Soil nutrient competition: observations, theories, and implementation in earth system land model

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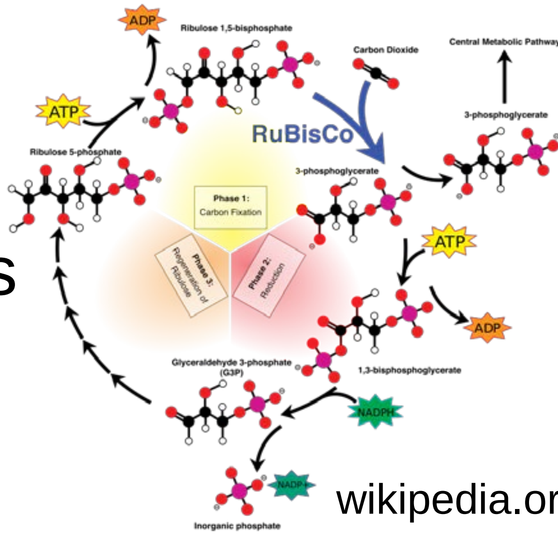
Overview

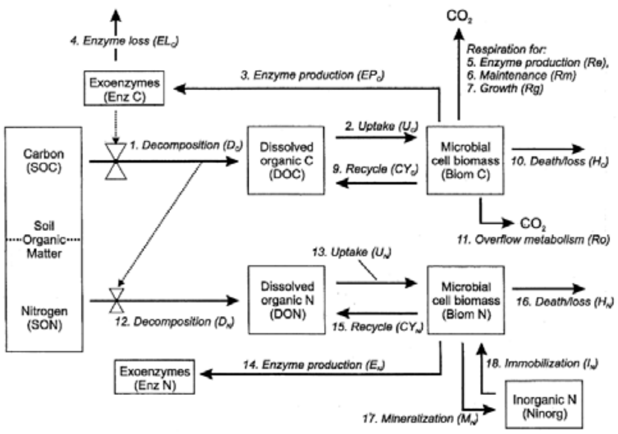
- Background
  - Why does competition occur?
- ^{15}N competition observations
  - What can we learn?
- Existing competition theories
- New competition theory
- Competition models vs. data
  - Tropical forests, alpine grassland, arctic tundra

Why does competition occur?

- N affect ecosystem C cycle
  - nitrogen-rich RuBisCO enzymes
  - nitrogen-rich extracellular enzymes
- P affect ecosystem C cycle
  - phosphorus-rich ATP
- Temperate and boreal
  - nitrogen limited
- Tropical forests
  - phosphorus limited

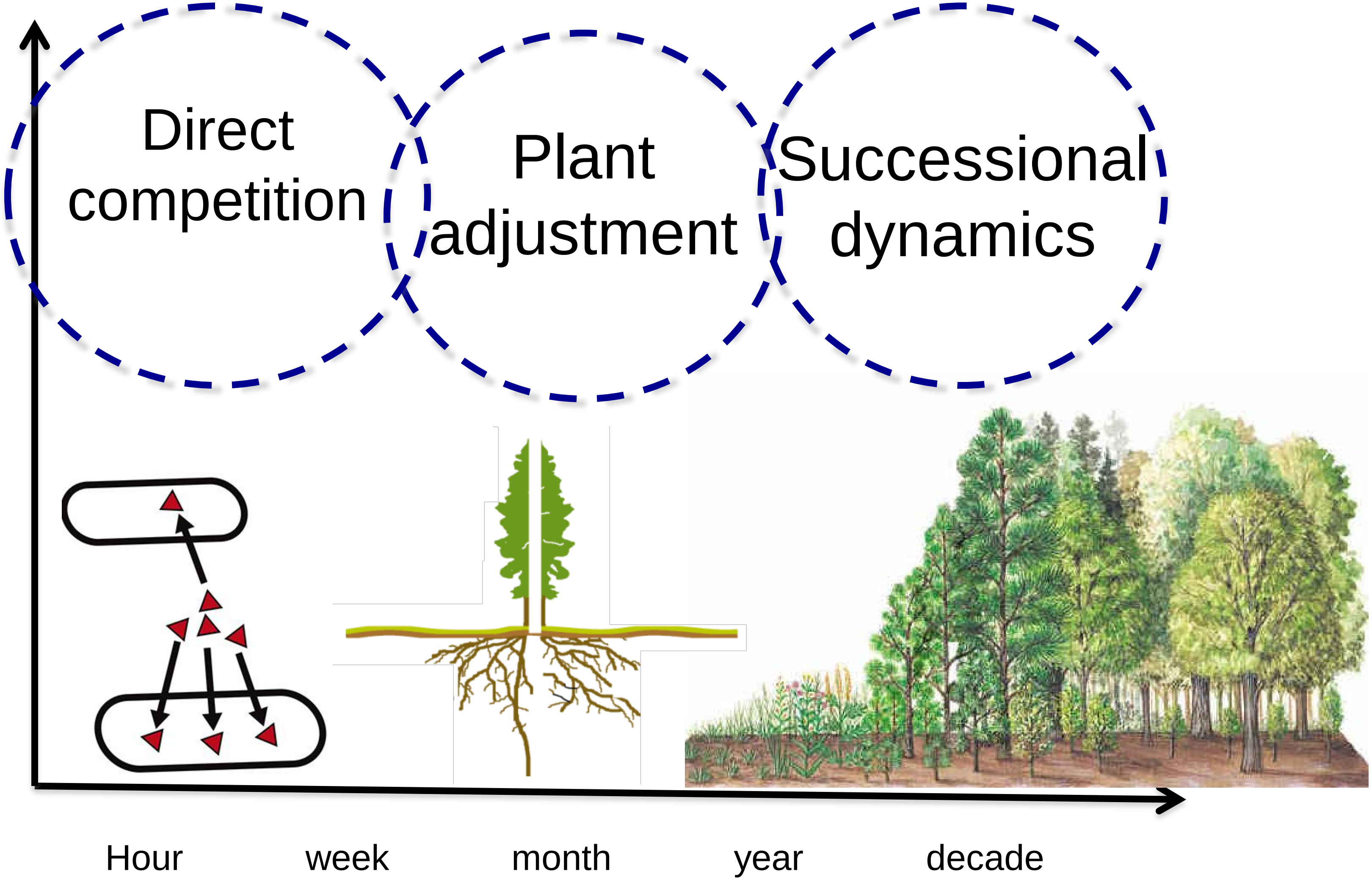


wikipedia.org

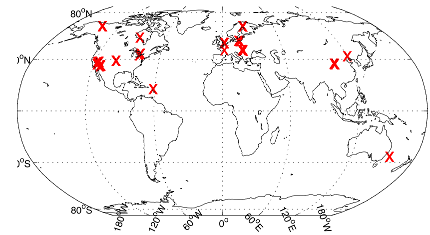


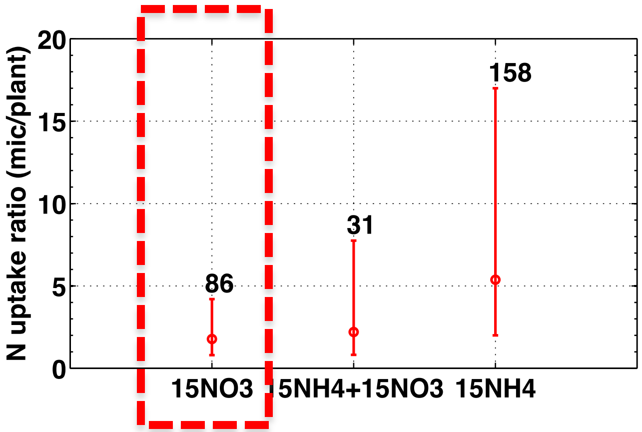
schimel and weintraub 2003

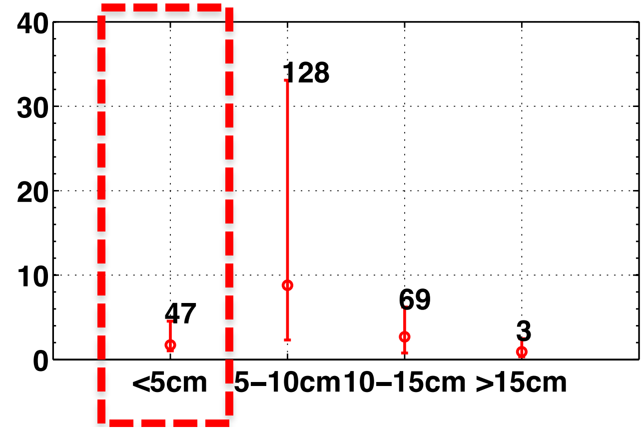
Competition hierarchy

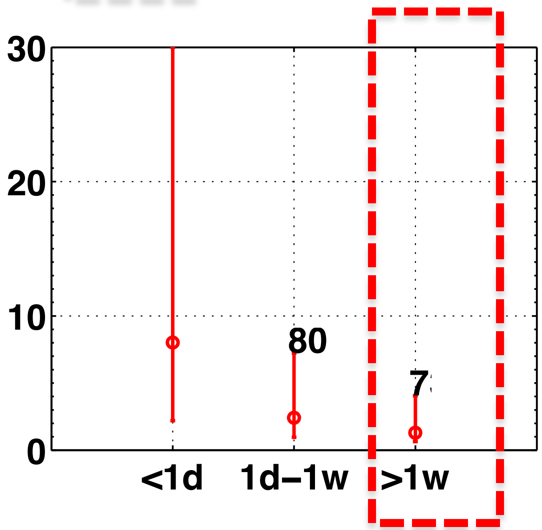


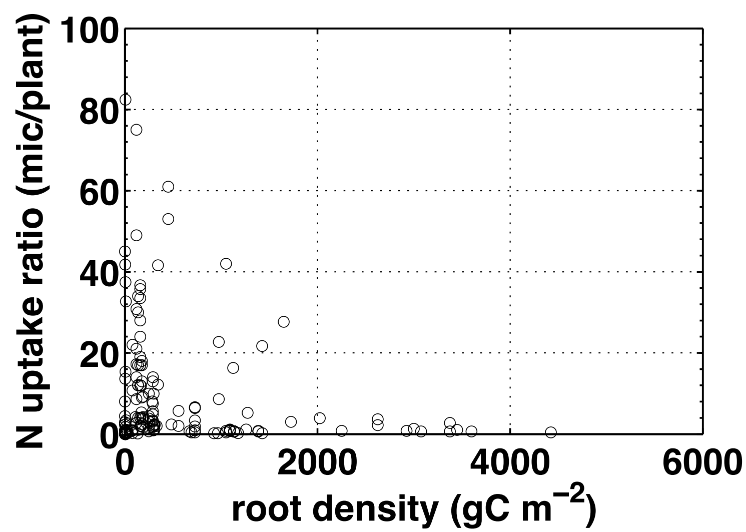
^{15}N competition observations











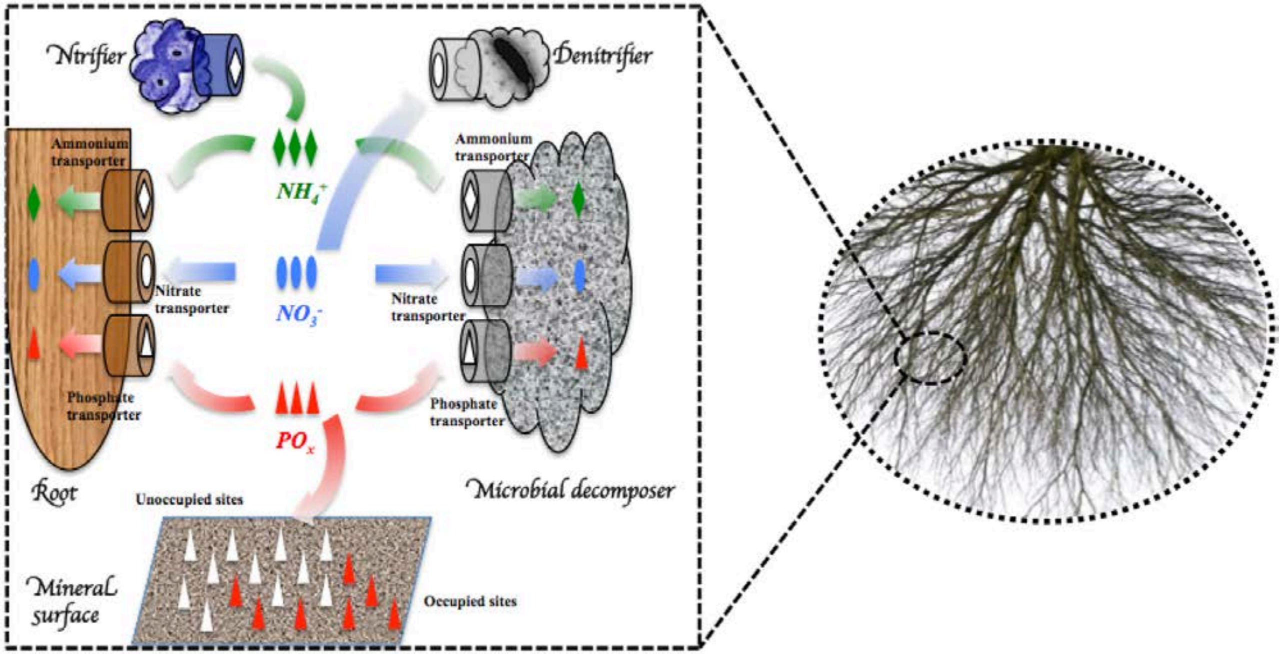
Prevailing competition theories

Competition Theory	Rationale	Implementation
CT1. No competition	(1) Plants are nutrient limited; microbial decomposers are carbon limited. (2) Plants rely on inorganic nitrogen; microbial decomposers rely on organic nitrogen.	-
CT2. Microbial decomposers outcompete plants	(1) Microbial decomposers are ubiquitous. (2) Microbial decomposers release inorganic nitrogen as "waste product" during soil organic matter decomposition.	(1) Separately simulate plant and microbial decomposer nutrient uptake. (2) If soil inorganic nutrient is limited, immobilization is satisfied prior to plant uptake.
CT3. Competition depends on pore-scale soil fertility heterogeneity	(1) Plants do not completely lose the competition. (2) Existence of plants exacerbates microbial nutrient limitation and suppress microbial immobilization at both microsite and whole-soil scales.	Explicit modeling of microsite scale soil fertility heterogeneity, nutrient diffusion, root-microbe interactions (~ mm spatial scale).
CT4. Plant-microbe Relative Demand controls competition	(1) Plant nutrient demand is a proxy of nutrient uptake capacity. (2) Expedient approach to implement competition in large-scale models. (3) No need to introduce parameters describing nutrient uptake and competition.	(1) Separately simulate plant and microbial decomposer nutrient uptake. (2) If soil inorganic nutrient is limited, both fluxes are down regulated proportional to demand.

Competition hypotheses in ESMs

ESMs	Land component	Plant N uptake	Soil N immobilization	Competition
BNU-ESM	CoLM + BNU-DGVM	$N_{demand} \cdot N_{stress}$	No gross mineralization and immobilization, net mineralization is directly calculated	Microbial decomposers outcompete plants
CESM	CLM4.5-BGC/CLM4-CN/CLM4-CNP	$N_{demand} \cdot N_{stress}$ or $N_{require} \cdot min\{N_{stress}, P_{stress}\}$	Carbon fluxes between soil organic matter pools scaled by their soil C:N ratios	Relative Demand
ISPL	ORCHIDEE (now O-CN)	$Vmax \cdot C_{root} \cdot [N_{av}] \cdot f_T \cdot f_{NC}$	Carbon fluxes between soil organic matter pools scaled by their soil C:N ratios	Microbial decomposers outcompete plants
GFDL	LM3 (now LM3-TAN)	$Vmax \cdot C_{root} \cdot \frac{[N_{av}]}{Km + [N_{av}]}$	Carbon fluxes between soil organic matter pools scaled by their soil C:N ratios	Microbial decomposers outcompete plants
HadGEM2	JULES (now JULES+ECOSSE)	$N_{demand} \cdot f_T$	Carbon fluxes between soil organic matter pools scaled by their soil C:N ratios	Microbial decomposers outcompete plants
MPI-ESM	JSBACH (now JSBACH-CNP)	$N_{demand} \cdot min\{N_{stress}, P_{stress}\}$	Carbon fluxes between soil organic matter pools scaled by their soil C:N ratios	Relative Demand
NorESM	CLM-CN	$N_{demand} \cdot N_{stress}$	Carbon fluxes between soil organic matter pools scaled by their soil C:N ratios	Relative Demand

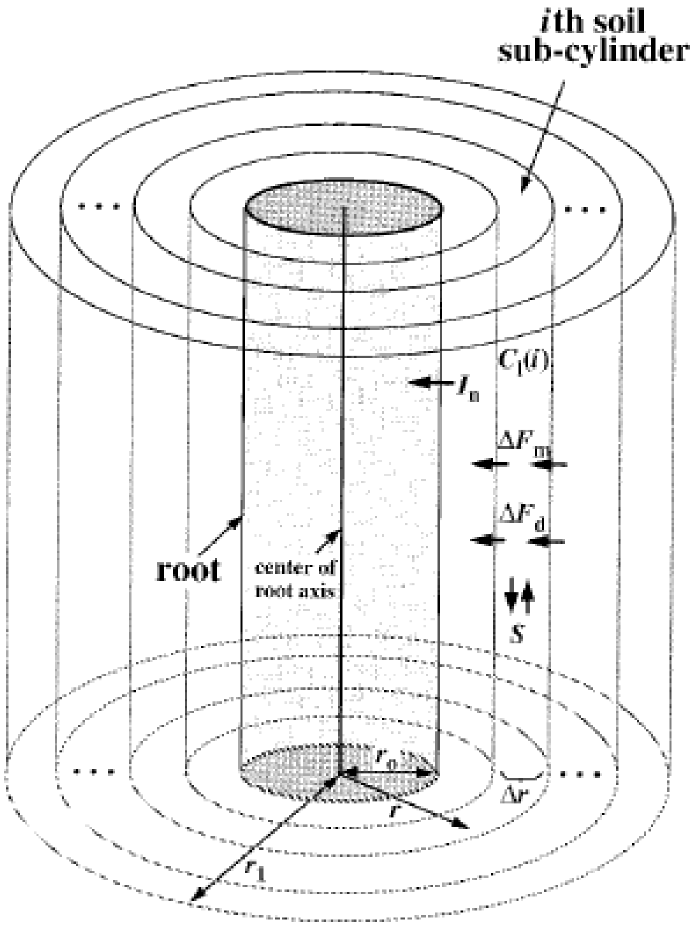
ECA Competition hypothesis: Enzyme-enzyme battle



$$S + E_{plant} \underset{k^{-}_{1,plant}}{\overset{k^{+}_{1,plant}}{\rightleftharpoons}} C_{plant} \xrightarrow{k_{2,plant}} P + E_{plant}$$

$$S + E_{mic} \underset{k^{-}_{1,mic}}{\overset{k^{+}_{1,mic}}{\rightleftharpoons}} C_{mic} \xrightarrow{k_{2,mic}} P + E_{mic}$$

Substrate diffusivity limitation

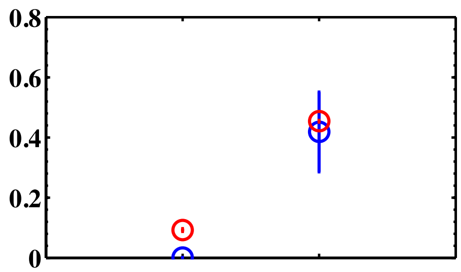


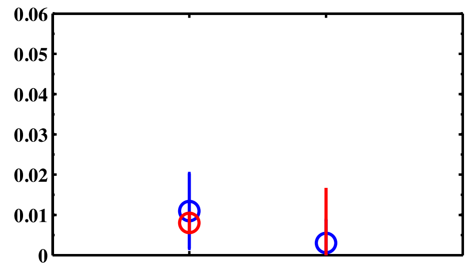
1. Explicit modeling of nutrient heterogeneity

2. Implicitly aggregated diffusivity limitation in kinetics parameter

(model $K_M \neq$ observed K_M)

Tropical forest sites





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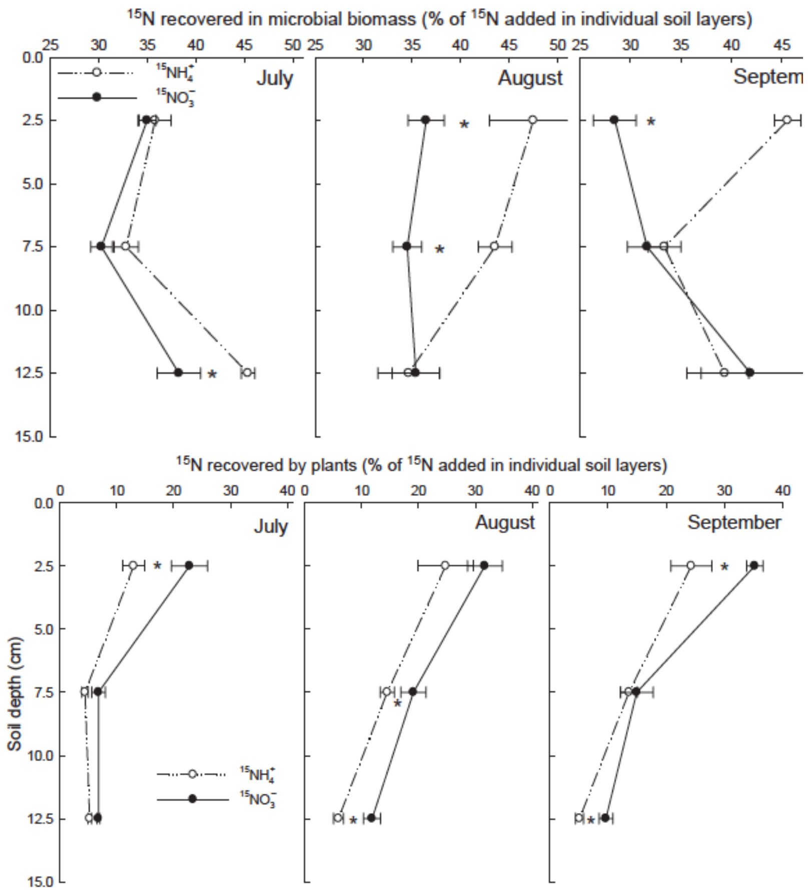
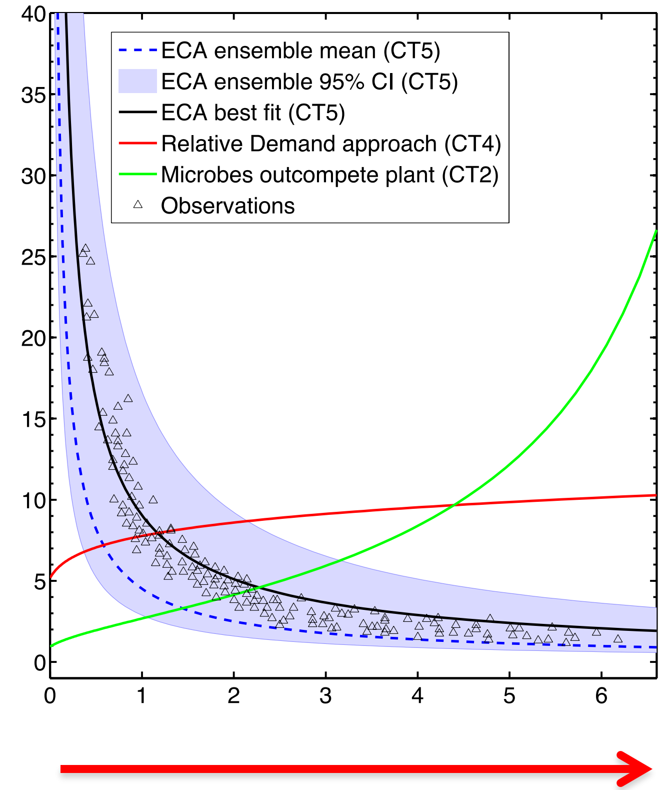
Datasets	Dose	Competitors			Duration	References
$^{32}PO_4^{3-}$ fertilization	10 μg g^{-1}	I. Mineral surface	II. Decomposing microbe		48h	[*Olander and Vitousek*, 2005]
$^{15}NH_4^+$ fertilization	4.6 μg g^{-1}	I. Plant	II. Decomposing microbe	III. Nitrifier	24h	[*Templer et al.*, 2008]
$^{15}NO_3^-$ fertilization	0.92 μg g^{-1}	I. Plant	II. Decomposing microbe		24h	[*Templer et al.*, 2008]

Alpine grassland site

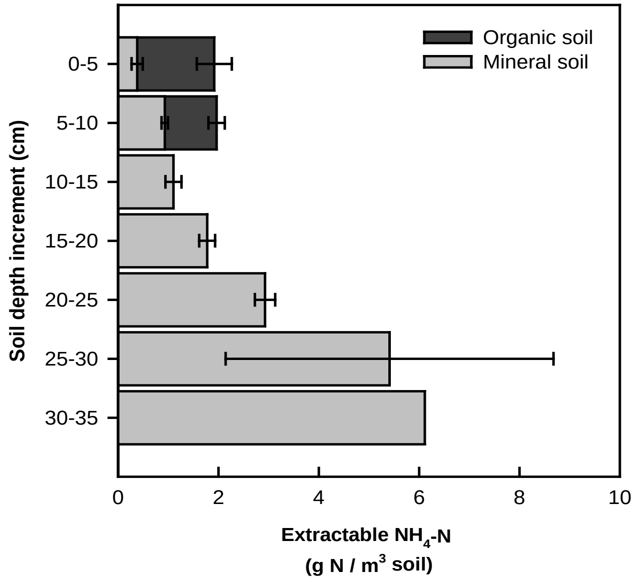


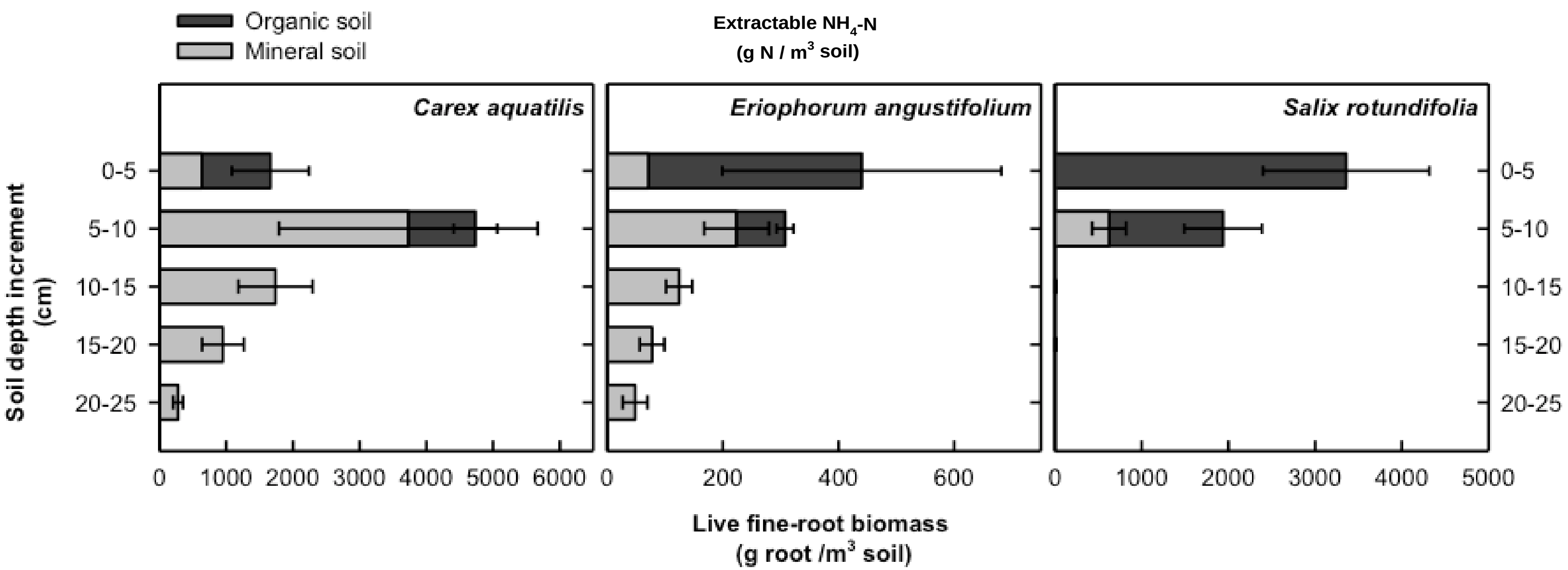


Deep soil Top soil

$^{15}N\text{-}NH_4^+/^{15}N\text{-}NO_3^-$ fertilization study (24~48 h)
Xu et al., 2011

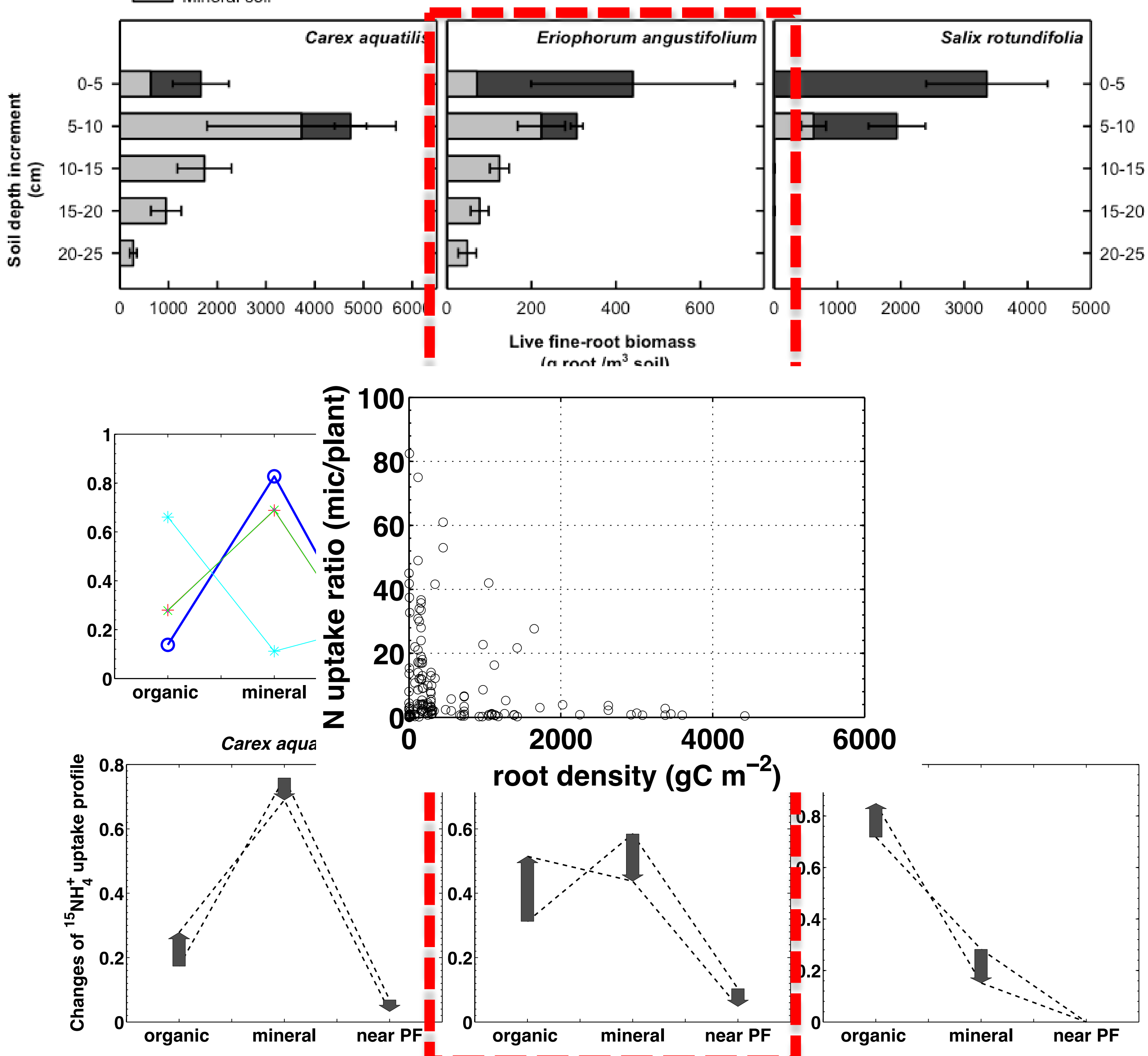
Arctic tundra sites: ^{15}N tracer data





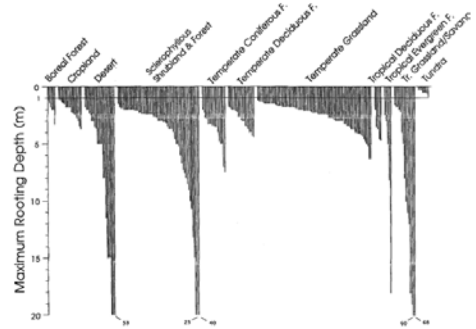
Competitive traits

- Carex: competitive species
  - High affinity nitrogen carrier enzyme (low KM) (McRoy 1975)
- Salix: competitive species
  - mycorrhizal fungi (Kroehler 1988)
- Eriophorum: uncompetitive species
  - low affinity nitrogen carrier enzyme (high KM) (Leadley 1997)
  - no mycorrhizal fungi (Lavoie 2005)

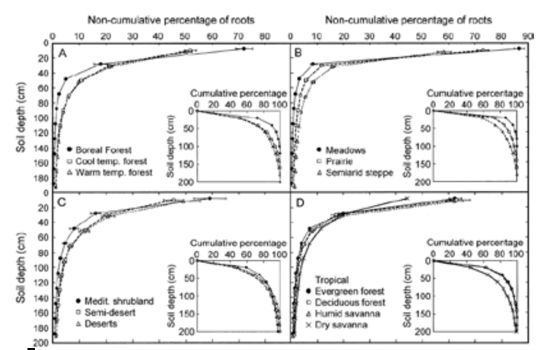

Carex aquatilis
Eriophorum angustifolium
Salix rotundifolia
Soil depth increment (cm)
0-5
5-10
10-15
15-20
20-25
Live fine-root biomass
N uptake ratio (mic/plant)
root density (gC m^{-2})
organic
mineral
near PF
Changes of $^{15}NH_4^+$ uptake profile

Root trait data

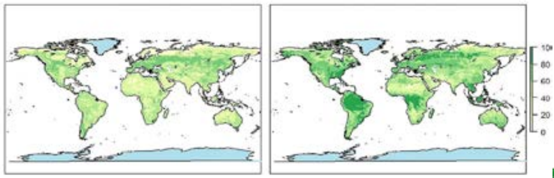
- Root nitrogen uptake kinetics parameter
- Root depth
  - – Canadell 1996 (global)
  - – Iversen 2015b (tundra)



- Root density profile
  - – Zeng 2001
  - – Schenk 2002



- Mycorrhizal fungi association
  - – Soudzilovskaia 2015



Conclusions

- There are multiple competition theories (MIC win, RD, micropore-to-micropore, no competition)
- Two of them are not applicable in ESM (micropore-to-micropore, no competition)
- Two of them are not successful in ESM (MIC win, RD)
- The new competition theory (ECA) is best one so far.

Thanks!

Questions?