https://doi.org/10.5194/egusphere-2026-217
Preprint. Discussion started: 5 March 2026

Soil water content and salinity regulate the temperature sensitivity of CO_2 and CH_4 emissions in a coastal salt-affected land

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https://doi.org/10.5194/egusphere-2026-217
Preprint. Discussion started: 5 March 2026

Abstract

Soil carbon emissions from coastal saline-alkaline ecosystems significantly influence the global carbon cycle, yet their responses to key environmental drivers such as soil water content and salinity remain insufficiently understood. This study employed controlled incubation experiments using soils collected from the Yellow River Delta, China, to systematically investigate the effects of varying soil water content (5%, 15%, 30%, 45%, and 60%) and salinity levels (S1: EC=1.9 dS/m; S2: 10.8 dS/m; S3: 58.8 dS/m; S4: 66.3 dS/m; S5: 96.0 dS/m) on CO_2 and CH_4 emissions and their temperature sensitivity (Q_{10}). The results demonstrated that under constant temperature conditions, CO_2 emission flux followed a unimodal pattern in response to increasing soil water content, peaking at 45% water content, with CH_4 flux exhibiting a similar trend. Soil salinity significantly suppressed the fluxes of both greenhouse gases, with reductions observed across all temperature levels as salinity increased. Both soil water content and salinity played substantial regulatory roles in modulating the Q_{10} of gas emissions. Specifically, Q_{10} values for CO_2 and CH_4 initially decreased and then increased with rising soil water content. Along the salinity gradient, the Q_{10} of CO_2 decreased from S2 to S4, whereas the Q_{10} of CH_4 increased progressively from S2 to S5. These findings reveal the complex and interactive effects of soil water content and salinity on carbon cycling processes in coastal saline-alkaline lands. The study provides crucial theoretical insights for improving the prediction of carbon cycle dynamics under climate change and offers a scientific basis for the adaptive management and conservation of these vulnerable ecosystems.

Keywords: Coastal saline-alkaline land; Soil water content; Soil salinity; CO_2 and CH_4 emissions; Temperature sensitivity (Q_{10})

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1. Introduction

Saline-alkaline lands are strategically significant for enhancing regional carbon sinks and mitigating global environmental change(Ma et al. 2024). Their unique stressors (e.g., high salinity and osmotic pressure) alter soil properties and biogeochemical cycles, regulating organic carbon preservation and carbon pool stability (Wong et al. 2010). While greenhouse gas research has largely focused on non-saline soils—typically CO_2 sources and CH_4 sinks, with positive CH_4 fluxes mainly in wetlands (Gao et al. 2018, Zhan et al. 2023)—drivers of gas fluxes in saline-alkaline soils remain poorly understood (Tang et al. 2016, Feng et al. 2022). Existing studies concentrate on inland saline lands (Wang et al. 2021), leaving coastal systems, with distinct salinity and hydrological dynamics, understudied. Investigating carbon emissions in coastal saline-alkaline lands is thus critical, especially as soil salinization constrains emission reduction efforts in China (Huang et al. 2024).

The temperature sensitivity (Q_{10}) of greenhouse gas emissions—the increase per 10 °C rise—is a key parameter in climate-carbon feedback models (Alster et al. 2018). Q_{10} of soil respiration varies with temperature, soil water content, soil properties, microbial communities, and vegetation (Lloyd et al. 1994, Wang et al. 2014), generally higher in cold ecosystems due to microbial reliance on recalcitrant carbon (Li et al. 2020, Li et al. 2021). For example, temperate forests show higher Q_{10} than tropical forests, linked to microbial composition and carbon quality (Johnston et al. 2018, Wang et al. 2018). However, Q_{10} studies in saline-alkaline lands are scarce, limiting understanding under global warming.

Soil water content regulates carbon gas production and emissions by affecting redox potential, aeration, microbial activity, and diffusion (Capooci et al. 2019). Optimal soil water content supports microbial activity, while extremes suppress it (Cao et al. 2023). Soil water content effects on respiration vary spatially and temporally (Schaufler et al. 2010, Wang et al. 2013, Gao et al. 2018), and drive CH_4 flux thresholds—uptake at 30–60% field capacity, emission at 75–90% (Suh et al. 2009). Soil water content also interacts with temperature to indirectly influence Q_{10}(Hansen et al. 2013).

Salinity critically regulates carbon cycles in coastal wetlands(Ho et al. 2024). It reduces CO_2 production potential by decreasing labile carbon and inhibiting microbial metabolism (Huang et al. 2019), while suppressing CH_4 oxidation (Saari et al. 2004). Low salinity can enhance CH_4 uptake, whereas high salinity induces osmotic stress and toxicity, inhibiting microbial activity and diversity(Pathak et al. 1998). Warming

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further stimulates CO_2 emissions by accelerating organic matter decomposition (SUN et al. 2016).

China has extensive saline-alkaline land 9.9×10^6 ha (Liu et al. 2024). The Yellow River Delta, a dynamic coastal delta with severe salinization (50.9% saline soil)(Ma et al. 2025) , is ideal for studying these interactions. This study examines how soil water content and salinity affect CO_2 and CH_4 emissions and their temperature sensitivity through incubation experiments, providing insights into the role of saline-alkaline lands in the carbon cycle and their response to climate change. This study proposes the following three core hypotheses: 1) soil water content will significantly regulate CO_2 and CH_4 emission fluxes and their temperature sensitivity (Q_{10}) in saline-alkaline soil. An optimal soil water content threshold is expected, beyond or below which emissions are suppressed, and increased soil water content may decrease the Q_{10} of CO_2 emissions. 2) Elevated salinity will inhibit the emission potential of CO_2 and CH_4 and alter their Q_{10}. Salinity directly weakens emission intensity by suppressing microbial and enzymatic activities, and may indirectly affect Q_{10} by altering substrate availability. 3) There will be significant interactive effects between soil water content and salinity on greenhouse gas emissions and their Q_{10}. Under high temperatures, high salinity may exacerbate the suppression of microbial activity due to water stress, thereby significantly reducing the Q_{10} of CO_2 emissions. For CH_4, the interaction between soil water content and salinity is likely to dominate the balance between production and oxidation processes, ultimately determining the net emission direction and the strength of the temperature response.

2. Materials and methods

2.1. Study Site

Soil samples were collected from a coastal saline-alkaline area within the Agricultural High-tech Industrial Demonstration Zone of the Yellow River Delta, Dongying City, Shandong Province, China (37.3°N, 118.7°E; ~6.7 m altitude) (Yang et al. 2025). The region has a warm temperate monsoon climate characterized by distinct seasonal variation, with a mean annual temperature of 12.8°C and mean annual precipitation of 555.9 mm, predominantly in summer. The soil is classified as coastal saline-alkaline, covering approximately 36% of Dongying City's total soil area along the Bohai Sea coast.

2.2. Soil Sampling and Analysis

In May 2022, soil sampling was conducted across the main salinity gradients of the study area. Based on vegetation distribution, ten 50-meter transects were randomly established. Five sampling

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points were randomly selected along each transect, resulting in 50 points in total (Yang et al. 2025). Topsoil (0–20 cm depth) was collected at each point using a soil corer. Soils from points with identical vegetation types were composited, placed in sealed polyethylene bags, and transported to the laboratory.

The composited samples were air-dried, passed through a 2-mm sieve to remove roots and debris, and homogenized. A subsample was then analyzed for key physicochemical properties: electrical conductivity (EC, measured in a 1:5 soil:water extract), pH (determined in a 1:5 soil:water suspension), and total carbon (TC) and total nitrogen (TN) via elemental analysis. Based on EC values, soils were categorized into five salinity gradients (S1–S5), representing a spectrum from non-saline to extremely saline conditions (Table 1). The remaining soil was stored for incubation experiments.

2.3. Incubation Experiment Design

Air-dried soil was packed into PVC columns (20 cm diameter × 30 cm height), with a 10-cm headspace for gas sampling and a sealed bottom (Fig. S1). To isolate the effects of salinity and soil water content, two controlled incubation experiments were conducted across a temperature gradient (5, 10, 15, 20, 25, and 30°C): 1) Salinity experiment: Five salinity levels (S1–S5) were incubated at constant soil water content (60% water content). 2) Soil water content experiment: Five soil water content levels (5%, 15%, 30%, 45%, 60%) were incubated using soil from the lowest salinity gradient (S1). Each treatment combination had five replicates, totaling 150 experimental units. soil water content was maintained by weighing and replenishing with deionized water every 1–2 days. Temperature was controlled using artificial climate chambers. After a 7-day stabilization period at each target temperature, gas fluxes were measured.

2.4. Gas Flux Measurement

CO_2 and CH_4 fluxes were measured using a portable greenhouse gas analyzer (LI-7810, LI-COR Biosciences, USA). Measurements were taken between 9:00 and 11:00 local time. For each column, three consecutive flux readings were recorded and averaged. Flux measurements were conducted over a 10-day period at each temperature. The instrument was calibrated before each session (calibration error$\leqslant$1%).

2.5. Statistical Analysis

Data were processed and analyzed using Microsoft Excel 2019 and SPSS 19.0. The effects of

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experimental factors (salinity, soil water content, temperature, and their interactions) were tested using one-way and two-way analysis of variance (ANOVA). Where ANOVA indicated significant effects ($P < 0.05$), post-hoc comparisons among treatment groups were performed using the Least Significant Difference (LSD) test. All results are reported as the mean ± standard error (SE).

The relationship between soil respiration rate (R) and incubation temperature (T) was modeled using an exponential function: $R = ae^{(bT)}$

where a is the theoretical respiration rate at 0 °C and b is the temperature sensitivity coefficient.

The temperature sensitivity index, Q_{10} (representing the factor change in respiration rate per 10 °C increase in temperature), was calculated as: $Q_{10} = e^{(10b)}$

The parameter b was estimated for each salinity or soil water content gradient via nonlinear regression, and the corresponding Q_{10} values were derived and reported as mean ± SE(Lang et al. 2017) . Data visualization and figure generation were completed using Origin 2020.

3. Results

3.1. Effects of soil water content on CO_2 and CH_4 emissions and their temperature sensitivity

Soil CO_2 emission flux demonstrated a strong positive correlation with temperature across the entire soil water content gradient (5%, 15%, 30%, 45%, and 60%). At each fixed soil water content level, flux increased significantly ($P < 0.05$) with rising incubation temperature from 5°C to 30°C. Conversely, under a constant temperature, CO_2 flux exhibited a distinct unimodal relationship with soil water content: it initially increased, peaked at 45% soil water content, and subsequently decreased. Differences in CO_2 flux among soil water content treatments at the same temperature were statistically significant ($P < 0.05$). The highest mean CO_2 flux was observed under the combined condition of 30°C and 45% soil water content, whereas the lowest flux occurred at 5°C and 60% soil water content (Fig. 1). The temperature sensitivity (Q_{10}) of CO_2 emissions varied between 1.48 and 1.87 across soil water content treatments. Interestingly, Q_{10} itself showed a unimodal response to increasing water content, reaching its minimum value of 1.48 at 45% soil water content (Table 2).

Soil acted as a net source of CH_4 across all experimental conditions, with emission fluxes consistently positive. CH_4 flux displayed a similar response pattern to CO_2: a significant increase with temperature ($P < 0.05$) under constant soil water content, and a unimodal relationship with soil water

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content under constant temperature, again maximizing at 45% soil water content. Fluxes differed significantly ($P < 0.05$) among soil water content levels at a given temperature. Peak CH_4 emission was recorded at 30°C and 45% soil water content, while the minimum was found at 5°C and 5% soil water content (Fig. 2). The Q_{10} for CH_4 emissions ranged from 1.13 to 1.29, mirroring the trend observed for CO_2 by declining to its lowest value (1.13) at the optimal soil water content content of 45% (Table 2).

These patterns were further validated by exponential models fitted to the data (Fig. 3 and 4). The models confirmed that for both gases, flux at constant temperature first rose and then fell with increasing soil water content, while at constant soil water content, flux increased exponentially with temperature. A highly significant positive correlation ($P < 0.01$) was found between the treatment variables (temperature × soil water content) and gas fluxes. Regression analysis indicated that soil temperature alone explained 34.7–58.2% of the variance in CO_2 flux, and 3–10% of the variance in CH_4 flux across treatments (Figs. 2 and 3).

3.2. Effects of Soil Salinity on CO_2 and CH_4 Emissions and their temperature sensitivity

All soils, regardless of salinity gradient (S1 to S5, with S1 being lowest), functioned as net sources of CO_2 under the experimental conditions (Fig. 5). However, the nature of the temperature response was modulated by salinity level. For gradients S1, S2, and S5, CO_2 flux generally increased with rising temperature, though significant differences ($P < 0.05$) were not always present between adjacent temperature points (e.g., between 20°C and 25°C in S2). In contrast, the S3 gradient exhibited an atypical response, with peak flux occurring at 20°C, which was significantly higher ($P < 0.05$) only than fluxes at 5°C, 10°C, and 15°C. The S4 gradient showed a bell-shaped response, with flux increasing up to 25°C before declining at 30°C. The Q_{10} for CO_2 emissions across salinity levels ranged from 1.44 to 1.75 (Table 3).

A clear inhibitory effect of salinity on CO_2 flux was observed. Across all incubation temperatures, mean flux significantly decreased with increasing salinity gradient. The specific pattern of significant differences among gradients was temperature-dependent. At lower temperatures (e.g., 10°C, 15°C), the low-salinity gradients (S1, S2) often showed significantly higher fluxes ($P < 0.05$) than the higher-salinity ones (S3-S5). At higher temperatures (e.g., 20°C, 25°C), the lowest salinity gradient (S1) was typically significantly different ($P < 0.05$) from all others, while differences among higher-salinity

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gradients were less consistent.

Salinity exerted a significant influence on CH_4 emissions (Fig. 6). Similar to CO_2, CH_4 flux increased with temperature for all salinity levels ($P < 0.05$). However, at a fixed temperature, CH_4 flux displayed a general decreasing trend with increasing salinity. This suppression by high salinity was statistically significant ($P < 0.05$) at lower incubation temperatures (5°C, 10°C, 15°C). Notably, at higher temperatures (⩾20°C), although the decreasing trend persisted, differences in CH_4 flux among the various salinity gradients were no longer statistically significant ($P > 0.05$). The temperature sensitivity of CH_4 emissions (Q_{10}) increased with salinity, ranging from 1.12 at the lowest salinity to 1.39 at the highest (Table 3).

Exponential modeling revealed a consistent and significant negative correlation ($P < 0.05$) between both CO_2 and CH_4 emission fluxes and soil salinity at each individual temperature level (Fig. 7 and 8). Conversely, under a constant salinity level, a significant positive correlation ($P < 0.05$) was observed between gas fluxes and incubation temperature (Figs. 4 and 5).

4. Discussion

This study elucidates the individual and interactive regulatory roles of soil water content and salinity on CO_2 and CH_4 emissions and their temperature sensitivity (Q_{10}) in a coastal saline-alkaline ecosystem. Our results robustly support the proposed hypotheses. First, soil water content exhibited a pronounced unimodal effect on the fluxes of both gases, with an optimal threshold around 45%, aligning with Hypothesis 1. Notably, the Q_{10} values for both CO_2 and CH_4 were also minimized at this soil water content level, confirming soil water content's critical role in modulating temperature response. Second, increasing salinity significantly suppressed the emission potential of CO_2 and CH_4 across most temperatures, consistent with Hypothesis 2. Furthermore, salinity altered the Q_{10}, particularly for CH_4 emissions where sensitivity increased with salinity. Finally, significant interactive effects were observed (Hypothesis 3). The suppressive effect of high salinity on emissions was often most pronounced at lower temperatures, and the inhibitory effect of salinity on CH_4 flux became less distinct at higher temperatures (⩾ 20°C), indicating a complex temperature-soil water content-salinity interplay governing microbial processes.

4.1. The unimodal moisture response and its impact on Q_{10}

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The unimodal relationship between gas flux and soil water content is a classic pattern, typically attributed to opposing constraints (Peng et al. 2025). This study, along with previous work, demonstrates that CO_2 and CH_4 emission fluxes exhibit this classic unimodal relationship with soil water content, with the optimal threshold generally occurring in the medium soil water content range (e.g., around 45%). This pattern results from the physical constraints of soil water content on microbial activity and substrate diffusion, as well as its regulation of redox conditions (Yin et al. 2025). Under low soil water content conditions (e.g., 5%–15%), water deficit directly limits microbial physiological activity and the diffusion of substrates such as soluble organic carbon, thereby inhibiting gas emissions. Under these conditions, soils often act as a net sink for CH_4 because aerobic methanotroph activity dominates (Wang et al. 2025).

When soil water content increases to the optimal level, these physical constraints are alleviated. For CO_2 emissions, suitable water content optimizes soil aeration, significantly promoting microbial metabolic activity dominated by aerobic respiration, which drives CO_2 release to its peak(Ma et al. 2024, Niu et al. 2024). For CH_4 emissions, this soil water content range creates a delicate balance: on one hand, it provides favorable anaerobic microsites for methanogens, promoting CH_4 production; on the other hand, the soil maintains a certain capacity for oxygen diffusion, allowing aerobic methane oxidation to partially proceed. This dynamic balance between methanogenesis and methane oxidation leads to the peak net CH_4 flux (Gondwe et al. 2021). Water content conditions, by influencing the accumulation and spatial distribution of soluble organic carbon, profoundly affect microbial activity and function, thereby serving as a key mechanism driving changes in emission fluxes (Yang et al. 2022). When water content exceeds the optimal threshold (e.g., >50%), soil pores approach water saturation, severely impeding oxygen diffusion. This shift redirects the dominant microbial metabolic pathway from efficient aerobic respiration to less efficient anaerobic fermentation pathways, thereby suppressing CO_2 production (Zeeshan et al. 2022). For CH_4, while strongly anaerobic conditions favor methanogenesis, excessively high soil water content may simultaneously inhibit methanotroph activity and alter substrate transformation pathways, causing the net CH_4 emission flux to stabilize or decline (Fairbairn et al. 2023, Zhang et al. 2024).

This study found that the temperature sensitivity (Q_{10}) of both CO_2 and CH_4 emissions reached its

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minimum value under optimal soil water content conditions. This key finding suggests that under non-limiting, suitable water conditions, microbial metabolic processes exhibit a relatively reduced dependence on temperature changes. Research indicates that this may imply that under such conditions, substrate availability replaces the activation energy required for reaction kinetics as the dominant rate-limiting factor controlling respiration rates (He et al. 2023). Simultaneously, changes in soil water content conditions further modulate the expression of temperature sensitivity by influencing the transport and transformation of dissolved organic carbon (Feng et al. 2020). However, a complete consensus has not been reached in the academic community regarding the effect of soil water content on Q_{10}. These discrepancies highlight the complexity of the soil water content-temperature response relationship, which may be modulated by a combination of factors such as ecosystem type, soil matrix conditions, and microbial community structure (Domeignoz‐Horta et al. 2023).

In the specific context of saline-alkaline soils, the soil water content effect also exhibits significant interactions with salinity. For instance, regarding CO_2 emissions, appropriate soil water content can to some extent alleviate the osmotic stress and ion-specific toxicity imposed by salinity on microorganisms. Consequently, the inhibitory effect of salinity is often weaker at medium soil water content levels (e.g., 60% WFPS) than at high soil water content levels (e.g., 90% WFPS) (Thapa et al. 2017, Zhang et al. 2018).

4.2. Salinity as a key suppressor and modifier of temperature response

Salinity is another core environmental factor regulating greenhouse gas emissions and their temperature responses in saline-alkaline ecosystems. This study, along with extensive literature, confirms that elevated salinity generally suppresses both CO_2 and CH_4 emission fluxes (Haj-Amor et al. 2022, Yang et al. 2023). The underlying inhibitory mechanisms primarily include the following aspects: First, salinity directly affects microbial physiological activity and biomass by inducing osmotic stress and ion-specific toxicity (Lin et al. 2021). Second, it reduces the availability of labile carbon and nitrogen substrates and inhibits the activity of extracellular enzymes crucial for organic matter decomposition, such as β-glucosidase (Qu et al. 2022). Third, salinity profoundly alters the abundance and composition of microbial communities and functional genes. For instance, in saline-alkaline soils, the abundance of methanogenesis-related functional genes (e.g., mcrA) decreases with increasing salinity, while methane

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oxidation-related genes (e.g., pmoA) may also decline. Overall, the microbial community balance shifts toward suppressing net CH_4 production (Yang et al. 2023). Low substrate availability is a significant factor limiting gas production in saline soils, although the addition of organic amendments can partially alleviate this limitation (Nguyen et al. 2020).

A key and more complex finding is that while salinity suppresses the absolute magnitude of gas emissions, it can significantly alter their temperature sensitivity (Q_{10}). For CO_2 emissions, although cumulative emissions are lower in high-salinity soils, their Q_{10} values (reported in the range of 2.6 to 5.2) increase significantly with rising salinity(Yu et al. 2020, Haj-Amor et al. 2022). This implies that under climate warming, saline-alkaline soils may release a proportionally greater amount of CO_2 per degree of temperature increase compared to non-saline soils, potentially amplifying the positive feedback to warming. This enhancement of Q_{10} may be related to salinity altering the thermodynamics of organic matter decomposition, for example, by shifting the microbial community toward reliance on more recalcitrant carbon pools or changing the dominant decomposition pathways(Zhang et al. 2023). For CH_4 emissions, the observed decrease in net flux with increasing salinity in this study indicates severe suppression of methanogenesis. The response pattern of its Q_{10} to salinity exhibits unique characteristics. This study found an increase in CH_4 Q_{10} with rising salinity, suggesting that the residual methanogenic microbial communities or processes in high-salinity environments may have stronger temperature dependence(Cai et al. 2025). This could result from a shift in community structure toward more stress-tolerant taxa whose metabolism is highly temperature-sensitive, or from a temperature-dependent alleviation of ionic stress. However, other evidence suggests that due to severe limitations in methanogen activity and substrate availability, the overall temperature sensitivity of CH_4 emissions in high-salinity soils may be lower (Zhou et al. 2018). Such discrepancies likely arise from differences in specific environmental conditions and experimental designs.

4.3. Implications and future perspectives

This study provides novel empirical data on the Q_{10} of greenhouse gases in coastal saline-alkaline soils, addressing a research gap that has previously focused largely on forests and peatlands (Heffernan et al. 2024, Li et al. 2025). The results demonstrate that the temperature sensitivity of carbon cycling is not a fixed ecosystem property but is dynamically regulated by abiotic stressors such as soil water

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content and salinity. A key management implication from this study is that optimal soil water content conditions can minimize the Q_{10} of carbon emissions. This suggests that through rational water management, it may be possible not only to regulate the immediate carbon emission flux from saline-alkaline lands but also to reduce the sensitivity of these emissions to future climate warming.

For predictive modeling, incorporating the nonlinear and interactive effects of soil water content and salinity is crucial for improving the accuracy of climate-carbon feedback projections in vulnerable coastal zones under scenarios of sea-level rise, altered precipitation patterns, and increased evaporation (Valiela et al. 2018, Richey et al. 2025). Future research needs to further elucidate the specific mechanisms by which salinity-moisture-temperature interactions affect microbial functions and community succession. Integrating these multi-factor coupled responses into regional and global carbon cycle models is essential to enhance the predictive capability for carbon dynamics in saline-alkaline ecosystems, thereby providing a solid scientific foundation for addressing climate change and achieving sustainable land management.

5. Conclusions

This study demonstrates that soil water content and salinity jointly regulate the temperature sensitivity (Q_{10}) of CO_2 and CH_4 emissions in coastal saline-alkaline land. The unimodal response of gas fluxes to soil water content, with optimal emissions and minimized Q_{10} at 45% soil water content, highlights soil water content's critical role. Elevated salinity generally suppressed emissions but increased the Q_{10} of CH_4, revealing a stress-induced shift in microbial temperature dependence. Significant interactions between these factors were observed, underscoring that their combined effects, rather than individual impacts, dictate the net climate feedback. These findings validate our initial hypotheses and fill a key knowledge gap regarding carbon cycling in dynamic coastal ecosystems. Incorporating such non-linear interactions into carbon-climate models is essential for improving predictions of greenhouse gas emissions under global change in vulnerable saline-affected regions.

Acknowledgments

This study was supported by grants from the China Agriculture Research System (CARS-34-19), and the “Youth Innovation Team Plan” of Universities in Shandong Province (2022KJ166).

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Table 1 Basic properties of the incubation soil for the experiment

Soil properties	S1	S2	S3	S4	S5
EC (dS/m)	1.9 (0.1)	10.8(1)	58.8 (6.2)	66.3 (7.3)	96.0 (12)
Salt (g/kg)	1.19 (0.38)	1.49 (0.26)	5.15 (0.66)	7.56 (0.97)	8.10 (1.32)
pH	8.29 (0.05)	8.29 (0.09)	7.92(0.04)	7.86 (0.07)	8.03 (0.05)
TC (g/kg)	14.71 (0.10)	12.99 (0.17)	15.88 (0.18)	13.65 (0.26)	12.67 (0.09)
TN (g/kg)	0.34 (0.01)	0.29 (0.01)	0.33 (0.01)	0.31 (0.01)	0.27 (0.01)
C/N ratio	43.48 (1.00)	45.15 (1.11)	48.06 (0.57)	44.63 (0.96)	47.26 (1.00)

Table 2 Effect of soil water content on CO_2 and CH_4 temperature sensitivity

Water content (%)	CO_2		CH_4	
	b	Q_{10}	b	Q_{10}
5	0.0573±0.0045	1.7735±0.0816	0.0216±0.0062	1.2411±0.0794
15	0.0625±0.0055	1.8681±0.1056	0.0251±0.0063	1.2853±0.0836
30	0.0538±0.0061	1.7125±0.1077	0.0201±0.0069	1.2230±0.0873
45	0.0393±0.0042	1.4814±0.0635	0.0118±0.0054	1.1252±0.0624
60	0.0593±0.0039	1.8093±0.0719	0.0151±0.0041	1.1630±0.0487

Table 3 Effect of soil salinity (EC) on CO_2 and CH_4 temperature sensitivity

EC (ds/m)	CO_2		CH_4	
	b	Q_{10}	b	Q_{10}
1.9	0.0489±0.0035	1.6306±0.0581	0.0156±0.0031	1.1688±0.0368
10.8	0.0556±0.0051	1.7458±0.0912	0.0113±0.0058	1.1196±0.0669
58.8	0.0412±0.0064	1.5098±0.0998	0.0183±0.0064	1.2008±0.0794
66.3	0.0362±0.0042	1.4361±0.0616	0.0255±0.0055	1.2904±0.0730
96.0	0.0467±0.0055	1.5951±0.0902	0.0326±0.0057	1.3854±0.0813

Figure captions

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Figure 1. CO_2 emission flux across temperature gradients under different soil water content treatments. Significant differences ($P < 0.05$) among water content treatments at the same temperature are indicated by lowercase letters; differences among temperature treatments at the same water content are indicated by uppercase letters.

Figure 2. CH_4 emission flux across temperature gradients under different soil water content treatments. Significant differences ($P < 0.05$) among water content treatments at the same temperature are indicated by lowercase letters; differences among temperature treatments at the same water content are indicated by uppercase letters.

Figure 3. Exponential relationships between soil CO_2 emission flux and soil water content at six incubation temperatures (5, 10, 15, 20, 25, and 30°C; panels a–f). All relationships are significant ($P < 0.05$), with the coefficient of determination (R^2) shown in each panel.

Figure 4. Exponential relationships between soil CH_4 emission flux and soil water content at six incubation temperatures (5, 10, 15, 20, 25, and 30°C; panels a–f). All relationships are significant ($P < 0.05$), with the coefficient of determination (R^2) shown in each panel.

Figure 5. CO_2 emission flux across temperature gradients under different soil salinity (EC) treatments. Significant differences ($P < 0.05$) among salinity treatments at the same temperature are indicated by lowercase letters; differences among temperature treatments at the same salinity level are indicated by uppercase letters.

Figure 6. CH_4 emission flux across temperature gradients under different soil salinity (electrical conductivity, EC) treatments. Significant differences ($P < 0.05$) among salinity treatments at the same temperature are indicated by lowercase letters; differences among temperature treatments at the same salinity level are indicated by uppercase letters.

Figure 7. Exponential relationships between soil CO_2 emission flux and soil salinity (EC) at six incubation temperatures (5, 10, 15, 20, 25, and 30°C; panels a–f). All relationships are significant ($P < 0.05$), with the coefficient of determination (R^2) shown in each panel.

Figure 8. Exponential relationships between soil CH_4 emission flux and soil salinity (EC) at six incubation temperatures (5, 10, 15, 20, 25, and 30°C; panels a–f). All relationships are significant ($P < 0.05$), with the coefficient of determination (R^2) shown in each panel.

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478 **Figure 1**

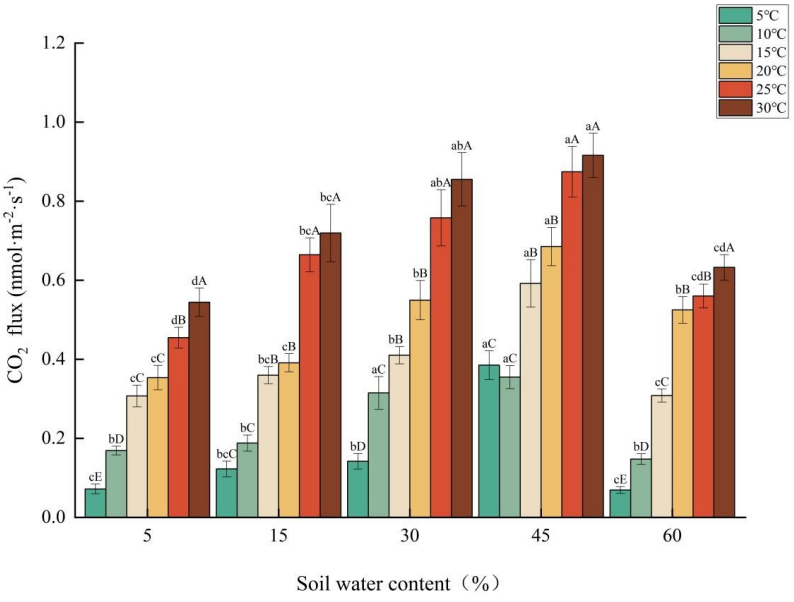

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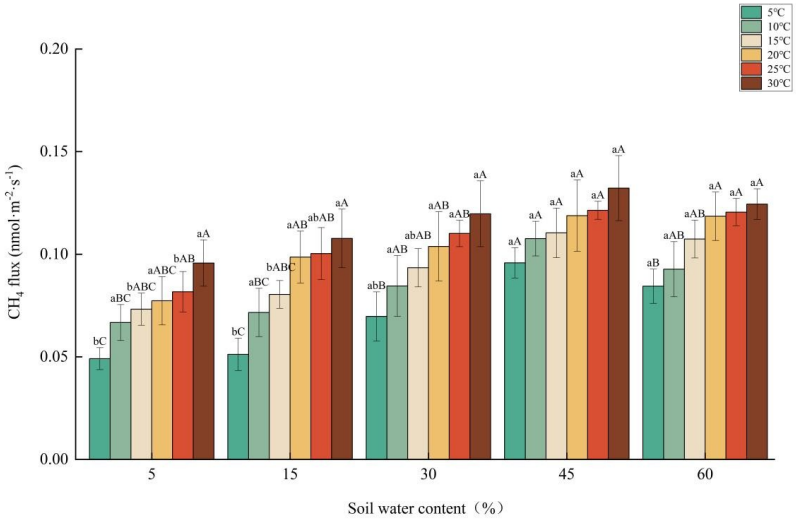
Figure 2



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484 **Figure 3**

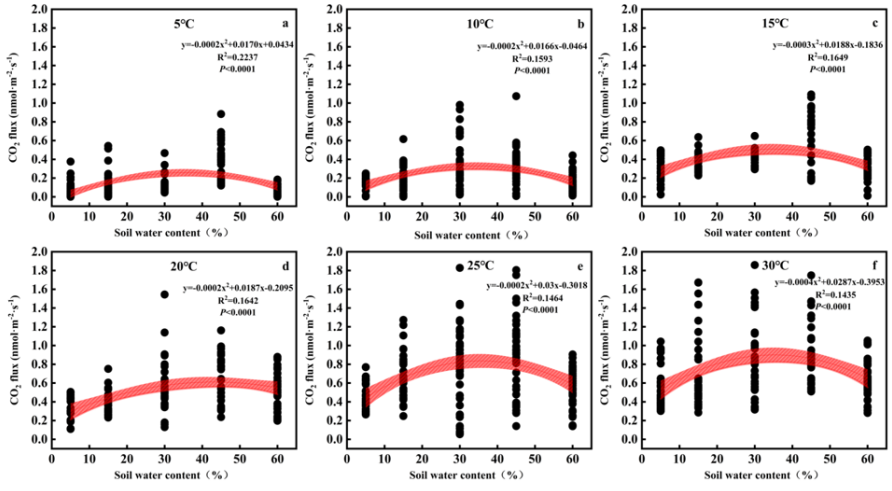

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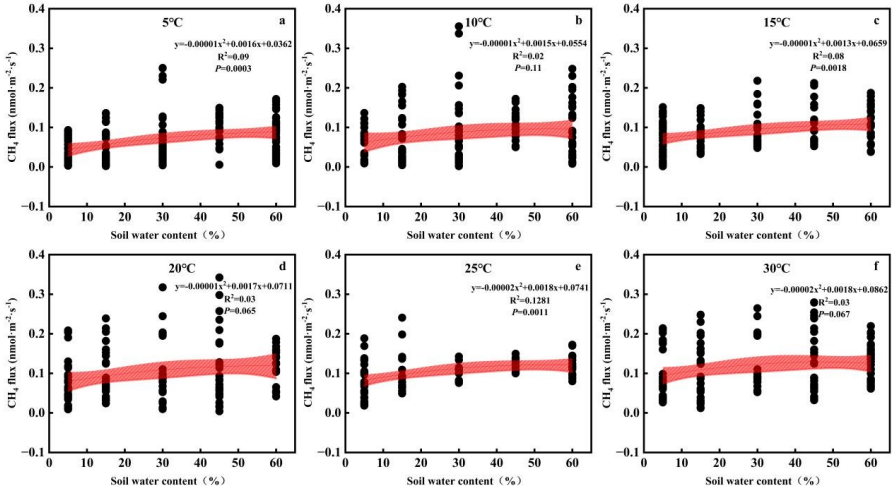
Figure 4



https://doi.org/10.5194/egusphere-2026-217
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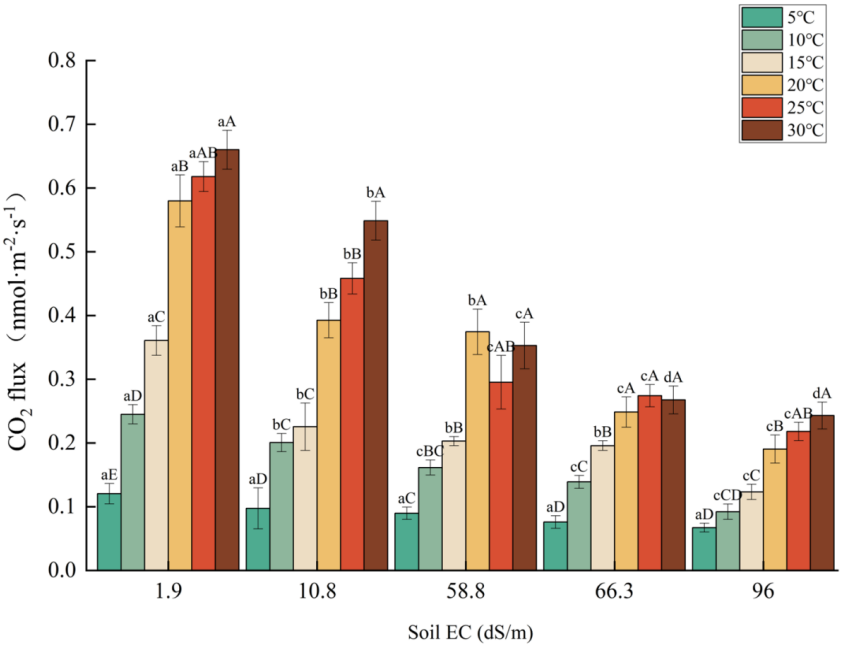
490 **Figure 5**



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493 **Figure 6**

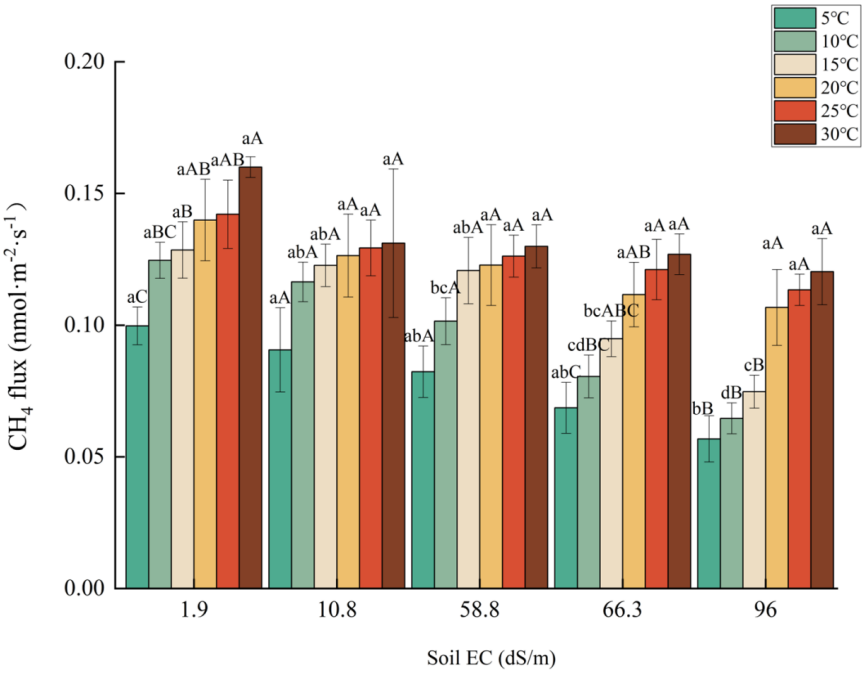

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Figure 7

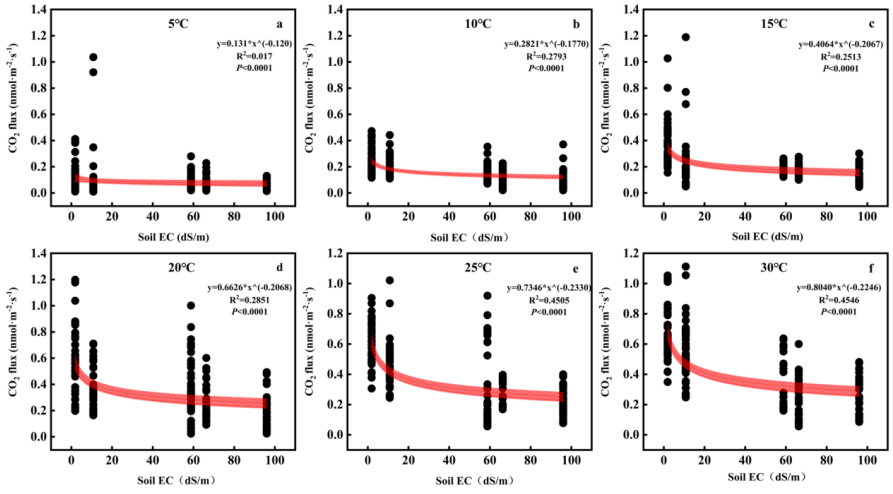

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Figure 8