A new strategy for microbial nutrient acquisition in reduced oxygen environments

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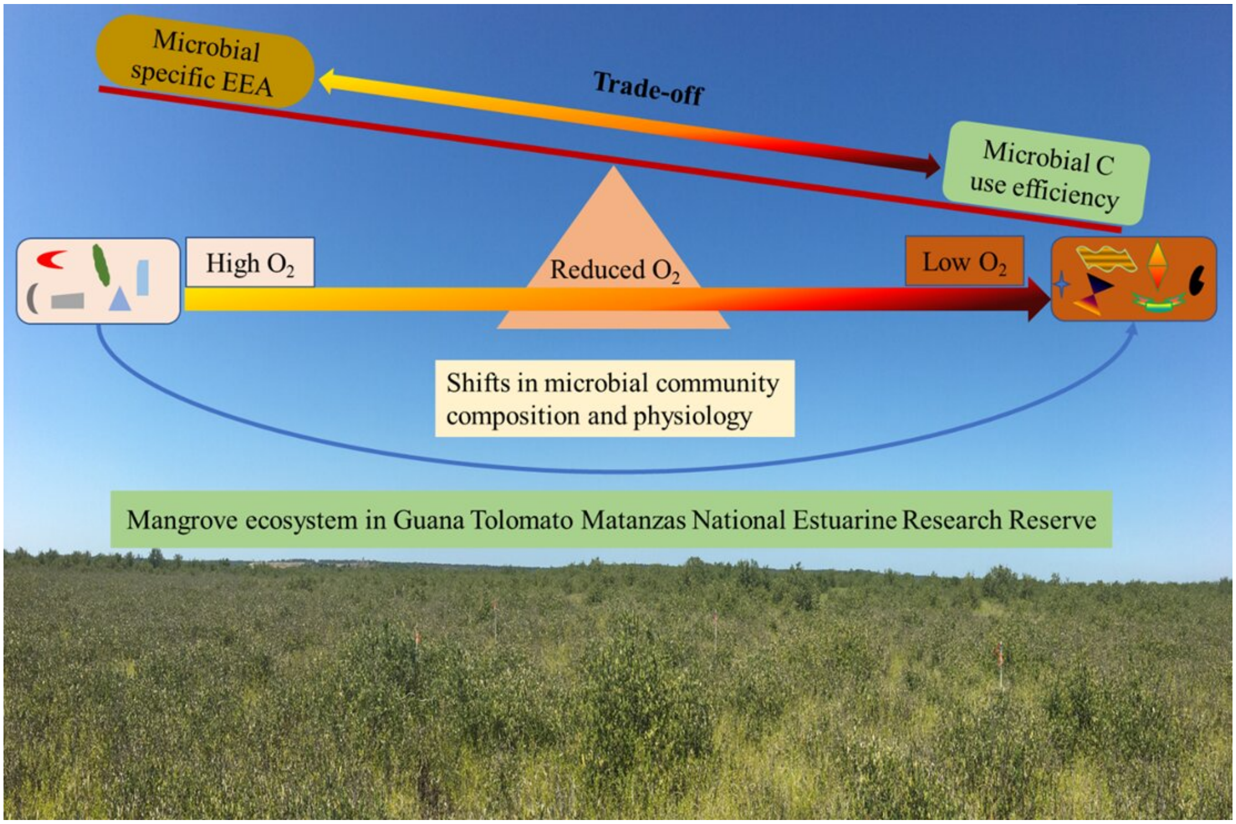

Trade-off between microbial carbon use efficiency and specific nutrient-acquiring extracellular enzyme activities under reduced oxygen. Credit: Higher Education Press Limited Company

Mangroves have been recognized globally as one of the most carbon (C) rich ecosystems although they only occupy about 0.1% of the Earth's land surface. Mangroves are regarded as an important C sink due to their waterlogged conditions, high sedimentation rates, high primary productivity, unique root structures, and anoxic soils resulting in low C decomposition rates. In recent decades, nitrogen (N) and phosphorus (P) loadings to mangroves have substantially increased due to intensified human activities and coastal development, but the effects on soil C, N and P cycling are unclear.

Moreover, mangrove areas that are currently exposed at low tide will be underwater for longer periods in progressive tidal cycles due to rising sea level, which will have cascading effects on soil C, N and P cycling due to oscillating aerobic and anaerobic conditions. However, the patterns and drivers of soil C cycling under N and P additions and reduced oxygen availability in mangroves are not fully understood, which limits our ability to manage mangroves as soil C sinks.

In this study, Dr. Ji Chen revealed a novel trade-off relationship between microbial carbon use efficiency (CUE) and specific nutrient-acquiring extracellular enzyme activities under reduced oxygen, regardless of the N and P levels. The researchers' findings appeared on December 29, 2022 in *Soil Ecology Letters*.

A series of studies on the essential roles of soil microorganisms and extracellular enzymes in modulating soil C, N and P cycling have been conducted in Dr. Ji Chen's lab at Department of Agroecology, Aarhus University. For example, Dr. Chen provides the first evidence that N-induced stimulation of hydrolytic C-degrading enzyme activity enhances soil respiration, whereas N-induced suppression of oxidative C-degrading enzyme activity increases soil organic C stock.

Dr. Chen finds that long-term experimental warming promotes the shift from hydrolytic to oxidative C-degrading enzyme activity, which indicates that long-term warming may facilitate soil organic C loss.

However, the relationships between microbial CUE and microbial specific nutrient-acquisition enzyme activity remain unclear.

Soil microorganisms and extracellular enzymes play essential roles in modulating soil C, N and P cycling, and preferentially invest resources for enzyme production to acquire resources that are limiting growth. For example, soil microorganisms will primarily allocate C and N for phosphatase production when P limits growth.

However, enzyme production for nutrient acquisition is energetically and C costly, which can couple or decouple microbial C, N and P cycling under different conditions. The microbial metabolic quotient (qCO_2), the ratio of microbial respiration to microbial biomass, is reported to evaluate microbial CUE. If soil microorganisms invest more C and energy for nutrient acquisition, this will result in higher qCO_2 and lower microbial CUE.

It has been hypothesized that soil microorganisms would likely decrease CUE to maintain metabolic activity when adapting to unfavorable conditions. However, it remains unclear whether soil microorganisms will shift their CUE to cope with both N and P loadings and reduced oxygen. Meanwhile, external N and P loadings have substantially altered microbial C, N and P cycling by altering nutrient stoichiometry, and are anticipated to have impacts on microbial CUE and enzyme production.

For example, N loading increased microbial phosphatase production in many ecosystems, and was expected to decrease CUE. In addition, both microbial CUE and enzyme production are highly sensitive to many biotic and abiotic factors, such as soil pH, nutrient availability, soil moisture, and microbial biomass. However, the separate and interactive effects of N and P loadings and reduced oxygen on microbial CUE and enzyme production are unclear, impeding predictions of mangroves' ecological functions under changing climate scenarios.

This study advances on our previous work (Craig et al., 2021) by demonstrating the trade-off between microbial CUE and specific EEAs under reduced oxygen, suggesting a higher energy cost per unit enzyme production. This relationship can substantially advance the understanding of microbially mediated C and nutrient cycling.

For example, by considering the relationship between microbial CUE and enzyme production, researchers have significantly improved model projections of soil C dynamics. However, this trade-off has not been resolved in experimental or model frameworks to predict soil resource acquisition and nutrient cycling in anaerobic ecosystems.

In addition, shifts in microbial community composition may play essential roles in microbial enzyme production under reduced oxygen, underscoring the need for more advanced research on microbial community composition. Given the large areas of global anaerobic ecosystems and their huge amount of C stocks, more research on the relationships between microbial CUE and specific EEA and the underlying mechanisms are needed.

There are several limitations and uncertainties that need to be further addressed. First, only a few related studies have concurrently investigated MBC, microbial respiration and EEAs under reduced oxygen in mangroves, limiting the comparison of our results to other studies from mangroves.

It is possible that our results may differ with studies from other different ecosystems. For example, N loading significantly increased soil pH and decreased soil phosphatase activity due to the unique soil redox conditions in the studied mangrove ecosystem, which contrasts with studies from many other ecosystems. These inconsistent results highlight the value of our study for advancing the understanding of an understudied ecosystem.

Second, the laboratory incubation used in the present study did not fully represent in situ microbial respiration due to soil disturbance, short-term incubation, and lack of plant-derived C inputs. Thus, future research may consider incubating intact soil cores for a longer duration.

Third, there are several different kinds of C-, N- and P-acquiring enzymes, whereas only BG, NAG and AP were considered in enzyme vector analysis. One reason for this selection was to follow the classical enzyme studies and vector analysis, so that our results are comparable.

Moreover, different kinds of enzymes with shared ecological functions or within the same group usually respond similarly to experimental treatments, which may reduce the uncertainties when calculating the enzyme vectors. Fourth, microbial CUE is the ratio of C allocated to growth and C taken up by microorganisms, but it varies with scale and methods of calculation, such as our use of qCO_2, so that caution is required when comparing studies.

In addition, shifts in soil microbial community composition are thought to explain the trade-off between microbial CUE and specific EEAs, but direct evidence linking changes in specific microbial communities and to microbial respiration is lacking. To further explore the links between microbial community composition, CUE and EEAs, integration of state-of-the-art microbial functional gene abundance and advanced statistical analysis are needed.

More information: Ji Chen et al, Trade-off between microbial carbon use efficiency and specific nutrient-acquiring extracellular enzyme activities under reduced oxygen, *Soil Ecology Letters* (2022). DOI: 10.1007/s42832-022-0157-z

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