Supplementary Materials: Variations in the Use of Resources for Food: Land, Nitrogen Fertilizer and Food Nexus

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1. Supplementary Material 1: Validation of the Calculation of Nitrogen Fertilizer Use per Ton of Food

We have calculated the use of nitrogen fertilizer per ton of food for each food category in the diet (Tables 1 and 2) to calculate the nitrogen fertilizer use per person. We have used country level data to illustrate differences of production systems. Several assumptions had to be made due to the availability of data.

First, we combined crop production data from two databases: nitrogen application rate from FertiStat (FAO, 2007) and crop yield from FAOSTAT (FAO, 2013a). These databases give country level data averaging the crop production systems of each country. The production systems within each country can differ due to local conditions (climate, type of soil, management practices, others).

Second, in some cases, only a share of the harvested area in a country is fertilized. FertiStat indicates, for each crop, the average application rate of the fertilized area, and the share of the harvested area that is fertilized. In the cases that only a share of the harvested area is fertilizer, we calculate a "weighted" application rate and we used it as the application rate of country for that crop. The reason to use this "weighted" application rate is because we combine it with crop yield data of all the harvested area of the country given by FAOSTAT.

It is questionable whether with these assumptions our results illustrate real situations of production systems. In order to validate our assumptions, we compare the data we have used and our calculations of kilogram of nitrogen fertilizer per ton of crop with some case studies. These case studies have crop field scale production data of nitrogen application rate and crop yields for several crops. Similar to Table 1, we combined the nitrogen application rate and crop yield to calculate the kilograms of nitrogen fertilizer per ton of crop (Table S1).

Table S1 show that for each food category, the nitrogen application rate, the crop yield and the kilogram of nitrogen fertilizer per ton of crop is in the same order of magnitude as the values of Table 1. The crops for each food category in Table S1 are ordered from high to low nitrogen application, similar to Table 1. In this way, it is easier to compare the values.

For cereals, the case study of maize in the USA in Table S1 has a similar nitrogen application rate (155 kg·N/ha), crop yields (9 ton/ha) and kg nitrogen fertilizer per ton of crop (16 kg·N/ton) than the maize production of the High Input Systems (HIS A and B) that we used for our calculations (Table 1). Similarly, the wheat production in the USA and in the valley farm in India (Table S1) has similar values than the maize production in the MIS A and in LIS, respectively, used in our calculations (Table 1). Similar comparisons are shown in the other food categories.

Also, the differences among food categories in the kilogram of nitrogen fertilizer per ton of crop resulted from the case studies (Table S1) is similar to our calculations (Table 1). The kilogram of nitrogen fertilizer per ton of cereals of Table S1 ranges from 2 kg·N/ton to 24 kg·N/ton, similar to Table 1 in which it ranges from 7 kg·N/ton to 26 kg·N/ton. Roots, vegetables and fruits show lower values in both tables: lower than around 10 kg·N/ton. Vegetable oils show large deviations among the crops, similar in both tables.

To conclude, Table S1 validate our assumption in order to use our methodology to illustrate global differences among production systems.

Table S1. Crop field scale production data from several sources.

Crop	N Application (kg·N/ha)	Crop Yield (ton/ha)	kg·N/ton Crop	Case Study Area	Source
Cereals					
Maize	155	9.4	16	USA	Pimentel (2009)
Barley	84	4.9	17	Iran	Mobtaker et al. (2010)
Wheat	68	2.9	24	USA	Pimentel (2009)
Wheat	8	1.5	5	Valley farm, India	Triphati and Sah (2001)
Wheat	2	0.9	2	Mid-hill farm, India	Triphati and Sah (2001)
Roots					
Potato	319	44	7	USA	Pimentel (2009)
Cassava	90	19	5	Nigeria	Pimentel (2009)
Potato	33	3	12	Valley farm, India	Triphati and Sah (2001)
Pulses					
Peas	27	4.6	6	High-hill farm, India	Triphati and Sah (2001)
Dry beans	16	1.5	11	USA	Pimentel and Pimentel (2008)
Pulses	0	0.5	0	Valley farm, India	Triphati and Sah (2001)
Oil crops					
Soybeans	156 [1]	3.2	48	Iran	Mohammedi (2013)
Soybeans	4	2.6	1	USA	Pimentel (2009)
Rapeseed	3	0.2	17	Valley farm, India	Triphati and Sah (2001)
Vegetables					
Tomato	75	80	1	USA	Pimentel (2009)
Cabbage	27	11	2	High-hill farm, India	Triphati and Sah (2001)
Fruits					
Apple	50	54	1	USA	Pimentel (2009)

[1] The application rate is not only for Nitrogen (N) but also includes Potassium (K) and Phosphorus (P).

2. Supplementary Material 2: Discussion of Our Assumption of Using Maize as the Only Feed Crop for Livestock

One of the assumptions that we have made in our calculations is that all livestock is fed with maize. We have decided to do this in order to have only one value for both nitrogen application and crop yield for each animal food product. In this way, it is possible to illustrate how each factor of the feed crops drives the use of nitrogen fertilizer per kilogram of animal food product (e.g., beef, poultry, etc.). For example, if the rate of nitrogen application is small but also the crop yield is small, then the nitrogen fertilizer per kilogram of food could be similar to another production system in which the nitrogen fertilizer rate is larger but can give larger crop yields (see Table 1).

However, in reality, livestock is fed with a mixture of feed crops as well as with grass from pastures. The mixture of feed can vary not only from country to country but also from farm to farm. It can vary daily due to international food prices and availability of feed crops, as well as many other factors. Therefore, our calculations do not illustrate the real use of nitrogen fertilizer of each country. However, by using only one feed crop, it illustrates how different production systems can drive the use of nitrogen fertilizer by using country level data as examples of real production systems.

Nevertheless, the variation that can result from our assumption in comparison with using other type of feed crops is not significant for the purpose of our paper. The reason for this is that by looking at the values of kg·N/ton-food, the differences among the types of animal food products are larger than the differences that can result from using different types of feed crops. This is shown in Table S2. This table shows the same calculations as Table 2 for the use of nitrogen fertilizer to produce a ton of animal food product but in this case it is calculated by using other types of feed crops. This table shows the values for all main feed crops which are available in the FertiStat Database for each country. Note that the numbers of each column are in the same order of magnitude (comparing the different type of feed) in comparison with the rows for which the difference is larger (comparing the type of animal food product). For example, for France, the kg·N/ton food varies around 1% to up to 40% among feed crops, but the differences among animal food products is larger: pig meat is five times smaller than beef, and milk is 15 times smaller than beef. Similar differences are shown for the other countries.

Note that if soya is used as feed crop, then the kg·N/ton food is significantly smaller in comparison with the other feed crops. Soya is a legume in comparison with the other feed crops which are cereals. The reason for this difference is that legumes are nitrogen fixators therefore they require much less synthetic nitrogen fertilizer as other crops. Therefore, it is important to point out that our results in general are an overestimation if the feed crop is a legume. However, this is not always the case since in some production systems the nitrogen application for legumes could be relatively large resulting in high use of nitrogen per amount of food. For example, see the case of Mexico in which the kg·N/ton food for barley is only 15% larger than soya.

Table S2. Use of nitrogen fertilizer per amount of food for all animal food products by using different feed crops.

Feed Crop	Feed Factors			Animal Food Product kg·N/ton Food [c]					
	Nitrogen Application [a] (kg·N/ha)	Crop Yield [b] (ton/ha)	kg·N/ton Feed [c]	Beef	Mutton	Pig Meat	Poultry	Milk	Eggs
France (High Input System A)									
Maize	170	9.1	18.7	356	249	7	52	21	43
Wheat	80	7.1	11.2	214	149	44	31	12	26
Barley	120	6.3	19.0	360	252	74	53	21	44
USA (High Input System B)									
Maize	150	8.4	17.8	338	236	69	50	20	41
Wheat	63	2.9	21.7	412	289	85	61	24	50
Sorghum	90	4.2	21.3	405	283	83	60	23	49
Mexico (Middle Input System A)									
Maize	60	2.3	25.6	487	341	100	72	28	59
Wheat	104	4.2	24.7	470	329	96	69	27	57
Sorghum	48	3.3	14.5	275	193	56	41	16	33
Barley	32	1.5	20.8	396	277	81	58	23	48
Soya	28.5	1.6	17.8	339	237	70	50	20	41
Philippines (Middle Input System B)									
Maize	46.4	1.8	25.5	484	339	99	71	28	59
Rice	43.35	3.2	13.6	258	181	53	38	15	31
Soya	4	1.2	3.3	62	44	13	9	4	8
Tanzania (Low Input System)									
Maize	8	1.2	6.8	130	91	27	19	8	16
Millet	2	1.0	2.0	39	27	8	6	2	5
Sorghum	2	0.9	2.3	44	31	9	6	3	5
Rice	8	1.3	6.4	121	85	25	18	7	15

Data sources: [a] FAO (2007); [b] FAO (2013a); [c] Calculations from the authors. See text for details.

3. Supplementary Material 3: Impact of Nutritional Value of Food Products on the Use of Resources

In this paper, the calculations of per capita use of nitrogen fertilizer and land were based on data of kilograms of food and not in data of other nutritional values such as calories or proteins. For the production data crop yield were used in ton per hectare, and for the consumption data kilograms of food supply per person were used (see Tables 1–3). Another approach to calculate the "footprints" (use of nitrogen fertilizer and land per person) would be to use the nutritional value of the food products; this means to base the calculation in terms of kilocalories, proteins or fats instead of kilograms. In order to do this, the values of Tables 1 and 2 should be converted into these units. In this appendix, we discuss the differences in nutritional value of the food products and the impact of doing this study using different nutritional units.

Table S3 show the nutritional content per 100 g of the food products used in this paper. The data was gathered from the Food Composition Tables given by the FAO.

Table S3. Nutritional content per 100 g of food product.

Food Product	Kcal	Protein (g)	Fats (g)
wheat	334	12.2	2.3
rice paddy	280	6	1.4
maize	356	9.5	4.3
potatoes	67	1.6	0.1
sweet potatoes	92	0.7	0.2
beans, dry	341	22.1	1.7
pulses nes	340	22	2
sugar, centrifugal raw	373	0	0
oil of soyabeans	884	0	100
oil of sunflower seed	884	0	100
oil of coconuts	884	0	100
oil of cotton seed	884	0	100
cabbages	19	1	0.1
apples	48	0.1	0.3
beer barley	49	0.5	0
rice fermented beverage	133	0.3	0
fermented beverages, cider etc.	47	0.1	0
beef boneless	150	18.5	7.9
chicken meat	122	12.3	7.7
mutton and lamb	263	13.5	22.8
pork	220	13.4	18
cow milk, whole fresh	61	3.3	3.3
hen eggs	139	10.7	9.8

Source: Food Composition Tables FAO: http://www.fao.org/docrep/003/x9892e/X9892e05.htm#P8217_125315.

The nutritional content of each food product differs greatly depending on the type of food. For instance, oils have a relatively high content of calories and fats but no proteins; pulses have a relatively high content of proteins and calories but few fats; vegetables and fruits have a relatively low content of calories, and no proteins or fats; milk has a relatively high content of calories, proteins and fats in comparison with the meat products because of its high content of water.

By using the data from Table S3, we can calculate the data of Tables 1 and 2 in terms of different nutritional values such as kilocalories, proteins and fats (see Table S4). This table shows the fairly consistent differences among types of food products as Table S3 which was discussed above. For some food products and some nutritional values, this table shows that no nitrogen fertilizer was used. However, this does not mean that the production system does not use nitrogen fertilizer but means that the nutritional content of the food product is very small or nil. For example, the production of sugars show nil nitrogen fertilizer use per kg of protein or fat because of the low content of proteins and fats per gram of sugar. Therefore, it is important to note this because if the calculation of nitrogen fertilizer use was done based on proteins, then the production of sugars would show no use of nitrogen fertilizer. For this reason, we have made the calculations of nitrogen fertilizer use and land use per person per amount of food. Other studies have discussed the implications of studying the use of nitrogen fertilizer in relation to other nutritional values. For instance, Pierer et al. (2014) discuss the variations that result from using proteins or kilograms to calculate the use of nitrogen fertilizer.

Table S4. Data of Tables 1 and 2 in different nutritional values.

Production System	Food Product	g·N/kg Food (from Tables 1 and 2)	g·N/ 1000 Kcal	g·N/kg Protein	g·N/kg Fats
		Cereals			
HIS B	Wheat	21.7	6	178	943
HIS A	Wheat	11.2	3	92	489
MIS B	Rice paddy	17.5	6	292	1253
MIS A	Maize	25.6	7	270	596
LIS	Maize	6.8	2	72	159
		Roots			
HIS B	Potatoes	5.4	81	340	5439
HIS A	Potatoes	0.9	13	55	885
MIS B	Potatoes	5.5	82	343	5482
MIS A	Potatoes	5.3	79	329	5269
LIS	Sweet potatoes	0.3	3	39	136
		Pulses			
HIS B	Beans, dry	36.0	106	163	2118
HIS A	Beans, dry	49.2	144	223	2897
MIS B	Beans, dry	10.0	29	45	590
MIS A	Beans, dry	28.1	82	127	1653
LIS	Pulses nes	1.5	4	7	73
		Sugar & Sweeteners			
HIS B	Sugar (Raw Eq.) from sugar beet	12.7	34	0	0
HIS A	Sugar (Raw Eq.) from sugar beet	10.2	27	0	0
MIS B	Sugar (Raw Eq.) from sugar cane	12.1	32	0	0
MIS A	Sugar (Raw Eq.) from sugar cane	14.4	39	0	0
LIS	Sugar (Raw Eq.) from sugar cane	0.1	0	0	0
		Vegetable Oils			
HIS B	oil of soyabeans	21.2	24	0	21
HIS A	oil of sunflower seed	148.3	168	0	148
MIS B	oil of coconuts	6.9	8	0	7
MIS A	oil of sunflower seed	226.5	256	0	227
LIS	oil of cotton seed	66.9	76	0	67
		Vegetables *			
HIS B	Cabbages	6.7	351	668	6677
HIS A	Cabbages	2.0	104	198	1978
MIS B	Cabbages	0.0	0	0	3
MIS A	Cabbages	2.7	140	266	2664
LIS	Cabbages	1.5	81	154	1540
		Fruits *			
HIS B	Apples	3.9	80	3863	1288
HIS A	Apples	4.6	95	4576	1525
MIS B	Apples	3.3	69	3321	1107
MIS A	Apples	3.5	74	3529	1176
LIS	Apples	0.3	7	322	107
		Alcoholic Beverages			
HIS B	Beer barley	2.8	57	557	0
HIS A	Beer barley	2.8	58	569	0
MIS B	rice fermented beverage	2.4	18	794	0
MIS A	Beer barley	3.1	64	625	0
LIS	fermented beverages, cider etc.	0.1	2	108	0

Table S4. *Cont.*

Production System	Food Product	g·N/kg Food (from Tables 1 and 2)	g·N/ 1000 Kcal	g·N/kg Protein	g·N/kg Fats
		Animal products			
HIS B	beef boneless	338	2252	1826	4275
HIS A	beef boneless	356	2372	1924	4504
MIS B	beef boneless	484	3230	2619	6132
MIS A	beef boneless	487	3244	2630	6159
LIS	beef boneless	130	866	702	1643
HIS B	Mutton and lamb	236	899	1751	1037
HIS A	Mutton and lamb	249	947	1845	1093
MIS B	Mutton and lamb	339	1289	2512	1487
MIS A	Mutton and lamb	341	1295	2523	1494
LIS	Mutton and lamb	91	346	673	399
HIS B	Pork	69	315	517	385
HIS A	Pork	73	332	545	406
MIS B	Pork	99	452	742	552
MIS A	Pork	100	454	745	555
LIS	Pork	27	121	199	148
HIS B	Chicken meat	50	408	405	646
HIS A	Chicken meat	52	430	426	681
MIS B	Chicken meat	71	585	580	927
MIS A	Chicken meat	72	588	583	931
LIS	Chicken meat	19	157	156	248
HIS B	Cow milk, whole fresh	20	321	593	593
HIS A	Cow milk, whole fresh	21	338	624	624
MIS B	Cow milk, whole fresh	28	460	850	850
MIS A	Cow milk, whole fresh	28	462	854	854
LIS	Cow milk, whole fresh	8	123	228	228
HIS B	hen eggs	41	294	382	417
HIS A	hen eggs	43	310	403	440
MIS B	hen eggs	59	422	548	598
MIS A	hen eggs	59	424	550	601
LIS	hen eggs	16	113	147	160

* For vegetables and fruits, Tables 1 and 2 was calculated using the average values for total vegetables and total fruits given by the FAO, for this tables, we used cabbages and apples as examples of vegetables and fruits to illustrate the differences in the use of N per kilograms, kcal, protein and fats.

4. Supplementary Material 4

In this supplementary material, we present the data of Figures 1 and 2 to be able to compare diets and production systems more easily among these figures.

Table S5. Data of Figure 1.

Food Categories	HIS A & Affluent Diet A		HIS B & Affluent Diet B		MIS A & Transition Diet A		MIS B & Transition Diet B		LIS & Basic Diet	
	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap
Staple food	1.5	188	2.8	389	4.6	905	2.89	672	0.8	2061
Affluent vegetal food products	4.7	451	2.9	490	3.8	664	0.75	286	0.5	881
Animal food products	19.0	1119	23.7	1577	16.7	2786	5.50	1185	1.3	1614
TOTAL	25	1758	29	2456	25	4355	9	2142	3	4557

Table S.6. Data of Figure 2.

Food Categories	Affluent Diet									
	High Input System A (HIS A)		High Input System B (HIS B)		Middle Input System A (MIS A)		Middle Input System B (MIS B)		Low Input System (LIS)	
	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap
Staple food	1.5	181	2.8	389	3.2	566	2.26	544	0.8	1299
affluent vegetal food products	5.8	543	2.9	490	8.3	1431	1.57	733	2.1	2825
animal food products	24.9	1466	23.7	1577	34.1	5681	33.94	7314	9.1	11,369
TOTAL	32	2190	29	2456	46	7678	38	8591	12	15,493
	Transition Diet									
	High Input System A (HIS A)		High Input System B (HIS B)		Middle Input System A (MIS A)		Middle Input System B (MIS B)		Low Input System (LIS)	
	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap
Staple food	2.4	271	4.0	564	4.6	905	3.05	831	1.1	1646
affluent vegetal food products	2.8	293	1.8	254	3.8	664	1.20	408	0.8	1345
animal food products	12.2	719	11.6	773	16.7	2786	16.64	3586	4.5	5574
TOTAL	17	1283	17	1592	25	4355	21	4825	6	8566
	Basic Diet									
	High Input System A (HIS A)		High Input System B (HIS B)		Middle Input System A (MIS A)		Middle Input System B (MIS B)		Low Input System (LIS)	
	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap	kg·N-cap	m²-cap
Staple food	2.3	253	3.9	408	4.1	861	2.92	818	0.8	2061
affluent vegetal food products	1.7	184	1.0	152	2.2	420	0.57	237	0.5	881
animal food products	3.5	208	3.4	224	4.8	807	4.82	1038	1.3	1614
TOTAL	8	645	8	784	11	2087	8	2094	3	4557