Carbon Flux Monitoring: Comparing Emerging Sensor Networks with Eddy Covariance in a Cropland Ecosystem

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Accurate and spatially representative measurements of ecosystem carbon fluxes are essential for assessing agricultural carbon budgets and evaluating land–atmosphere exchange processes. Conventional eddy covariance (EC) towers provide long-term, high-frequency flux measurements, but their high cost and spatial footprint constrain their capacity to detect within-field heterogeneity. Emerging low-cost, distributed sensors offer the potential to complement EC systems by capturing finer spatial gradients in carbon, water, and energy exchange.

This study assesses the performance and comparability of a network of LI-COR carbon node (LI-720), water nodes (LI-710) sensors deployed at a soybean-corn rotation site in Mead, Nebraska. Four measurement positions were established, including a central reference site co-located with a traditional EC tower and three satellite points distributed across the field. Each position was equipped with a carbon node (LI-720), measuring CO_2 flux, H_2O flux, sensible heat, and wind vectors, alongside paired water nodes (LI-710) that record evapotranspiration and atmospheric conditions. To support cross-instrument evaluation, carbon and water nodes from Positions 1–3 are rotated to Position 4 at fortnightly intervals, while each location retains its original IoE module for uninterrupted cloud-based data continuity. Data was collected for a single growing season (May-November) until harvest.

This distributed design enables evaluation of (i) agreement between node-based fluxes and the EC reference system, (ii) inter-node consistency across space, and (iii) the influence of landscape variability on flux interpretation. Ancillary datasets, including soil moisture, vegetation phenology, crop yield history, and remote-sensing products, are integrated to contextualise spatial patterns in carbon exchange and to explore how microtopography and land-use heterogeneity affect flux behaviour.

By benchmarking emerging sensors against established EC measurements, this work aims to determine the feasibility of low-cost, scalable sensor networks for carbon-budget monitoring in agricultural systems. The results will inform best-practice guidelines for distributed flux observations and support the development of high-resolution, field-scale carbon monitoring strategies.

Figure 1: Aerial view of the study field showing the spatial arrangement of carbon nodes (triangles), water nodes (circles), and eddy covariance (EC) towers across four LENS positions. Sensors were deployed to capture fine-scale spatial variability in CO_2 fluxes and evapotranspiration within the EC tower footprint.

Carbon Nodes vs Eddy Covariance Tower: CO2 FLUX

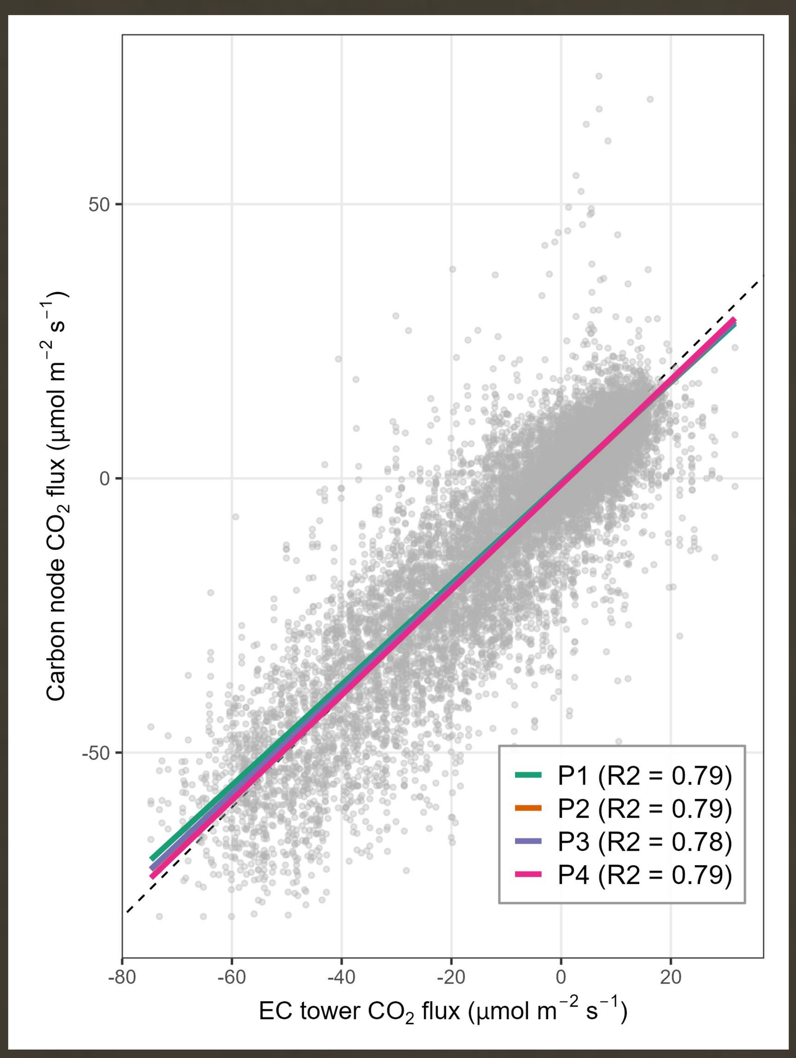

Figure 2: Comparison of 30-min CO_2 fluxes measured by distributed carbon nodes and a collocated eddy covariance (EC) tower.

- Carbon-node CO_2 fluxes closely tracked EC tower measurements across the full flux range.
- All nodes showed strong linear agreement with the tower, with R^2 values of 0.78–0.79.
- Regression slopes were close to the 1:1 line, indicating good consistency in flux magnitude.
- Residual scatter likely reflects spatial footprint differences between the EC tower and individual node locations.

Quality control: Data were filtered for instrument flags, non-physical values, and short-term spikes prior to comparison. Only time-matched, post-QC 30-min fluxes were used.

Water Nodes vs Carbon Nodes : Evapotranspiration

- Evapotranspiration (ET) estimates from water and carbon nodes were strongly correlated after quality control.
- A timing offset at Position 4 was corrected, substantially improving agreement.
- Across all positions, regression fits closely followed the 1:1 line, with R^2 = 0.85–0.87.
- Remaining spread reflects local heterogeneity in soil moisture, vegetation, and microclimate conditions.

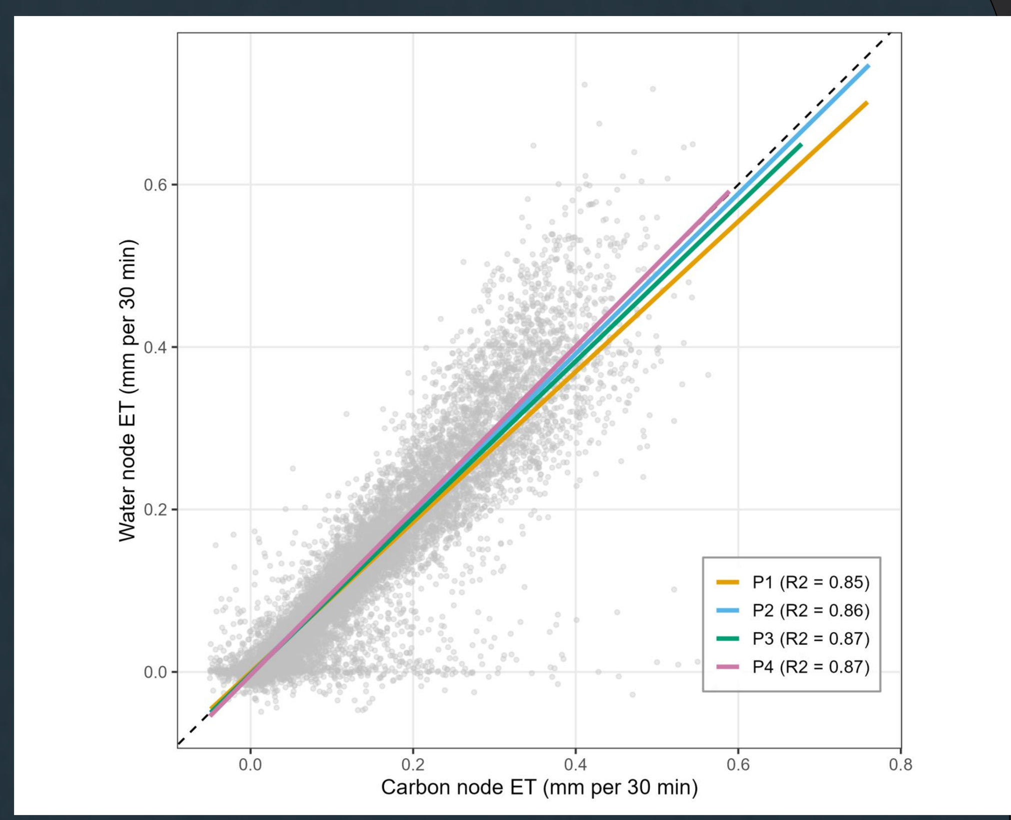

Figure 3: Comparison of 30-min evapotranspiration(mm) measured by distributed carbon nodes and a collocated water nodes.

Quality Control:

- Removal of invalid and non-physical values.
- Rolling median and median-absolute-deviation filters applied to remove short-duration spikes.
- Step-change filtering used to eliminate abrupt, non-physical jumps between consecutive 30-min intervals.
- Flat-line detection applied to remove periods of sensor stagnation.

Internode comparison and agreement

Direct comparisons between carbon nodes show strong internal consistency. Pairwise regressions between neighbouring nodes exhibit near 1:1 scaling, low bias, and high coefficients of determination, indicating that observed spatial variability reflects real ecosystem heterogeneity rather than sensor artefacts.

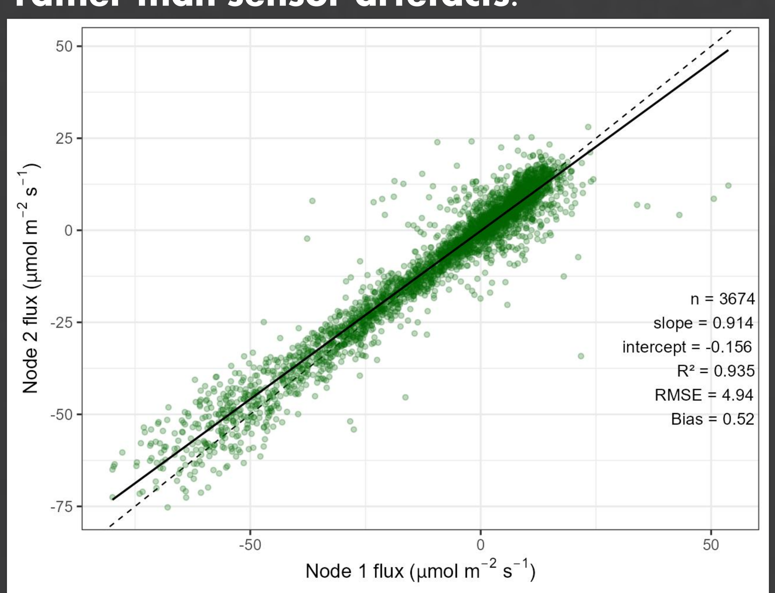

Figure 4: Pairwise comparison of CO_2 fluxes between co-located carbon nodes.

Minor divergence between nodes is most apparent during periods of high flux magnitude, consistent with small-scale variation in soil moisture, vegetation structure, and footprint overlap. Importantly, the absence of systematic offsets or nonlinear behaviour demonstrates that the carbon-node network provides a stable and internally coherent representation of field-scale CO_2 exchange.

Geospatial analysis (GWR)

Each node's 30-min CO_2 flux was paired with footprint-weighted landscape variables:

- NDVI – vegetation 'greenness' (Daily)
- TWI – topographic wetness index calculated from a high resolution digital elevation model (Fixed in time)
- Yield – crop productivity (Annual)

A spatially varying Geographically and Temporal Weighted Regression (GTWR) was used to quantify how these landscape features influence CO_2 flux differently across the field and through time. Node-specific coefficients were then interpolated to continuous maps and overlaid on high-resolution imagery to visualise spatial controls on carbon exchange.

Key findings:

TWI (soil wetness) was the dominant spatial predictor of CO_2 flux across the growing season (May – October)

Large negative coefficients in wetter depressions ⇒ suppressed respiration / lower CO_2 efflux.

Positive coefficients on higher, drier ground ⇒ enhanced respiration / higher CO_2 efflux.

NDVI_fp and Yield_fp showed much weaker spatial effect. Implications for the carbon-node network

Carbon nodes successfully captured real spatial heterogeneity in CO_2 flux driven by microtopography and soil moisture.

The footprint-weighted GTWR approach allows nodes to act as localised flux samplers.

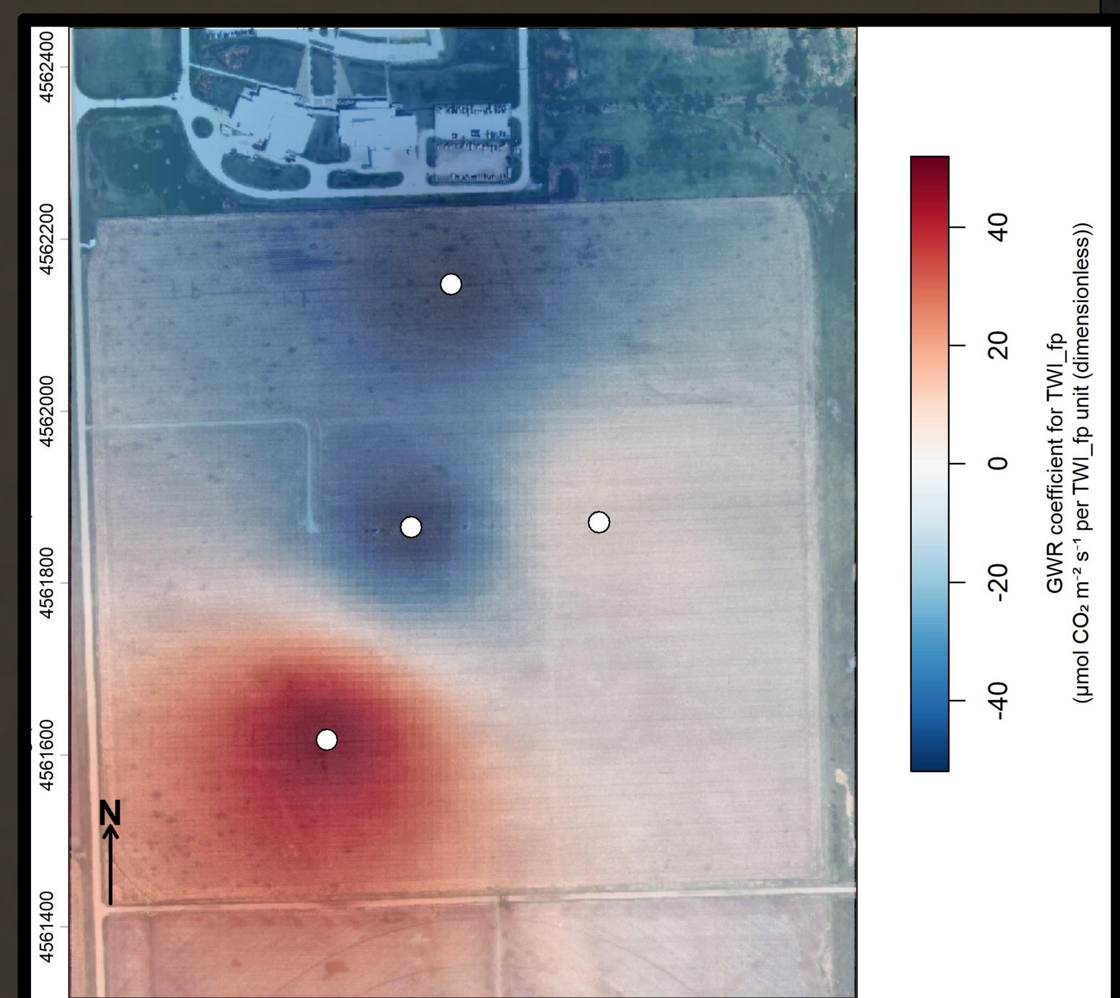

Figure 5: Spatial patterns in CO_2 flux drivers derived using footprint-weighted geographically (and temporally) weighted regression. Maps show node-specific coefficients interpolated across the field, highlighting microtopographic wetness as a dominant control on CO_2 exchange relative to other dependent variables.

Summary

- Distributed carbon and water nodes show strong agreement with established EC measurements after quality control.
- Internal consistency across nodes indicates that observed variability reflects real spatial heterogeneity.
- ET comparisons demonstrate that timing alignment and QC are critical for cross-sensor integration.
- Combined, these results support the use of low-cost, distributed sensor networks to complement EC towers and capture field-scale variability in carbon and water fluxes.

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