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Final Technical Report

Greenhouse gas flux response in biochar- and compost-amended urban soils under simulated soil hydrologic dynamics

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Abstract

Understanding greenhouse gas emission dynamics in lawn soils is essential for improving climate change mitigation strategies in urban and suburban environments. This project measured fluxes of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) fluxes from turfgrass soil columns amended with biochar, compost, biochar-compost blend, control (no amendment) in a controlled greenhouse mesocosm experiment. This project simulated contrasting water saturation regimes consisting of normal irrigation with sprinkler, transient half or full saturation by water table manipulation, and subsequent drying phase under both sod or seeded grass conditions. Compost-amended columns (compost or biochar-compost blend) exhibited higher average CO_2 fluxes (6 µmol m^{-2} s^{-1}) compared to biochar or control columns (4.5 – 5.0 µmol m^{-2} s^{-1}) across all saturation levels under sod conditions. Seeded grass conditions generally resulted in less CO_2 emissions. The CO_2 fluxes were positively correlated with air temperature and negatively correlated with soil moisture. Biochar-amended columns retained high soil moisture (~95 %) throughout experiments, demonstrating superior moisture retention compared to compost. CH_4 and N_2O fluxes exhibited temporal increases (5-8 nmol m^{-2} s^{-1}) during saturation and drainage phases, indicating their sensitivity to hydrologic conditions. These findings suggest that temperature and amendment types are primary driver of CO_2 emissions, while CH_4 and N_2O fluxes are more responsive to water saturation dynamics in lawn soils.

Project Description

This report presents key findings of soil greenhouse gas emissions affected by soil hydrologic conditions (water saturation by water table) and organic soil amendments (biochar, compost, and biochar-compost blend). Two separate soil mesocosm experiments were conducted representing urban soil installed with grass sod and urban soil seeded with grass seeds, respectively. Specific objectives were to 1) investigate the impacts of varying soil hydrologic conditions (water saturation) on GHG emissions by controlling water table in the soil columns, 2) investigate the effects of the organic amendments on GHG emission fluxes and 3) explore the effects of redox chemistry on GHG emissions.

Task 1: Soil mesocosm experiment with grass sod

Briefly a total of 12 soil columns (5-gallon bucket) packed with garden soil and surface-amended with biochar, compost, biochar + compost, or no amendment as control received three different water table conditions (full saturation, half-saturation, unsaturated condition) under grass sod setting (Figure 2a). Overall saturation condition began with normal irrigated condition for all columns (24 days) followed by saturation treatments (2 weeks) for selected columns and then drained and dried (24 days) for all columns. LI-COR trace gas analyzers (LI-7810 for CO_2 and CH_4, LI-7820 for N_2O, LI-COR, Inc., Lincoln, NE, USA) were used in conjunction with a LI-COR smart chamber (LI-8200-01S) to measure soil GHG fluxes (Figure 2b). Detailed methodologies were documented in a MS thesis (Salinas, 2024) and a submitted manuscript (Salinas et al., 2025).

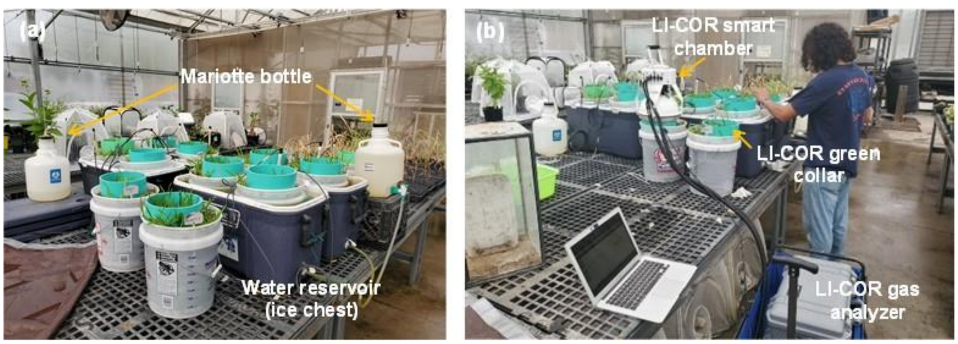


Figure 1. Experiment setup: (a) Water reservoir connected to Mariotte bottle and (b) GHG flux measurements using LI-COR instruments.

<u>Key findings</u>

Our results indicated that compost amendment (compost and bio-com) elevated CO_2 emissions as the soils undergo transient soil saturation followed by drying phase (Figure 2). The saturated conditions by raising water table resulted in lower CO_2 emissions. Positive correlation between air temperature and CO_2 emission was profound while there was a negative correlation between soil moisture and CO_2 emission. Biochar amendment showed the strong moisture retention and resulted in lower CO_2 emission. In general, soil CO_2 emissions are produced through root respiration, plant leaf respiration, and soil microbial activity (Hanson et al., 2000). In lawn environment, root respiration and microbial decomposition of organic matter (e.g., compost) can account for most of the soil respiration (Carbone et al., 2008). The compost amendment containing labile C in current study was likely attributed to the higher CO_2 emission than relatively inert biochar (containing stable C), thus stimulating higher soil respiration from the compost-amended columns (Cross et al., 2011).

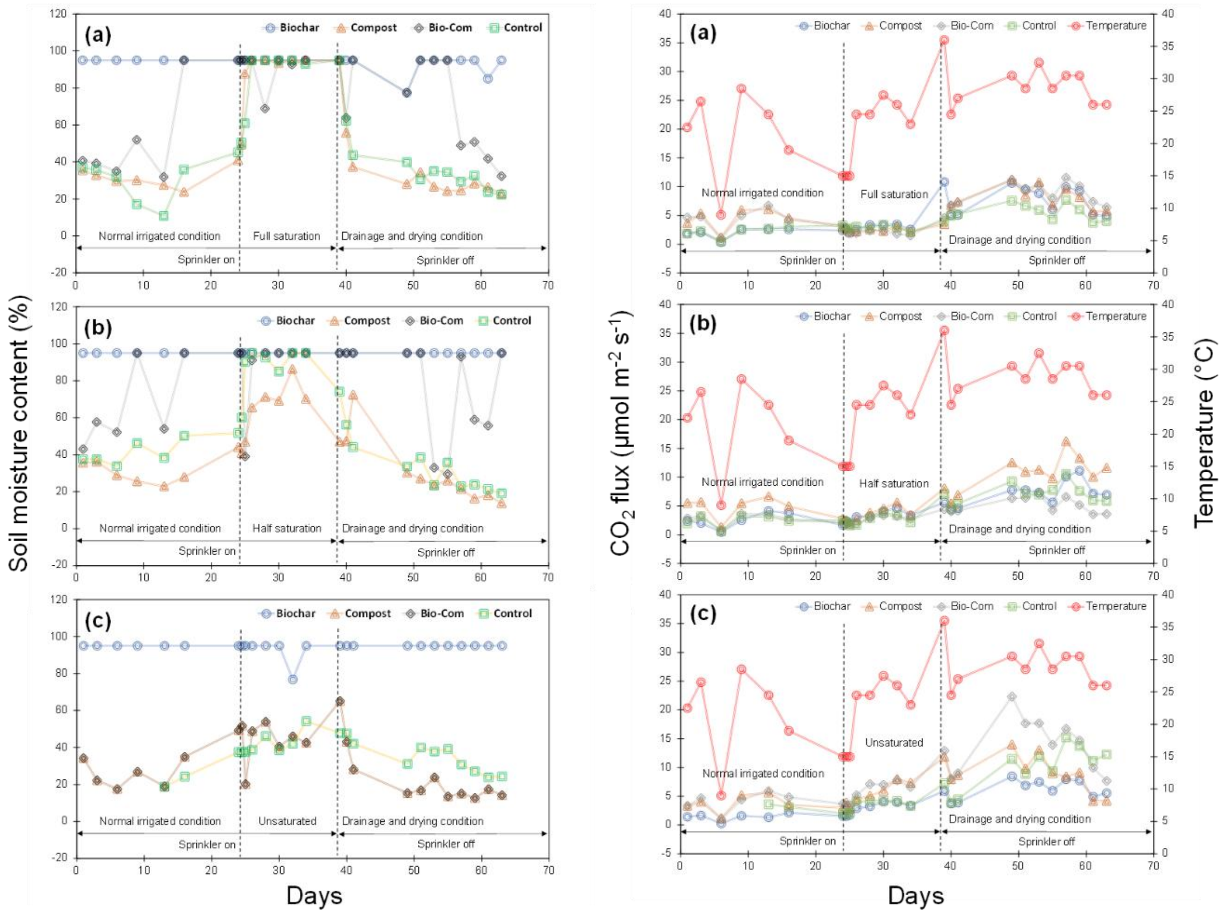


Figure 2. Soil moisture content, CO_2 flux, and air temperature: (a) full saturation, (b) half-saturation, and (c) unsaturated.

The CH_4 emissions were temporal depending on water saturation conditions and subsequent drainage (Figure 3). Biochar-amended columns yielded the lowest CH_4 emission. In the unsaturated columns, there was a sharp peak of CH_4 from control columns (up to 271 nmol m^{-2} s^{-1}) upon drying over the same period. Previous studies suggested that lawn field is a sink for CH_4 emission, but it was not the case in current study [21, 22]. The N_2O flux was low close to zero while there were intermittent releases from saturated columns and its emission was more pronounced with compost (4.73 nmol m^{-2} s^{-1}) and biochar columns (up to 3.69 nmol m^{-2} s^{-1}).

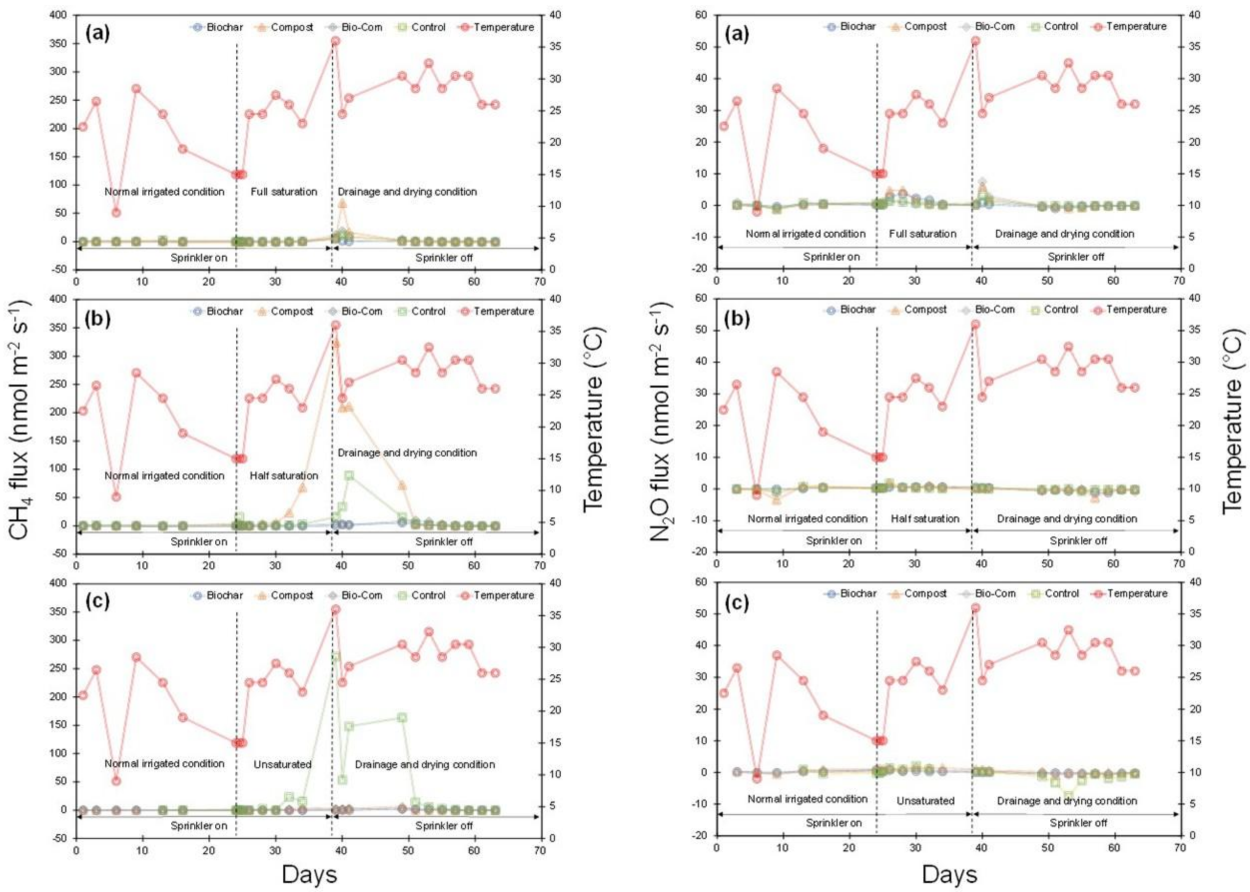


Figure 3. CH_4 and N_2O flux: (a) full saturation, (b) half-saturation, and (c) unsaturated.

Task 2: Soil mesocosm experiment with seeded grass

The same soil material from task 1 was used for task 2 and Texas Bermuda turfgrass was seeded instead of sod. For task 2, soil redox probes were installed midway of each soil column. Simulated hydrologic cycles began with normal irrigated condition (day 1-8) followed by saturation treatments (day 9-20) and then drained and dried (day 21-46). Task 2 extended the drying period to see its effects on GHG emissions and the data were extrapolated into cumulative GHG emissions over the 46 days period.

<u>Key findings</u>

Similar to task 1, compost-amended columns (compost and biochar-compost blend) resulted in higher CO_2 emissions than biochar and control columns while unsaturated columns showed higher CO_2 emissions than full and half saturated columns. Extending dry period (day 21-46) increased cumulative CO_2 emissions while there were less CO_2 emissions during saturation period (day 9-20) (Figure 4).

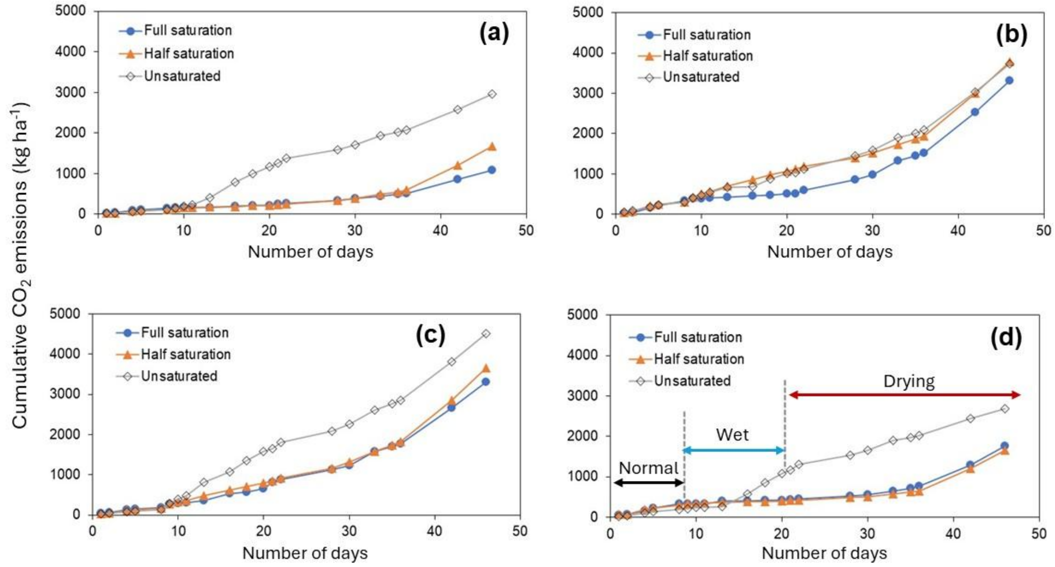


Figure 4. Cumulative CO_2 emissions: (a) biochar, (b) biochar-compost blend, (c) compost, and (d) control (no amendment).

The CH_4 emissions were found right after drainage events on full-saturated columns (Figure 5). By amendment, compost or biochar columns showed a steep pulse from full-saturated columns and lesser extent from half-saturated columns, indicating the positive role of water saturation in triggering CH_4 emissions. It was notable that biochar-compost blend columns showed the least CH_4 emissions.

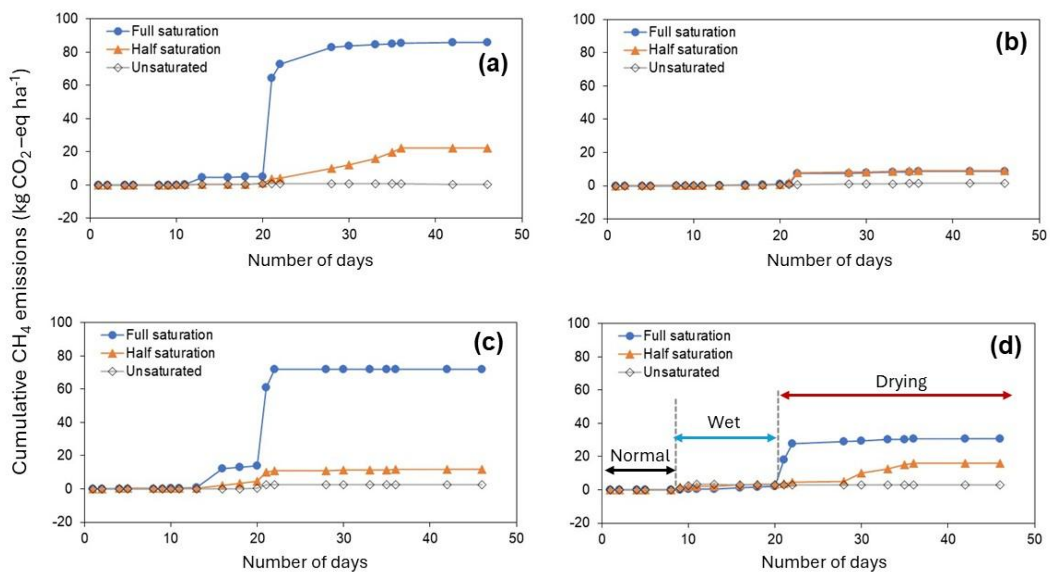


Figure 5. Cumulative CH_4 emissions: (a) biochar, (b) biochar-compost blend, (c) compost, and (d) control (no amendment). Note that emissions data were presented in CO_2-equivalent.

The N_2O emissions were higher in half-saturated columns and overall unsaturated columns showed the least (Figure 6). By amendment types, compost columns showed the highest N_2O emission followed by biochar columns. The pulses of N_2O emissions were found at the beginning of saturation period (day 9-10) from half-saturated columns while there were continuous, steady increase during the drying period in all columns.

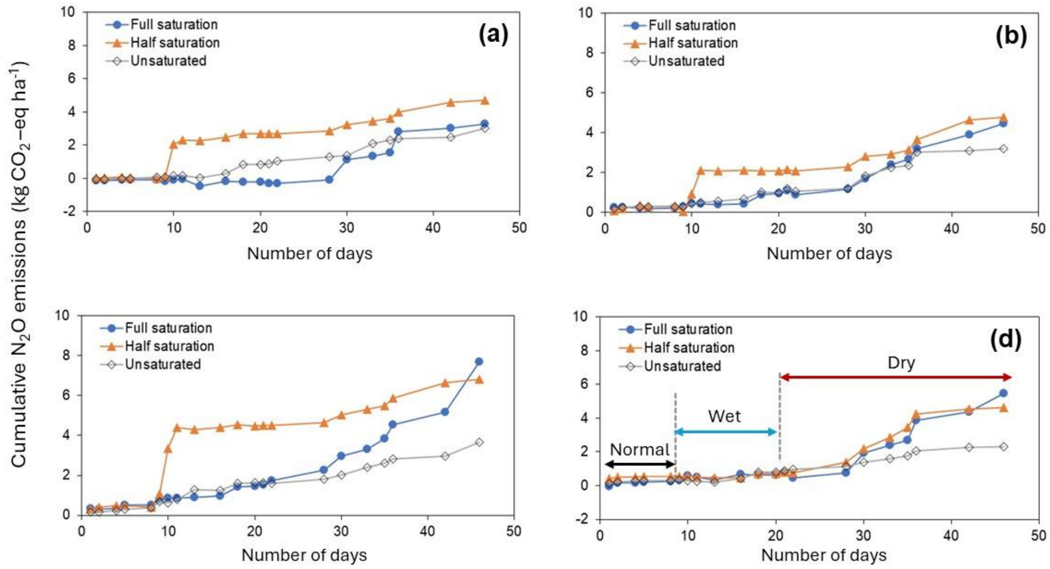
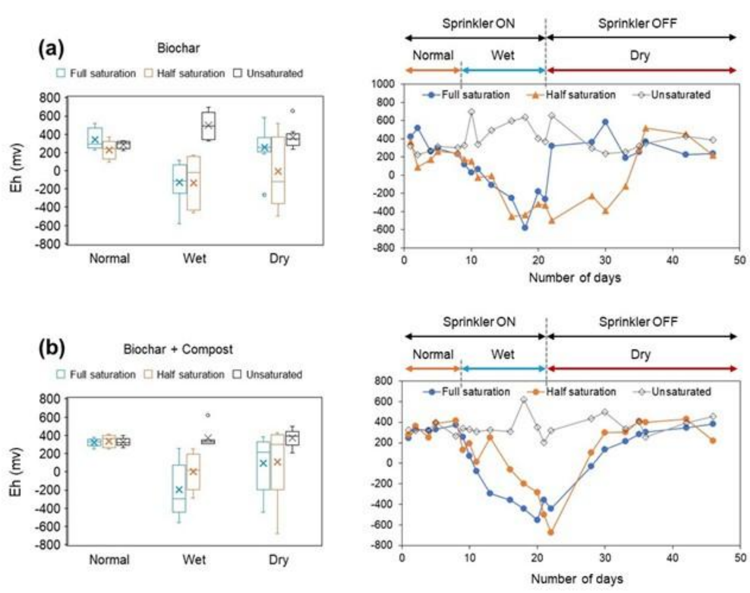


Figure 6. Cumulative N_2O emissions: (a) biochar, (b) biochar-compost blend, (c) compost, and (d) control (no amendment). Note that emissions data were presented in CO_2-equivalent.

The redox potential (Eh) responded to temporal water saturation conditions. During the wet period, full and half-saturated showed a negative Eh range while unsaturated columns stayed positive range (Figure 7). Note that it took some time (~ 10 days) from water saturated columns (negative Eh) reached back to aerobic condition (positive Eh) under the drying period.



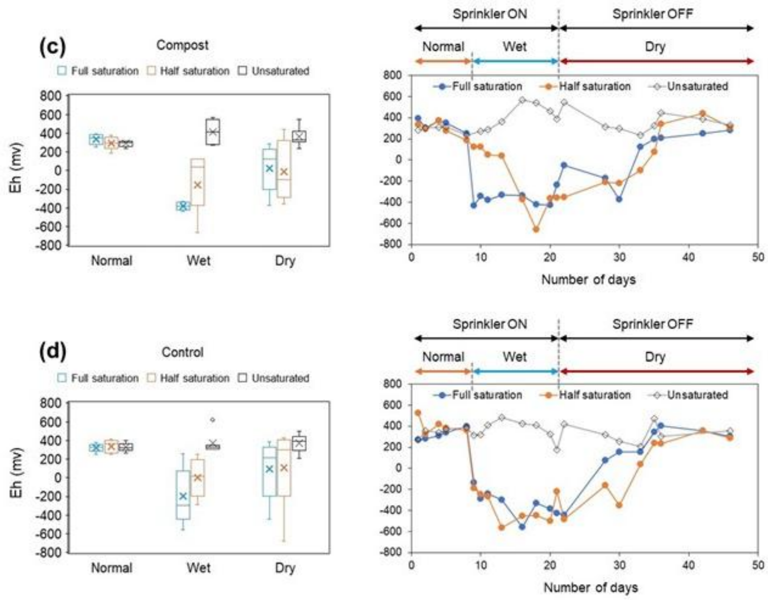


Figure 7. Redox potential (Eh in mv): (a) biochar, (b) biochar-compost blend, (c) compost, and (d) control (no amendment). Note that emissions data were presented in CO_2-equivalent. Box and whisker plots on the left column.

Conclusions

This project used biochar and/or compost as organic amendments for grass sodding (task 1) or seeding (task 2) and evaluated them for GHG fluxes under contrasting water saturation conditions. Our results indicated that compost amendment (compost and bio-com blend) can elevate CO_2 emissions as the soils undergo transient soil saturation followed by drying phase. Biochar alone did not increase soil CO_2 emissions while maintaining higher soil moisture content than compost or unamended soils. For urban lawn soil management in the context of GHG emissions, blending compost with biochar may be beneficial in reducing CO_2 emissions. Temporal increases in CH_4 and N_2O emissions are expected in saturated lawn soils followed by drying conditions while their emissions are limited under normal irrigated conditions.

References

Carbone, M.S., G.C. Winston, and S.E. Trumbore, Soil respiration in perennial grass and shrub ecosystems: Linking environmental controls with plant and microbial sources on seasonal and diel timescales. Journal of Geophysical Research-Biogeosciences, 2008. 113(G2).

Cross, A. and S.P. Sohi, The priming potential of biochar products in relation to labile carbon contents and soil organic matter status. Soil Biology & Biochemistry, 2011. 43(10): p. 2127-2134.

Hanson, P.J., et al., Separating root and soil microbial contributions to soil respiration: A review of methods and observations. Biogeochemistry, 2000. 48(1): p. 115-146.

Salinas, A. (2024). Greenhouse Gas Emissions From Urban Lawn Soil Amended With Biochar and Compost Under Contrasting Redox Conditions (Master's thesis, The University of Texas Rio Grande Valley). https://scholarworks.utrgv.edu/etd/1604/

Salinas, A.**, Cheng, C. L., Pereira, E, Almeida, R.M. & Kang, J.J. (2025) Greenhouse gas emissions from lawn soils in response to organic amendments and simulated water saturation conditions (Submitted to CLEAN Soil Air Water, June 2025).

Conference presentations from this project (graduate, * undergraduate student mentees)**

Kang, J. J., Salinas, A.**, Reyes, J.*, Cheng, C. L., Pereira, E. I. P., & Almeida, R. (2024) Greenhouse gas emission dynamics affected by soil saturation-drying cycles in biochar- and compost-amended urban lawn soil [Abstract]. ASA, CSSA, SSSA International Annual Meeting, San Antonio, TX. https://scisoc.confex.com/scisoc/2024am/meetingapp.cgi/Paper/158214

Reyes, J.*, Salinas, A.**, Kang, J. J., Cheng, C. L., Pereira, E. I. P., & Almeida, R. (2024) Evaluation of biochar vs. compost for turfgrass germination, water retention, and greenhouse gas emissions [Abstract]. ASA, CSSA, SSSA International Annual Meeting, San Antonio, TX. https://scisoc.confex.com/scisoc/2024am/meetingapp.cgi/Paper/158231

Kang, J. J., Salinas, A.**, Bettini, M.*, Casillas Rodriguez, A. Y.*, Garcia, E.*, Cheng, C. L., Pereira, E. I. P., & Almeida, R. (2023) Greenhouse Gas Emission and Redox Chemistry in Biochar- and Compost-Amended Urban Soil Under Contrasting Water Saturation Conditions [Abstract]. ASA, CSSA, SSSA International Annual Meeting, St. Louis, MO. https://scisoc.confex.com/scisoc/2023am/meetingapp.cgi/Paper/151011.

Salinas, A.**, Bettini, M.*, Casillas Rodriguez, A. Y.*, Cheng, C. L., Pereira, E. I. P., & Kang, J. J. (2023) Greenhouse Gas Flux Dynamics Affected By Water Table Conditions and Organic Amendments in Soils [Abstract]. ASA, CSSA, SSSA International Annual Meeting, St. Louis, MO. https://scisoc.confex.com/scisoc/2023am/meetingapp.cgi/Paper/149293

Bettini, M.*, Casillas Rodriguez, A. Y.*, Salinas, A.**, Garcia, E.*, Kang, J. J., Cheng, C. L., Pereira, E. I. P., & Almeida, R. (2023) Redox Chemistry of Urban Soils Undergoing Simulated Flooding and Drainage Cycles. [Abstract]. ASA, CSSA, SSSA International Annual Meeting, St. Louis, MO. https://scisoc.confex.com/scisoc/2023am/meetingapp.cgi/Paper/148825

Manuscript submitted from this project

Salinas, A.**, Cheng, C. L., Pereira, E, Almeida, R.M. & Kang, J.J. (2025) Greenhouse gas emissions from lawn soils in response to organic amendments and simulated water saturation conditions (Submitted to CLEAN Soil Air Water, June 2025).