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Supplement of

Invited review: Resource inputs and land, water and carbon footprints from the production of edible protein of animal origin

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Table S1: Protein content (nitrogen content x 6.25) of some edible animal products/food by various authors (in g per kg edible product).

Authors	Product/Food				
	Milk (Cows)	Beef	Pork	Poultry	Eggs
Flachowsky (2002)	34	190	150	200	120
GfE (2008, 1995, 1999, 2001)	34	170-210	157 (129-178)	no data	121 (110-124)
Souci et al. (2006)	33.3 (30.8-37.0)	220 (206-227)	220 (195-240)	199	125
de Vries and de Boer (2010)	30	190	190	190	130
Mekonnen and Hoekstra (2010)	33	138	105	127	111
Souci et al. (2006)	34	206-212	183-216	182-242	125
Lesschen et al. (2011)	34.4	206	156	206	119
Nijdam et al. (2012)	35	200	200	200	130
USDA (2016)	34	173	139	186	126

Table S2: Assumed plant yields for further calculations (kg dry matter ha⁻¹ year⁻¹).

Yield	Grassland or perennial crops (Roughage)	Arable land or cultivated crops (Concentrate)
A (low)	5 000	2 000
B (medium)	10 000	5 000
C (high)	20 000	10 000

Table S3: Crude protein content of some feeds (Jeroch et al., 1993) and their human-edible fraction (hef; %) used by Wilkinson (2011) and, for three different scenarios, by Ertl et al. (2015).

Feedstuff	Crude protein (g kg ⁻¹ DM ¹⁾)	human-ediblefractions (in %) by Wilkinson (2011)	human-edible-fractions (in %) by Ertl et al. (2015)		
			Low	Medium	High
Barley	125	80	40	65	80
Maize	106	80	70	80	90
Wheat	138	80	60	80	100
Soybeans	404	80	50	92	93
Rapeseed meal	406	20	30	59	87
Soybean meal	513	80	50	71	92
Wheat bran	160	20	0	10	20
Maize silage	86	0	19	29	45
Others ²⁾		0	0	0	0

¹⁾ Dry matter

²⁾ Other co-products (e.g. sugar beet pulp; brewers grains; distillers dried grains with solubles) and roughages (e.g. fresh grass, silage, hay)

Table S4: Calculation of the net protein contribution of milk production to the food chain considering various amounts of co-products in concentrate feeds (based on data of Tables S1 and S3).

Milk yield (kg day ⁻¹)	DM ¹⁾ -intake (kg day ⁻¹)	Concentrate intake (kg DM day ⁻¹)	Portion co-products in concentrate (%)	Human-edible protein input (g day ⁻¹)	Human-edible protein output (g day ⁻¹)	Proportion output to input (protein score) (g g ⁻¹)
2	8	0	0	0	67	>
5	10	0.5	100 ²⁾	8	163	20
10	12	1.2	100 ²⁾	96	323	3.4
20	16	4.0	50 ³⁾	262	646	2.4
40	25	12.5	25 ⁴⁾	1450	1292	0.9

¹⁾ Dry matter; ²⁾ 50% concentrate wheat bran; 50% dried sugar beet pulp; ³⁾ 25% concentrate wheat bran; 25% dried sugar beet pulp; 30% concentrate as cereals; 10% soybean meal; 10% rapeseed meal; ⁴⁾ 12.5% concentrate wheat bran; 12.5% dried sugar beet pulp; 50% concentrate as cereals; 15% soybean meal; 10% rapeseed meal (see Table S1; human-edible-fractions according to Wilkinson (2011))

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Table S5: Calculation of the net protein contribution of food of animal origin to the food chain with and without co-products and under consideration of 50% of concentrate based on co-products (on the basis of data of Tables S1 and S3).

Protein source	Animal yield	DM-intake (kg day ⁻¹)	Concentrate intake (kg DM day ⁻¹) ¹	Co-products in concentrate (kg DM day ⁻¹) ²	Human-edible protein input (g day ⁻¹) ³	Human-edible protein output (g day ⁻¹) ⁴	Proportion output to input (protein score) (g g ⁻¹)
Cow's milk	20 kg day ⁻¹	16	4	0	493	646	1.3
				2	262		2.4
Beef	1 kg ADG ⁵	7	1.05	0	130	95	0.7
				0.52	70		1.3
Pork	700 g ADG	2	1.8	0	224	63	0.3
				0.9	127		0.5
Chicken	60 g ADG	0.08	0.08	0	10	7.2	0.7
				0.04	6		1.2
Eggs	70% LP ⁶	0.11	0.1	0	12	4.8	0.4
				0.05	7		0.7

¹) 80% cereal grains; 20% protein sources (soybeans, rapeseed) ²) 50% co products; 30% cereals; 20% protein sources (soybeans, rapeseed), ³) see Table S1; (human-edible fractions by Wilkinson (2011)); ⁴) see Table S3; ⁵) Average Daily Gain; ⁶) Laying Performance

Table S6: Influence of animal species, categories and performances on yield of edible protein (Flachowsky, 2002; Flachowsky and Kamphues, 2012).

Protein source	Performance	Dry matter intake	Roughage part	Edible fraction	Protein in edible fraction	Edible protein yield	Edible protein yield
(Body mass)	(per day)	(kg day ⁻¹)	(DM ¹) basis, (%)	(% of product or body mass)	(g kg ⁻¹)	(g day ⁻¹)	(g kg body mass day ⁻¹)
Dairy cow							
(650 kg)	2 kg day ⁻¹	8	100			67	0.1
	5 kg day ⁻¹	10	95	95	34	163	0.25
	10 kg day ⁻¹	12	90			323	0.5
	20 kg day ⁻¹	16	75			646	1.0
	40 kg day ⁻¹	25	50			1292	2.0
Dairy goat							
(60 kg)	0.5 kg day ⁻¹	1	100			17	0.3
	1 kg day ⁻¹	1.5	90	95	36	34	0.55
	2 kg day ⁻¹	2	80			68	1.1
Beef cattle							
(350 kg)	200 g ADG ²⁾	6.0	100			19	0.05
	500 g ADG	6.5	95	50	190	48	0.14
	1 000 g ADG	7.0	85			95	0.27
	1 500 g ADG	7.5	70			143	0.41
Growing/ fattening pig							
(80 kg)	200 g ADG	1.5	30			18	0.22
	500 g ADG	1.8	20	60	150	45	0.56
	700 g ADG	2	10			63	0.8
	1 000 g ADG	2.2	0			90	1.1
Chicken for fattening							
(1.5 kg)	20 g ADG	0.06	15			2.4	1.6
	40 g ADG	0.07	10	60	200	4.8	3.2
	60 g ADG	0.08	0			7.2	4.8
Laying hen							
(1.8 kg)	20% LP ³⁾	0.09	30			1.4	0.8
	50% LP	0.10	20	95	120	3.4	1.9
	70% LP	0.11	10			4.8	2.7
	90% LP	0.12	0			6.2	3.4

¹⁾ Dry matter; ²⁾ Average daily gain; ³⁾ Laying performance

Table S7: Model calculations for land use per kg of edible protein depending on animal species and category, plant yields (see Table S2), and animal performances (Flachowsky et al., 2017).

Protein source	Animal yield (per day)		Edible protein yield (g/day)	Grassland or perennial crops			Arable land or cultivated crops		
				$(\text{m}^2 \text{ kg protein}^{-1})^3$			$(\text{m}^2 \text{ kg protein}^{-1})$		
				Plant yield level ⁴⁾			Plant yield level		
				A	B	C	A	B	C
Cow's milk	2	kg	67	240	120	60	0	0	0
	5	kg	163	120	60	30	15	6	3
	10	kg	323	70	35	18	18	8	4
	20	kg	646	38	20	9	30	12	6
	40	kg	1292	20	10	5	50	20	10
Goat's milk	0.5	kg	17	120	60	30	0	0	0
	1	kg	34	80	40	20	22	9	5
	2	kg	68	50	25	12	30	12	6
Beef	200	g ADG ¹⁾	19	630	315	160	0	0	0
	500	g ADG	48	260	130	65	35	15	7
	1 000	g ADG	95	125	60	30	55	22	11
	1 500	g ADG	143	75	40	20	80	30	15
Pork	200	g ADG	18	50	25	12	300	120	60
	500	g ADG	45	16	8	4	160	65	32
	700	g ADG	63	8	4	2	140	55	28
	1 000	g ADG	90	0	0	0	120	50	24
Chicken meat	20	g ADG	2.4	8	4	2	100	40	20
	40	g ADG	4.8	3	2	1	65	25	13
	60	g ADG	7.2	0	0	0	60	25	12
Eggs	20	% LP ²⁾	1.4	40	20	10	220	90	45
	50	% LP	3.4	12	6	3	110	50	25
	70	% LP	4.8	5	2	1	100	40	25
	90	% LP	6.2	0	0	0	95	40	20

¹⁾ Average daily gain, ²⁾ Laying performance

³⁾ Some authors (e.g. Peters et al. (2010)) calculated this without perennial crops in non-ruminant (pigs and poultry) feeding

5 ⁴⁾ Plant yields levels A (low), B (medium) and C (high); see Table S2

Table S8: Model calculations for the land use per kg edible protein depending on animal species and categories, plant yields, animal performances and agricultural co-products, food and fuel industries.

Protein source	Animal yield (per day)		Edible protein yield (g day ⁻¹)	Grassland or perennial crops (m ² kg protein ⁻¹) Plant yield level B ³⁾			Arable land or cultivated crops (m ² kg protein ⁻¹) Plant yield level B		
				Replacement by co-products			Replacement by co-products		
				10 20 30 (%)			15 30 45 (%)		
Cow's milk	2	kg milk	67	108	96	84	0	0	0
	5	kg milk	163	54	48	42	5	4	3
	10	kg milk	323	32	28	24	7	6	5
	20	kg milk	646	16	14	12	11	10	8
	40	kg milk	1292	9	8	7	17	14	11
Goat's milk	0.5	kg milk	17	54	48	42	0	0	0
	1	kg milk	34	34	28	21	8	6	5
	2	kg milk	68	20	18	14	10	8	6
Beef	200	g ADG ¹⁾	19	280	250	220	0	0	0
	500	g ADG	48	115	105	90	13	10	8
	1 000	g ADG	95	54	48	42	19	15	12
	1 500	g ADG	143	36	32	28	26	21	16
Pork	200	g ADG	18	22	20	18	102	84	65
	500	g ADG	45	7	6	5	55	46	36
	700	g ADG	63	4	3	3	47	39	30
	1 000	g ADG	90	0	0	0	42	35	28
Chicken meat	20	g ADG	2.4	4	3	3	34	28	22
	40	g ADG	4.8	2	2	1	21	18	14
	60	g ADG	7.2	0	0	0	21	18	14
Eggs	20	% LP ²⁾	1.4	18	16	14	76	63	50
	50	% LP	3.4	5	5	4	42	35	28
	70	% LP	4.8	2	2	1	34	28	22
	90	% LP	6.2	0	0	0	34	28	22

¹⁾ Average daily gain, ²⁾ Laying performance

³⁾ Plant yields: Levels A (low), B (medium) and C (high); see Table S2

Table S9: Land use per unit of livestock product and protein (in m² kg product⁻¹ and m² kg protein⁻¹; n=16; (de Vries and de Boer, 2010)).

Food of animal origin	Land use (m ² kg product ⁻¹)			Land use (m ² kg protein ⁻¹)		
Milk	1.1	–	2.0	33	–	59
Beef	27	–	49 ¹⁾	144	–	258
Pork	8.9	–	12.1	47	–	64
Chicken meat	8.1	–	9.9	42	–	52
Eggs	4.5	–	6.2	3	–	48

¹⁾ Suckler cows with calves

Table S10: Land use (both total and grassland) per kg product and per kg edible protein (Nijdam et al., 2012).

Food of animal origin		Total land use (m ² kg product ⁻¹)	Proportional grassland use (m ² kg product ⁻¹)	Total land use (m ² kg protein ⁻¹)
Milk	(n=14)	1 - 2	about 1	26 - 54
Beef all	(n=26)	7 - 420	2 - 420	37 - 2100
Industrial systems	(n=11)	15 - 29	2 - 26	75 - 143
Suckler herds	(n=8)	33 - 158	25 - 140	164 - 788
Extensive pastoral systems	(n=4)	286 - 420	250 - 420	1430 - 2100
Mutton	(n=5)	20 - 33	18 - 30	100 - 165
Pork	(n=11)	8 - 15	Not applicable	40 - 75
Chicken meat	(n=5)	5 - 8	Not applicable	23 - 40
Eggs	(n=5)	4 - 7	Not applicable	29 - 52

n=number of studies