Climate warming and atmospheric pollution effects on denitrification rates from forested wetlands

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1. Rationale

Substantial differences in gaseous N_2O efflux among topographic positions, including upland, ecotone, and wetland, have been shown in the Turkey Lakes Watershed (TLW). In areas of nitrogen (N) deposition at 15 kg/ha/yr (Creed, unpublished) and dissolved organic carbon (DOC) through-fall at 0.04 g/ha/day (Casson, unpublished MSc thesis), wetlands export substantially more gaseous N_2O than uplands. Potential for differential export among soil horizons, within one topographic location (Figure1), under variable climates also exists.

The ***purpose*** of this study was to explore the interactive effects of climate warming and changing atmospheric nitrogen deposition rates on gaseous nitrogen (N) loss from forested catchment soil horizons.

Hypotheses:

1. **N_2O production occurs mainly in the litter-fibric layer of the wetland soil that has a lower carbon to nitrogen (C:N) quotient and more labile carbon than the deeper hemic/peat deposits;**
2. **Climate warming and atmospheric pollution will have additive or multiplicative effects on N_2O effluxes from the wetland soils.**

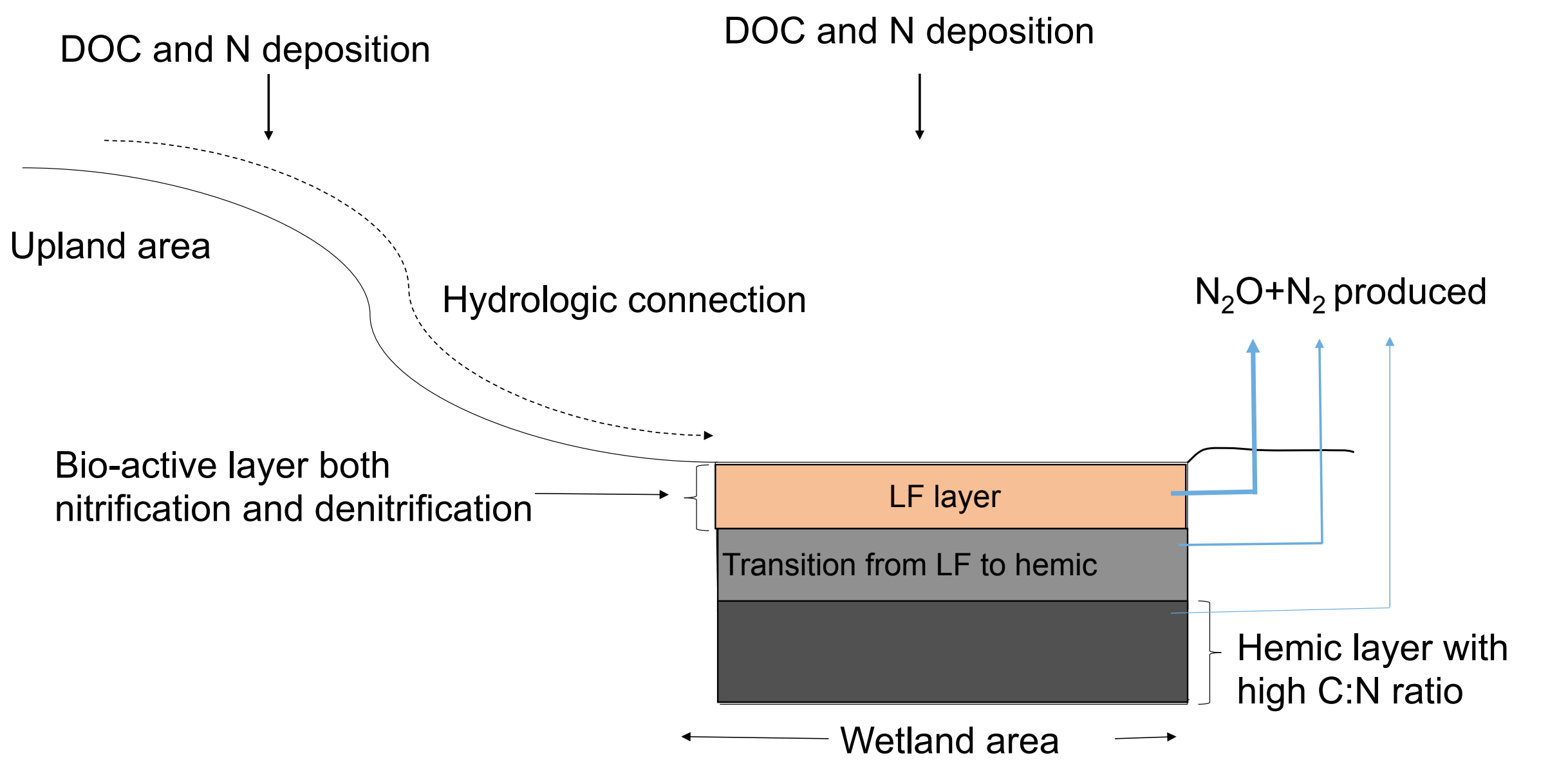

Figure 1: Conceptual model showing the bio-active litter fibric (LF) layer and the less active lower layers within a wetland (peat) core . Arrow thickness indicates the hypothesized differential export among horizons within the wetland area, with thicker arrows corresponding to greater N_2O efflux.

2. Methods

2.1 Soil Collection Site

The TWL is an experimental forest in the Algoma Highlands on the northern edge of the Great Lakes-St. Lawrence Forest Region in Canada. Its climate is continental with an average annual precipitation of 1200 mm and an average annual temperature of 5.0°C (Mengistu et al., 2012). Within TWL, thin and discontinuous till overlays the bedrock (Jeffries, 2002) and the soils are primarily podzols, with organic soils found adjacent to streams and lakes and in depressions (Canada Soil Survey Committee, 1978).

2.2 Soil Collection Protocol

- Soil cores were collected from 6 locations within one TLW catchment 60 wetland.
- Each core was separated into litter-fibric (LF), 0-30 cm and 30-60 cm sections.
- Replicate (5) core sections, per site, were homogenized relative to their core section (LF, 0-30 cm, 30-60 cm).
- In total, each sample location (6) resulted in three soil horizon samples (LF, 0-30cm and 30-60cm) for a total of 18 total field soil samples for experimentation.

2.3. Experimental Design

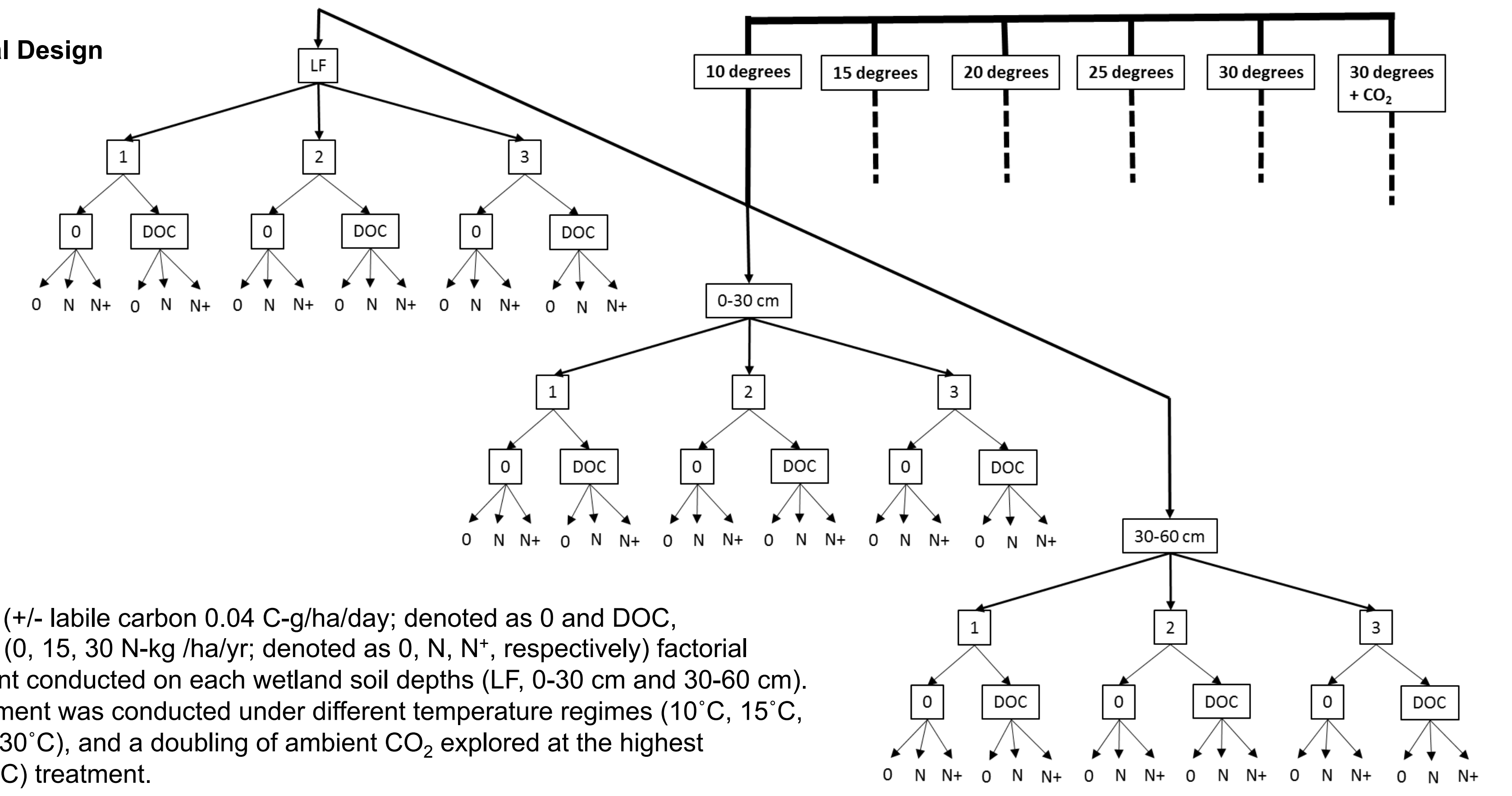

Figure 2. The 2 (+/- labile carbon 0.04 C-g/ha/day; denoted as 0 and DOC, respectively) × 3 (0, 15, 30 N-kg /ha/yr; denoted as 0, N, N^+, respectively) factorial design experiment conducted on each wetland soil depths (LF, 0-30 cm and 30-60 cm). Each 2x3 experiment was conducted under different temperature regimes (10˚C, 15˚C, 20˚C, 25˚C, and 30˚C), and a doubling of ambient CO_2 explored at the highest temperature (30˚C) treatment.

2.4 Experimental Protocol

- Cores (LF, 0-30, 30-60cm segments), were randomly assigned to a biome: 10˚C, 15˚C, 20˚C, 25˚C, and 30˚C with 750 ppm CO_2.
- Per biome, soil horizons (LF, 0-30 cm, 30-60 cm) were divided into 18-100 gram units and placed in open 1L glass mason jars for experimentation (Figure 2, Figure 3).
- Per soil horizon unit (LF, 0-30 cm, 30-60 cm), 10 mL of DOC (14.6 C-g glucose/ha/year equivalent) was randomly applied to 9 units and 10mL of ultra pure water (MilliQ) was applied to the remaining 9 units as a control (Figure 2).
- Per DOC regime (-/+DOC, 9 units each), N treatments were randomly added to three units per treatments and included: N (15 N-kg as NH_4NO_3/ha/year equivalent), N+ (30 N-kg as NH_4NO_3/ha/year equivalent) and MilliQ (control, Figure 2).
- Once treated, units were placed in respective temperature regimes for 21 days, rewetted on day 21 and exposed for an additional 14 days.

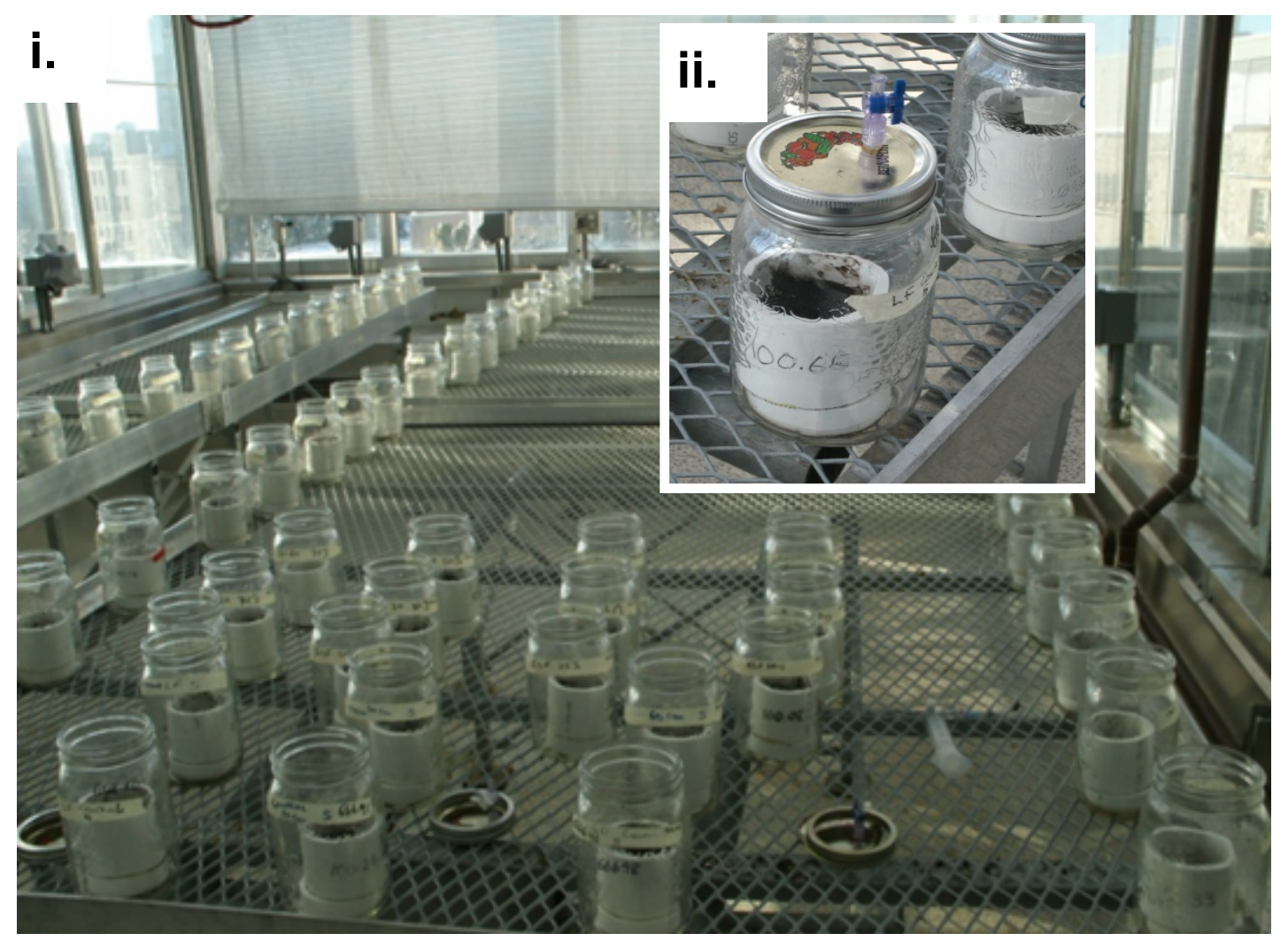

Figure 3: Experimental layout within one of six temperature biomes (i) and the 1L sample chambers used for experimentation, fitted with the gas collection housing (ii.).

- Gas samples were collected under conditions of full (day 1 and 21-post wetting) and declining/low saturation (day 2, day 3, day 9 and day 21-pre wetting). After re-wetting on day 21, gas samples were collected on day 22, day 23, day 24 and day 30.
- For gas measurements, each treatment jar was sealed. 25mL of headspace air within each jar was collected at 0, 30, 60 minute intervals in 12.5 mL glass vials containing 0.1g of magnesium perchlorate as desiccant and stored at room temperature.
- N_2O and CO_2 efflux was measured using a SRI 8610C Gas Chromatography with ECD and FID detectors for N_2O and $CO_{2,}$ respectively.

3. Major Findings

3.1. Comparison of activity among horizons

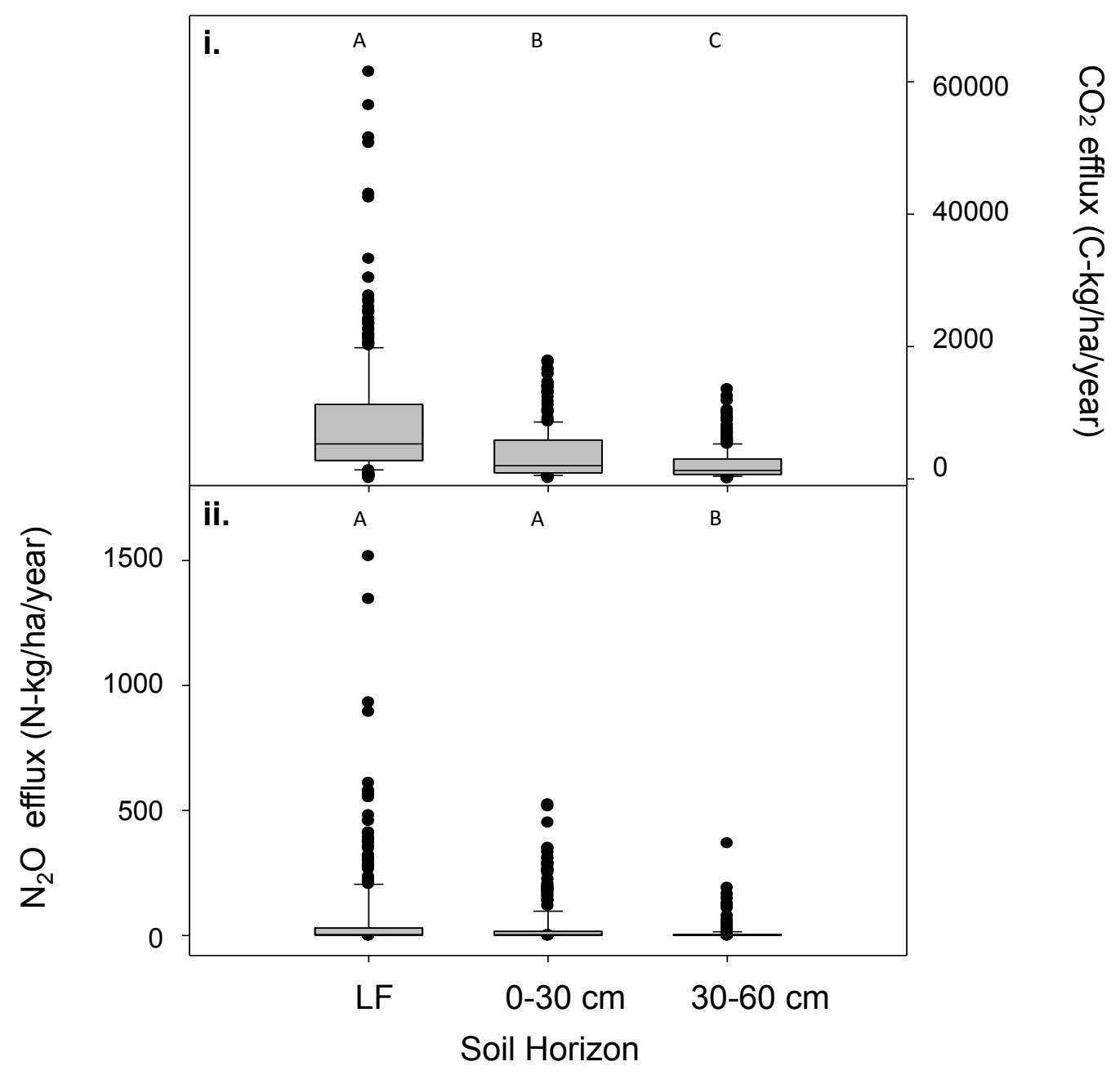

Figure 4: Box whisker plots of CO_2 (i.) and N_2O (ii.) efflux (kg/ha/year) from experimental soil horizons, showing 25th and 75th percentiles. Different letters denote significant differences among horizons (p<0.05).

4. Results

- The highest N_2O efflux was observed from the litter fibric (LF) layer in all biomes. (Figure 4). Significant differences were observed between LF and 30-60 cm, and also between 0-30 cm and 30-60 cm (p<0.05, Figure 4).
- Respiration rates (CO_2 efflux) were the highest in the LF and the 0-30cm horizons, and significantly differed from the 30-60 cm horizon (p<0.05, Figure 4).
- Doubling of ambient CO_2 to 750 ppm at 30 °C had no significant effect on N_2O and CO_2 efflux when considering each soil horizon independently (Figure 5).
- Addition of N, with or without DOC, triggered an increased denitrification response in all soil horizons (Figure 6).
- N_2O efflux from the LF layer was the greatest under cool conditions (10°C; 298 N-kg/ha/year) when amended with DOC (0.04 g glucose/ha/day) and an N source (30 N-kg NH_4NO_3/ha/year, Figure 7).
- Addition of N resulted in significantly higher N_2O efflux (p<0.05) and respiration (CO_2 efflux; Figure 7).
- Respiration rate (CO_2 efflux) was the highest in the cooler biome (10°C).

5. Significance

Our findings confirm that the litter-fibric layer is the most active denitrification layer of wetland soils. Furthermore, our findings indicate that this surface layer is extremely sensitive to climate warming and to atmospheric pollution.

These results suggest

1. Climate had an “overriding” control on the denitrification process– as temperature increased, denitrification rates decreased irrespective of the additional N load from atmospheric N deposition.

2. Climate warming in the face of anticipated increases in atmospheric N deposition is likely to lead to lower soil denitrification rates. As a result, more N will be available for export to downstream waters, with corresponding consequences associated with N loading to aquatic ecosystems.

3. Nitrogen inputs to a system elicit substantial responses in soil microbial activity, responses that are not substantial when carbon is input to the same system.

Acknowledgements

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3.2 Temperature/biome's impact on soil horizon efflux

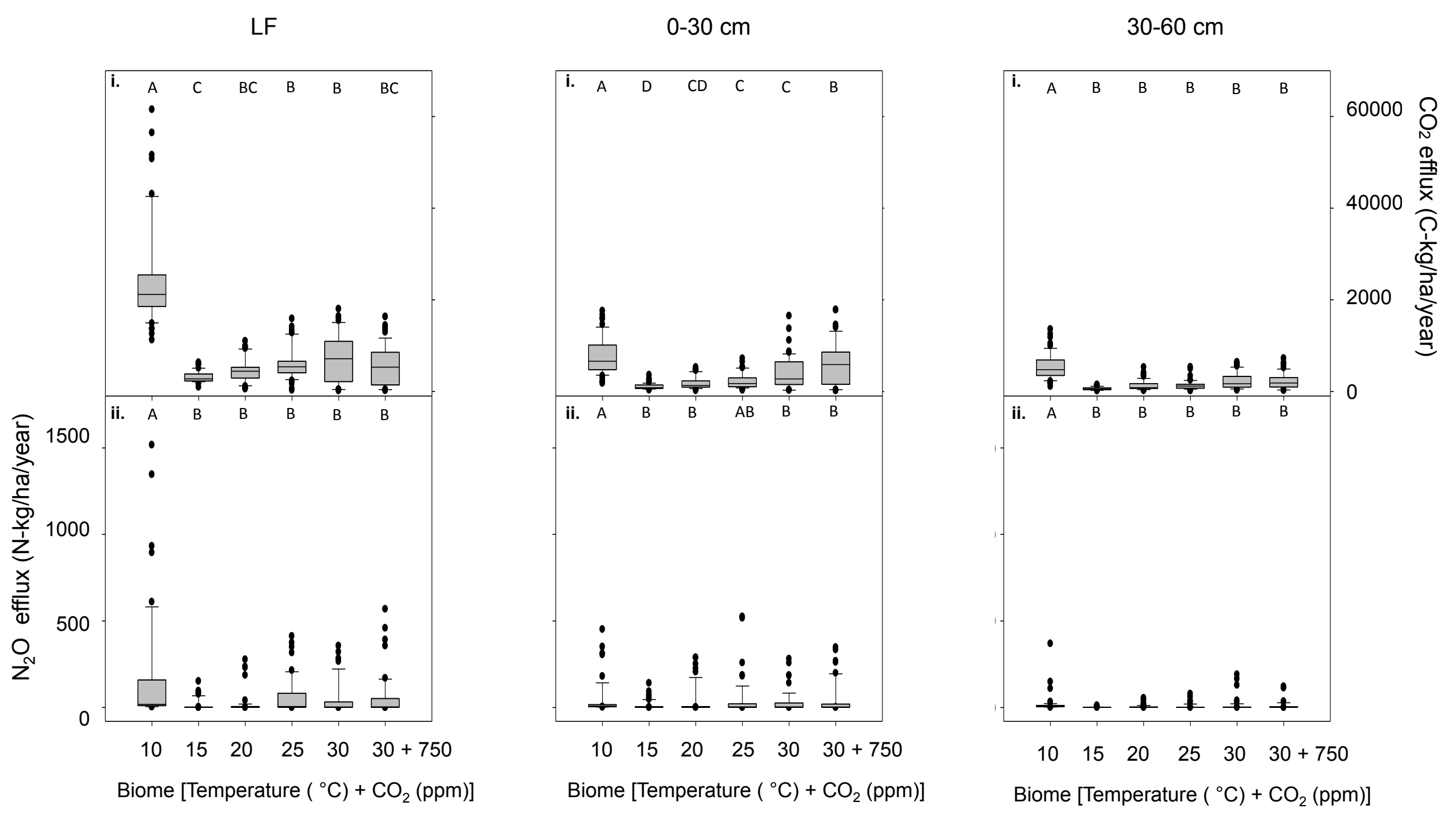

Figure 5: Box whisker plots of CO_2 (i.) and N_2O (ii.) efflux (kg/ha/year) from soil horizons (LF, 0-30 cm, 30-60 cm) exposed to variable biome conditions (10˚C, 15˚C, 20˚C, 25˚C, 30˚C, and 30˚C + 750 ppm CO_2). 25th and 75th percentiles illustrated, and significant differences among biomes denoted by lettering (temperature regime, p<0.05).

3.3 Carbon and nitrogen's impact on soil horizon efflux

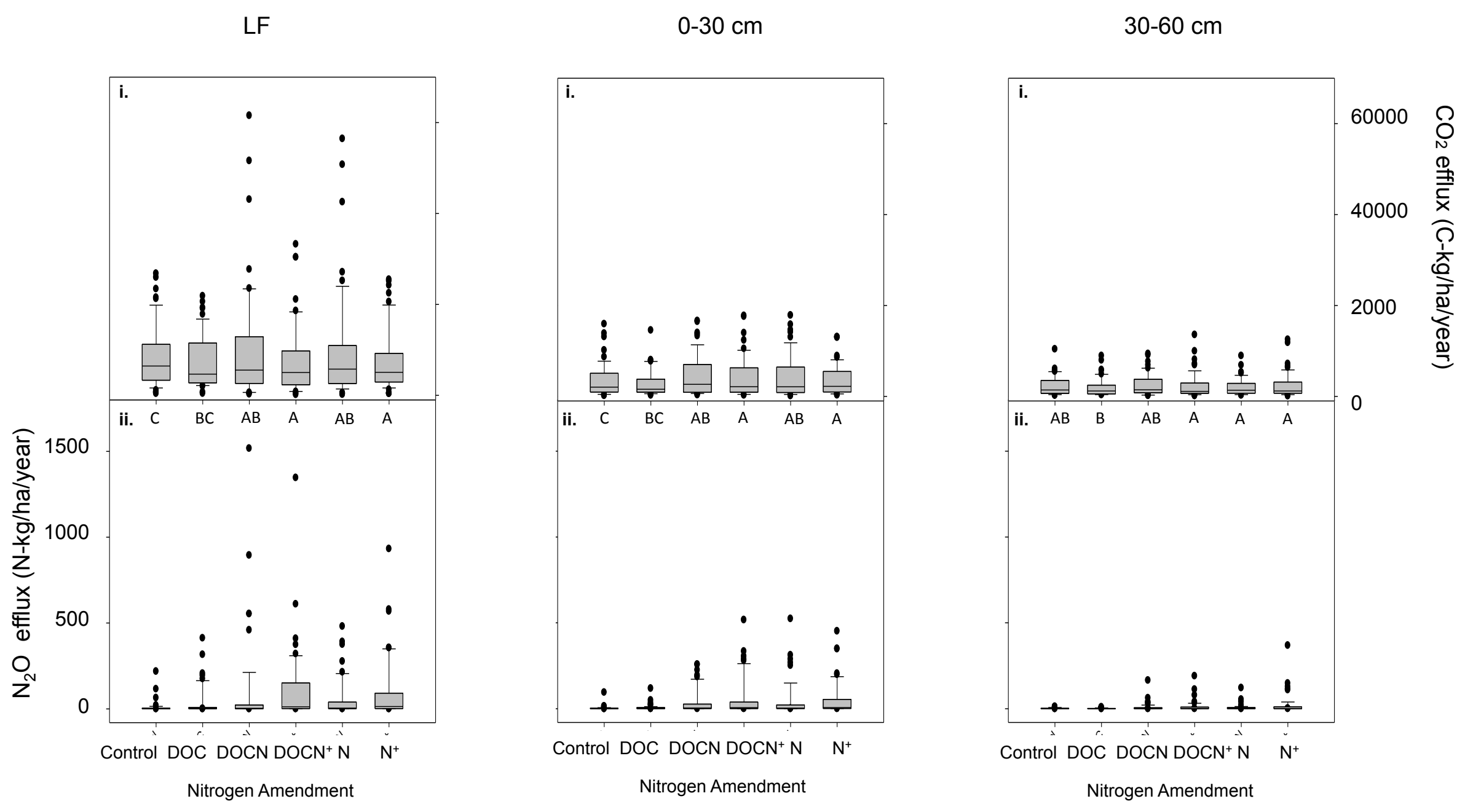

Figure 6: Box whisker plots of CO_2 (i.) and N_2O (ii.) efflux (kg/ha/year) from soil horizons (LF, 0-30 cm, 30-60 cm) exposed to variable carbon and nitrogen amendments (Control, DOC, DOC N, DOC N+, N, N+). 25th and 75th percentiles displayed and significant differences among carbon and nitrogen amendments (p<0.05) denoted by lettering.

3.4 Temperature and carbon/nitrogen impacts on LF layer efflux.

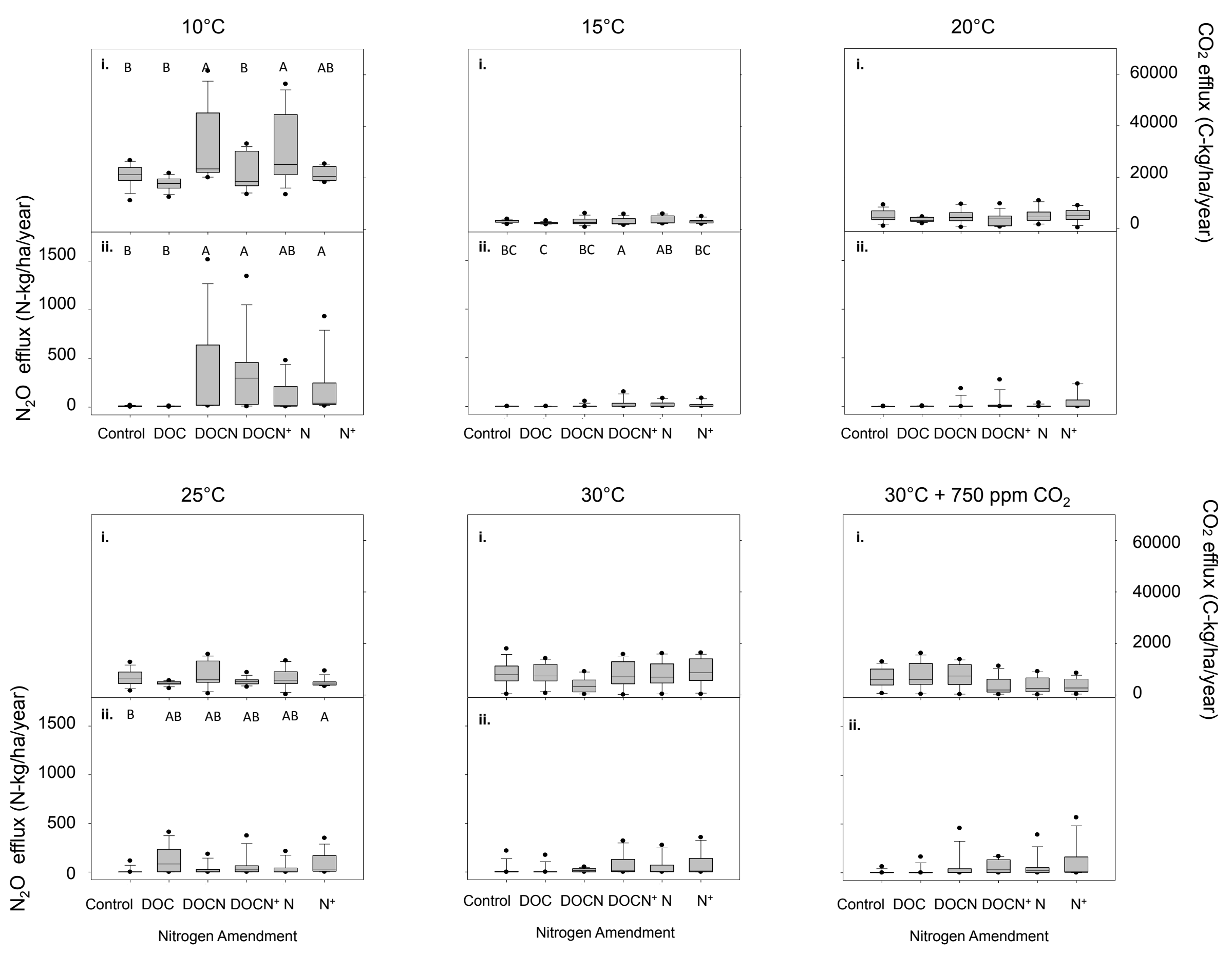

Figure 7: Box whisker plots of CO_2 (i.) and N_2O (ii.) efflux (kg/ha/year) from the LF layer under variable temperature/biome conditions (10˚C, 15˚C, 20˚C, 25˚C, 30˚C, and 30˚C + 750 ppm CO_2) and carbon and nitrogen amendments (Control, DOC, DOC N, DOC N+, N, N+). 25th and 75th percentiles are displayed and different letters indicate significant differences among carbon and nitrogen amendments (p<0.05) within each biome/temperature condition.

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