# Effect of biochar on soil greenhouse gas emissions at the laboratory and field scales:

*Supplementary Information*

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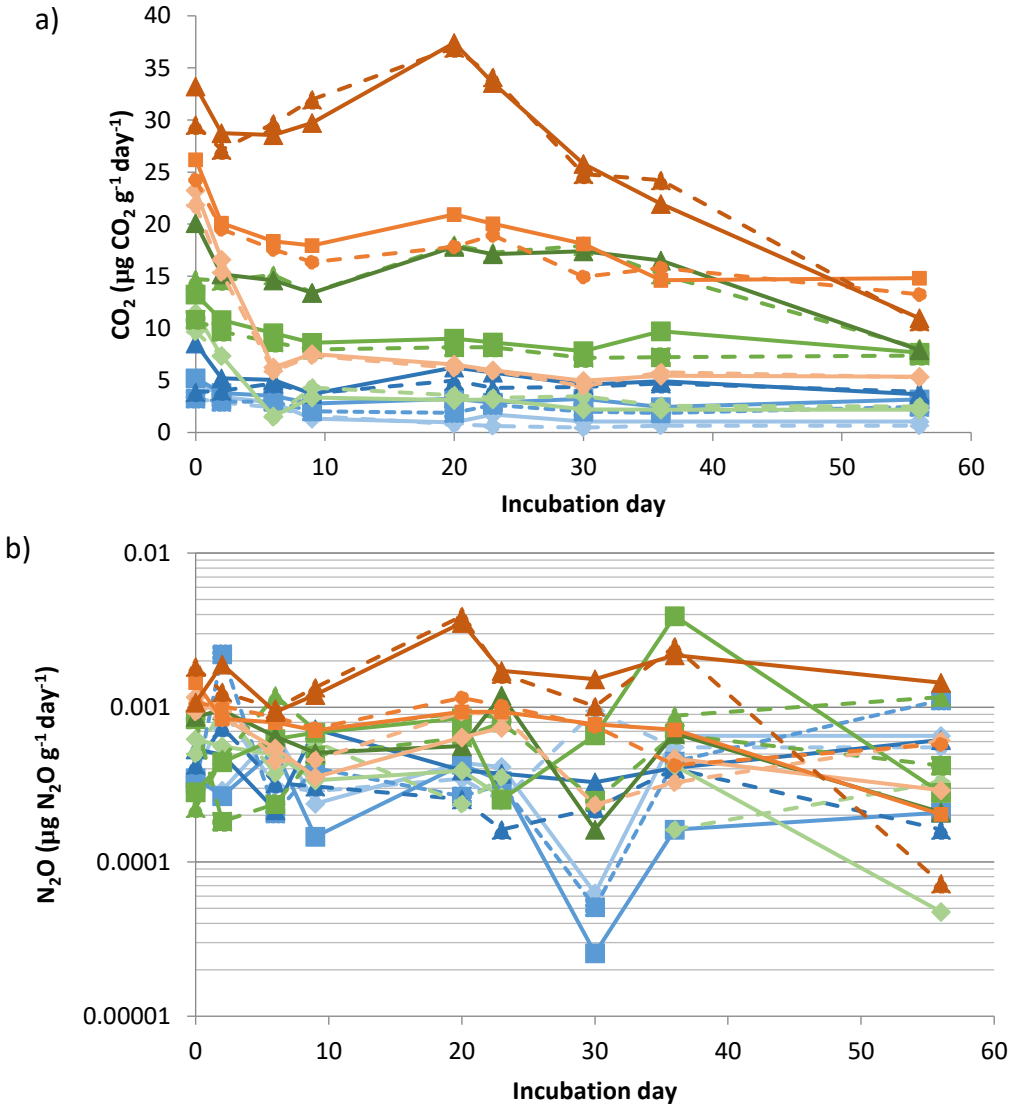


**Figure S1.** Daily soil (a) $CO_2$ and (b) $N_2O$ emissions measured during the equilibration period of the laboratory incubation study (pre-fertilization). (blue = 10°C, green = 20°C, orange = 30°C; diamonds = 27%, squares = 31%, and triangles = 35% moisture; dashes = controls, solid lines = biochar)

**Table S1.** Accumulated total $CO_2$ emissions during pre-fertilization period.**(± standard deviation).**

| | | Soil amendment | |
|---|---|---|---|
| **Temperature (C)** | Moisture (%) | Control (none) | Biochar |
| 10 | 27 | 0.152 ±0.01 | 0.195 ±0.043 |
| 10 | 31 | 0.23 ±0.03 | 0.3 ±0.02 |
| 10 | 35 | 0.38 ±0.02 | 0.47 ±0.03 |
| 20 | 27 | 0.43 ±0.11 | 0.37 ±0.03 |
| 20 | 31 | 0.76 ±0.02 | 0.84 ±0.03 |
| 20 | 35 | 1.36 ±0.01 | 1.4 ±0.04 |
| 30 | 27 | 0.79 ±0.05 | 0.9 ±0.1 |
| 30 | 31 | 1.6 ±0.05 | 1.76 ±0.09 |
| 30 | 35 | 2.9 ±0.12 | 2.8 ±0.1 |

**Table S2.** Daily post-fertilization $CO_2$-C emissions, in mg of $CO_2$-C per gram of soil per day (5 replicates). *Same data as Figure 1 in main text.*

| T (°C) | %moist-ure | Amend-ment | 0 | 1 | 2 | 3 | 7 | 10 | 16 | 38 | 52 | 62 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10** | 27 | none | 55 ±3 | 24 ±3 | 4 ±0 | 4 ±0 | 14 ±1 | 15 ±1 | 10 ±1 | 2.9 ±0.2 | 7 ±0.2 | 5.5 ±0.4 | 4.9 ±0.5 |
| **10** | 27 | biochar | 51 ±2 | 25 ±3 | 5 ±1 | 4 ±1 | 13 ±1 | 12 ±1 | 9 ±1 | 2.7 ±0.2 | 6.6 ±0.7 | 5.4 ±0.4 | 4.4 ±0.4 |
| **10** | 31 | none | 43 ±4 | 25 ±4 | 6 ±1 | 5 ±0 | 11 ±1 | 12 ±1 | 9 ±1 | 2.9 ±0.1 | 7.7 ±0.3 | 6.1 ±0.1 | 5.2 ±0.2 |
| **10** | 31 | biochar | 37 ±7 | 28 ±4 | 8 ±2 | 5 ±0 | 12 ±1 | 11 ±1 | 12 ±1 | 3 ±0.4 | 8.2 ±0.3 | 6.8 ±0.4 | 5.5 ±0.5 |
| **10** | 35 | none | 41 ±3 | 33 ±2 | 6 ±1 | 5 ±0 | 15 ±1 | 14 ±1 | 13 ±0 | 2.6 ±0.6 | 9 ±1 | 6.9 ±0.5 | 5.7 ±0.3 |
| **10** | 35 | biochar | 46 ±4 | 29 ±2 | 5 ±0 | 5 ±1 | 15 ±1 | 15 ±2 | 14 ±1 | 2.6 ±0.5 | 11 ±1 | 8.4 ±0.6 | 6.5 ±0.4 |
| **20** | 27 | none | 111 ±6 | 55 ±4 | 18 ±1 | 15 ±1 | 41 ±5 | 34 ±3 | 33 ±8 | 7 ±2 | 15 ±3 | 11 ±1 | 8.5 ±0.9 |
| **20** | 27 | biochar | 108 ±7 | 40 ±2 | 20 ±1 | 18 ±2 | 39 ±3 | 31 ±2 | 30 ±4 | 5 ±2 | 15 ±3 | 11 ±1 | 10 ±2 |
| **20** | 31 | none | 102 ±7 | 57 ±4 | 16 ±1 | 13 ±1 | 42 ±6 | 36 ±3 | 33 ±4 | 5 ±3 | 16 ±2 | 13 ±2 | 10 ±2 |
| **20** | 31 | biochar | 100 ±3 | 37 ±6 | 17 ±1 | 15 ±2 | 54 ±14 | 36 ±4 | 43 ±7 | 6 ±2 | 13 ±2 | 10.1 ±0.8 | 9.9 ±0.8 |
| **20** | 35 | none | 104 ±4 | 55 ±10 | 22 ±1 | 17 ±2 | 41 ±2 | 37 ±3 | 44 ±3 | 5 ±2 | 11 ±1 | 9 ±0.8 | 9 ±2 |
| **20** | 35 | biochar | 98 ±4 | 50 ±3 | 22 ±1 | 17 ±2 | 40 ±3 | 35 ±3 | 55 ±11 | 4 ±1 | 13 ±2 | 10 ±1 | 9 ±0.9 |
| **30** | 27 | none | 182 ±4 | 80 ±6 | 42 ±6 | 39 ±7 | 59 ±4 | 39 ±3 | 38 ±8 | 10 ±1 | 17 ±1 | 17 ±2 | 17 ±2 |
| **30** | 27 | biochar | 174 ±9 | 82 ±4 | 39 ±3 | 40 ±2 | 70 ±5 | 42 ±1 | 36 ±4 | 10 ±2 | 17 ±1 | 15 ±1 | 14 ±1 |
| **30** | 31 | none | 162 ±7 | 66 ±2 | 32 ±4 | 34 ±6 | 69 ±6 | 45 ±5 | 47 ±7 | 10 ±1 | 17 ±2 | 15.8 ±0.9 | 18 ±5 |
| **30** | 31 | biochar | 164 ±8 | 66 ±5 | 28 ±3 | 28 ±5 | 67 ±9 | 46 ±4 | 43 ±10 | 7 ±1 | 18 ±4 | 18 ±3 | 15 ±2 |
| **30** | 35 | none | 162 ±6 | 84 ±4 | 35 ±3 | 33 ±5 | 77 ±13 | 55 ±6 | 32 ±4 | 8.7 ±0.4 | 14 ±2 | 13 ±1 | 13 ±1 |
| **30** | 35 | biochar | 159 ±6 | 80 ±8 | 36 ±6 | 31 ±5 | 72 ±6 | 51 ±3 | 33 ±5 | 6.7 ±0.8 | 13.6 ±0.5 | 12.7 ±0.3 | 14 ±1 |

**Table S3.** Daily $N_2O$-N emissions during the first 10 days of the post-fertilization period, in μg of $N_2O$-N per gram of soil per day (emissions below detection limit after day 10). Note logarithmic scale. (5 replicates) (Same data as in Figure 1 in main text).

| T (°C) | %moisture | Amendment | 0 | 1 | 2 | 3 | 7 | 10 |
|---|---|---|---|---|---|---|---|---|
| **10** | 27 | none | 0.003 ±0.001 | 0.001 ±0.001 | 0.0013 ±0.0008 | 0.0012 ±0.0004 | 0.0008 ±0.0002 | 0.0007 ±0.0002 |
| **10** | 27 | biochar | 0.003 ±0.002 | 0.002 ±0.001 | 0.0009 ±0.0002 | 0.0007 ±0.0007 | 0.0007 ±0.0003 | 0.0007 ±0.0006 |
| **10** | 31 | none | 0.002 ±0.001 | 0.002 ±0.001 | 0.0007 ±0.0003 | 0.0006 ±0.0006 | 0.0007 ±0.0003 | 0.0003 ±0.0003 |
| **10** | 31 | biochar | 0.003 ±0.003 | 0.001 ±0.001 | 0.0005 ±0.0006 | 0.0004 ±0.0004 | 0.0006 ±0.0003 | 0.0002 ±0.0001 |
| **10** | 35 | none | 0.008 ±0.009 | 0.016 ±0.021 | 0.0008 ±0.0003 | 0.0005 ±0.0006 | 0.0009 ±0.0005 | 0.0004 ±0.0004 |
| **10** | 35 | biochar | 0.01 ±0.01 | 0.002 ±0.001 | 0.0007 ±0.0006 | 0.0005 ±0.0006 | 0.0006 ±0.0006 | 0.0004 ±0.0003 |
| **20** | 27 | none | 0.02 ±0.01 | 0.002 ±0.001 | 0.0009 ±0.0007 | 0.0011 ±0.0008 | 0.001 ±0.0005 | 0.0002 ±0.0002 |
| **20** | 27 | biochar | 0.01 ±0.01 | 0.002 ±0 | 0.0013 ±0.0005 | 0.0019 ±0.0007 | 0.0009 ±0.0002 | 0.0008 ±0.0008 |
| **20** | 31 | none | 0.06 ±0.05 | 0.002 ±0.001 | 0.0014 ±0.0009 | 0.0008 ±0.0009 | 0.0012 ±0.0003 | 0.0008 ±0.0006 |
| **20** | 31 | biochar | 0.02 ±0.01 | 0.003 ±0.002 | 0.0019 ±0.0004 | 0.0013 ±0.001 | 0.0016 ±0.0003 | 0.0006 ±0.0006 |
| **20** | 35 | none | 0.55 ±0.19 | 0.076 ±0.066 | 0.0011 ±0.0007 | 0.0008 ±0.001 | 0.0014 ±0.0007 | 0.0011 ±0.0007 |
| **20** | 35 | biochar | 0.72 ±0.37 | 0.3 ±0.152 | 0.0021 ±0.0008 | 0.0013 ±0.0005 | 0.0009 ±0.0005 | 0.0011 ±0.0011 |
| **30** | 27 | none | 0.08 ±0.03 | 0.004 ±0.002 | 0.0024 ±0.0008 | 0.0024 ±0.001 | 0.0016 ±0.0003 | 0.0007 ±0.0004 |
| **30** | 27 | biochar | 0.06 ±0.03 | 0.003 ±0.001 | 0.0026 ±0.0007 | 0.0024 ±0.0011 | 0.0019 ±0.0007 | 0.0008 ±0.0007 |
| **30** | 31 | none | 0.3 ±0.2 | 0.003 ±0.001 | 0.0024 ±0.0007 | 0.0024 ±0.0004 | 0.002 ±0.0005 | 0.0009 ±0.0003 |
| **30** | 31 | biochar | 0.3 ±0.2 | 0.003 ±0.001 | 0.0011 ±0.0002 | 0.002 ±0.0014 | 0.0021 ±0.0007 | 0.001 ±0.0007 |
| **30** | 35 | none | 1.8 ±0.7 | 0.1 ±0.1 | 0.0023 ±0.0002 | 0.0023 ±0.001 | 0.0072 ±0.0042 | 0.0007 ±0.0004 |
| **30** | 35 | biochar | 2 ±0.5 | 0.2 ±0.1 | 0.003 ±0.001 | 0.002 ±0.001 | 0.008 ±0.002 | 0.002 ±0.001 |

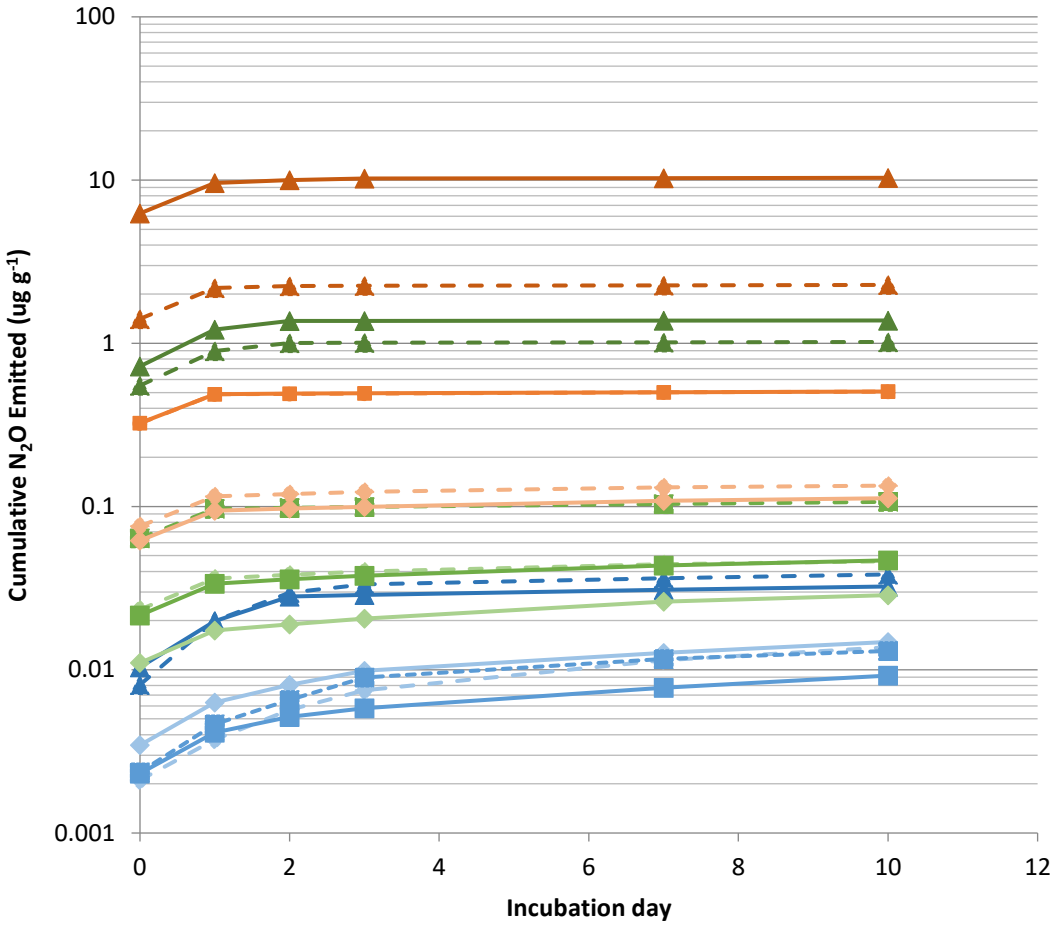


**Figure S2.** Cumulative $N_2O$ emissions measured post-fertilization during the incubation study. (blue = 10°C, green = 20°C, orange = 30°C; diamonds = 27%, squares = 31%, and triangles = 35% moisture; dashes = controls, solid lines = biochar).

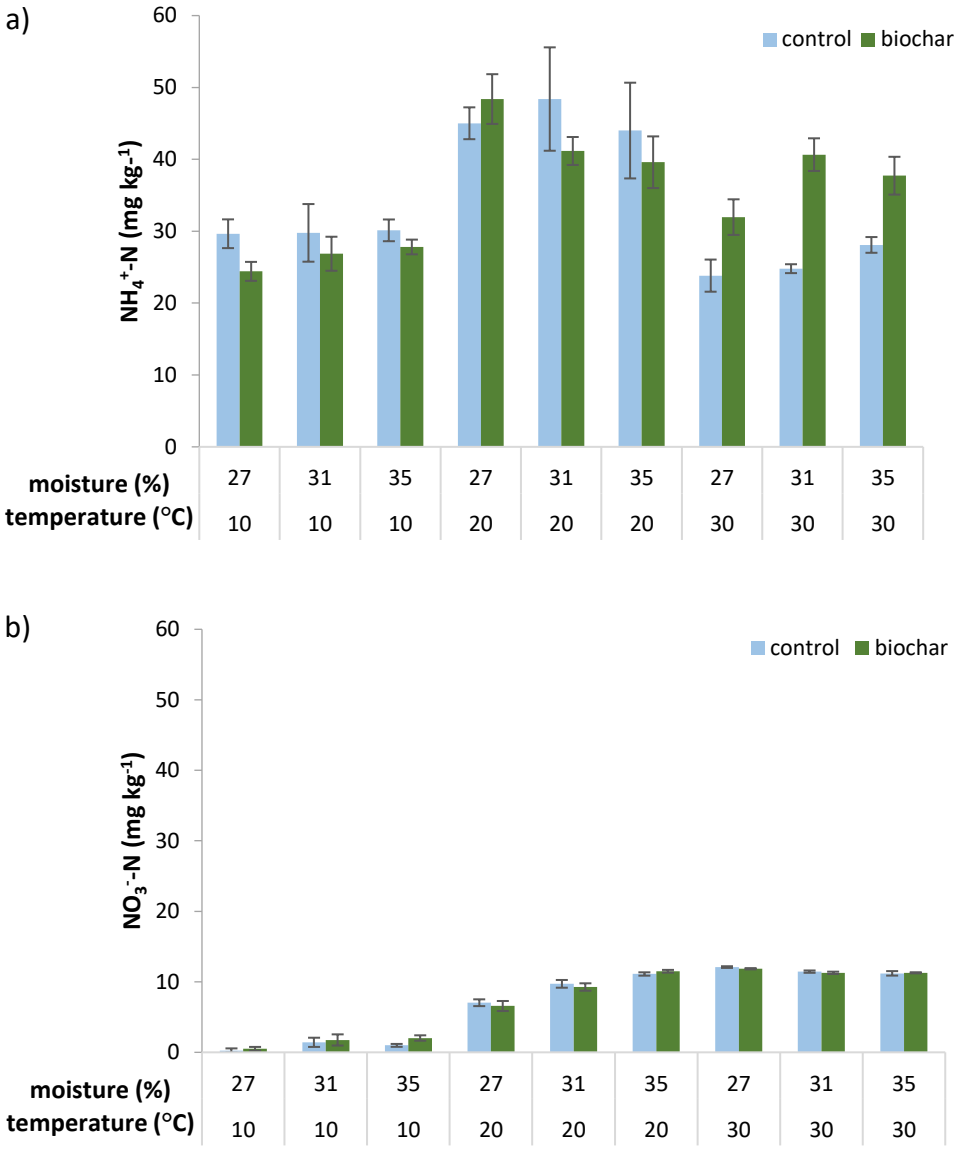


**Figure S3.** Final (a) $NH_4^+$ and (b) $NO_3^-$ concentrations, in mg of N per kg soil, after 140 day incubation at three temperatures and moistures, with and without biochar.

**Table S4.** Repeated measures statistical results from analysis of daily post-fertilization soil incubation emissions data, presented as p-values (significance evaluated at $p<0.05$).

| Effect | $N_2O$ | $CO_2$ |
|---|---|---|
| *biochar* | 0.2996 | 0.0382 |
| *temp* | <.0001 | <.0001 |
| *moist* | <.0001 | 0.0003 |
| *day* | <.0001 | <.0001 |
| *biochar*temp* | 0.7375 | 0.3441 |
| *biochar*moist* | 0.2427 | 0.603 |
| *char*day* | 0.6844 | <.0001 |
| *temp*moist* | <.0001 | <.0001 |
| *temp*day* | <.0001 | <.0001 |
| *biochar*temp*moist* | 0.7807 | 0.1429 |
| *biochar*temp*day* | 0.9751 | <.0001 |
| *biochar*moist*day* | 0.4465 | 0.0794 |
| *temp*moist*day* | <.0001 | <.0001 |
| *biochar*temp*moist*day* | 0.9954 | <.0001 |

**Table S5.** ANOVA statistical results from analysis cumulative post-fertilization soil incubation emissions data, presented as p-values (significance evaluated at $p<0.05$).

| Effect | $CO_2$ | $N_2O$ |
|---|---|---|
| *biochar* | 0.6234 | 0.1878 |
| *temp* | <.0001 | <.0001 |
| *moist* | 0.0079 | <.0001 |
| *temp*moist* | <.0001 | <.0001 |
| *biochar*temp* | 0.0875 | 0.4225 |
| *biochar*moist* | 0.0953 | 0.116 |
| *biochar*temp*moist* | 0.1494 | 0.4767 |

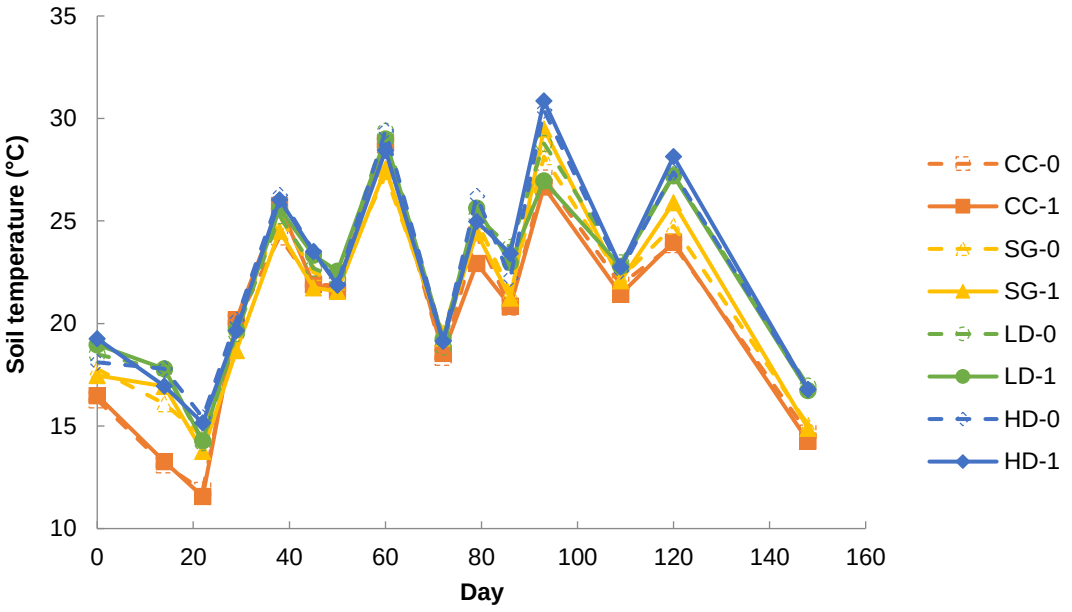


**Figure S4.** Average soil temperatures measured for each cropping system with biochar and without biochar on each day that GHG emissions were measured (CC = continuous corn, SG = switchgrass, LD = low diversity grass mix, HD = high diversity grass and forb mix; 0 = control, 1 = biochar-amended). *No significant effects of biochar observed.*

**Table S6.** Repeated measures statistical results from analysis of daily soil emissions data measured in the field, presented as p-values (significance evaluated at p<0.05).

| Effect. | $CO_2$ | $N_2O$ |
|---|---|---|
| *block* | <.0001 | 0.0014 |
| *crop* | <.0001 | <.0001 |
| *biochar* | 0.7808 | 0.3695 |
| *day* | <.0001 | <.0001 |
| *block*crop* | 0.0025 | 0.0094 |
| *block*biochar* | 0.2598 | 0.2371 |
| *block*day* | <.0001 | <.0001 |
| *crop*biochar* | 0.7937 | 0.304 |
| *crop*day* | <.0001 | <.0001 |
| *biochar*day* | 0.3391 | 0.9986 |
| *block*crop*biochar* | 0.1531 | 0.1897 |
| *block*crop*day* | <.0001 | <.0001 |
| *block*biochar*day* | 0.3662 | 0.0479 |
| *crop*biochar*day* | 0.1508 | 0.2275 |
| *block*crop*biochar*day* | 0.5105 | 0.1917 |

**Table S7.** ANOVA statistical results from analysis of cumulative soil emissions data measured in the field, presented as p-values (significance evaluated at $p<0.05$).

| Effect | $CO_2$ | $N_2O$ |
|---|---|---|
| *crop* | 0.0071 | 0.0214 |
| *biochar* | 0.8915 | 0.4761 |
| *crop*biochar* | 0.941 | 0.3378 |

**Table S8.** Repeated measures statistical results from analysis of daily soil moisture and temperature data measured in the field, presented as p-values (significance evaluated at $p<0.05$).

| Effect | moisture | temperature |
|---|---|---|
| **block** | <.0001 | <.0001 |
| **crop** | <.0001 | <.0001 |
| **char** | 0.0155 | 0.812 |
| **day** | <.0001 | <.0001 |
| **block*crop** | 0.0252 | 0.0032 |
| **block*char** | 0.0394 | 0.7458 |
| **block*day** | <.0001 | <.0001 |
| **crop*char** | 0.2505 | 0.3218 |
| **crop*day** | <.0001 | <.0001 |
| **char*day** | 0.0768 | 0.0669 |
| **block*crop*char** | 0.0138 | 0.5888 |
| **block*crop*day** | 0.0009 | <.0001 |
| **block*char*day** | 0.0466 | <.0001 |
| **crop*char*day** | 0.1592 | 0.0292 |
| **block*crop*char*day** | 0.1452 | 0.0038 |