Nitrous and nitric oxide emissions from a cornfield and managed grassland: 11 years of continuous measurement with manure and fertilizer applications, and land-use change.

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**Figure S1**: Layout of the treatment plots in the field experiment. The treatment plots were located in a large experimental field (100 x 200 m) of the Hokkaido university experimental farm. Each treatment plot was 5x5 m in size and was replicated 4 times (as shown in figure below) for gas, soil and biomass sampling. M is manure only treatment, MF is manure plus chemical fertilizer, F is chemical fertilizer only; and CT is the control with neither manure nor inorganic fertilizer application. Manure and chemical fertilizer in the treatment plots were applied by hand, but within one day after the rest of the field was applied with manure or chemical fertilizer by farm management.

M

F

MF

F

M

CT

MF

M

F

MF

CT

F

M

CT

MF

Outside of experimental plots: Manure and supplemental chemical fertilizer applied by farm management

Outside of experimental plots:

No manure, only chemical fertilizer application by farm management

100m

100m

ROAD

Drainage ditch

 CT

5x5 m

Table S1 Winter NO emissions (g N ha–1) and their contribution to total annual emissions in brackets (%)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | CT | F | MF | M |
| 2005 | 5.8 (10) | 10.0 (6) | 7.1 (2) |  |
| 2006 | 10.6 (7) | 10.0 (4) | 8.3 (2) |  |
| 2007 | 12.3 (23) | 40.0 (29) | 16.0 (5) |  |
| 2008 | 8.0 (55) | 6.7 (17) | 8.5 (15) |  |
| 2009 | -4.4 (-33) | 20.5 (3) | 1.0 (0.5) |  |
| 2010 | 2.4 (6) | 0.0 (0) | 9.9 (3) |  |
| 2011 | 4.4 (2) | 2.0 (0.4) | 46.7 (3) | 46.7 (7) |
| 2012 | 8.6 (9) | 9.4 (2) | 14.3 (2) | 14.4 (11) |
| 2013 | 0.0 (0) | -3.2 (-3) | -3.2 (-2) | 7.0 (3) |
| 2014 | 9.7 (28) | 9.7 (14) | -25.8 (-666) | -25.8 (200) |
| 2015 | -1.2 (-6) | -2.5 (--2) | -3.6 (2.2) | -1.9 (-8) |

CT is control plot; F is chemical fertilizer plot; MF is combined chemical fertilizer and manure plot; M is manure only plot

Table S2 Thawing period NO emissions (g N ha–1) and their contribution to total annual emissions in brackets (%)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | CT | F | MF | M |
| 2005 | 6.1 (11) | 6.3 (4) | 7.1 (2) |  |
| 2006 | 9.1 (6) | 7.4 (3) | 13.7 (3) |  |
| 2007 | 6.0 (8) | 1.8 (1) | 4.8 (2) |  |
| 2008 | 3.4 (23) | 3.5 (9) | 14.2 (25) |  |
| 2009 | -0.9 (-7) | 1.0 (0.1) | 1.5 (1) |  |
| 2010 | 10.1 (25) | 0.0 (0) | 86.9 (27) |  |
| 2011 | 60.9 (32) | 20.1 (4) | 30.3 (2) | 30.3 (5) |
| 2012 | 11.9 (13) | 5.0 (1) | 121.7 (16) | 8.1 (6) |
| 2013 | 0.8 (1) | -0.9 (-1) | -0.9 (0) | 3.2 (1) |
| 2014 | 10.3 (30.2) | 7.9 (11.6) | -17.2 (-442) | -16.1 (130) |
| 2015 | 0.3 (2) | 7.1 (5) | -0.9 (1) | -1.9 (-8) |

CT is control plot; F is chemical fertilizer plot; MF is combined chemical fertilizer and manure plot; M is manure only plot

Table S3 Average annual heterotrophic soil respiration (RH; Mg C ha-1yr-1) and estimated total mineralized N (kg N ha-1yr-1) from 2005-2015.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | CT | F | MF | M |
| OG | 2005 | RH | 4.8±0.8 | 4.8±0.8 | 5.3±1.5 | – |
|  |  | Mineralized N | 444.4 | 444.4 | 464.6 | – |
|  | 2006 | RH | 4.6±0.7 | 4.6±0.7 | 6.4±1.2 | – |
|  |  | Mineralized N | 425.9 | 425.9 | 519.7 | – |
|  | 2007 | RH | 4.9±0.5 | 4.9±0.5 | 9.2±1.9 | – |
|  |  | Mineralized N | 453.7 | 453.7 | 638.3 | – |
|  | 2008 | RH | 4.0±1.1 | 4.0±1.1 | 5.1±2.7 | – |
|  |  | Mineralized N | 370.4 | 370.4 | 412.5 | – |
|  | 2009 | RH | 4.5±2.5 | 4.5±2.5 | 7.8±1.8 | – |
|  |  | Mineralized N | 416.7 | 416.7 | 599.0 | – |
| Corn | 2010 | RH | 6.8±0.8 | 6.9±1.1 | 10.2±0.7 | – |
|  |  | Mineralized N | 646.7 | 654.0 | 872.4 | – |
|  | 2011 | RH | 6.5±0.9 | 6.1±1.1 | 7.8±1.1 | 7.8±1.1 |
|  |  | Mineralized N | 612.8 | 574.3 | 627.9 | 653.4 |
|  | 2012 | RH | 6.8±1.2 | 4.9±0.3 | 8.8±0.6 | 10.3±0.5 |
|  |  | Mineralized N | 642.3 | 461.7 | 628.9 | 793.5 |
| NG | 2013 | RH | 4.4±0.3 | 4.8±0.3 | 9.4±0.8 | 9.2±0.9 |
|  |  | Mineralized N | 415.3 | 455.6 | 734.2 | 707.6 |
|  | 2014 | RH | 4.0±0.5 | 4.3±0.4 | 5.5±0.5 | 5.9±0.5 |
|  |  | Mineralized N | 376.4 | 406.7 | 475.0 | 484.3 |
|  | 2015 | RH | 5.0±0.9 | 5.0±0.9 | 6.8±1.0 | 7.0±1.4 |
|  |  | Mineralized N | 477.1 | 481.3 | 552.0 | 557.9 |
|  |  |  |  |  |  |  |
|  |  | ANOVA | RH |  |  |  |
|  |  |  | d.f. | MS | F | p |
|  |  | Plot | 4 | 15.55 | 14.03 | <0.001 |
|  |  | Land-use | 2 | 12.88 | 11.62 | <0.001 |
|  |  |  |  |  |  |  |

CT is control plot; F is chemical fertilizer plot; MF is combined chemical fertilizer and manure plot; M is manure only plot. Mineralized N is sum of soil organic matter and manure N mineralization.

**Table S4** Plant N uptake and surplus N (kg ha-1yr-1).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | CT | F | MF | M |
|  |  |  |  |  |  |
| 2005 | Plant N uptake | 106.3 | 231.3 | 185.3 | – |
| 2005 | Surplus N | 338.2 | 377.2 | 409.3 | – |
|  |  |  |  |  |  |
| 2006 | Plant N uptake | 106.3 | 194.0 | 178.3 | – |
| 2006 | Surplus N | 319.7 | 415.0 | 474.4 | – |
|  |  |  |  |  |  |
| 2007 | Plant N uptake | 116.9 | 179.0 | 146.9 | – |
| 2007 | Surplus N | 336.8 | 348.7 | 512.4 | – |
|  |  |  |  |  |  |
| 2008 | Plant N uptake | 85.0 | 130.5 | 118.9 | – |
| 2008 | Surplus N | 285.4 | 313.8 | 293.6 | – |
|  |  |  |  |  |  |
| 2009 | Plant N uptake | 81.5 | 145.5 | 139.9 | – |
| 2009 | Surplus N | 335.2 | 362.6 | 459.1 | – |
|  |  |  |  |  |  |
| 2010 | Plant N uptake | 54.8 | 106.5 | 159.0 | \_ |
| 2010 | Surplus N | 591.9 | 651.5 | 817.4 | \_ |
|  |  |  |  |  |  |
| 2011 | Plant N uptake | 57.3 | 117.8 | 193.6 | 95.2 |
| 2011 | Surplus N | 555.4 | 560.6 | 538.3 | 558.1 |
|  |  |  |  |  |  |
| 2012 | Plant N uptake | 86.5 | 109.9 | 218.5 | 113.5 |
| 2012 | Surplus N | 555.7 | 448.3 | 507.0 | 680.0 |
|  |  |  |  |  |  |
| 2013 | Plant N uptake | 35.2 | 49.3 | 75.2 | 59.4 |
| 2013 | Surplus N | 380.1 | 446.3 | 699.1 | 648.2 |
|  |  |  |  |  |  |
| 2014 | Plant N uptake | 63.2 | 108.6 | 109.7 | 80.7 |
| 2014 | Surplus N | 313.3 | 448.3 | 412.1 | 403.6 |
|  |  |  |  |  |  |
| 2015 | Plant N uptake | 43.8 | 145.3 | 62.6 | 66.3 |
| 2015 | Surplus N | 433.3 | 439.8 | 546.3 | 491.7 |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| ANOVA |  | Plant N uptake |  | Surplus N |  |
|  | d.f. | MS | F | MS | F |
| Plot | 4 | 9909 | 8.68\*\* | 21202 | 2.89\* |
| Land-use | 2 | 13043 | 11.43\*\* | 128953 | 17.6\*\* |

CT is control plot; F is chemical fertilizer plot; MF is combined chemical fertilizer and manure plot; M is manure only plot. Surplus N was calculated as difference between total N input (total mineralized N from soil organic matter and manure, and chemical fertilizer N) and the plant N uptake.

\*\*p<0.01, \*p<0.05