Incorporating Microbial Ecophysiology Into New Microbial-based Soil Organic Matter Frameworks

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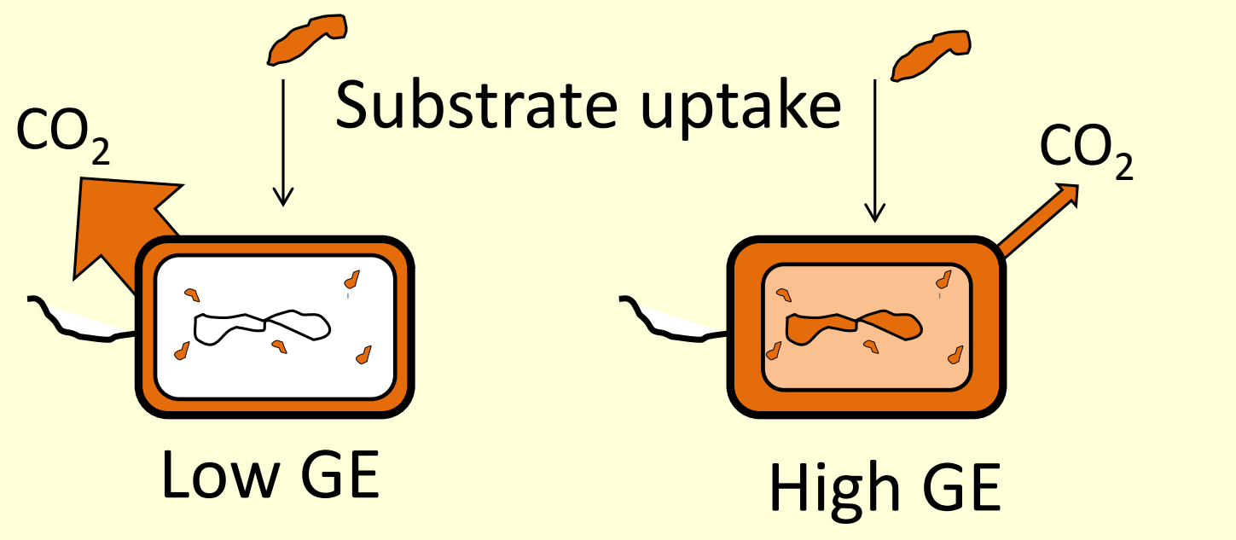
Background

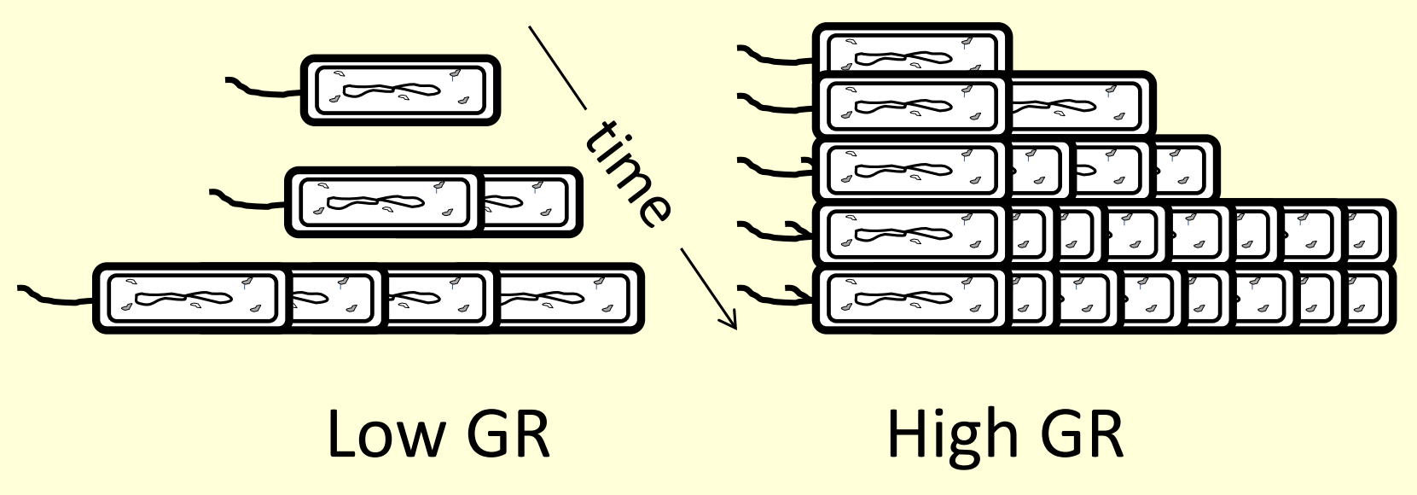
In recent decades there has been an overwhelming amount of evidence that stable soil organic matter (SOM) is largely composed of microbial necromass and microbial byproducts stabilized through a variety of organo-mineral interactions. This is in contrast to our previous models of stable SOM, which suggest that this pool is dominated by biochemically recalcitrant (e.g. lignin) plant compounds. Despite an increased focus on microbial-based models of stable SOM, the specific factors which influence microbial inputs, both in terms of quantity and chemistry (i.e. the potential to form organo-mineral associations) have largely been ignored. We anticipate that microbial ecophysiology will have a direct influence on both accumulation and stability of SOM. Specifically, we explore the relationships between growth rates, efficiency, cell size and chemistry as key regulators of microbial necromass accumulation and stability. Many of these traits have long been explored by microbiologists in simple homogenous environments, yet, their expression across variable soil environments and how they relate to stable SOM remains unclear.

Microbial physiological traits hypothesized to impact necromass accumulation and stability

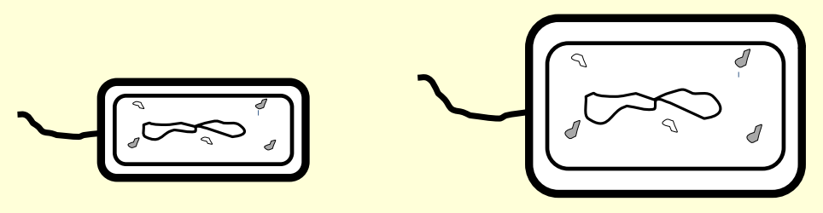
- **Microbial growth efficiency** (MGE): amount of biomass generated per unit of substrate consumed



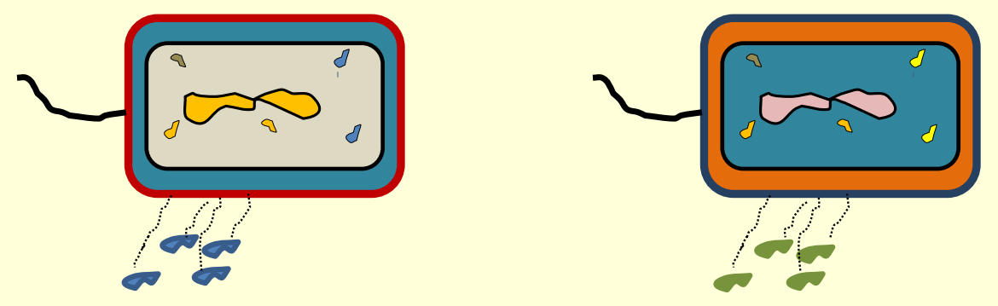
- **Microbial growth rate** (MGR): number of cells generated per unit of time



- **Cell size**: mass or volume of biomass per individual

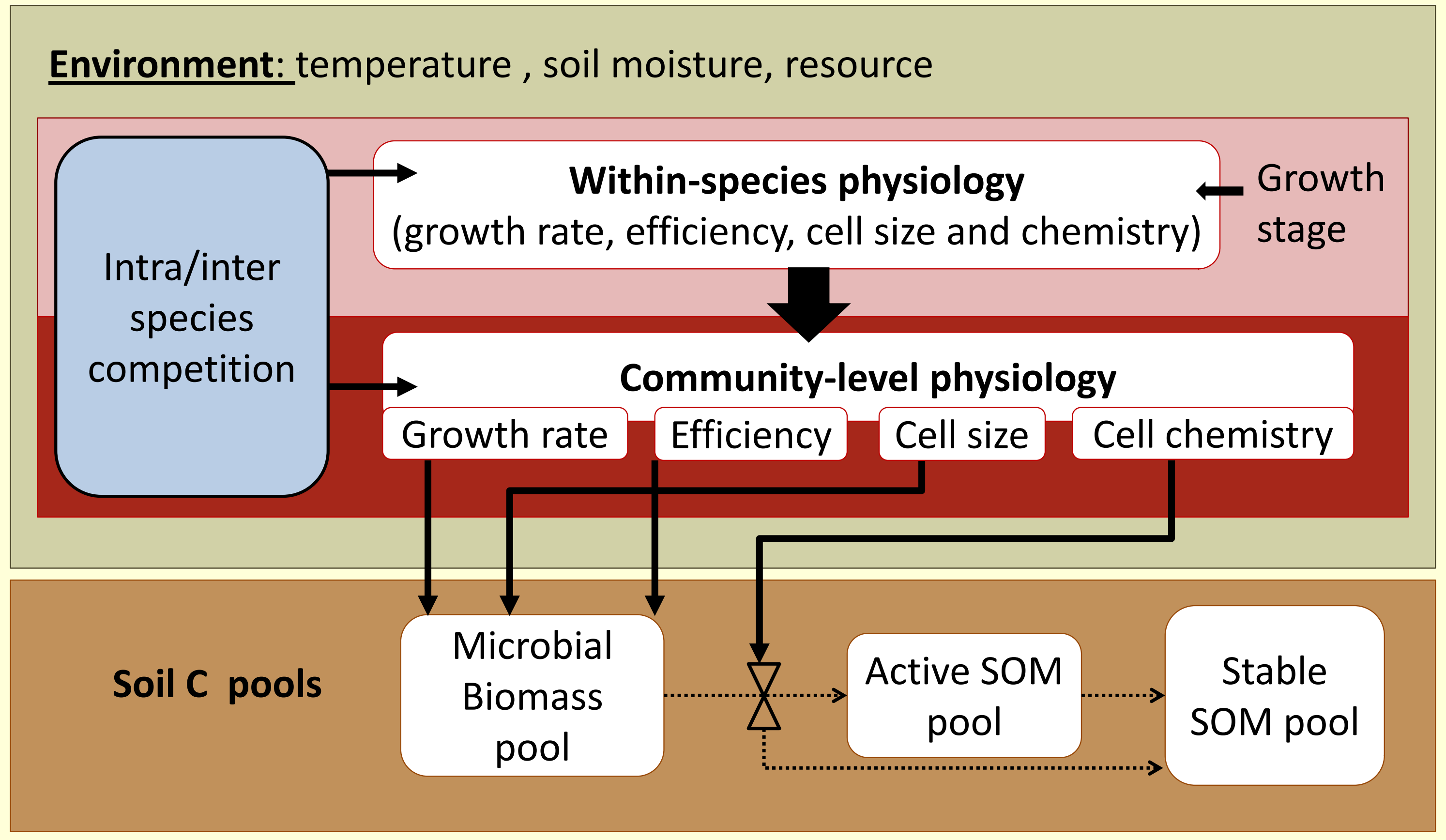


- **Chemistry**: chemistry of cell walls, proteins, metabolites, and extracellular excretions



Relevant eco-physiological questions to understanding stable SOM

1. What is the relative importance of each of these traits in determining necromass accumulation?
2. Are there physiological tradeoffs associated with MGR,MGE, and cell size?
3. What environmental conditions (substrate supply) are likely to optimize necromass production?
4. Do microbial products and their chemistries (cell wall material vs. secondary metabolites and excretions) vary in their capacities to form organo-mineral interactions?
5. How does microbial species diversity and abundance influence community-level expression of these traits and ultimately necromass production and microbial SOM chemistry?



Environment: temperature , soil moisture, resource

Intra/inter species competition

Within-species physiology
(growth rate, efficiency, cell size and chemistry)

Growth stage

Community-level physiology

Growth rate | Efficiency | Cell size | Cell chemistry

Soil C pools

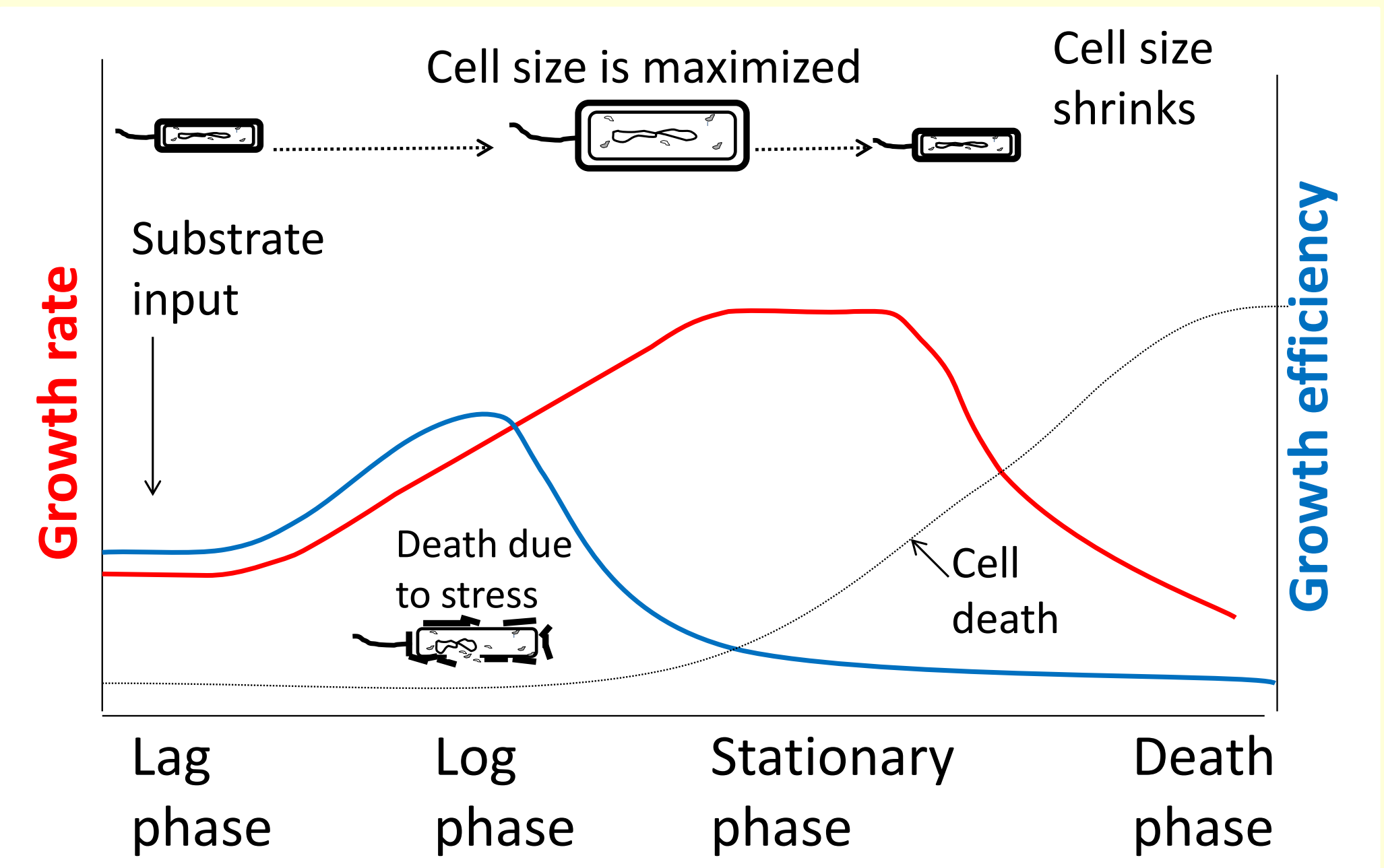
Microbial Biomass pool

Active SOM pool

Stable SOM pool

Figure 1. At the **species-level:** Microbial growth rate (MGR), efficiency (MGE), cell size and chemistry differ with the environment, competitive interactions and across growth stages, where each species will have a unique optimum GR and GE. The **community-level** expression of these traits is influenced by the relative abundances of species, their interactions with each other and the environment. MGR, MGE and cell size have a direct impact on the amount of microbial biomass generated that could contribute to SOM, while cellular chemistry influences how much of that biomass might be stabilized.

Growth stages and shifts in physiology



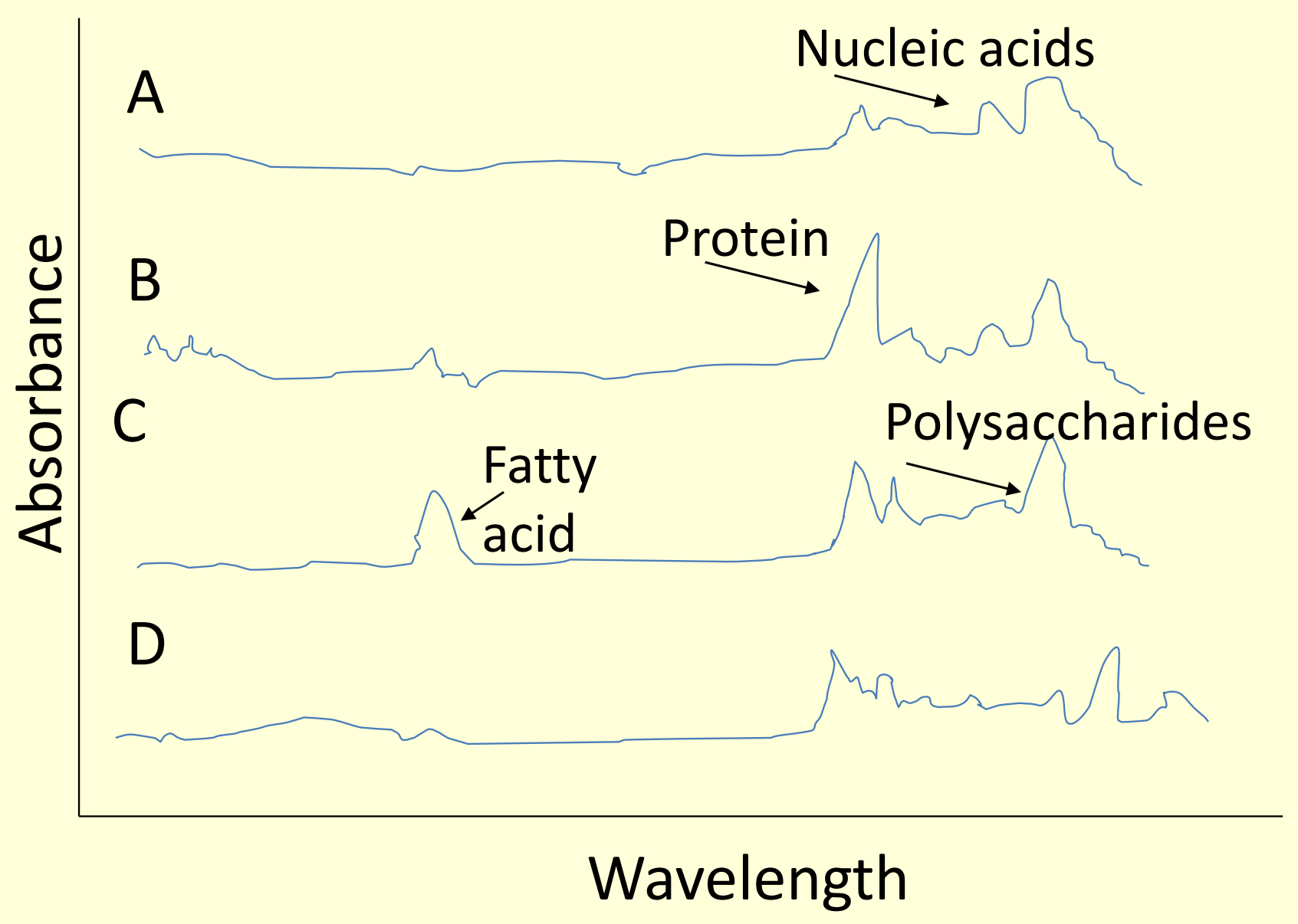
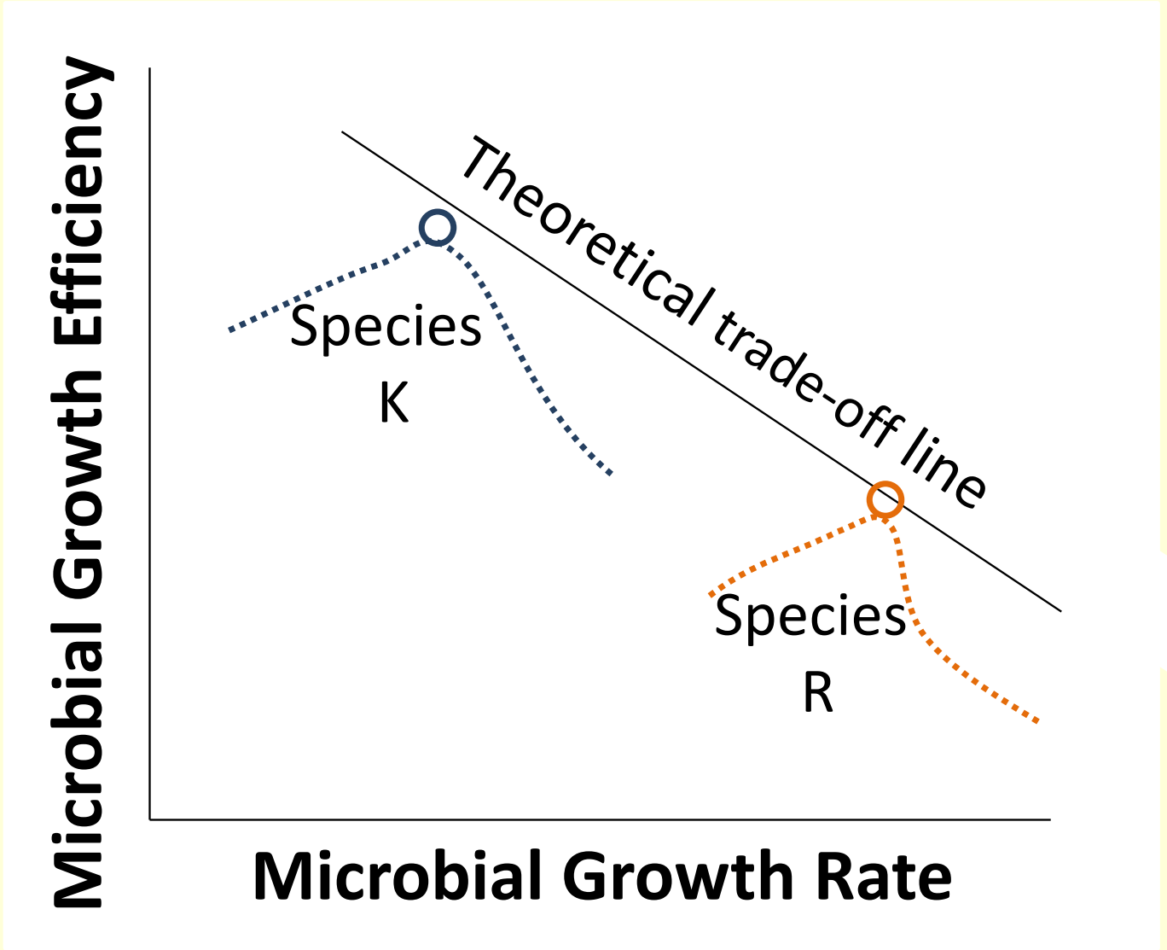


Figure 2. Cell production rate (GR) and cell size is maximized during the log (exponential) and stationary growth phases such that generation of cell biomass might be highest during these periods. However, accumulation of necromass only occurs following cell death, after cell size has diminished. Cell death can also occur during the log phase due to rupture of cells from environmental stress (i.e. freeze/thaw).

Figure 3. E. *coli* cellular chemistry across growth phases. Lag phase; A, log phase, B; stationary phase, C; death phase, D. (adapted from Al-Qadiri, 2008). Increase in sporulation and secondary metabolites increases during stationary and death phase, while polysaccharide and protein content are maximized during the log and stationary phase. It remains unclear how differences in the chemistry and abundances of these compounds influences organo-mineral stabilization mechanisms.

Variation in physiology across species

Field and laboratory evidence has shown fast growing *R*-strategists and slow growing *K*-strategists have different optimum growth rates, efficiencies and cell size.



***K*-Strategist**

Low growth rates
High growth efficiency
Large cell size
Longer period of dormancy

***R*-Strategist**

High growth rates
Low growth efficiency
Smaller cell size

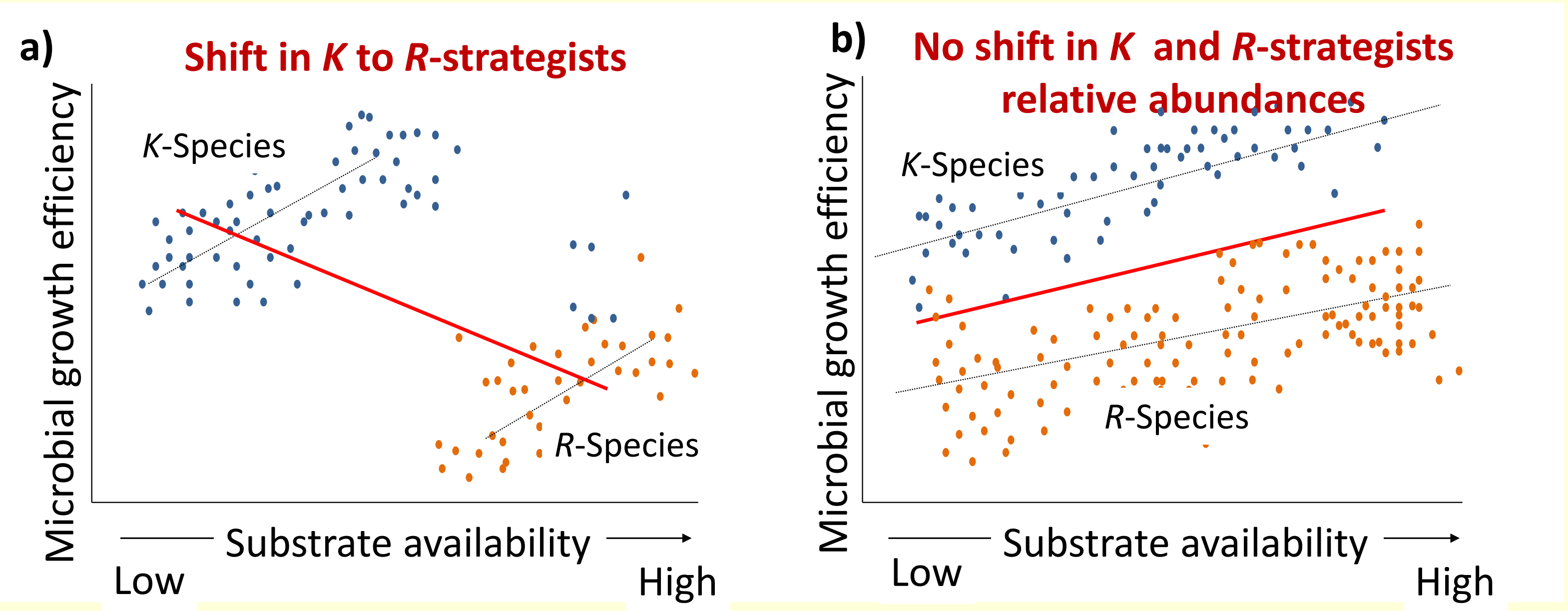


Figure 4. Proposed trade-off between microbial growth rate (MGR) and growth efficiency (MGE) for *R* and *K*-strategist organisms (adapted from Novak et al., 2006). Solid line represents theoretical trade-off where MGE declines linearly with MGR. However, microbes are more likely to exhibit a convex relationship with an initial increase in MGE with MGR until a point of trade-off (circle symbols) is reached. This point of trade-off is likely to vary with a specie's life-history traits.

Figure 5. Effect of species abundance on community-level microbial growth efficiency (MGE). Within species optimum MGE (dotted black line) increases with an increase in substrate availability (a). However, as substrate availability increases, species with a lower optimum MGE may dominate, driving the community level MGE (solid red line) downward. Alternatively, if no shift in the relative abundance of species occurs (b), community-level MGE should increase with an increase in substrate availability .

Potential shifts in physiology and necromass accumulation across environmental gradients

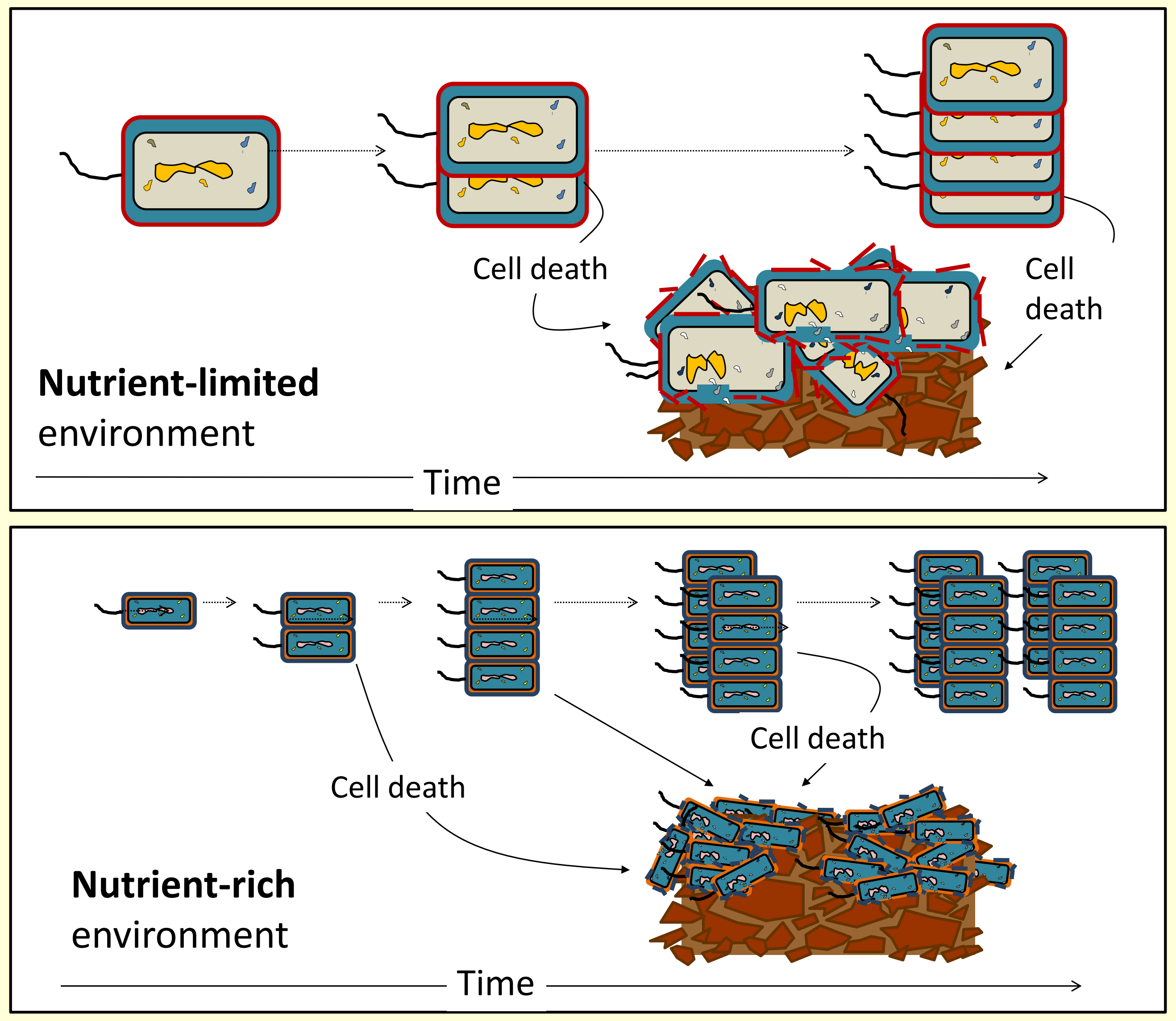


Figure 6. Potential variation in biomass accumulation in soil. Nutrient-limited environments are likely to select for microbes with larger cell size and higher growth efficiencies but lower rates of cell generation relative to nutrient-rich environments. Such physiological variations may influence how much biomass is ultimately accumulated at the mineral interface.

References: Al-Qadiri et al., 2008. J. Rapid Methods & Automation Micro. ;Novak et al., 2006. The Americ. Nat. ;Frey, et al., In review. Nature: Clim. Ch.

Acknowledgements: This work was funded by the Great Lakes Bioenergy Research Center and the University of New Hampshire Agricultural Experimental Station.

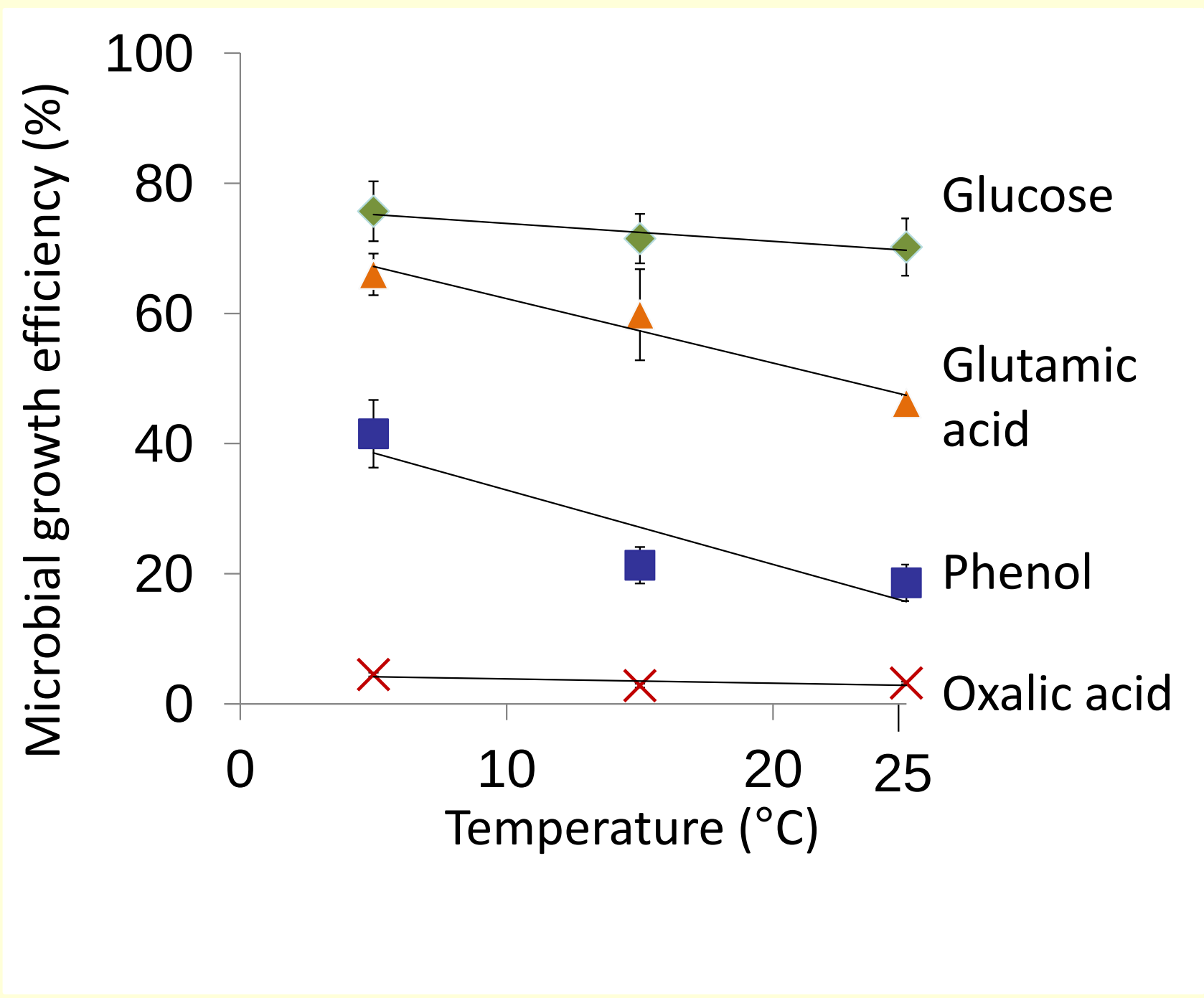


Figure 7. Soil samples from Harvard Forest show higher growth efficiencies with higher substrate quality, with a significant decrease in growth efficiency with temperature (Frey et al., in review). Substrate quality goes from high (glucose) to low (oxalic acid).

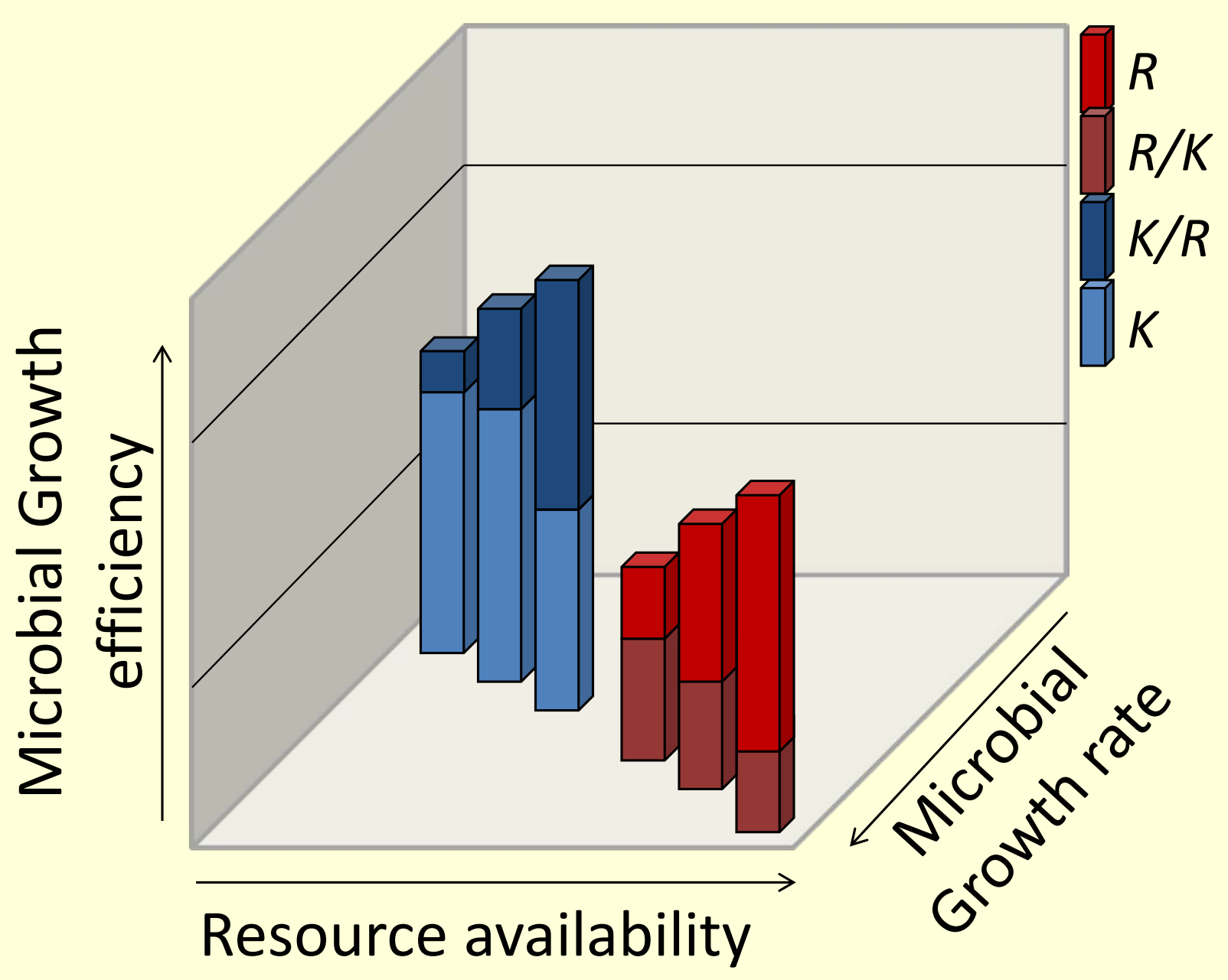


Figure 8. Change in microbial growth rates (MGR) and efficiency (MGE) with shifts in resource availability and community composition. MGE declines with increases MGR as the community becomes dominated by fast growing *R*-strategists, relative to slower growing *K*-strategists.

Conclusions

Stable soil organic matter (SOM) is largely comprised of microbial necromass and microbial byproducts. In order to understand the factors regulating the size and stability of SOM we must begin to consider microbial characteristics that influence microbial input rates and cellular chemistry to soil. We propose that microbially-based SOM models and the development of mechanistic research questions include microbial ecophysiology as a significant regulator of SOM accumulation rates and stabilization. We argue that the accumulation and stability of microbial inputs to SOM are a function of: microbial growth rate, growth efficiency, cell size, and chemistry. These factors vary within a specie's growth stage, between species and across environments. Thus, the optimization of biomass inputs is a function of complex interactions between resource availability, microbial community activity and composition.