Supplementary material to the BG article:

Greenhouse gas emissions from the grassy outdoor run of organic broilers

Towards a net GHG budget of the outdoor run

Emission factors are needed from an inventory viewpoint (IPCC), but to assess the whole climate change impact of a production system, a total net GHG exchange (NGHGE), taking into account all global warming potential (GWP) contributions by CO_2, N_2O and CH_4 fluxes should be calculated, expressed in CO_2 equivalents (Soussana et al., 2007). We calculated a tentative NGHGE according to Eq. (1) adapted from Soussana et al. (2007):

$$NGHGE = \frac{44}{28} F_{N2O,a} \,.\, GWP_{N2O} + \frac{16}{12} F_{CH4,a} \,.\, GWP_{CH4} + \frac{44}{12} NEE_{G+B} \qquad (1)$$

where $F_{N2O,a}$ and $F_{CH4,a}$ are respectively the annual N_2O and CH_4 fluxes from the run (in kg N_2O-N ha^{-1} yr^{-1} and kg CH_4−C ha^{-1} yr^{-1}, respectively); GWP_{N2O} and GWP_{CH4} the respective GWPs of CH_4 (25 CO_2 eq.) and N_2O (298 CO_2 eq.) (IPCC, 2007a); NEE_{G+B} is the net ecosystem exchange (kg CO_2−C ha^{-1} yr^{-1}) defined as the sum of NEE_G (kg CO_2−C ha^{-1} yr^{-1}), the net ecosystem exchange of grassland (vegetation+soil), and $R_{broilers}$ the respiration of broilers on the run. CH_4 emissions from enteric fermentation of broilers is neglected given the lack of knowledge (IPCC, 2006a), but is certainly very small.

Usually, NEE_G is measured by eddy covariance (Soussana et al., 2007) or by chambers, and Gross Primary Production (GPP) is calculated by difference between NEE and R_{eco}, which is derived from night-time measurements (Woodwell and Whittaker, 1968; Reichstein et al., 2005). By convention, a negative value of NEE_G indicates a net sink. In this study we only measured R_{eco} but not NEE, and thus no GPP estimates could be made either. However, a tentative estimate of NEE_G may be made according to Eq. (2) adapted from Ammann et al. (2007) and Loubet et al. (2011), based on the measured changes in soil organic carbon over the time scale of the experiment and assumptions regarding other C fluxes into and out of the ecosystem:

$$NEE_G = C_{import} - \frac{\Delta SOC}{\Delta t} - C_{export} - C_{leaching} - F_{CH4} \qquad (2)$$

where C_{import} is the import of C on the outdoor by broiler excretion; $\frac{\Delta SOC}{\Delta t}$ the measured change in SOC with time (a positive value corresponding to a carbon sequestration in the grassland); C_{export} the export of C out of the run; $C_{leaching}$ the organic carbon leached out of the soil and $F_{CH4,a}$ the annual methane flux measured in our study.

In this study, C_{export} is only due to the consumption of vegetation, soil or soil fauna by the broilers, as the grassland was not cut, and was estimated according to Eq. (3) in which the total C export for each batch is calculated as the difference between total C ingestion on the run and the part of this C excreted on the run.

$$C_{export} = n_{out} \,.\, n_{broilers} \,.\, \left[I_{soil} \,.\, C_{soil} \,.\, (1 - EI_{soil} \,.\, r_{out}) + I_{veg} \,.\, C_{veg} .\left(1 - EI_{veg} \,.\, r_{out}\right) + I_{fauna} \,.\, DM_{fauna} \,.\, C_{fauna} \,.\, \left(1 - EI_{fauna} \,.\, r_{out}\right)\right] \quad (3)$$

with n_{out} the number of days with outdoor access; $n_{broilers}$ the number of broilers; I_{soil}, I_{veg} and I_{fauna} are the daily intake of soil, vegetation and soil fauna per broiler (in kg dry matter (DM) for soil and vegetation, in kg fresh matter for fauna); C_{soil}, C_{veg}, C_{fauna} are the carbon content of soil, vegetation and fauna (in kg C per kg DM); DM_{fauna} the DM content of soil fauna (in %); EI_{soil}, EI_{veg}, EI_{fauna} are the Excretion/Intake ratio (in %) for soil, vegetation and fauna, respectively; r_{out} is the ratio of outdoor excretion to total excretion used previously to estimate N outdoor excretion. Values and references used for the estimation of C_{export} are given in Table S2.

Total ingestion of carbon from vegetation, soil and soil fauna was estimated about 2541 kg C ha^{-1} yr^{-1}, which was equivalent to less than 10% of C ingested from feed in the house. This value is consistent with the values given by Rivera-Ferre et al. (2007) who estimated that consumption of vegetation by broilers represented less than 10% of energy and protein daily requirements. C_{export} was estimated at about 2111 kg C ha^{-1} yr^{-1} for the year 2010 as shown in Table S3, with about 65% due to vegetation C, 34% to fauna C and less than 1% to soil C. C_{export} represented about 83% of total C ingestion from the run.

The other terms of Eq. (2) were more straightforward, and probably less uncertain. $\frac{\Delta SOC}{\Delta t}$ can be only be viewed as a short-term C change, but not necessarily as long-term C sequestration, and was estimated from measurements at 3765 kg C ha^{-1} yr^{-1} (Table S3). C_{import} was estimated from calculated N outdoor excretion assuming a C:N ratio in fresh droppings of 10 (Sasáková et al., 2010) and estimated to 3440 kg C ha^{-1} yr^{-1} for the year 2010 (Table S3), which is of a comparable magnitude to $\frac{\Delta SOC}{\Delta t}$. $C_{leaching}$ was estimated at 294 kg C ha^{-1} yr^{-1} according to the average value for a range of grazed grasslands given by Kindler et al. (2011). By difference between all these terms (Eq. 2), NEE_G would be a C sink of about −2730 kg CO_2−C ha^{-1} yr^{-1} (Table S3).

$R_{broilers}$ is an additional term needed for the calculation of the NGHGE, and can be estimated using the heat production of broilers, which is a function of live weight and air temperature (CIGR, 2002). However, heat production of broilers (in W) has been studied with fast-growing strains in claustration conditions (metabolic chambers) and this equation is probably not well adapted to slow-growing strains such as the one reared in our study because of differences in animal metabolism (slower growth rate). In order to take into account these differences of growth rate, heat production was weighted for each batch by the ratio between average daily gain (ADG in kg d^{-1}) of a fast-growing strain (0.05 kg d^{-1} i.e. about 2 kg in 42 d) and the ADG of the batch (about 0.02 kg d^{-1}). $R_{broilers}$ was then calculated assuming that 0.185 m^3 of CO_2 are produced per hour per kW of total heat produced (CIGR, 2002). For 2010, $R_{broilers}$ was estimated to about 1567 kg CO_2−C ha^{-1} yr^{-1} as shown in Table S3, roughly one third of R_{eco}.

The estimate of NEE_{G+B} thus obtained (−1163 kg C ha^{-1} yr^{-1}, i.e. −4264 kg CO_2 eq. ha^{-1} yr^{-1}) implies that the whole (soil+vegetation+broilers) ecosystem would still have been a net sink of CO_2. This sink was offset by roughly one third by N_2O emissions, which represented a net emission of +1722 kg CO_2 eq. ha^{-1} yr^{-1} (Table S3). The impact of CH_4 (about −19 kg CO_2 eq. ha^{-1} yr^{-1}, mean of the values estimated with two different interpolation methods) could be neglected, as CH_4 oxidation compensated only 1.1% of the N_2O forcing effect.

Overall, the NGHGE of −2561 kg CO_2 eq. ha^{-1} yr^{-1} would suggest that the outdoor part of the rearing system behaves as a net sink of greenhouse gases, though uncertainties are very large and this would have to be confirmed by plot-scale measurements of all component terms of Eq. (2), including NEE by eddy covariance (which should include $R_{broilers}$) as well as DOC leaching. Furthermore, an estimate of CO_2 eq. emissions from the house should also be estimated in order to propose a full GHG budget of the rearing system (broiler house+run) (Meda, 2011).

No published data concerning GHG outdoor emissions from “grazing poultry” were found in the literature, but studies concerning grassland grazed by cattle (Allard et al., 2007; Gilmanov et al., 2007; Soussana et al., 2007) can serve as reference points. In these studies, grassland management practices concerns cutting, grazing and fertilization. In our study, the grassland was “grazed” but not cut and we consider that it was fertilized because nutrients excreted on the run are mainly due to droppings enriched by feed consumption, which is not part of the ecosystem. In grazed grassland studies, the measurement of NEE by eddy covariance is assumed to include both soil/vegetation as well as animal respiration, and constitutes therefore a reference for our estimated NEE_{G+B}. The average value of NEE in the afore-mentioned studies from the GREENGRASS project (2002–2004) is about −8260 kg CO_2 ha^{-1} yr^{-1} whereas our estimate of NEE_{G+B} (−4263 kg CO_2 ha^{-1} yr^{-1}) was 48% lower. This may be partly explained by a combined effect of lower GPP (lower leaf area index, drier conditions at Le Magneraud) and lower respiration values in our study (Table S3), compared to average values of 48 220 and 39 960 kg CO_2 ha^{-1} yr^{-1} respectively for GPP and respiration calculated from Allard et al. (2007) and Gilmanov et al. (2007). Stocking density in our study was equivalent to 5.5 Livestock Unit (LU) ha^{-1} yr^{-1} whereas for cattle studies stocking density was closer to 1 LU ha^{-1} yr^{-1} (Allard et al., 2007). The high stocking density was responsible for vegetation destruction in the first part of the run where broilers were frequently observed, and for trampling and soil compaction in that area. This may have led to a decrease in the capacity of the grassland to assimilate carbon and could explain the lower GPP value that we estimated. However, our estimation of NEE_{G+B} mostly relies on estimates of $R_{broilers}$ and C_{export} with strong hypotheses, and this estimate should be treated with caution. In future experiments, NEE_{G+B} should be measured directly using eddy-covariance technique such as in the pasture studies (Allard et al., 2007; Gilmanov et al., 2007; Soussana et al., 2007), and ensuring that the flux footprint of the EC tower includes the flock of broilers.

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Table S1. Temporal variations (between initial (March 2009) and final (December 2010) measurements) of C, N and P stocks in the topsoil (0-15 cm) layer, for the composite samples from 25 equally-sized (94 m²) sampling squares of the paddock.

		C stock per sampling square				N stock per sampling square				P stock per sampling square			
Soil sampling Square ID	Mean distance to house door (m)	Initial (kg)	Final (kg)	Variation (final-initial, kg)	Variation (g m^{-2} yr^{-1})	Initial (kg)	Final (kg)	Variation (final-initial, kg)	Variation (g m^{-2} yr^{-1})	Initial (kg)	Final (kg)	Variation (final-initial, kg)	Variation (g m^{-2} yr^{-1})
1	19	349	340	-9	-56	35	33	-1	-9	4.25	6.30	2	12
2	11	352	371	19	113	31	36	4	27	4.04	7.76	4	23
3	5	301	380	79	480	32	37	6	36	4.09	10.18	6	37
4	11	339	366	28	167	36	36	-1	-3	4.82	7.22	2	15
5	19	341	458	117	710	37	44	7	43	4.14	6.90	3	17
6	24	300	345	45	273	31	34	2	15	3.74	5.61	2	11
7	18	298	327	29	176	31	31	1	3	4.93	5.50	1	3
8	15	317	383	66	403	34	38	4	25	7.90	11.04	3	19
9	18	372	437	64	391	37	43	6	36	7.31	9.89	3	16
10	24	374	382	8	46	38	37	-1	-4	4.00	5.55	2	9
11	31	288	381	94	569	30	36	6	37	3.13	4.07	1	6
12	27	332	414	82	497	34	39	5	30	4.43	5.41	1	6
13	25	318	416	98	595	34	40	6	34	5.62	6.68	1	6
14	27	346	415	69	418	38	41	3	17	5.66	5.65	0	0
15	31	358	459	101	611	39	45	6	37	3.71	5.31	2	10
16	40	279	377	98	594	28	35	7	41	2.44	2.74	0	2
17	36	293	329	37	222	30	31	1	7	2.84	3.09	0	2
18	35	304	383	79	480	31	37	6	34	2.88	3.67	1	5
19	36	322	392	70	423	33	37	4	26	3.01	3.46	0	3
20	40	382	407	25	150	36	40	4	27	3.17	3.90	1	4
21	49	298	341	43	259	29	33	4	23	2.10	2.04	0	0
22	46	262	363	101	611	27	35	9	52	2.37	2.97	1	4
23	45	321	388	67	408	34	38	4	23	3.02	3.44	0	3
24	46	321	391	69	421	34	40	7	40	2.95	3.56	1	4
25	49	338	412	74	452	37	41	4	25	3.45	3.67	0	1
Sum (paddock)		8104	9655	1551	377	833	936	103	25	100	136	36	9

Table S2. Parameters used in the estimation of carbon export out of the outdoor run (C_{export}). See text for details.

	Value	Source
Daily soil intake I_{soil} (g DM d^{-1} broiler^{-1})	0 – 1.6[a]	Jurjanz *et al.*, 2011
Daily vegetation intake I_{veg} (g DM d^{-1} broiler^{-1})	1.3 – 15.4[a]	Jurjanz *et al.*, 2011
Daily soil fauna intake I_{fauna} (g d^{-1} broiler^{-1})	20.0	de Vries *et al.*, 2006
Soil organic C content C_{soil} (g C kg^{-1} DM)	31.0	measured in this study
Vegetation C content C_{veg} (kg C kg^{-1} DM)	0.4	Dutton *et al.*, 1988
Soil fauna C content C_{fauna} (kg C kg^{-1} DM)	0.5	IPCC, 2003
Soil fauna DM content DM_{fauna} (%)	19%	Devliegher and Verstraete, 1995
Soil Excretion:Ingestion ratio EI_{soil} (%)	100%[b]	Germain et al., 2011
Vegetation Excretion:Ingestion ratio EI_{veg} (%)	50%[c]	Germain et al., 2011
Soil fauna Excretion:Ingestion ratio EI_{fauna} (%)	25%[d]	-

DM = Dry matter
[a]Values were determined for different seasons.
[b]Assuming that soil is not digestible (in agreement with Germain et al., 2011).
[c]Assuming that vegetation is rich in non digestible fibers (in agreement with Germain et al. 2011).
[d]Assuming that fauna is highly digestible.

Table S3. An assessment of annual carbon budget, greenhouse gases fluxes and their net budget (NGHGE) in CO_2 equivalents (CO_2 eq.) for the outdoor run in 2010.

C fluxes (kg C ha^{-1} yr^{-1})[a]				CO_2 fluxes (kg CO_2−C ha^{-1} yr^{-1})[d]				GHG fluxes (kg CO_2 eq. ha^{-1} yr^{-1})[h]			
ΔSOC/Δt[b]	C_{import}[c]	C_{export}[c]	$C_{leaching}$[c]	NEE_G[e]	R_{eco}[f]	GPP_G[g]	$R_{broilers}$[c]	F_{N2O}[i]	F_{CH4}[j]	NEE_{G+B}	NGHGE[k]
3765	3440	2111	294	-2730	4351[c]	-7081[f]	1567	1722	-19	-4264	-2561

[a]ΔSOC/Δt, change in soil organic carbon with time; C_{import}, C imported on the outdoor by droppings; C_{export}, C exported by the consumption by broilers of soil, vegetation and soil fauna; $C_{leaching}$ C losses by leaching.
[b]Measured.
[c]Estimated (see text of Supplementary material for details).
[d]NEE_G, net ecosystem exchange (includes soil and vegetation but not the broilers); R_{eco}, respiration of the soil+vegetation ecosystem; GPP_G, Gross Primary Production of the grassland; $R_{broilers}$, respiration of broilers on the outdoor run.
[e]Calculated according to Eq. 2 (see text of Supplementary material for details).
[f]Mean of the 3 estimates given in Table 4 of main paper.
[g]Calculated as the difference between NEE_G and R_{eco}.
[h]F_{N2O}, F_{CH4}, N_2O and CH_4 fluxes; NEE_{G+B}, net ecosystem exchange (defined as the sum of NEE_G and $R_{broilers}$); NGHGE, net greenhouse gas exchange.
[i]Calculated as the mean of the 3 N_2O estimated fluxes (Table 4 of main paper) multiplied by its Global Warming Potential (298 kg CO_2 eq. per kg of N_2O).
[j]Calculated as the mean of the 2 CH_4 estimated fluxes (Table 4 of main paper) multiplied by its Global Warming Potential (25 kg CO_2 eq. per kg of CH_4).
[k]Calculated as the sum of F_{N2O}, F_{CH4} and NEE_{G+B} in CO_2 equivalents (Eq. 1).