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# Effects of Bulk Density and Soil Water Content on $N_2O$ Emission from Agriculture Soil

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# Introduction

Aggregate turnover rates (Six et al., 1999).

C availability (Rasmussen and Collins, 1991)

Macroporosity; Total porosity (Pierce et al., 1994),

Consumption of OM (Bowman et al., 1990)

$O_2$ and $CO_2$ Exchange (Rasmussen and Collins, 1991)

Exposure to wind,water erosion (Bowman et al., 1990).

Surface area available for microbial attack (Blevins et al., 1984).

**Plowing Activities**

Soil Strength

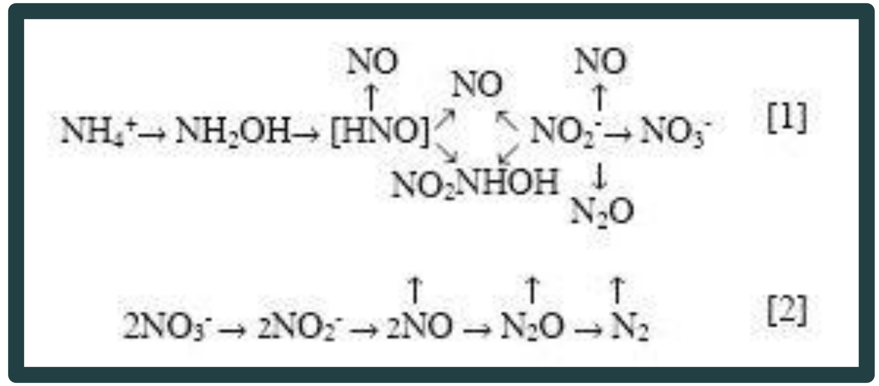
Bulk Density

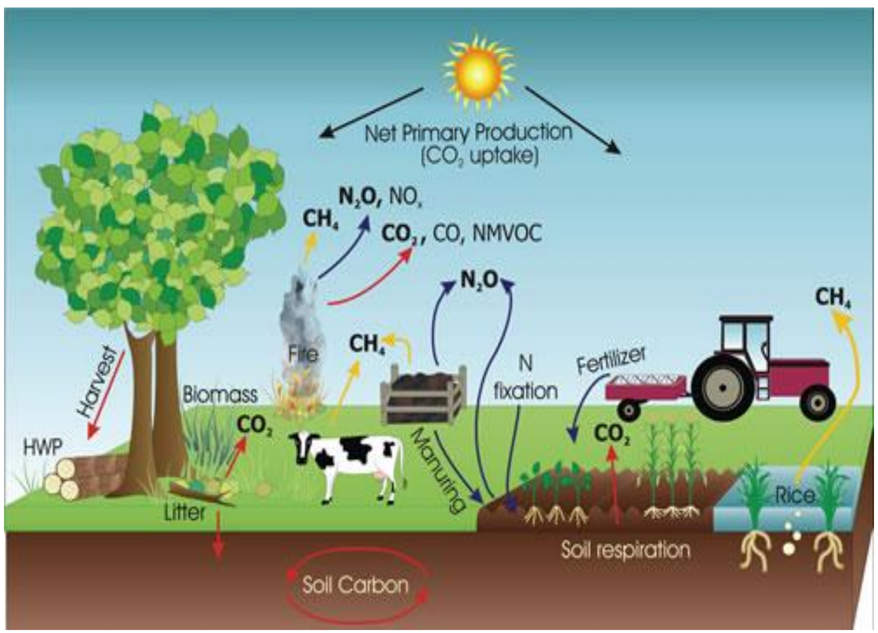
Soil aggregates (Rasmussen and Collins, 1991); (Angers, et al. 1992).

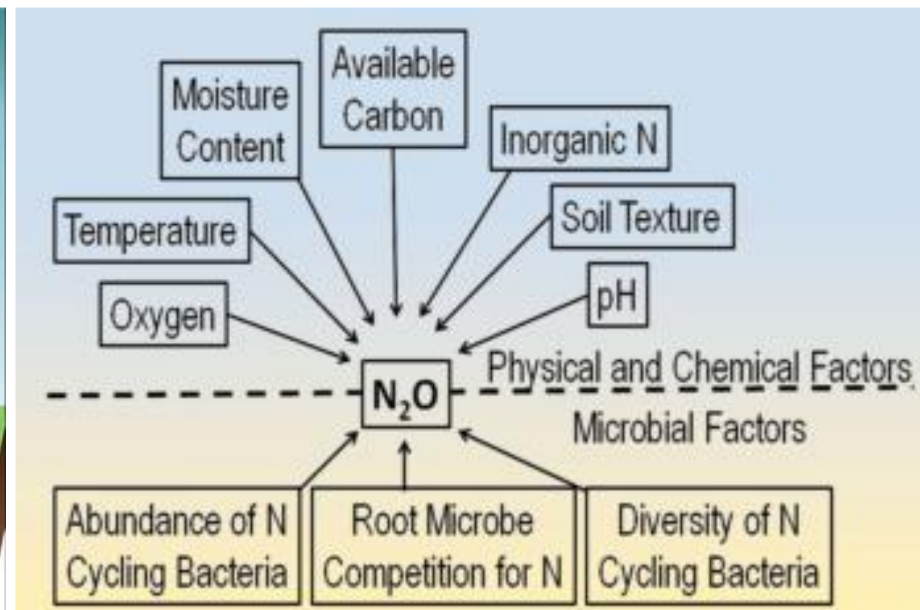
Microporosity (F. J. Pierce et al.,1994).

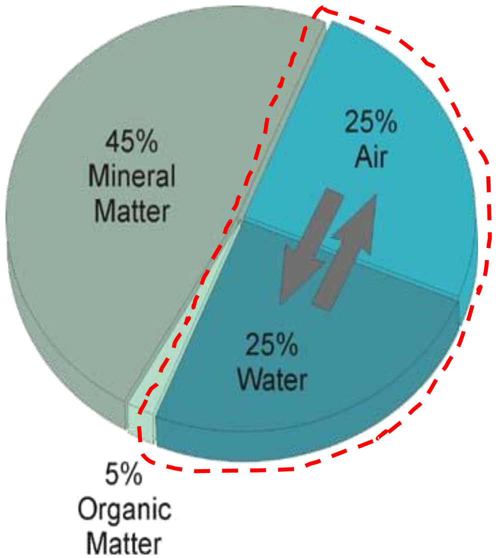
C in macro-aggregates (Gupta and Germida, 1988).

The production of $N_2O$ in agricultural systems is complex . Reducing these emissions will be challenging.



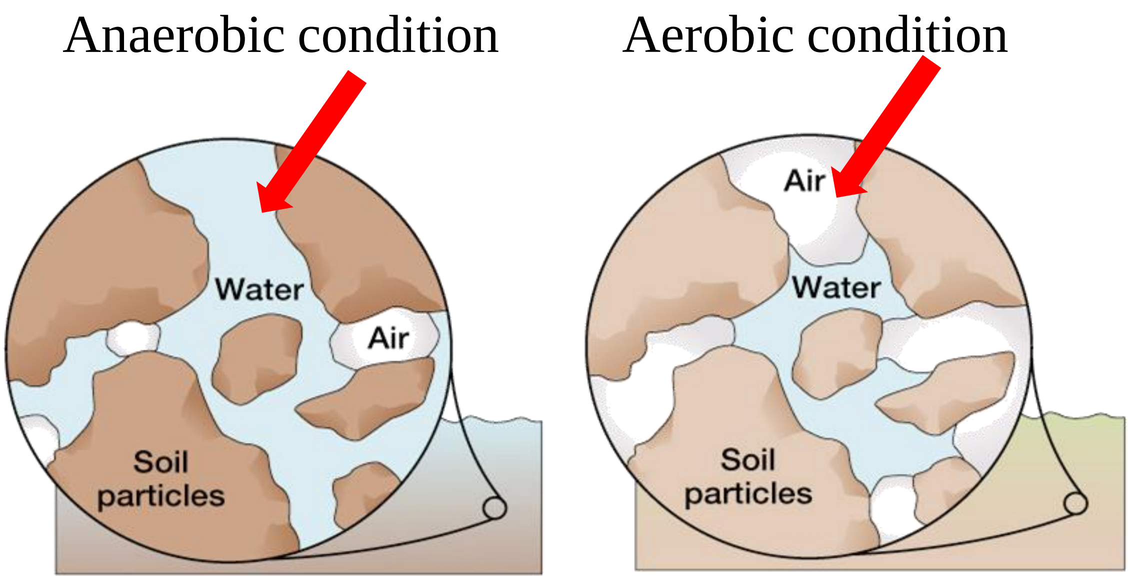






**Moisture content** of soil indirectly affected denitrification by inhibiting the diffusion of $O_2$ into soil, resulting in more denitrification (*Wijler and Delwiche 1954*).

**WFPS** is primary independent variable used in empirical analyses of $N_2O$ fluxes from agricultural soils (Linn& Doran, 1984; Conen et al., 2000; Dobbie & Smith, 2003; del Prado et al., 2006; Ruser et al., 2006).




(a) Wet soil (b) Dry soil

**WFPS<60%:** soil microbial processes are often limited by diffusion of SOC and inorganic-N substrates in soil water films;

**WFPS>60%:** diffusion of $O_2$ in soil atmosphere limits aerobic processes.

The difference of Bulk Density is largely attributable to variation in total pore space.

Macropores (>0.05 mm in diameter) can drain easily to allow in air within hours of being saturated and enhance horizontal pore water movement across the bank face.

Micropores continue to contain only water.

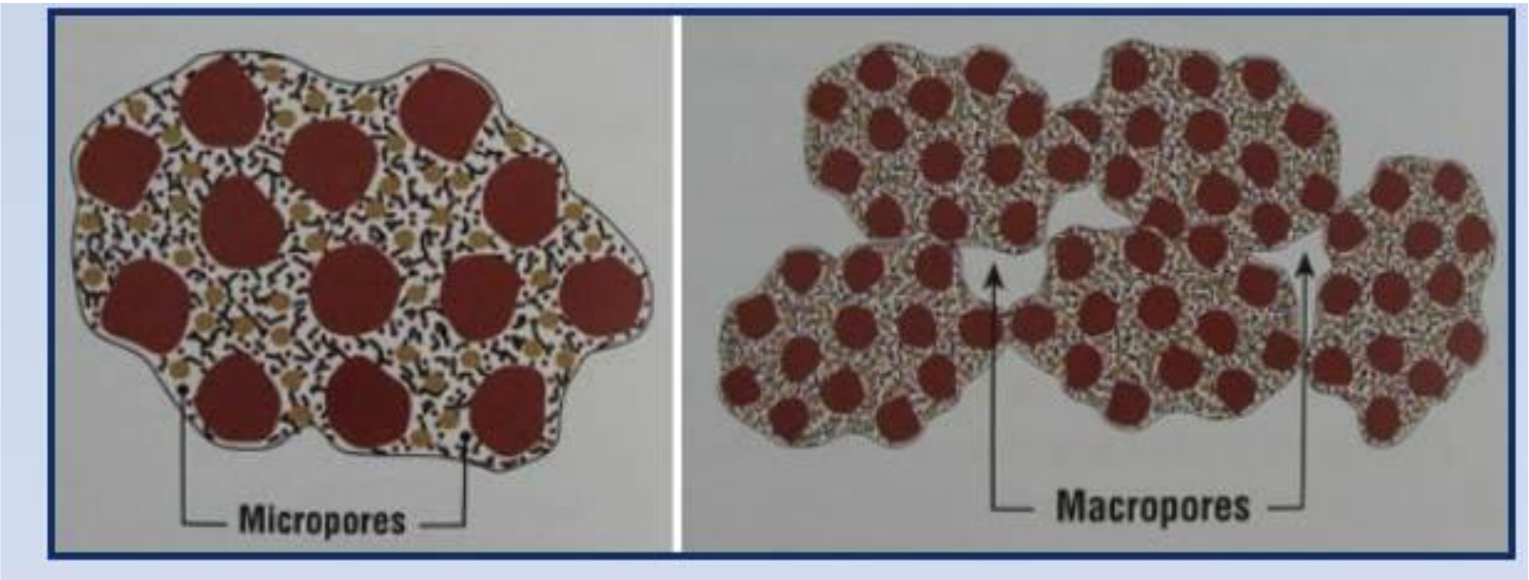



**Figure:** Micropores – the spaces within a soil aggregate
Macropores – the spaces between soil aggregates

# Objective

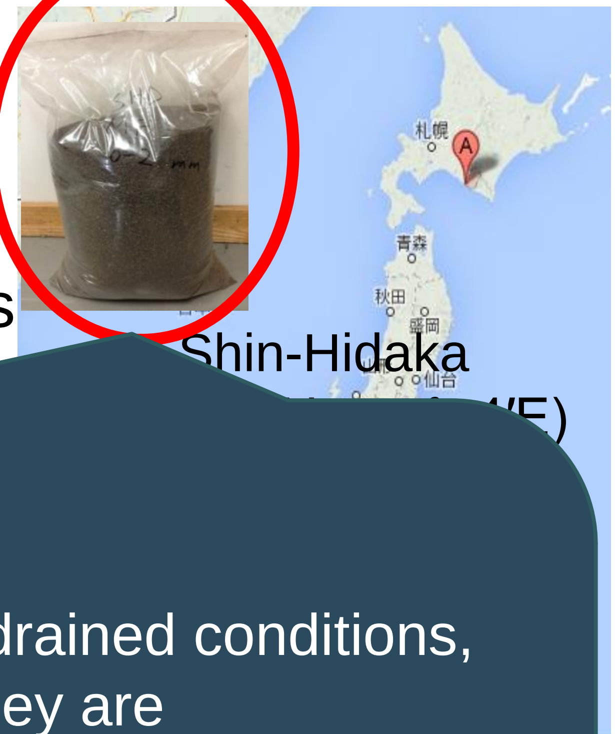
- Many studies state non-tillage caused higher $N_2O$ emission (Vinten and et al, 2002; Xuejun J and et al, 2006; Cai Y and et al, 2011), but which factors, changed by tillage, control $N_2O$ emission was not so clear and need deeper study.

- Soil core incubation under aerobic environment was conducted to study:

  the combined effect of bulk density (BD), soil water content (WC), and nutrient management (NM) on $CO_2$, $N_2O$, NO emission from agriculture soil.

# Material & Method

- **Soil Samples:**
  - collected from 0–20cm depth soil of fertilizer (F), manure + fertilizer (MF) plots Shin-Hidaka in Hokkaido(SHD), Japan

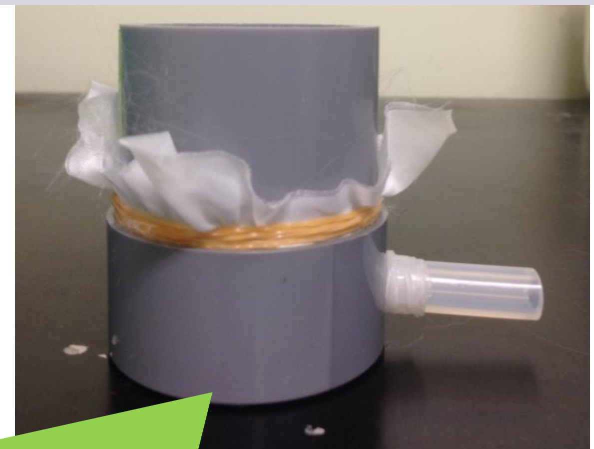



Andosol soil:

formed by weathering of volcanic ash in well-drained conditions, cover about 50% of upland fields in Japan. They are characterized by low bulk density (Classification Committee of Cultivated Soils,1996, <0.8 g $cm^{-3}$ ) and are favorable for keeping aerobic conditions. This suggests that the control of nitrification is important for decreasing $N_2O$ and NO emissions from Andosol fields in Japan where urea and $NH_4^+$-N are popular forms of N fertilizer.

All the jars will be sealed tightly and incubated for 10 days, Air samples will be taken from the headspace of jar 7 times during incubation for $N_2O$, $CO_2$, NO analyses at 1, 2, 3, 4, 6, 8 and 10days respectively. After each gas sampling, replacing the headspace air again.

Incubation Jar



After adjusting BD (to achieve a range of water filled pore space (WFPS) from 29% to 83%) and WC, soil will be packed in 50.24 ml rings and then put into a 1.54 L of Mason jar.

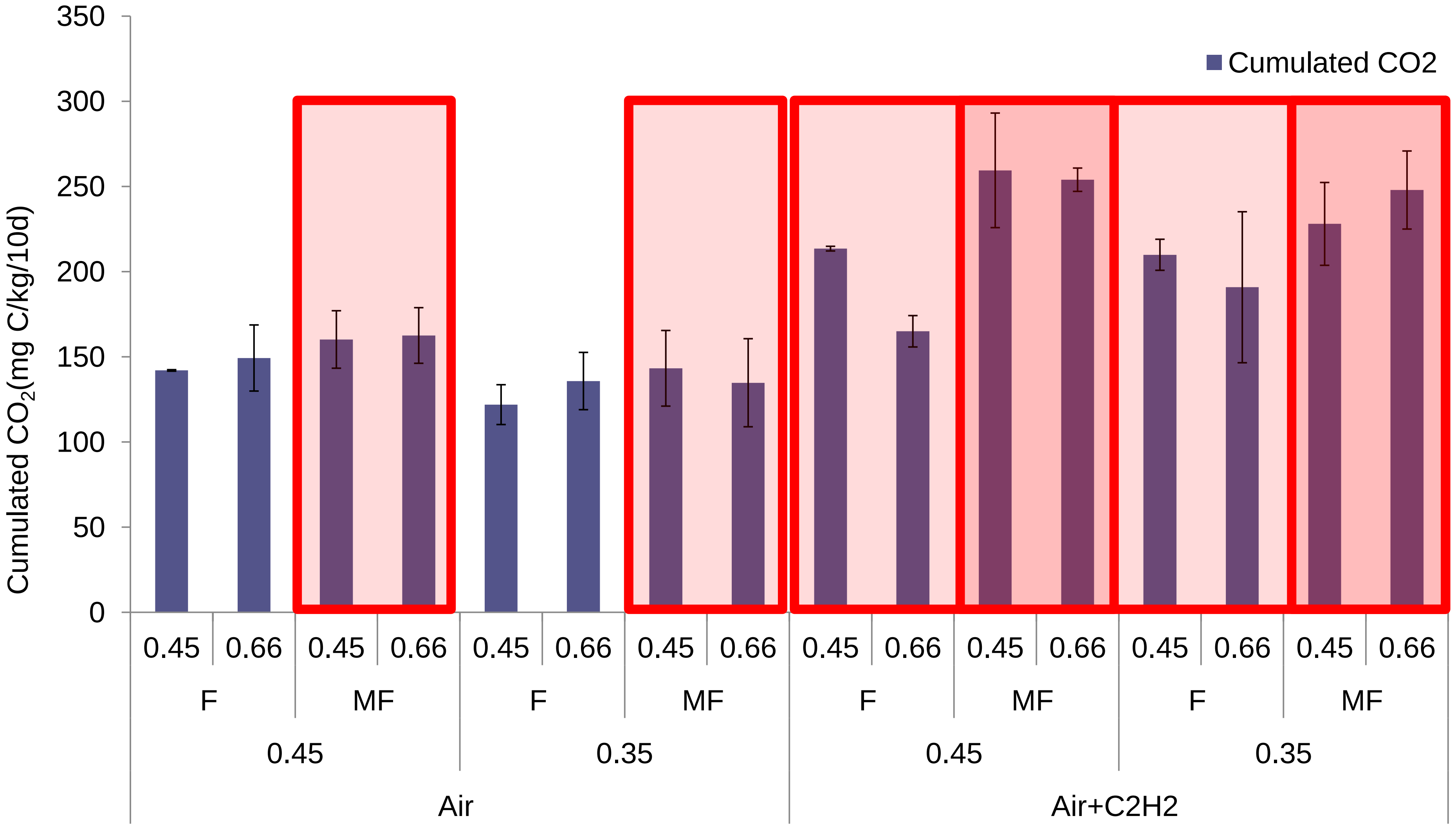
# The properties analysis

- Just after water adjustment and after incubation, all these items as below will be tested and all analyses will be conducted with 3 replicates:
- pH, $NO_3^-$, $SO_4^{2-}$, $NH_4^+$, WEOC, soil microbial biomass C (MBC) and N (SMBN), WC and Gas diffusion coefficient (D/D0), Actual bulk density. Then WFPS($m^3 m^{-3}$) was calculated accordingly.
- Denitrifying enzyme activity (DEA) was measured after incubation and was calculated as $N_2O$ in headspace between 2 and 4 h under $N_2$ atmosphere.
- Net ammonification and net nitrification (mg N/kg dwt) are estimated as the difference of $NH_4^+$ or $NO_3^-$ before and after incubation respectively.
- Net mineralization is estimated as the sum of net ammonification and net nitrification.

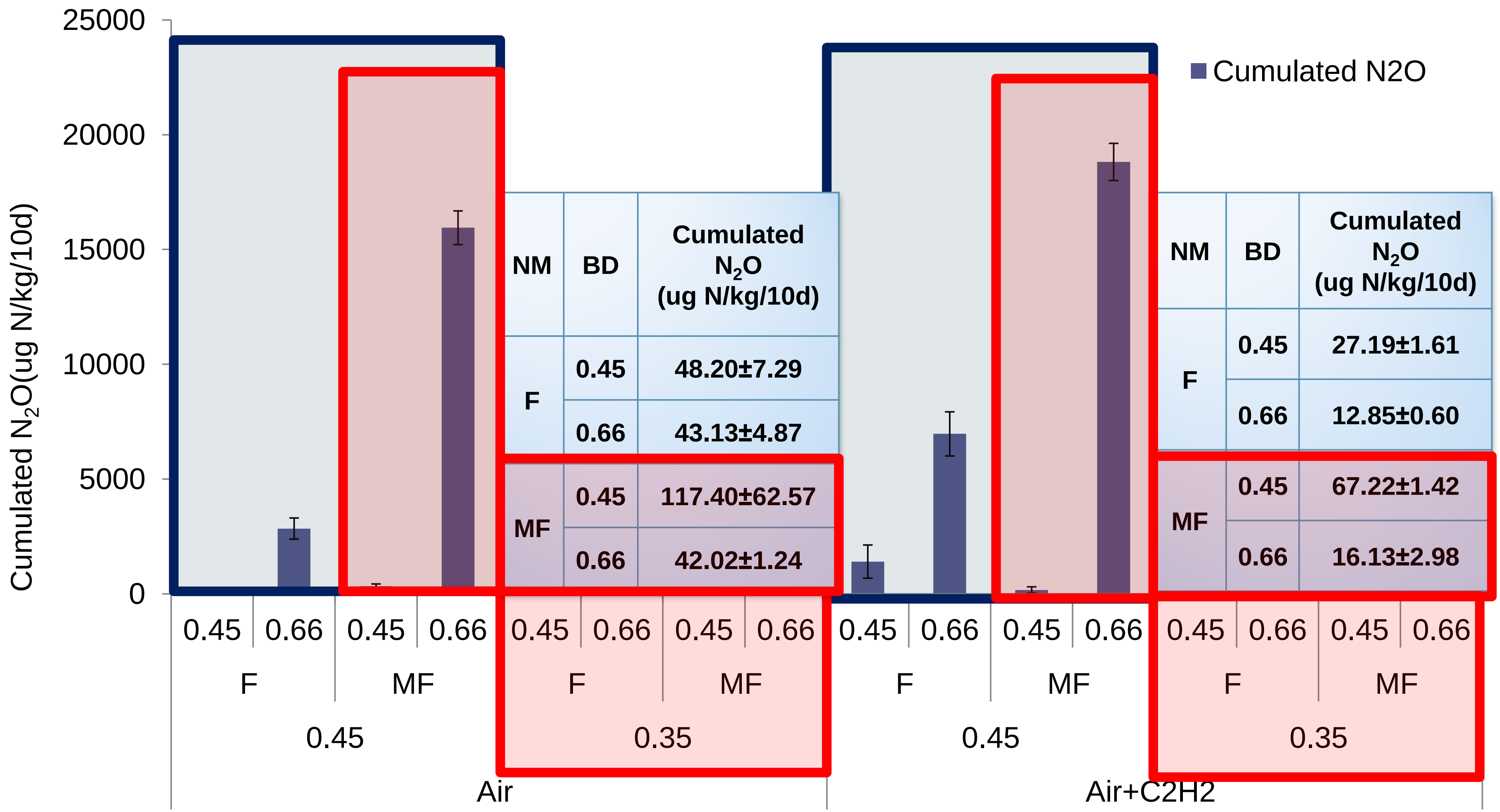
# Result

## ------ Accumulated emission

# Accumulated $CO_2$ emission



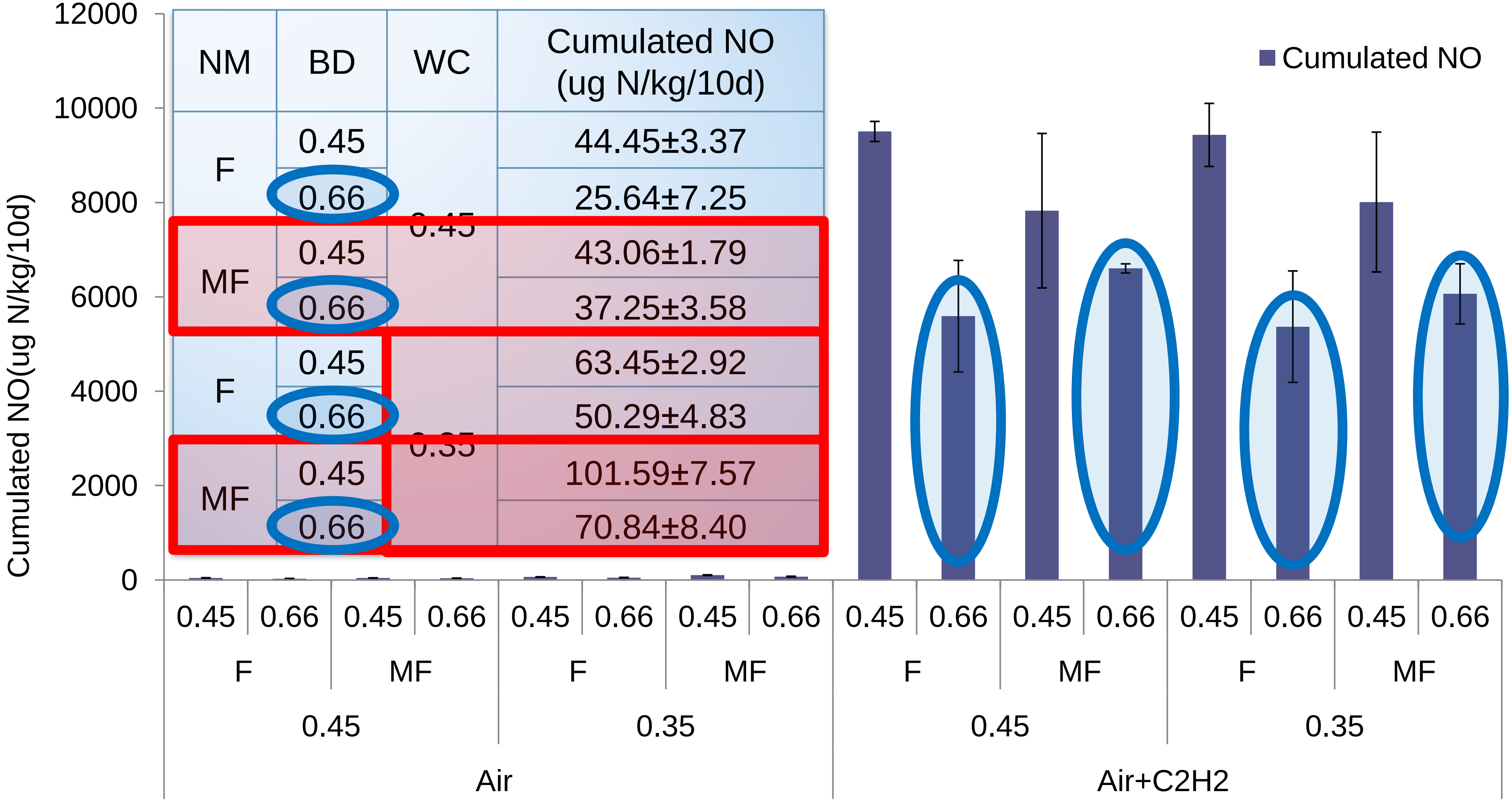
# Accumulated $N_2O$ emission




| NM | BD | Cumulated $N_2O$ (ug N/kg/10d) |
|---|---|---|
| F | 0.45 | 48.20±7.29 |
| | 0.66 | 43.13±4.87 |
| MF | 0.45 | 117.40±62.57 |
| | 0.66 | 42.02±1.24 |

| NM | BD | Cumulated $N_2O$ (ug N/kg/10d) |
|---|---|---|
| F | 0.45 | 27.19±1.61 |
| | 0.66 | 12.85±0.60 |
| MF | 0.45 | 67.22±1.42 |
| | 0.66 | 16.13±2.98 |

# Accumulated NO emission




| NM | BD | WC | Cumulated NO (ug N/kg/10d) |
|---|---|---|---|
| F | 0.45 | 0.45 | 44.45±3.37 |
| | 0.66 | | 25.64±7.25 |
| MF | 0.45 | | 43.06±1.79 |
| | 0.66 | | 37.25±3.58 |
| F | 0.45 | 0.35 | 63.45±2.92 |
| | 0.66 | | 50.29±4.83 |
| MF | 0.45 | | 101.59±7.57 |
| | 0.66 | | 70.84±8.40 |

# Result

## ------ Chemical Properties

| NM | BD | WC | Gas | Net mineralization |
|---|---|---|---|---|
| F | 0.45 | 0.45 | Air | 31.11 |
| | 0.66 | | | 26.37 |
| MF | 0.45 | | | 40.62 |
| | 0.66 | | | 13.17 |
| F | 0.45 | 0.35 | | 28.15 |
| | 0.66 | | | 31.00 |
| MF | 0.45 | | | 51.42 |
| | 0.66 | | | 52.88 |
| F | 0.45 | 0.45 | Air+$C_2H_2$ | 33.13 |
| | 0.66 | | | 22.63 |
| MF | 0.45 | | | 34.36 |
| | 0.66 | | | 28.66 |
| F | 0.45 | 0.35 | | 29.43 |
| | 0.66 | | | 34.56 |
| MF | 0.45 | | | 38.65 |
| | 0.66 | | | 41.38 |

| NM | BD | WC | Gas | WEOC (mg/kg dwt) | | MBC (mg/kg dwt) | |
|---|---|---|---|---|---|---|---|
| | | | | Before | After | Before | After |
| F | 0.45 | 0.45 | Air | 97.02 | 62.50 | 226.4 | 473.8 |
| | 0.66 | | | 97.02 | 75.09 | | 601.5 |
| MF | 0.45 | | | 88.08 | 58.20 | 300.9 | 205.0 |
| | 0.66 | | | 88.08 | 70.78 | | 159.4 |
| F | 0.45 | 0.35 | | 99.12 | 62.81 | 206.8 | 432.5 |
| | 0.66 | | | 99.12 | 54.94 | | 581.8 |
| MF | 0.45 | | | 76.85 | 48.13 | 219.6 | 172.3 |
| | 0.66 | | | 76.85 | 49.95 | | 191.4 |
| F | 0.45 | 0.45 | Air+$C_2H_2$ | 97.02 | 72.47 | 226.4 | 442.9 |
| | 0.66 | | | 97.02 | 94.97 | | 331.8 |
| MF | 0.45 | | | 88.08 | 66.56 | 300.9 | 690.9 |
| | 0.66 | | | 88.08 | 67.10 | | 321.6 |
| F | 0.45 | 0.35 | | 99.12 | 64.99 | 206.8 | 604.9 |
| | 0.66 | | | 99.12 | 62.01 | | 407.6 |
| MF | 0.45 | | | 76.85 | 61.81 | 219.6 | 351.3 |
| | 0.66 | | | 76.85 | 64.31 | | 386.8 |

| NM | BD | WC | Gas | MBN (mg/kg dwt) | | pH | | EC | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Before | After | Before | After | Before | After |
| F | 0.45 | 0.45 | Air | 363 | 84.2 | 5.63 | 5.45 | 2.45 | 4.78 |
| | 0.66 | | | 363 | 77.0 | 5.63 | 5.51 | 2.45 | 4.30 |
| MF | 0.45 | | | 405 | 153.1 | 5.78 | 5.59 | 6.23 | 9.14 |
| | 0.66 | | | 405 | 108.9 | 5.78 | 5.87 | 6.23 | 6.71 |
| F | 0.45 | 0.35 | | 368 | 76.7 | 5.61 | 5.47 | 2.77 | 5.00 |
| | 0.66 | | | 368 | 61.9 | 5.61 | 5.45 | 2.77 | 5.43 |
| MF | 0.45 | | | 443 | 82.4 | 5.78 | 5.58 | 7.06 | 11.00 |
| | 0.66 | | | 443 | 52.6 | 5.78 | 5.57 | 7.06 | 11.21 |
| F | 0.45 | 0.45 | Air+$C_2H_2$ | 363 | 40.4 | 5.63 | 5.85 | 2.45 | 2.37 |
| | 0.66 | | | 363 | 48.8 | 5.63 | 5.90 | 2.45 | 2.05 |
| MF | 0.45 | | | 405 | 83.7 | 5.78 | 5.97 | 6.23 | 6.22 |
| | 0.66 | | | 405 | 104.5 | 5.78 | 6.15 | 6.23 | 5.36 |
| F | 0.45 | 0.35 | | 368 | 103.0 | 5.61 | 5.79 | 2.77 | 2.87 |
| | 0.66 | | | 368 | 54.3 | 5.61 | 5.79 | 2.77 | 2.90 |
| MF | 0.45 | | | 443 | 100.8 | 5.78 | 5.94 | 7.06 | 7.55 |
| | 0.66 | | | 443 | 107.8 | 5.78 | 5.97 | 7.06 | 7.59 |

# Result

## ------ Physical Properties

| NM | BD | WC | Air (%) | Liquid (%) | Solid (%) | WFPS (%) | Porosity (%) | D/D0 |
|---|---|---|---|---|---|---|---|---|
| F | 0.45 | 0.45 | 32.45 | 36.82 | 30.73 | 53.16 | 69.27 | 0.2230 |
| | 0.66 | | 10.90 | 54.70 | 34.40 | **83.39** | 65.60 | 0.0030 |
| MF | 0.45 | | 34.08 | 36.80 | 29.12 | 51.92 | 70.88 | 0.1747 |
| | 0.66 | | 13.43 | 54.68 | 31.89 | **80.29** | 68.11 | 0.0024 |
| F | 0.45 | 0.35 | 58.55 | 24.22 | 17.22 | 29.26 | 82.78 | 0.3078 |
| | 0.66 | | 36.27 | 36.23 | 27.49 | 49.97 | 72.51 | 0.1198 |
| MF | 0.45 | | 49.97 | 24.16 | 25.87 | 32.74 | 74.13 | 0.2633 |
| | 0.66 | | 25.55 | 36.14 | 38.30 | 58.61 | 61.70 | 0.0970 |

## Pearson Correlation: Accumulated emission & Physical indexes

| Air treatment | | | | | | |
|---|---|---|---|---|---|---|
| | Air | Liquid | Solid | WFPS | Porosity | D/D0 |
| $CO_2$ | -.438* | .436* | .327 | .416* | -.327 | -.358 |
| NO | .657** | -.781** | -.267 | -.723** | .267 | .605** |
| $N_2O$ | -.569** | .688** | .211 | .634** | -.211 | -.606** |
| Air+$C_2H_2$ treatment | | | | | | |
| $CO_2$ | .033 | -.115 | .120 | -.092 | -.120 | .075 |
| NO | .546** | -.503* | -.480* | -.536** | .480* | .716** |
| $N_2O$ | -.664** | .787** | .272 | .736** | -.272 | -.675** |

# Discussion

| NM | BD | WC | Gas | Net ammonification | Net Nitrification |
|---|---|---|---|---|---|
| F | [illegible] | [illegible] | [illegible] | [illegible] | 29.92 |
| | [illegible] | | | [illegible] | 21.83 |
| MF | [illegible] | | | [illegible] | 38.19 |
| | [illegible] | | | [illegible] | 2.00 |
| F | [illegible] | [illegible] | | [illegible] | 24.34 |
| | [illegible] | | | [illegible] | 28.99 |
| MF | 0.45 | | | 6.36 | 45.06 |
| | 0.66 | | | 5.27 | 47.62 |
| F | 0.45 | 0.45 | Air+$C_2H_2$ | 36.74 | -3.62 |
| | 0.66 | | | 31.91 | -9.28 |
| MF | 0.45 | | | 42.15 | -7.79 |
| | 0.66 | | | 46.82 | -18.16 |
| F | 0.45 | 0.35 | | 31.93 | -2.51 |
| | 0.66 | | | 36.59 | -2.03 |
| MF | 0.45 | | | 39.77 | -1.12 |
| | 0.66 | | | 41.44 | -0.06 |

Nitrification was inhibited by 10% $C_2H_2$

| NM | BD | WC | Gas | MBN (mg/kg dwt) | | $NO_3$—N (mg/kg dwt) | |
|---|---|---|---|---|---|---|---|
| | | | | Before | After | Before | After |
| F | [illegible] | [illegible] | [illegible] | [illegible] | 84.2 | 9.3 | 39.2 |
| | [illegible] | | | [illegible] | [illegible] | 9.3 | 31.1 |
| MF | [illegible] | | | [illegible] | [illegible] | 39.0 | 77.2 |
| | [illegible] | | | [illegible] | [illegible] | 39.0 | 41.0 |
| F | [illegible] | [illegible] | | [illegible] | [illegible] | 9.3 | 33.6 |
| | [illegible] | | | [illegible] | [illegible] | 9.3 | 38.3 |
| MF | [illegible] | | | [illegible] | [illegible] | 37.7 | 82.8 |
| | [illegible] | | | [illegible] | [illegible] | 37.7 | 85.3 |
| F | [illegible] | [illegible] | Air+$C_2H_2$ | [illegible] | [illegible] | 9.3 | 5.7 |
| | [illegible] | | | [illegible] | [illegible] | 9.3 | 0.0 |
| MF | [illegible] | | | [illegible] | 83.7 | 39.0 | 31.2 |
| | 0.66 | | | 405 | 104.5 | 39.0 | 20.9 |
| F | 0.45 | 0.35 | | 368 | 103.0 | 9.3 | 6.8 |
| | 0.66 | | | 368 | 54.3 | 9.3 | 7.3 |
| MF | 0.45 | | | 443 | 100.8 | 37.7 | 36.6 |
| | 0.66 | | | 443 | 107.8 | 37.7 | 37.6 |

Cumulative $N_2O$ of MF soil ＞ F soil ($p$<0.001), because $NO_3^-$ ($p$<0.001) and MBN ($p$<0.001) of MF soil were larger than F soil, providing enough reactants for denitrification and nitrification

# Ratio

| NM | BD | WC | Gas | $N_2O$-N/NO-N | $N_2O$-N/[$N_2O$-N+$N_2$-N] |
|---|---|---|---|---|---|
| F | | | | | 0.04 |
| | | | | | **0.41** |
| MF | | | | | 1.99 |
| | | | | | **0.85** |
| F | | | | | |
| MF | | | | | |

$N_2O$ emission/[$N_2O$ + $N_2$ emission] of 45%-WC with high BD were estimated as 0.4 in F plot and 0.8 in MF plot, and this might be attributed to the inhibition of $N_2O$ reductase by high $NO_3^-$ in MF plot.

- The $N_2O$–N/NO–N ratio: <1, $N_2O$ production from nitrification, 1–100 during both nitrification and denitrification, and >100 during denitrification (Farzana Diba, Mariko Shimizu, Ryusuke Hatano, 2012)
- $N_2O$-N/[$N_2O$-N+$N_2$-N]=[$N_2O$-N in Air]/[$N_2O$-N in Air+$C_2H_2$]

# DEA

| NM | BD | WC | Air | $N_2O$ average | STD |
|---|---|---|---|---|---|
| F | 0.45 | 0.45 | | 210 | 59.8 |
| | 0.66 | | | **344** | 17.2 |
| MF | 0.45 | | | 262 | 63.4 |
| | 0.66 | | | **369** | 48.0 |
| F | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | [illegible] | | | [illegible] | [illegible] |
| MF | [illegible] | | | [illegible] | [illegible] |
| | [illegible] | | | [illegible] | [illegible] |
| F | [illegible] | 0.45 | $Air+C_2H_2$ | [illegible] | [illegible] |
| | [illegible] | | | [illegible] | [illegible] |
| MF | 0.45 | | | 331 | 21.2 |
| | 0.66 | | | **345** | 68.6 |
| F | 0.45 | 0.35 | | 222 | 2.7 |
| | 0.66 | | | 242 | 6.2 |
| MF | 0.45 | | | 258 | 25.8 |
| | 0.66 | | | 250 | 6.1 |

**WFPS of 45%-WC with high BD treatment with greater DEA was around 80% which provide appropriate environment for denitrification.**

# Pearson Correlation : **Accumulated emission & chemical indexes**

| | $CO_2$ | NO | $N_2O$ | DEA | $\triangle NH_4^+$ | $\triangle$WEOC | pH | $\triangle$MBN | $\triangle$EC | $\triangle NO_2^-$ | $\triangle NO_3^-$ | $\triangle SO_4^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air treatment | | | | | | | | | | | | |
| $CO_2$ | 1 | -.243 | .380 | .392 | .178 | .249 | .350 | .080 | -.243 | .009 | -.143 | .174 |
| NO | -.243 | 1 | -.380 | **-.547**** | -.012 | -.117 | .368 | **-.681**** | **.702**** | **.663**** | **.629**** | -.166 |
| $N_2O$ | .380 | -.380 | 1 | **.580**** | **.740**** | **.543**** | .314 | .152 | **-.739**** | -.158 | **-.780**** | .388 |
| DEA | .392 | **-.547**** | **.580**** | 1 | .363 | **.431*** | .098 | .226 | **-.556**** | -.173 | **-.535**** | .334 |
| Air+$C_2H_2$ treatment | | | | | | | | | | | | |
| $CO_2$ | 1 | .371 | .008 | .304 | **.616**** | .056 | **.713**** | -.134 | .074 | -.132 | -.318 | .275 |
| NO | .371 | 1 | -.254 | -.142 | -.138 | -.166 | -.098 | .253 | .125 | .176 | **-.408*** | .053 |
| $N_2O$ | .008 | -.254 | 1 | **.544**** | .182 | .180 | .128 | .137 | **-.899**** | **-.922**** | -.191 | -.384 |
| DEA | .304 | -.142 | **.544**** | 1 | **.469*** | .083 | **.426*** | -.059 | **-.511*** | **-.654**** | -.359 | -.226 |

# Conclusion

- $CO_2$ emission tended to be higher in MF plot than in F plot, but there was no clear effect of BD and WC.
- $N_2O$ emission was controlled by WC and BD. High WC and high BD promoted $N_2O$ emission because of the contribution of denitrification.
- Most of time, cumulative $N_2O$ emission of MF plot was higher than F plot with more $NO_3^-$ and MBN.
- The inhibition of 10%$C_2H_2$ on nitrification might result in high NO emission.

Thank you very much!