 and A2 for animal feed

To estimate the amount of Nr lost during the production of feed for organic livestock we calculated weighted values for **N loss A1** and **N loss A2**, as well as *Crop N Uptake* and *Edible Crop N Uptake* based on the diet composition and N content of different livestock types. Data on diet composition derived from a literature review of peer-reviewed studies (see Table S6 for a list of sources) was summarized for each livestock type (see Table S5 for details on resulting diet composition). Weighting was based on the portion of Nr in diet from each diet component and not on the portion of mass. Table 2 (in main text) shows the *Crop N Uptake* (i.e. proportion of Nr applied that is taken up by crop) for each livestock type based on diet composition of different livestock types and organic crop VNFs.

Organic standards in the U.S. require that 30% of the diet of an organic cow (for beef or dairy production) comes from grazing (USDA 2011). Therefore, the analysis of organic animal VNFs required an estimate of Nr loss during plant growth for pasture systems. We used data from state extension services on conventional hay production in the U.S. including yield and Nr application rates to calculate an estimated pasture Nr uptake.

N Loss A3 (animal production)

The following calculations were carried out for each observation from each study where data on Feed Conversion Ratio (FCRs) (or feed efficiency ratios, FERs for dairy) was available or could be calculated. Data across different studies was again summarized using a random-effects model with study as the random factor (to control for non-independence between observations from the same study), and uncertainty around the average *Live Animal N Uptake* was calculated as 95% CIs for each livestock type.

Step 1: Calculation of Live Animal N Uptake

$$Live\ Animal\ N\ Uptake\ = \frac{1}{FCR} * Live\ Animal\ N\ Content * \frac{1}{N\ Content\ of\ Feed} \qquad \textbf{Eq. 13}$$

with *FCR* (kg feed kg gain^{-1}) as Feed Conversion Ratio (for meat products) from literature review (see Table S1 for sources and Table S8 for observations), *Live Animal N*

Content (kg N in animal kg animal^{-1}) as the Nr content of the live animal at slaughter (from Table S7) and *Feed N Content* (kg N in feed kg feed^{-1}) as the Nr content of the animal's feed weighted based on the composition of the diet (based on diet composition data from Table S6 and crop Nr content data from Table S3).

For pigmeat, beef and dairy, this calculation was adjusted to account for Nr intake during nursing (which is typically not included in FCRs):

Step 1: Calculation of Nr in live animal

$$Live\ Animal\ N\ = Animal\ Weight\ Gained\ * Live\ Animal\ N\ Content \quad \textbf{Eq. 14}$$

with *Live Animal N* as the total mass of Nr gained in the live animal at slaughter (kg N), *Animal Weight Gained* (kg) as the live animal weight gained from birth to slaughter (from Table S1 for sources), and *Live Animal N Content* as previously defined.

Step 2: Calculation of Nr in feed consumed

$$Feed\ N\ = Animal\ Weight\ Gained\ * FCR * \ Feed\ N\ Content \quad \textbf{Eq. 15}$$

with *Feed N* (kg N) as the total Nr consumed throughout the animal's life, *Animal Weight Gained* as defined above, *FCR* (kg feed kg gain^{-1}) as Feed Conversion Ratio (for meat products) from literature review (see Table S1 for sources and Table S8 for observations) and *Feed N Content* as previously defined.

Step 3: Calculation of Nr consumed during nursing

$$Nursing\ N\ \ = Milk\ Consumed\ * N\ Content\ of\ Milk \quad \textbf{Eq. 16}$$

with *Milk Consumed* (kg N) as the total mass of milk (or milk substitute) consumed before weaning, Nr Content of Milk (%) as the N content of milk or milk substitute and *Nursing N* (kg N) as the total Nr consumed during nursing.

Step 4: Calculation of proportion of Nr consumed over an animal's lifespan not converted to live animal mass (**N loss A3**)

$$Live\ Animal\ N\ Uptake = \frac{Live\ Animal\ N}{Feed\ N + Nursing\ N} \qquad \textbf{Eq. 17}$$

with *Live Animal N Uptake* as proportion of Nr in feed that is converted to live animal mass (kg N gained/kg N consumed), *Live Animal N* (kg N) and *Feed N* (kg N) as defined above. *Live Animal N Uptake* is a key parameter in the N footprint model (see Figure S2 for *Live Animal N Uptake* for organic and conventional meat products).

For dairy, the *Live Animal N Uptake* was replaced with *Animal Product N Uptake* calculation as:

$$Animal\ Product\ N\ Uptake\ = Milk\ Production\ * 1/FER *\ Feed\ N\ Content \qquad \textbf{Eq. 18}$$

with *Milk Production* (kg energy corrected milk) as the total milk produced over the lifetime of the animal, *FER* (kg energy corrected milk kg dry matter intake^{-1}) as Feed Efficiency Ratio (for dairy) from literature review (see Table S1 for sources and Table S9 for observations), and *Feed N* and *Feed N Content* as previously defined.

N loss A3 (i.e. the proportion of Nr consumed not converted to live animal mass, see Table 1, main text) then represents the inverse of *Live Animal N Uptake*, i.e.:

$$N\ Loss\ A3 = 1 -\ Live\ Animal\ N\ Uptake \qquad \textbf{Eq. 19}$$

Uncertainty in VNFs

Uncertainties around overall crop and animal VNFs (i.e. including losses during the food processing and consumption stage, which are not described in more detail here as they do not differ from the calculations described by Leach *et al.* 2012) were calculated by using the lower and upper values of individual key parameters (see above for how uncertainties around parameters were calculated). The higher range of the organic grains VNF represents, for example, the VNF calculated with the lower values (i.e. lower CI) for grain *Crop N Uptake* as well as the lower values (i.e. lower range) for grain *Edible Crop N Uptake*. Uncertainty around organic crop VNFs thus represents an estimate of the lower and higher efficiencies (across different primary studies for *Crop N Uptake*) in each crop group. Note that for conventional VNFs CIs around *Crop N Uptake* were calculated based on weighted averages (and weighted standard deviation) across data from different states and ranges around overall VNFs were calculated using lower and higher efficiencies (i.e. lower and higher CIs) across different states.

Similarly, uncertainty around organic animal product VNFs then represents the high and low VNF based on the lowest efficiencies (i.e. low CI or low range) and highest efficiencies (i.e. high CI or high range) respectively at each of the three steps where uncertainty around parameters estimates could be calculated, i.e. during *Crop N Uptake*, *Edible Crop N Uptake* (see description of how CIs and ranges for crop parameters were calculated above), as well as *Live Animal N Uptake*. For conventional animal VNFs, FCRs from the literature were used to estimate *Live Animal N Uptake*. Uncertainty around conventional animal VNFs was calculated using high and low efficiencies (ie. high and low 95% CIs) during *Crop N Uptake and Live Animal N Uptake*.

New N versus recycled N in pasture systems

Rates of recycled versus new Nr applied to pastures were estimated based on average BNF in pastures (Legard et al 2001, Table S10) and on estimates of Nr inputs from manure. BNF is considered a new Nr source and manure is considered a recycled Nr source.

Calculation of Nr inputs from manure:

$$N\ Manure = Stocking\ Rate * Manure\ Production * Manure\ N\ Content \quad \textbf{Eq. 20}$$

with *N Manure* (kg N ha^{-1}) as total Nr inputs to pasture from manure, *Stocking Rate* as the number of livestock units (LSU) per unit area (LSU ha^{-1}) from Table S10, *Manure Production* as the annual manure produced per livestock unit (kg LSU^{-1}) from Table S10, and *Manure N Content* (%) as percent Nr content of the manure on a wet basis from Table S10.

N New versus recycled N for crop and animal feed

Sources for new and recycled Nr are listed in Table S11. Input types were categorized as described in the main text. Average Nr inputs by type (%) for organic and conventional crop and animal products are listed in Table S12. Both organic and conventional animal data is scaled (from crop inputs) by diet composition (see Table S6 for diet composition data). The calculations of Nr input types for animal products assume that different types of N sources move through the food production system (e.g. are taken up by crops; Figure 1) at the same rate.

Conventional VNFs and N Losses

Conventional VNF parameters (*Crop N Uptake, Animal N Uptake* etc.) were calculated as described above for organic (Leach et al. 2018). Data on conventional crop yields (kg) was found using USDA reports (see Leach et al. 2018 for sources). As described above, these data were used with data on crop Nr content (see Table S3) and Nr application rates (see Leach et al. 2018 for sources) to calculate the *Crop N Uptake* for conventional production. Nr application rates were estimated based on state extension recommendations; in reality, N application rates may or may not reflect recommended N applications and there is likely to be a huge amount of variation. In combination with percent Nr data (see Table S7), conventional FCRs were used to calculate Animal Nitrogen Uptake (kg N gained kg N consumed^{-1}) for conventional animal production, as described above (see Leach et al. 2018 for sources).

SM Results

For crop production, the organic N footprint is 2.9 – 6.3 kg N year^{-1} for a consumer versus 3.0 – 4.5 kg N year^{-1} for a consumer eating only conventional products (Fig 3.). For meat and animal products (excluding beef), the organic N footprint is 11 – 21 kg N year^{-1} for a consumer versus 11 – 16 kg N year^{-1} for a consumer of conventional products (Fig. 3). For beef production, the organic N footprint is 17 – 25 kg N year^{-1} for a consumer, while the conventional N footprint is 7.4 – 11 kg N year^{-1} (Fig. 3).

SM Discussion

Organic vs. Conventional Crop Production

Nr in synthetic fertilizers is directly available for crops, while Nr in organic amendments is typically bound in organic Nr and first needs to be decomposed into plant-available Nr forms by soil microbes; although this varies depending on the organic amendment.

Organic systems can differ quite widely in Nr application rates (Table S2), as well as their NUEs (Fig. S1), depending on whether they mostly rely on external Nr inputs (like organic amendments or organic fertilizers) or Nr from BNF (i.e. legume-based systems) (Alaru *et al* 2014, Korsaeth and Elthun 2009, Riahi *et al* 2009). Direct comparisons of animal manure and compost versus legume-based systems are rare, and our understanding of Nr processes in these systems is limited. But there are numerous reasons that could potentially explain the improved NUE in plant-based systems. Improved NUE depends on synchrony between crop Nr demand and Nr supply, as well as the amount of Nr applied (Cassaman *et al* 2002). Legume-based systems could thus have a higher NUE simply because they often receive lower amounts of Nr inputs. However, some evidence also suggests that legume-based systems could have better nutrient synchrony, as crop growth and organic matter decomposition are governed by the same environmental factors (i.e. temperature and moisture) (Crews and Peoples 2005). Another potential explanation is that the ratios of nutrients in legumes and cover crops is closer to that of the crops harvested than that of composts and animal manures (which often leads to accumulation of Nr when trying to match crop P demand with animal manures and composts) (Edmeades 2003, Nelson and Janke 2007).

Although organic yields are, on average, lower than conventional yields, they can, under some circumstances, almost reach the levels of conventional agriculture (De Ponti *et al* 2012, Ponisio *et al* 2012, Seufert *et al* 2012). Improving yields in organic production and addressing non-Nr-related factors that currently limit organic yields (e.g. pest outbreaks, or the lack of crop varieties adapted to organic systems) is thus also very important for improving the Nr use efficiency of organic systems.

Organic vs. Conventional Animal Production

For conventional production of beef, the rate of efficiency is determined by the feed mixture (which is dominated by nursing in the early production stages and corn grain in the later production stages) and the feed conversion ratios. Conventional corn production is relatively efficient as compared to production of organic feed components, leading to lower Nr losses from the production of conventional beef and dairy feed (Leach *et al* submitted). In conventional beef systems, greater efficiencies in both food production and in conversion of feed to product, result in fewer Nr losses per unit Nr in product as compared to organic production.

Rates of Nr Recycling

Currently recycling rates of Nr in the food system are rather low. Typically, only a very small fraction of Nr in the food supply is recycled for agricultural use (Faerge *et al* 2001, Forkes 2007), but some studies have estimated that recycled Nr sources could potentially replace considerable portions of the current mineral fertilizer use (Smil 1999), especially if sewage and municipal waste are re-used for food production (Faerge *et al* 2001, Magid *et al* 2006).

While organic agriculture provides an important step towards increased Nr recycling, organic standards would need to be revised to allow the use of sewage sludge as fertilizer in order to further optimize Nr recycling rates (Singh and Agrawal 2008). In addition, the potential risks associated with widespread land application of human waste would need to be addressed. Another point that could enhance Nr recycling in organic agriculture would be to support the increased integration of crop and animal systems, e.g., as proposed by the revision of the EU organic standard (EU 2014).

Limitations and Uncertainties

The fertilizer application rates for conventional agriculture were recommended application rates from U.S. extension services (Leach *et al* submitted). These values represent the best practices in conventional production but may or may not represent typical Nr application rates by conventional farmers, which in practice are often higher (Yadav *et al* 1997). Similarly, the Nr application rates for organic are from studies that could represent best management practices or excess application, depending on the focus of the study.

Surveys of US farmers suggest that 40% of both organic and conventional farmers use conservation tillage practices, which leave at least 1/3 of the soil covered with crop residues after planting (NCRMS 2008, USDA 2014). Whether organic farmers thus actually leave more crop residues in the field than conventional farmers is not certain. Some of the Nr not recovered in the harvest could be accumulated in the soil rather than lost from the system. Organically managed soils also often have higher mineralization rates from increased microbial and mycorrhizal activity, as well as higher soil disturbance from increased tillage (Monokrousos *et al* 2006, Doltra *et al* 2010, Williams and Hedlund 2013).

Finally, we did not estimate uncertainty in several parameters, including crop and animal Nr content, harvest index factors, and moisture content (which did not differ between organic and conventional calculations) or feed composition (which did differ between organic and conventional calculations). Instead, we used central tendency values from the scientific literature or industry experts (see SM Methods).

Notwithstanding these challenges, our analysis is robust and represents the best state-of-the-art estimate of Nr loss in organic versus conventional food production for the U.S., as it is based on an extensive literature review, the first of its kind for organic production, and includes an assessment of uncertainty in the production steps that contribute most to Nr losses.

Table S1. Complete list of data sources for the calculation of the organic virtual nitrogen factors (VNFs). In some cases, a single paper had data for more than one crop or animal product. Each paper contributed a minimum of one observation. In some cases, a single paper contained a dozen or more observations.

		Organic Crop Products				Organic Animal Products			
Author	Year	Grains	Legumes	Starchy Roots	Vegetables	Poultry	Pigmeat	Beef	Dairy
Almeida et al.	2012					X			
Appireddy et al.	2008				X				
Aronsson et al.	2007	X							
Bartova et al.	2013			X					
Basset-Mens and van der Werf	2005						X		
Berthiaume et al.,	2006							X	
Bosco et al.	2011					X			
Bulluck et al.	2002	X			X				
Castellini et al.,	2002					X			
Cavigelli et al.	2009		X						
Cho et al.,	2009							X	
Citak & Sonmez	2010				X				
Cobanoglu et al.	2014					X			
Creamer et al.	1996				X				
Dal Bosco et al.,	2014					X			
Del Amor	2006				X				
Delate & Cambardella	2004		X						
Efthimiadou et al.	2009	X							
Eriksson et al.,	2009					X			
Esterhuizen et al.,	2008							X	
Fanatico et al.	2009					X			
Fernandez and Woodward	1999							X	
Fiorillo et al.	2005			X					
Gabriel et al.	2013	X							
Gelfand et al.	2010		X						
Gopinath et al.	2008	X							
Grela et al.,	2012						X		

Guerci et al.,	2013								X
Hansen et al.,	2006						X		
Hermansen et al	2004					X			
Khalili et al.,	2002								X
Kirchmann et al.	2007	X							
Kristensen and kristensen	1998								X
Lee et al.,	2009							X	
Liebhardt et al.	1989		X						
Lotter et al.	2003	X	X						
LTRAS, UC Davis		X			X				
Maeder et al.	2002	X		X					
Maggio et al.	2008			X					
Martini et al.	2004	X			X				
Millet et al.,	2004						X		
Moccia et al.	2006				X				
Mogensen et al.,	2007								X
Mortiz et al.,	2005					X			
Olsson et al	2014						X		
Pezzarossa	1995	X							
Porter et al.	2003	X	X						
Riahi et al.	2009				X				
Rodenburg et al.,	2008					X			
Sehested et al.,	2003								X
Simiz et al.,	2012					X			
Steinshamn et al	2004								X
Strudsholm and Hermansen	2005						X		
Teasdale et al.	2007	X							
Thanner et al	2014								X
Thomassen et al.,	2008								X
Trydeman Knudsen et al.	2010		X						
Varis et al.	1996			X					
Warman & Havard	1998	X		X					

Table S2. Complete list of N application and N yield data for organic crop products collected via a literature review. N applied (kg N ha^{-1}) is the sum of all nitrogen added to the field. N applied (kg N ha^{-1}) to legumes accounts for estimated fixation (see SM Methods). If a study design included a crop rotation, N applied (kg N ha^{-1}) was averaged over the entire crop rotation. Yields (kg ha^{-1}) may be averaged over several years. These literature values were used, in combination with harvest index values and N content data (see Table S3), to calculate whole plant N uptake for each observation. Data location indicates where yield data was reported in each study.

Author	Year	Crop Product	N Applied (kg N ha^{-1})	Yield (kg ha^{-1})	Data Location
Appireddy et al.	2008	Vegetables	190	18410	Table 2
Appireddy et al.	2008	Vegetables	190	18550	Table 2
Appireddy et al.	2008	Vegetables	190	19480	Table 2
Appireddy et al.	2008	Vegetables	190	20900	Table 2
Appireddy et al.	2008	Vegetables	190	23150	Table 2
Aronsson et al.	2007	Grains	49	1630	Table 5
Bartova et al.	2013	Starchy Roots	464	20200	Table 2
Bulluck et al.	2002	Grains	69	2530	Table 6
Bulluck et al.	2002	Vegetables	103	6320	Table 6
Bulluck et al.	2002	Vegetables	44	3950	Table 6
Bulluck et al.	2002	Vegetables	104	14350	Table 6
Bulluck et al.	2002	Vegetables	113	28070	Table 6
Bulluck et al.	2002	Vegetables	69	32820	Table 6
Citak & Sonmez	2010	Vegetables	150	7200	Table 4
Citak & Sonmez	2010	Vegetables	150	8300	Table 4
Citak & Sonmez	2010	Vegetables	150	8300	Table 4
Citak & Sonmez	2010	Vegetables	150	8400	Table 4
Citak & Sonmez	2010	Vegetables	150	8600	Table 4
Citak & Sonmez	2010	Vegetables	150	8800	Table 4
Citak & Sonmez	2010	Vegetables	150	8900	Table 4
Citak & Sonmez	2010	Vegetables	150	8900	Table 4
Citak & Sonmez	2010	Vegetables	150	9000	Table 4

Citak & Sonmez	2010	Vegetables	150	9600	Table 4
Citak & Sonmez	2010	Vegetables	150	9700	Table 4
Citak & Sonmez	2010	Vegetables	150	10000	Table 4
Citak & Sonmez	2010	Vegetables	150	10500	Table 4
Citak & Sonmez	2010	Vegetables	150	10500	Table 4
Citak & Sonmez	2010	Vegetables	150	11900	Table 4
Citak & Sonmez	2010	Vegetables	150	12100	Table 4
Citak & Sonmez	2010	Vegetables	150	12100	Table 4
Creamer et al.	1996	Vegetables	360	34800	Table 3
Creamer et al.	1996	Vegetables	360	36400	Table 3
Creamer et al.	1996	Vegetables	220	25300	Table 3
Creamer et al.	1996	Vegetables	220	26100	Table 3
Del Amor	2006	Vegetables	560	73300	Table 1
Efthimiadou et al.	2009	Grains	140	2804	Table 10
Efthimiadou et al.	2009	Grains	240	4905	Table 7
Efthimiadou et al.	2009	Grains	140	3353	Table 4
Efthimiadou et al.	2009	Grains	120	3795	Table 6
Efthimiadou et al.	2009	Grains	70	2802	Table 9
Efthimiadou et al.	2009	Grains	70	3354	Table 3
Efthimiadou et al.	2009	Grains	60	3267	Table 5
Efthimiadou et al.	2009	Grains	35	2681	Table 8
Fiorillo et al.	2005	Starchy Roots	200	49600	Table 2
Gabriel et al.	2013	Grains	150	4900	Table 1
Gabriel et al.	2013	Grains	150	5100	Table 1
Gabriel et al.	2013	Grains	150	4200	Table 1
Gopinath et al.	2008	Grains	150	3340	Figure 1
Gopinath et al.	2008	Grains	150	3720	Figure 1
Gopinath et al.	2008	Grains	120	3160	Figure 1
Gopinath et al.	2008	Grains	150	4000	Figure 1
Gopinath et al.	2008	Grains	120	3560	Figure 1
Gopinath et al.	2008	Grains	90	2740	Figure 1
Gopinath et al.	2008	Grains	120	3740	Figure 1
Gopinath et al.	2008	Grains	90	3090	Figure 1
Gopinath et al.	2008	Grains	90	3250	Figure 1
Gopinath et al.	2008	Grains	60	2290	Figure 1
Gopinath et al.	2008	Grains	60	2660	Figure 1
Gopinath et al.	2008	Grains	60	2660	Figure 1
Kirchmann et al.	2007	Grains	108	2105	Table 4
Kirchmann et al.	2007	Grains	108	4200	Table 4

Lotter et al.	2003	Grains	236	7107	Table 2
LTRAS, UC Davis		Grains	294	5905	http://ltras.ucdavis.edu/data
LTRAS, UC Davis		Vegetables	294	58059	http://ltras.ucdavis.edu/data
Maeder et al.	2002	Grains	99	3787	Figure 1
Maeder et al.	2002	Grains	93	3960	Figure 1
Maeder et al.	2002	Starchy Roots	99	30933	Figure 1
Maggio et al.	2008	Starchy Roots	200	5100	Figure 2
Maggio et al.	2008	Starchy Roots	150	4700	Figure 2
Maggio et al.	2008	Starchy Roots	200	18500	Figure 2
Maggio et al.	2008	Starchy Roots	50	6900	Figure 2
Maggio et al.	2008	Starchy Roots	150	23000	Figure 2
Maggio et al.	2008	Starchy Roots	200	33700	Figure 2
Maggio et al.	2008	Starchy Roots	150	34300	Figure 2
Maggio et al.	2008	Starchy Roots	50	13000	Figure 2
Martini et al.	2004	Grains	334	8780	Figure 1
Martini et al.	2004	Vegetables	299	73200	Figure 1
Martini et al.	2004	Vegetables	207	79260	Figure 1
Martini et al.	2004	Vegetables	115	66670	Figure 1
Moccia et al.	2006	Vegetables	45	1690	Table 6
Moccia et al.	2006	Vegetables	45	2170	Table 6
Moccia et al.	2006	Vegetables	30	1500	Table 6
Moccia et al.	2006	Vegetables	30	1690	Table 6
Moccia et al.	2006	Vegetables	45	3180	Table 6
Moccia et al.	2006	Vegetables	30	2520	Table 6
Moccia et al.	2006	Vegetables	45	5155	Table 4
Moccia et al.	2006	Vegetables	30	3829	Table 4
Moccia et al.	2006	Vegetables	11	1510	Table 6
Moccia et al.	2006	Vegetables	11	1530	Table 6
Moccia et al.	2006	Vegetables	11	2640	Table 6
Moccia et al.	2006	Vegetables	11	4366	Table 4
Pezzarossa	1995	Grains	325	9700	Table 8
Porter et al.	2003	Grains	156	6280	Figure 1
Porter et al.	2003	Grains	137	6120	Figure 1
Riahi et al.	2009	Vegetables	432	27600	Figure 1
Riahi et al.	2009	Vegetables	432	33000	Figure 1
Riahi et al.	2009	Vegetables	318	26000	Figure 1

Riahi et al.	2009	Vegetables	432	35500	Figure 1
Riahi et al.	2009	Vegetables	432	40500	Figure 1
Riahi et al.	2009	Vegetables	361	35000	Figure 1
Riahi et al.	2009	Vegetables	318	31800	Figure 1
Riahi et al.	2009	Vegetables	361	37000	Figure 1
Riahi et al.	2009	Vegetables	361	37500	Figure 1
Riahi et al.	2009	Vegetables	361	38700	Figure 1
Riahi et al.	2009	Vegetables	318	34500	Figure 1
Riahi et al.	2009	Vegetables	318	38000	Figure 1
Teasdale et al.	2007	Grains	161	4892	Table 3
Teasdale et al.	2007	Grains	161	2951	Table 3
Varis et al.	1996	Starchy Roots	159	23700	Figure 2
Varis et al.	1996	Starchy Roots	159	24000	Figure 2
Varis et al.	1996	Starchy Roots	159	26000	Figure 2
Warman & Havard	1998	Grains	200	7310	Table 6
Warman & Havard	1998	Starchy Roots	260	20990	Table 1

Table S3. Data and references used in calculations of N loss C1 and N loss C2 (see SI Methods for details on equations used). Note that these parameters are the same as used in conventional calculations (Leach et al. 2012, *updated*). Yield N content is on a wet basis and residue N content is on a dry basis.

Crop Product		Ratio of Residue: Yield	Yield N Content (%)	Residue N Content (%)
Grains	Corn	0.85[a]	1.2[b]	0.80[b]
	Wheat	1.3[a]	2.3[b]	0.75[b]
	Rice	0.87[a]	1.3[b]	0.85[b]
Vegetables	Tomato	0.16[a]	0.13[b]	0.19[b]
	Lettuce	0.16[a]	0.15[b]	0.19[b]
	Onion	0.16[a]	0.12[b]	0.19[b]
Starchy Roots		0.30[a]	0.31[b]	0.19[b]
Legumes		0.99[a]	5.5[b]	2.0[b]

[a] Smil 1999
[b]IPNI 4R Plant Nutrition Handbook

Table S4. Crop residue recycling rate for organic and conventional cropping systems. The recycling rate estimates the portion of N in total crop residues that is left on the field and later becomes plant available. Note that in actuality crop residue recycling is highly variable within both organic and conventional systems. For purposes of this study, we assumed a single recycling rate and did not take this variation into consideration in the VNF calculation.

Agricultural System	Recycling Rate	Source
Conventional Cropping	0.35	Leach et al 2012
Organic Cropping	0.5	Cavigelli et al 2008, Sarrantonio 2004

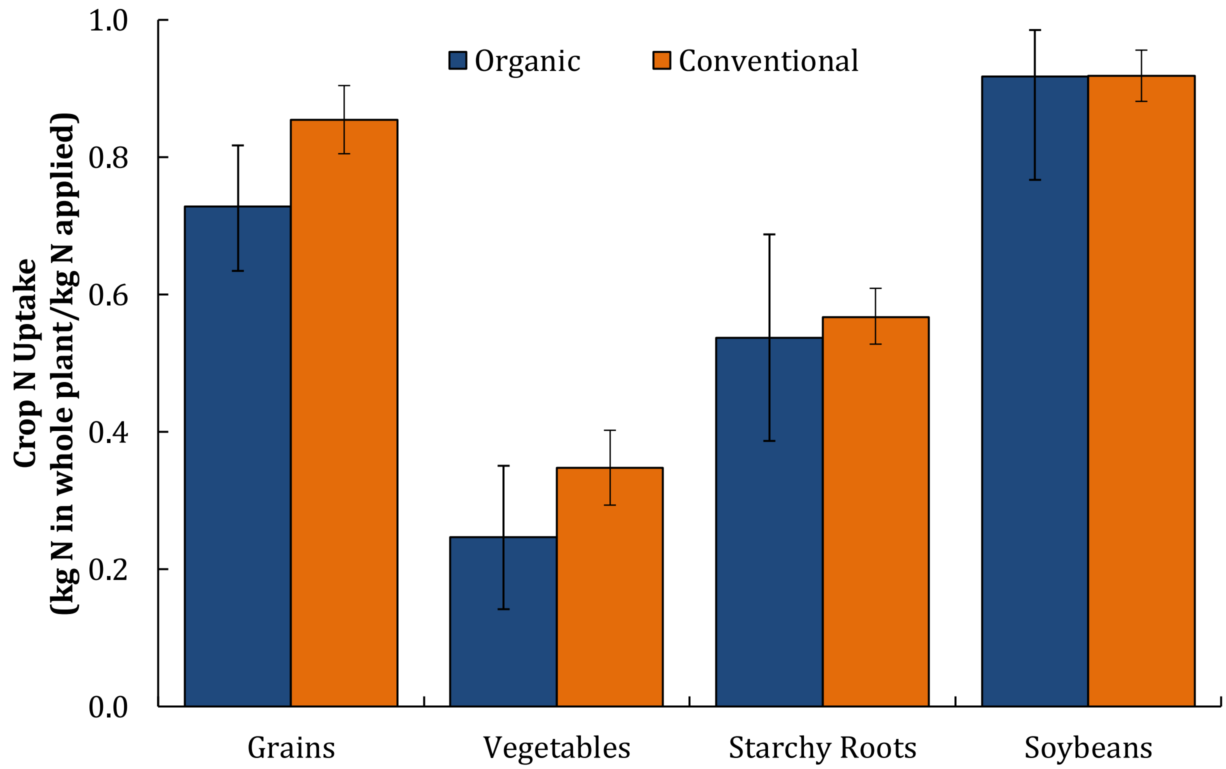

Figure S1. Crop N Uptake (kg N in whole plant/kg N applied) for organic and conventionally produced crop products, including grains, vegetables, starchy roots and soybeans. Crop N Uptake represents the proportion of N applied that is taken up by the plant (see equation 5) and thus represents an indicator of N use efficiency. This is a key parameter in the N footprint calculation.

Table S5. Complete list of data sources for the estimates of diet composition for organic animal production. Each paper contributed a minimum of one diet composition. In some cases, a single paper contained a dozen or more diets.

Author	Year	Animal Products			
		Poultry	Pigmeat	Beef	Milk
Berthiaume et al.,	2006			X	
Bjorklund et al.,	2014			X	
Bosco et al.	2011	X			
Castellini et al.,	2002	X			
Cederberg and Mattsson	2000				X
Cho et al.,	2009			X	
Dal Bosco et al.,	2014	X			
Eriksson et al.,	2009	X			
Esterhuizen et al.,	2008			X	
Fernandez and Woodward	1999			X	
Flaten and Lien	2009				X
Grela et al.,	2012		X		
Horsted et al.,	2010	X			
Khalili et al.,	2002				X
Lee et al.,	2009			X	
Marino et al.,	2006			X	
Millet et al.,	2004		X		
Mogensen et al.,	2007				X
Mortiz et al.,	2005	X			
Nielsen et al.,	2003				X
Rivera-Ferre et al.,	2006	X			
Rodenburg et al.,	2008	X			
Rosati and Aumaitre	2004				X
Sehested et al.,	2003				X
Simiz et al.,	2011	X			
Steinshamn et al	2004				X
Strudsholm and Hermansen	2005		X		
Thomassen et al.,	2008				X

Table S6. Average diet composition for organic animal products collected via a literature review (see TableS5 for list of sources). Diet composition is reported as a percentage of total mass consumed and as a percentage of total Nr consumed. Data were used to calculate weighted whole plant uptake and edible crop uptake for organic animal VNF calculation.

Animal Product	# of Obs.	# of Studies	Diet Composition (% of mass)			Diet Composition (% of N)		
			Grains (%)	Legumes (%)	Hay/Grazing (%)	Grains (%)	Legumes (%)	Hay/Grazing (%)
Poultry	67	9	63	37	-	36	64	-
Pigmeat	14	3	63	37	-	35	65	-
Beef	19	7	30	14	56	21	33	46
Milk	36	9	20	7.5	73	15	20	65

Table S7. Data and references used in calculation of N loss A3 (see SI Methods for details on equations used). Note that these parameters are the same as used in conventional calculations (Leach et al 2012, *updated*). N content of feed is weighted based on diet composition (see Table S6).

Animal Product	Weight N content of feed (%)	Live Animal N Content (%)	N Content of Animal Product (%)
Poultry	2.8[a]	2.3[b]	-
Pigmeat	2.9[a]	2.0[b]	-
Beef	2.3[a]	2.0[b]	-
Milk	2.1[a]	-	0.5[b]

[a]IPNI 4R Plant Nutrition Handbook, weighted based on diet (see Table S6)
[b]Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs (2003)

Table S8. Complete list of feed conversion ratios (FCRs) (kg feed kg gain^{-1}) for organic livestock collected via a literature review. In most cases, FCRs were directly reported; in a few cases FCRs were calculated based on reported feed consumption and weight gain. In combination with percent N data (see Table S7), FCRs were used to calculate *Live Animal N Uptake* (kg N gained kg N consumed^{-1}).

Author	Year	Livestock	Feed Conversion Ratio (kg feed kg gain^{-1})	Data Location
Almeida et al.	2012	Poultry	5.8	Table 1
Almeida et al.	2012	Poultry	5.3	Table 2
Basset-Mens and van der Werf	2005	Pigmeat	3.2	Table 3 and 4
Berthiaume et al.,	2006	Beef	6.3	Table 1, 4 and 5
Berthiaume et al.,	2006	Beef	7.1	Table 1, 4 and 5
Berthiaume et al.,	2006	Beef	7.1	Table 1, 4 and 5
Berthiaume et al.,	2006	Beef	11	Table 1, 4 and 5
Berthiaume et al.,	2006	Beef	9.1	Table 1, 4 and 5
Berthiaume et al.,	2006	Beef	7.7	Table 1, 4 and 5
Bosco et al.	2011	Poultry	3.9	Table 1 and 2
Bosco et al.	2011	Poultry	3.2	Table 1 and 2
Bosco et al.	2011	Poultry	3.9	Table 1 and 2
Bosco et al.	2011	Poultry	3.2	Table 1 and 2
Castellini et al.,	2002	Poultry	3.3	Table 4
Castellini et al.,	2002	Poultry	3.1	Table 4
Castellini et al.,	2002	Poultry	3.5	Table 4
Cho et al.,	2009	Beef	10	Table 2
Cho et al.,	2009	Beef	10	Table 2
Cho et al.,	2009	Beef	10	Table 2
Cobanoglu et al.	2014	Poultry	2.9	Table 1
Dal Bosco et al.,	2014	Poultry	2.7	Table 2
Dal Bosco et al.,	2014	Poultry	2.7	Table 2
Dal Bosco et al.,	2014	Poultry	2.8	Table 2
Dal Bosco et al.,	2014	Poultry	2.9	Table 2
Dal Bosco et al.,	2014	Poultry	2.9	Table 2
Dal Bosco et al.,	2014	Poultry	2.9	Table 2
Eriksson et al.,	2009	Poultry	2.9	Table 4

Eriksson et al.,	2009	Poultry	1.7	Table 4
Eriksson et al.,	2009	Poultry	1.7	Table 4
Eriksson et al.,	2009	Poultry	2.3	Table 4
Eriksson et al.,	2009	Poultry	2.1	Table 4
Eriksson et al.,	2009	Poultry	2.3	Table 4
Esterhuizen et al.,	2008	Beef	10	Table 3 and 5
Fanatico et al.	2009	Poultry	3.8	Table 1
Fanatico et al.	2009	Poultry	3.2	Table 1
Fanatico et al.,	2009	Poultry	2.4	Table 1
Fanatico et al.,	2009	Poultry	2.2	Table 1
Fernandez and Woodward	1999	Beef	7.6	Table 2, 3 and 5
Grela et al.,	2012	Pigmeat	3.2	Table 1 and 2
Grela et al.,	2012	Pigmeat	2.8	Table 1 and 2
Grela et al.,	2012	Pigmeat	2.4	Table 1 and 2
Grela et al.,	2012	Pigmeat	4.1	Table 1 and 2
Grela et al.,	2012	Pigmeat	3.9	Table 1 and 2
Grela et al.,	2012	Pigmeat	3.5	Table 1 and 2
Hansen et al.,	2006	Pigmeat	2.9	Table 1, 3 and 5
Hansen et al.,	2006	Pigmeat	2.5	Table 1, 3 and 5
Hansen et al.,	2006	Pigmeat	2.2	Table 1, 3 and 5
Hermansen et al	2004	Poultry	3.3	Table 5, 7 and 8
Hermansen et al	2004	Poultry	4.5	Table 5, 7 and 9
Lee et al.,	2009	Beef	8.2	Table 1 - 4
Lee et al.,	2009	Beef	11	Table 1 - 4
Millet et al.,	2004	Pigmeat	2.5	Table 1, 2 and 3
Millet et al.,	2004	Pigmeat	2.9	Table 1, 2 and 3
Millet et al.,	2004	Pigmeat	3.7	Table 1, 2 and 3
Mortiz et al.,	2005	Poultry	2.1	Table 4 and 5
Mortiz et al.,	2005	Poultry	2.1	Table 4 and 5
Mortiz et al.,	2005	Poultry	2.1	Table 4 and 5
Mortiz et al.,	2005	Poultry	2.1	Table 4 and 5
Mortiz et al.,	2005	Poultry	2.2	Table 4 and 8
Mortiz et al.,	2005	Poultry	2.4	Table 4 and 8
Mortiz et al.,	2005	Poultry	2.2	Table 4 and 8
Mortiz et al.,	2005	Poultry	2.3	Table 4 and 8
Olsson et al	2014	Pigmeat	3.2	Table 2 and 5
Olsson et al	2014	Pigmeat	3.1	Table 2 and 5
Olsson et al	2014	Pigmeat	2.6	Table 2 and 5
Olsson et al	2014	Pigmeat	2.7	Table 2 and 5

Rodenburg et al.,	2008	Poultry	2.6	Table 3
Rodenburg et al.,	2008	Poultry	2.6	Table 3
Rodenburg et al.,	2008	Poultry	2.7	Table 3
Simiz et al.,	2012	Poultry	2.1	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	1.8	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	1.8	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	2.8	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	2.9	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	2.7	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	2.9	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	2.7	Table 3, 5 and 6
Simiz et al.,	2012	Poultry	2.8	Table 3, 5 and 6
Simiz et al.,	2011	Poultry	2.7	Table 2 and 3
Simiz et al.,	2011	Poultry	3.7	Table 2 and 3
Strudsholm and Hermansen	2005	Pigmeat	2.8	Tables 1 - 3
Strudsholm and Hermansen	2005	Pigmeat	3.0	Tables 1 - 3
Strudsholm and Hermansen	2005	Pigmeat	3.0	Tables 1 - 3
Strudsholm and Hermansen	2005	Pigmeat	2.6	Tables 1 - 3
Strudsholm and Hermansen	2005	Pigmeat	3.2	Tables 1 - 3

Table S9. Complete list of feed efficiency ratios (FERs) (kg energy corrected milk (ECM) kg dry matter intake (DMI)$_{-1}$) for organic animal products collected via a literature review. In most cases, FERs were directly reported; in a few cases FERs were calculated based on reported feed consumption and milk production. In combination with percent N data (see Table S7, FERs were used to calculate Animal Product Nitrogen Uptake.

Author	Year	Animal Product	Feed Efficiency Ratio (kg ECM/kg DMI)	Data Location
Guerci et al.,	2013	Milk	0.9	Table 3
Guerci et al.,	2013	Milk	1.2	Table 3
Khalili et al.,	2002	Milk	1.4	Table 3 and 4
Khalili et al.,	2002	Milk	1.4	Table 3 and 4
Khalili et al.,	2002	Milk	1.4	Table 3 and 4
Khalili et al.,	2002	Milk	1.4	Table 3 and 4
Kristensen and Kristensen	1998	Milk	0.9	Table 5
Kristensen and Kristensen	1998	Milk	1.1	Table 5
Kristensen and Kristensen	1998	Milk	1.2	Table 5
Mogensen et al.,	2007	Milk	1.2	Table 2 and 5
Mogensen et al.,	2007	Milk	1.2	Table 2 and 5
Mogensen et al.,	2007	Milk	1.2	Table 2 and 5
Mogensen et al.,	2007	Milk	1.1	Table 2 and 5
Mogensen et al.,	2007	Milk	1.2	Table 2 and 5
Mogensen et al.,	2007	Milk	1.2	Table 2 and 5
Sehested et al.,	2003	Milk	1.0	Table 3 and 4
Sehested et al.,	2003	Milk	1.0	Table 3 and 4
Sehested et al.,	2003	Milk	1.1	Table 3 and 4
Steinshamn et al	2004	Milk	1.0	Table 1 and 2
Steinshamn et al	2004	Milk	1.1	Table 1 and 2
Steinshamn et al	2004	Milk	1.2	Table 1 and 2
Thanner et al	2014	Milk	2.0	Table 2
Thanner et al	2014	Milk	2.1	Table 2
Thomassen et al.,	2008	Milk	3.1	Table 5 and 1

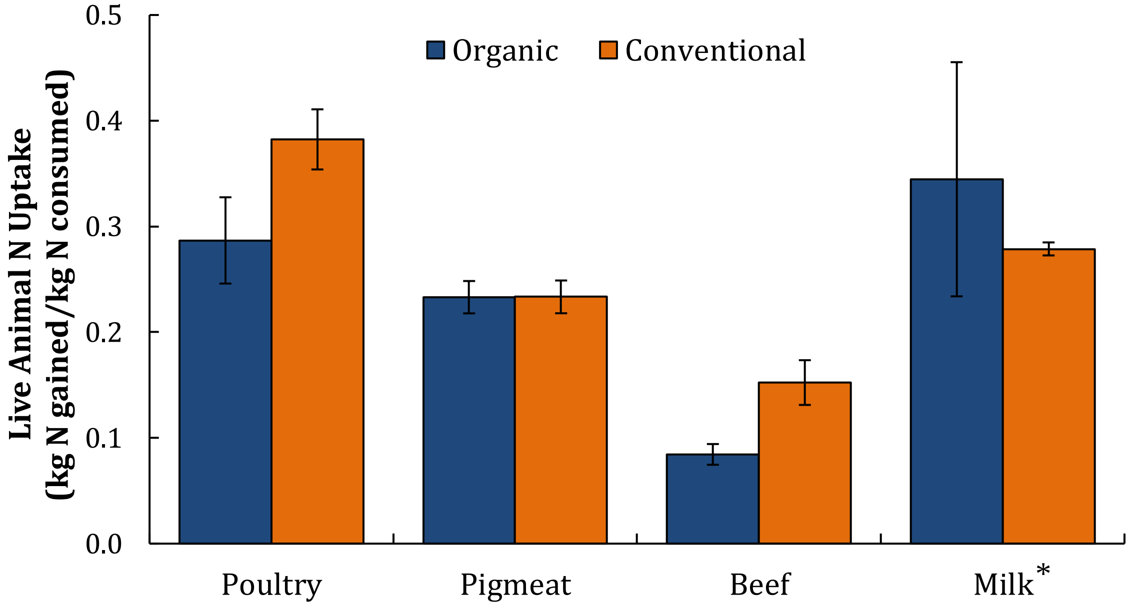

Figure S2. Live Animal N Uptake (kg N gained/kg N consumed) for organic and conventionally produced meat and animal products, including poultry, pigmeat, beef and *milk (kg N in milk/kg N consumed). Live Animal N Uptake is the total amount of N in the live animal at slaughter (or the total amount of N in the animal product) divided by the total amount of N consumed during the lifetime of the animal (including nursing for pigmeat, beef and milk) (see Eq. 18). Note milk is Animal Product N Uptake or the total amount of N in milk divided by the total amount of N consumed. This is a key parameter in the N footprint calculation.

Table S10. Data used to estimate New versus Recycled N inputs in organic pasture systems (see SI Methods for calculations).

Data Type	Observation	Units	Source
BNF	54	kg N ha^{-1}	Legard et al. 2001
Stocking Rate	1.2	LSU ha^{-1}	Dalgaard et al. 1998, Kamali et al 2014, Oleson 2006, Watson et al. 2002, Weller and Bowling 2004, Lynch et al. 2003
N content of manure	0.56%	% N (wet manure)	USDA 2016
Manure Production	12000	kg LSU^{-1}	USDA 2016

Table S11. Complete list of data sources for the estimates of N input types to crop products (new versus recycled N inputs). Each paper contributed a minimum of one observation. In some cases, a single paper contained a dozen or more observations. In most cases, papers contained data on N inputs to several organic systems and one conventional system.

Author	Year	Product	Organic	Conventional
Appireddy et al.	2008	Vegetables		X
Aronsson et al.	2007	Grains	X	X
Bartova et al.	2013	Starchy Roots	X	X
Bulluck et al.	2002	Grains	X	X
Bulluck et al.	2002	Vegetables	X	X
Cavigelli et al.	2009	Legumes	X	X
Citak & Sonmez	2010	Vegetables	X	X
Creamer et al.	1998	Vegetables	X	X
Del Amor	2006	Vegetables	X	X
Delate & Cambardella	2004	Legumes	X	X
Efthimiadou et al.	2009	Grains	X	X
Fiorillo et al.	2005	Starchy Roots	X	X
Gabriel et al.	2013	Grains	X	X
Gelfand et al.	2010	Legumes	X	X
Gopinath et al.	2008	Grains	X	X
Kirchmann et al.	2007	Grains	X	X
Liebhardt et al.	1989	Legumes	X	X
Lotter et al.	2003	Grains	X	X
Lotter et al.	2003	Legumes	X	X
Maeder et al.	2002	Grains		X
Maeder et al.	2002	Starchy Roots		X
Maggio et al.	2008	Starchy Roots	X	X
Martini et al.	2004	Grains	X	X
Martini et al.	2004	Vegetables	X	X
Moccia et al.	2006	Vegetables	X	X
Porter et al.	2003	Grains	X	X
Porter et al.	2003	Legumes	X	X
Riahi et al.	2009	Vegetables	X	X
Teasdale et al.	2007	Grains	X	X

Trydeman Knudsen et al.	2010	Legumes	X	X
Varis et al.	1996	Starchy Roots	X	X
Warman & Havard	1998	Grains	X	X
Warman & Havard	1998	Starchy Roots	X	X

Table S12. N input types for organic and conventional crop and animal products (see Table S11 for sources). Data from the literature on N inputs to organic and conventional crop production were averaged to estimate central tendency. Organic crop data is based on 115 observations from 31 studies. Conventional crop data is based on 59 observations from 33 studies. Both organic and conventional animal data is scaled (from crop inputs) by diet composition (see Table S6 for diet composition data).

		Number of Obs.	Number of Studies	Average New N Inputs (%)			Average Recycled N Inputs (%)					
				Synthetic Fertilizer	BNF	BNF (green manure)	BNF (by another crop)	Manure	Crop residue	Green manure	Compost	Animal By-products
Grains	Conv	21	12	84	-	11	3	2	-	-	1	-
	Org	34	11	-	-	15	11	52	5	-	17	-
Vegetables	Conv	15	8	95	-	-	-	5	-	-	-	-
	Org	53	7	-	-	9	4	23	1	4	50	9
Starchy Roots	Conv	8	6	69	-	-	-	31	-	-	-	-
	Org	15	5	-	-	-	-	76	-	-	18	6
Legumes	Conv	15	7	26	44	-	-	-	30	-	-	-
	Org	13	7	-	43	3	5	18	28	-	3	-
Poultry	Conv	-	-	82	3	10	1	2	2	-	1	-
	Org	-	-	-	23	8	7	33	18	-	10	-
Pigmeat	Conv	-	-	68	12	8	2	1	8	-	1	-
	Org	-	-	-	23	9	7	34	18	-	10	-
Beef	Conv	-	-	81	6	8	2	1	1	-	1	-
	Org	-	-	-	29	5	4	48	8	-	6	-
Milk	Conv	-	-	76	12	6	1	1	3	-	1	-
	Org	-	-	-	33	3	2	54	4	-	3	-

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