Nitrogen transformations in effluent irrigated soils:
experiments and modeling

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Effluent will compose 50% of the water used by agriculture by the year 2020

Advantages

- Water reuse
- Economic value
- **Efficiency of fertilization**

Disadvantages

- Salinity
- Boron
- Pathogens
- Soil structural damage
- **Organic matter**
- **Pollution by P and N**
- **Influence on N transformations**
- **Microbial changes**

N Balance –National Effluent Irrigation Survey,

(Tarchitzky et al. 2004, Israel Ministry of Agricutlure)

N kg/ 1000 m^2 per 5years		
	Effluent	**Fresh water**
Total Input	235.5	122.5
N – in fruits	50-75	50-75
N-removed (other)	25	25
Use Eff (fruit)	23-33%	40-60%
Estimated Losses	20-40%	60-70%

Problems associated with N supply via Effluent Irrigation

1. Synchronizing N demand with fertigation (continuous N) and increased leaching requirements
2. High BOD
3. Ammoniacal nutrition
4. High pH and bicarbonates
5. Organic N

➔ Excess N supply

  ➔ Increased leaching losses of **NO_3^-**

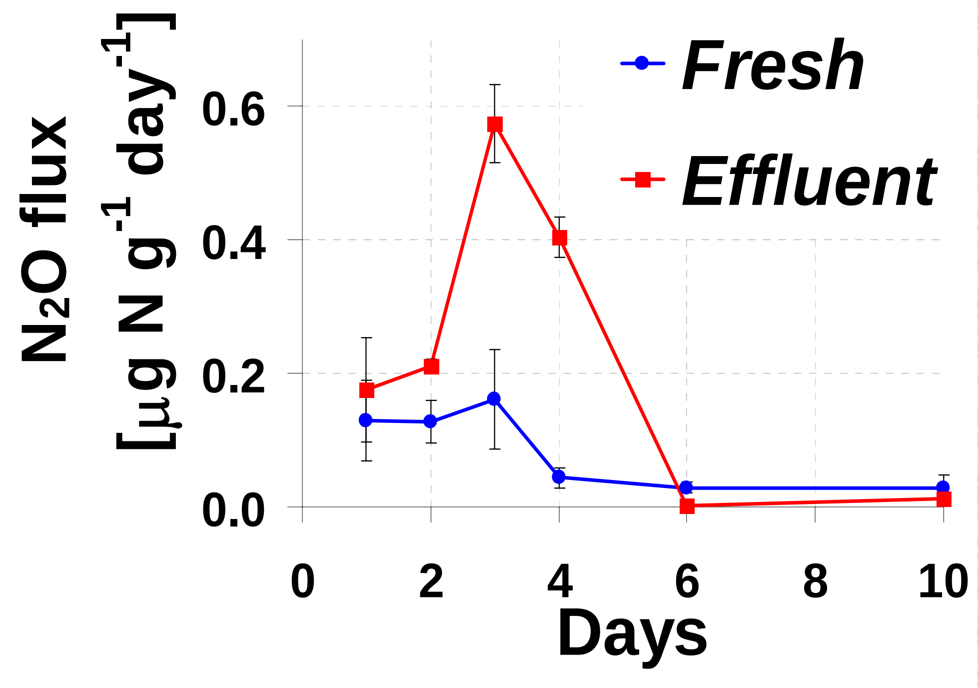
  ➔ Increased volatilization of **NH_3 , N_2O, N_2**

  ➔ Risk of **Nitrite** formation

Special case – Aggregated Soils

Laboratory experiments- N_2O fluxes

(Master et al. JEQ 2004)

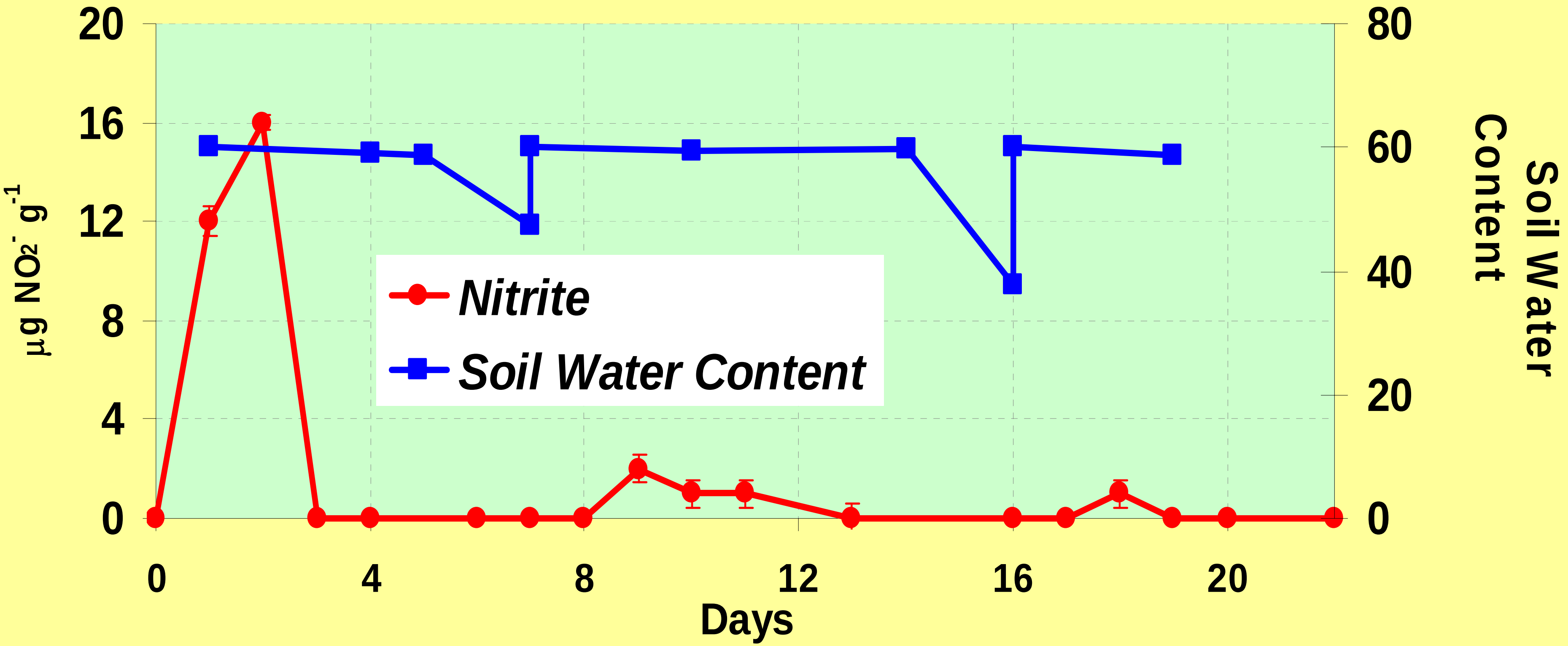


Effluent enhances the N_2O fluxes in the long-term

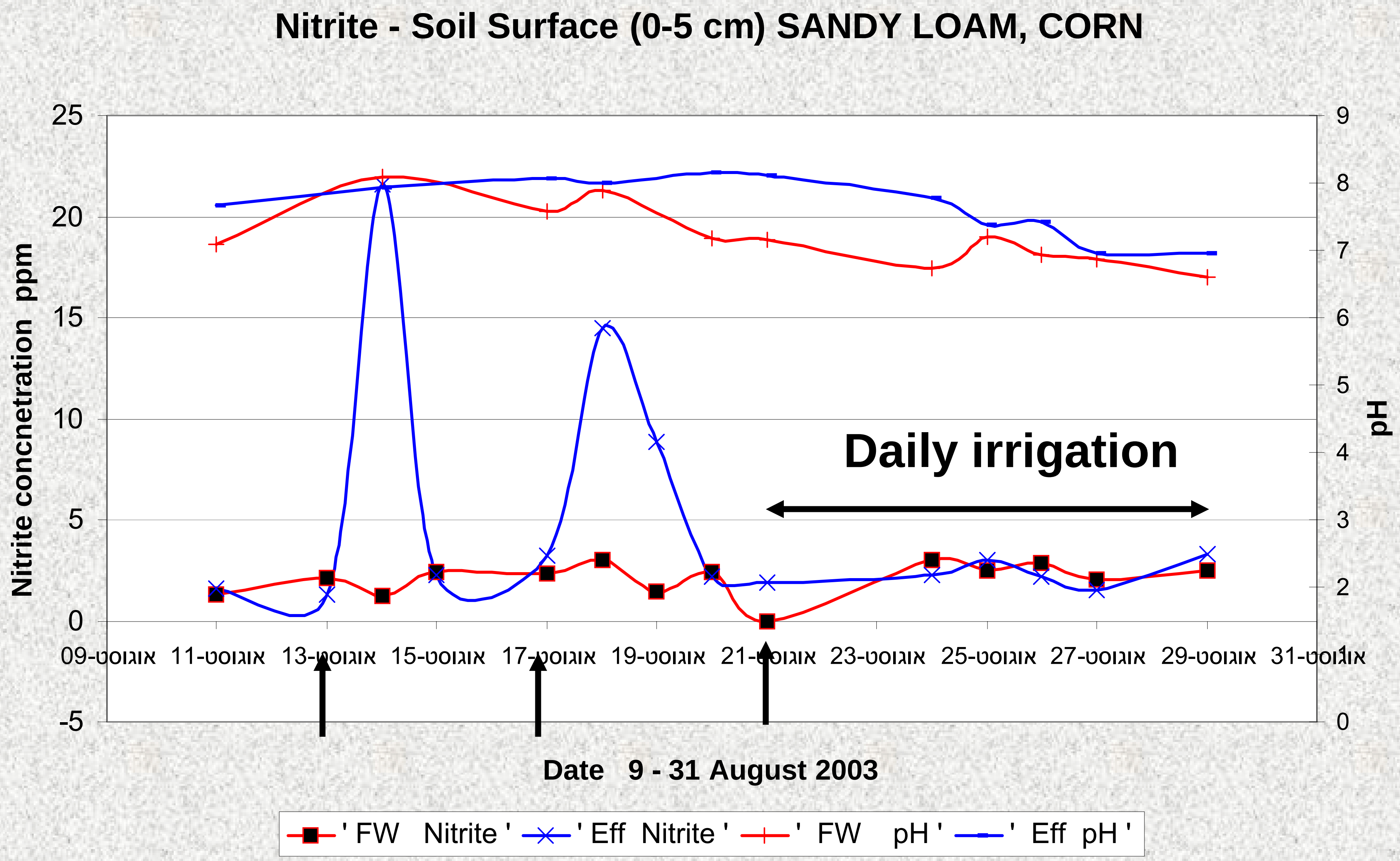
Saturated conditions result in high (3-4%) losses of N_2 and N_2O

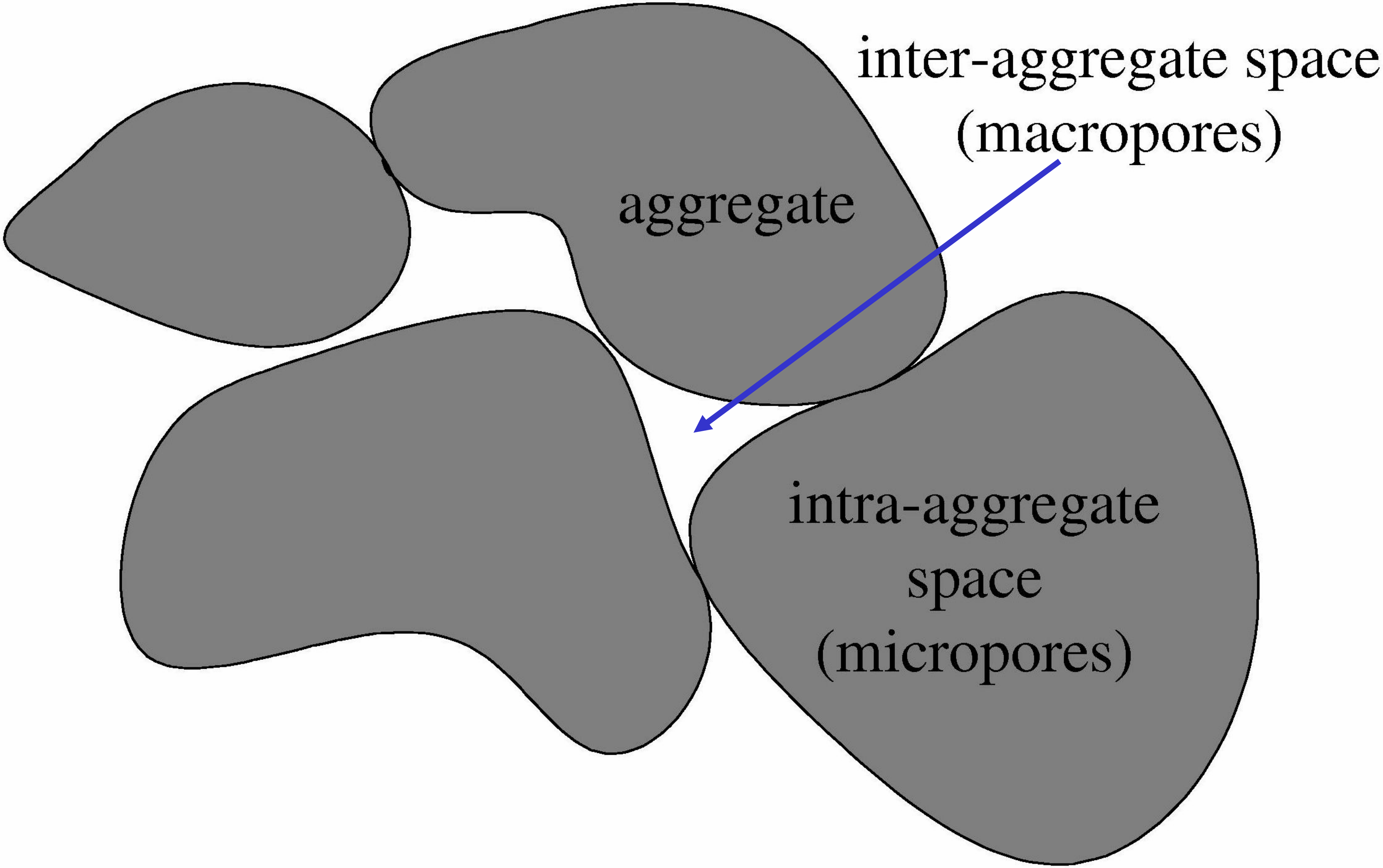
Saturated conditions result in higher ***denitrification*** *contribution to the N_2O flux*

NO$_2^-$ accumulation in grumosol (60 %w/w) at repetitive (weekly) NH$_4^+$



Effect of Irrigation Frequency on Nitrite Formation - Effluent vs. FW

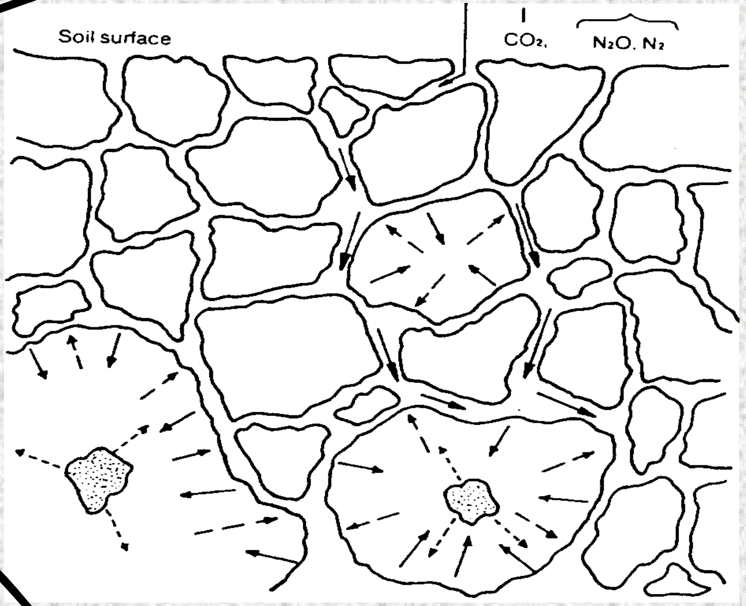



inter-aggregate space
(macropores)
aggregate
intra-aggregate
space
(micropores)

Denitrification, (non-aerobic, heterotophic)

$$NO_3^- \Rightarrow NO_2^- \Rightarrow NO \Rightarrow N_2O \Rightarrow N_2$$

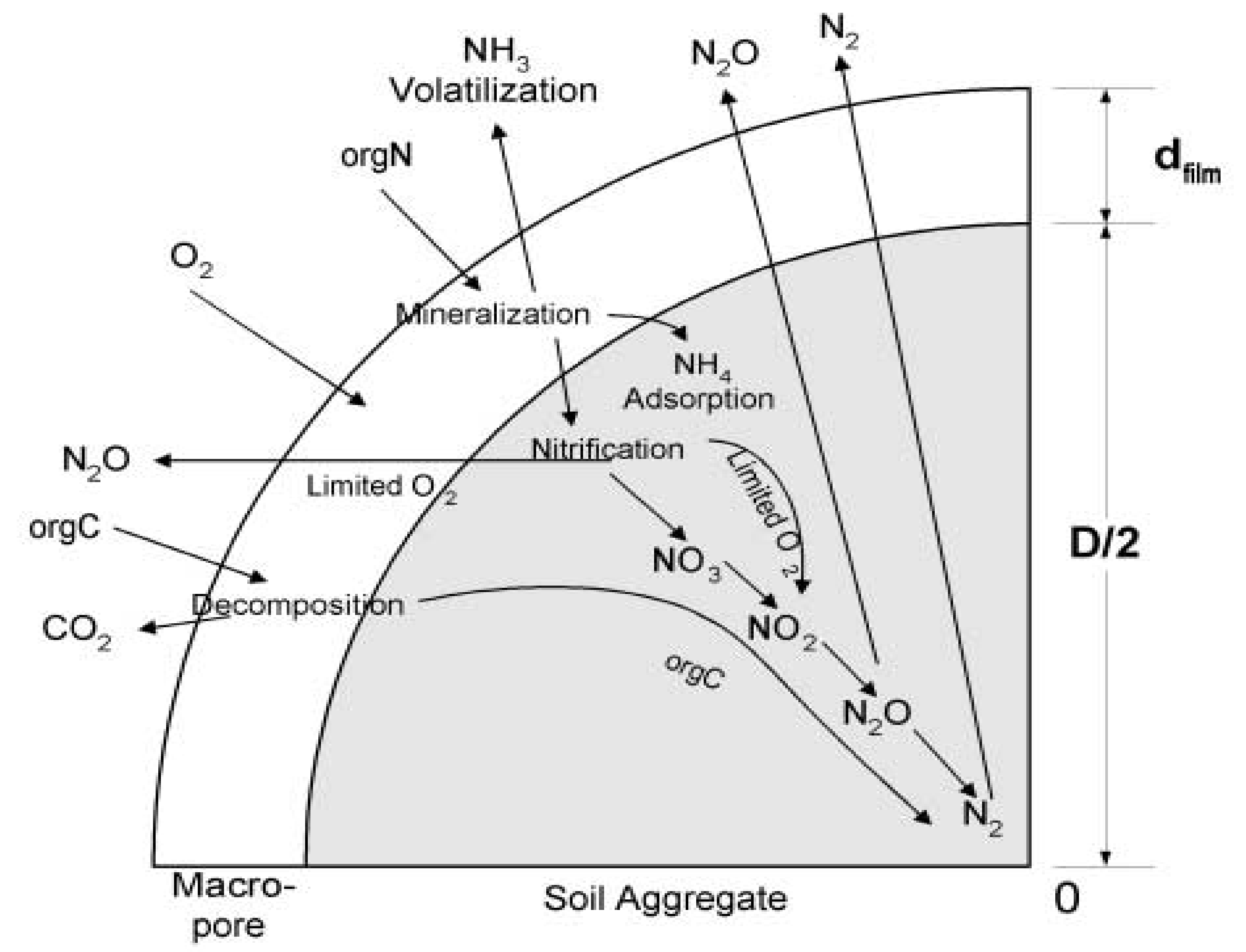
$$\mathbf{N_2O}$$



$$NH_4^+ \Rightarrow NO_2^- \Rightarrow NO_3^-$$

Nitrification (aerobic, autotrophic)

Aggregate Model, (Kremen et al. ES&T 2005)



$$R_f^{\gamma} \frac{\partial}{\partial t} c_{agg}^{\gamma} = D_{agg}^{*,\gamma} \nabla^2 c_{agg}^{\gamma} + \sum_{(prc)} R(c_{agg}^{\gamma})$$

Soil respiration for O_2 only consuming process

steady-state O_2 concentration profiles

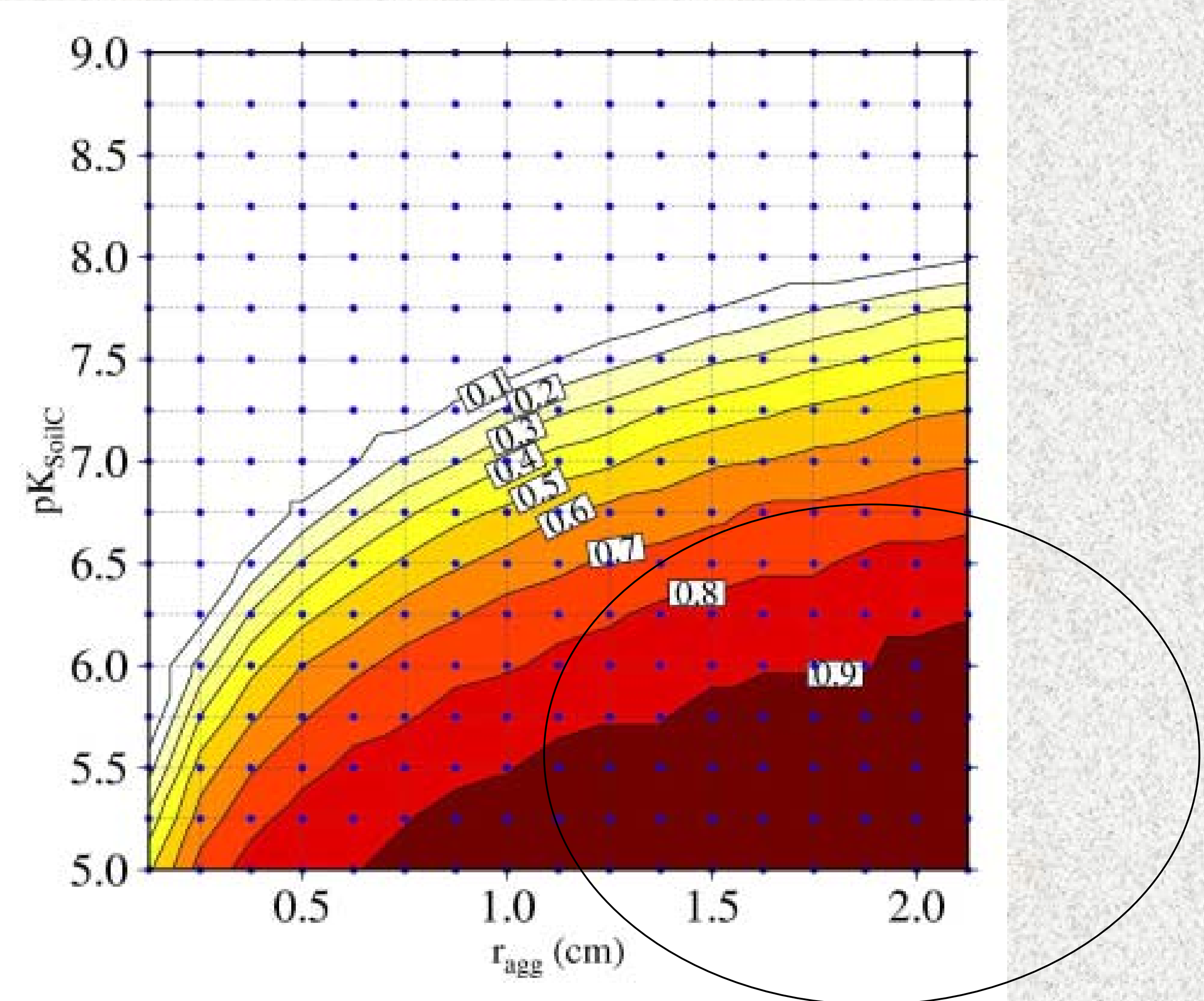
Employing Currie (1961) approach,

➔ *critical radius* of a spherical aggregate

$$r_c = \sqrt{\frac{6D_{agg}^{*,\gamma} c_{aq}^{O_2}}{k_{SoilC}}},$$

r_c radius of the largest aerobic aggregate

Calculated Anaerobic Volume Fraction AVF in Aggregates for K_{soil} vs r_{agg}



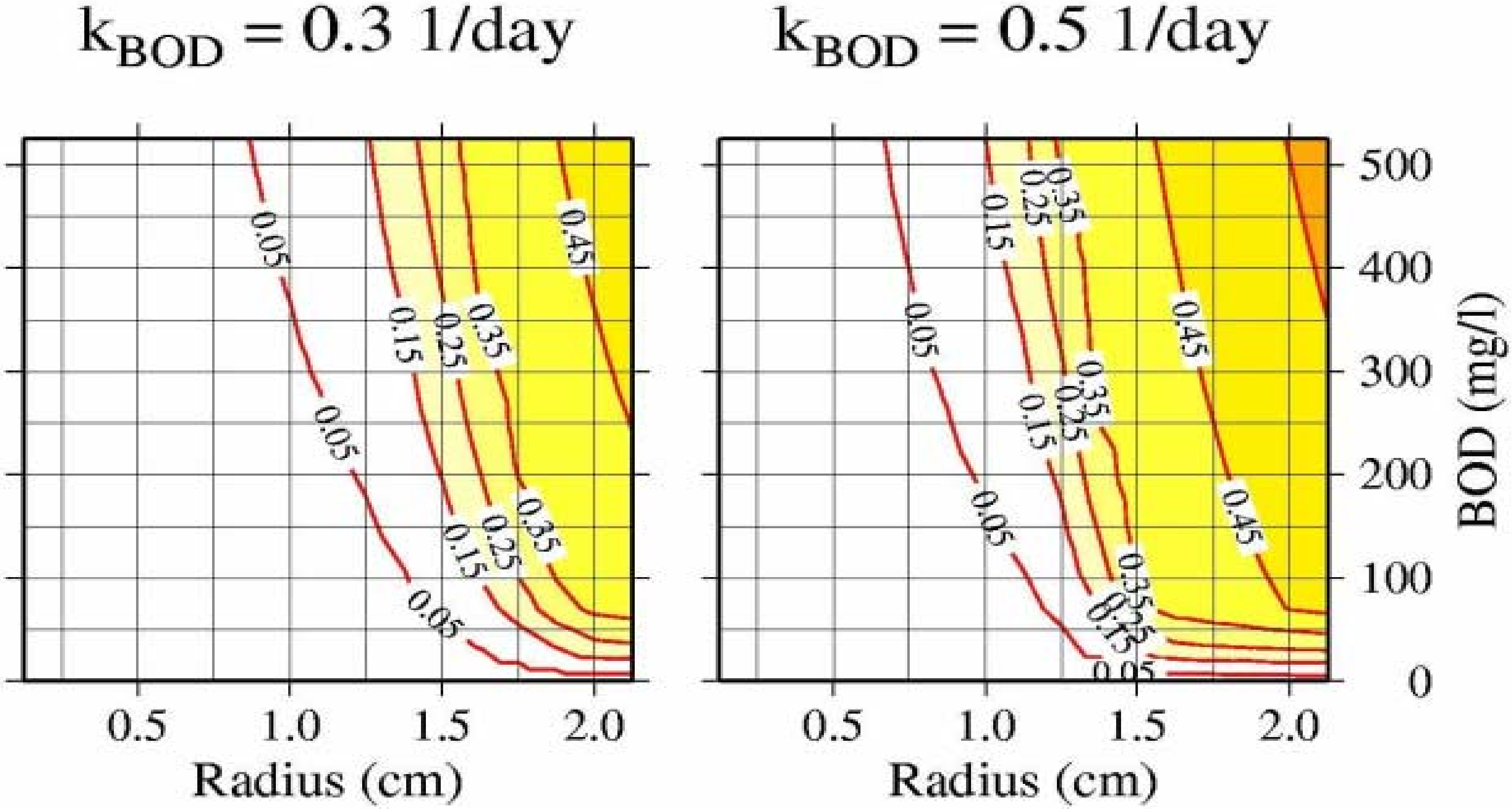
O_2 consumption via BOD

$$\left. R^{O_2} \right|_{BOD} = -k_{orgC}\left(L_{orgC} - c^{orgC}\right),$$

k_{orgC} - K_{BOD} is the BOD mineralization rate ,

L_{orgC} is the dissolved organic C, i.e. BOD, pool (Tchobanoglous, 1991).

BOD Decomposition Rate vs r_{agg}



Averaged Decrease of O2 Saturation

Two stage – nitrification kinetics

$$NH_4^+ \xrightarrow{k_{NH_4^+}} NO_2^- \xrightarrow{k_{NO_3^-}} NO_3^-$$

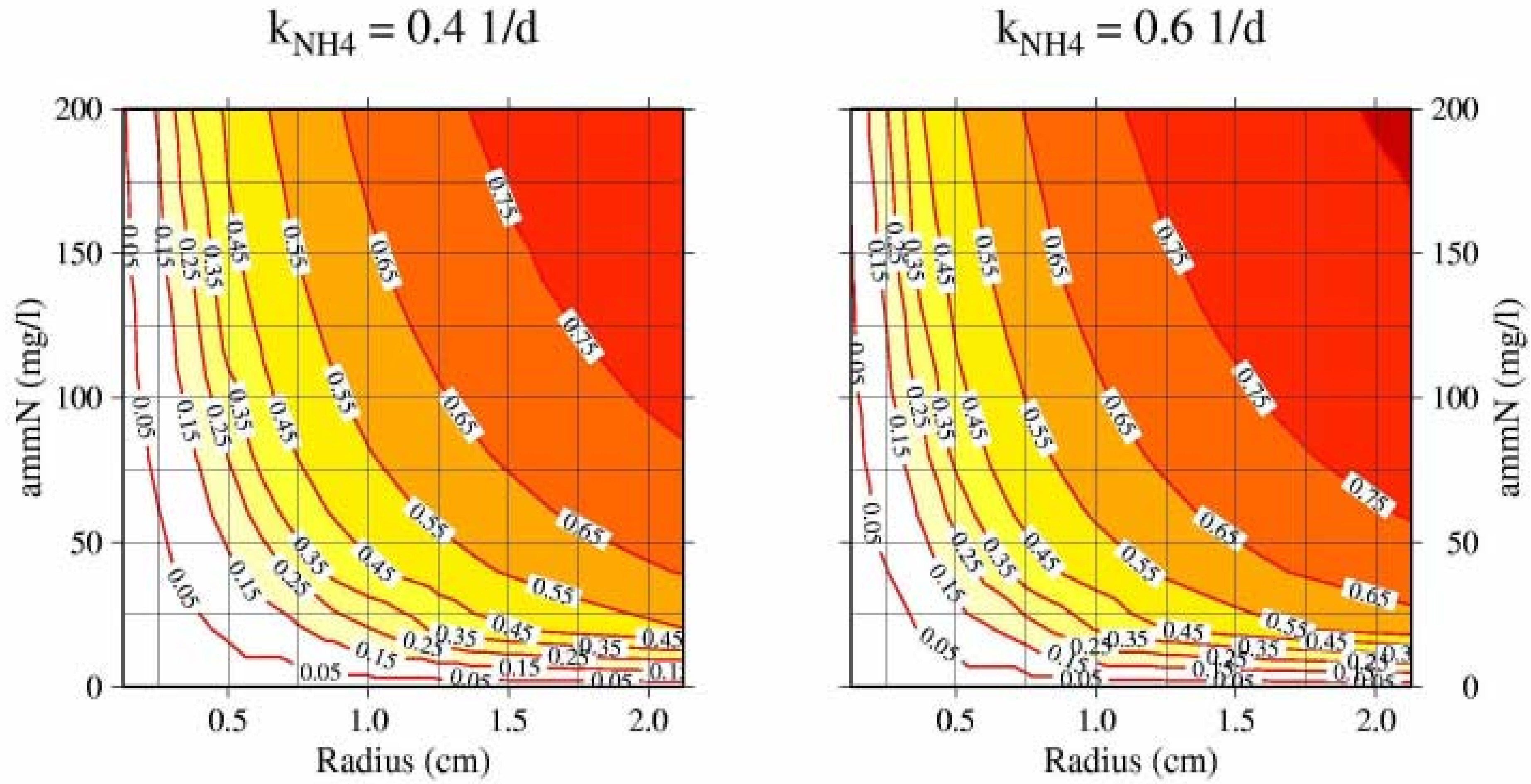
$$\left.\begin{array}{ll} 1. & R^{NH_4^+} = -k_{NH_4^+} C_{NH_4^+} \\ 2. & R^{NO_3^-} = k_{NO_3^-} C_{NO_2^-} \end{array}\right\} \textbf{\textit{First Order}}$$

$$3. \quad R^{NO_2^-} = -R^{NH_4^+} - R^{NO_3^-}$$

NO_3 Inhibition (LAG) → NH_3

$$\chi = \chi[t, NH_3, O_{2,} etc.]$$

Effect of NH_4, R_{agg} and Nitrification Rate on Anaerobic Fraction



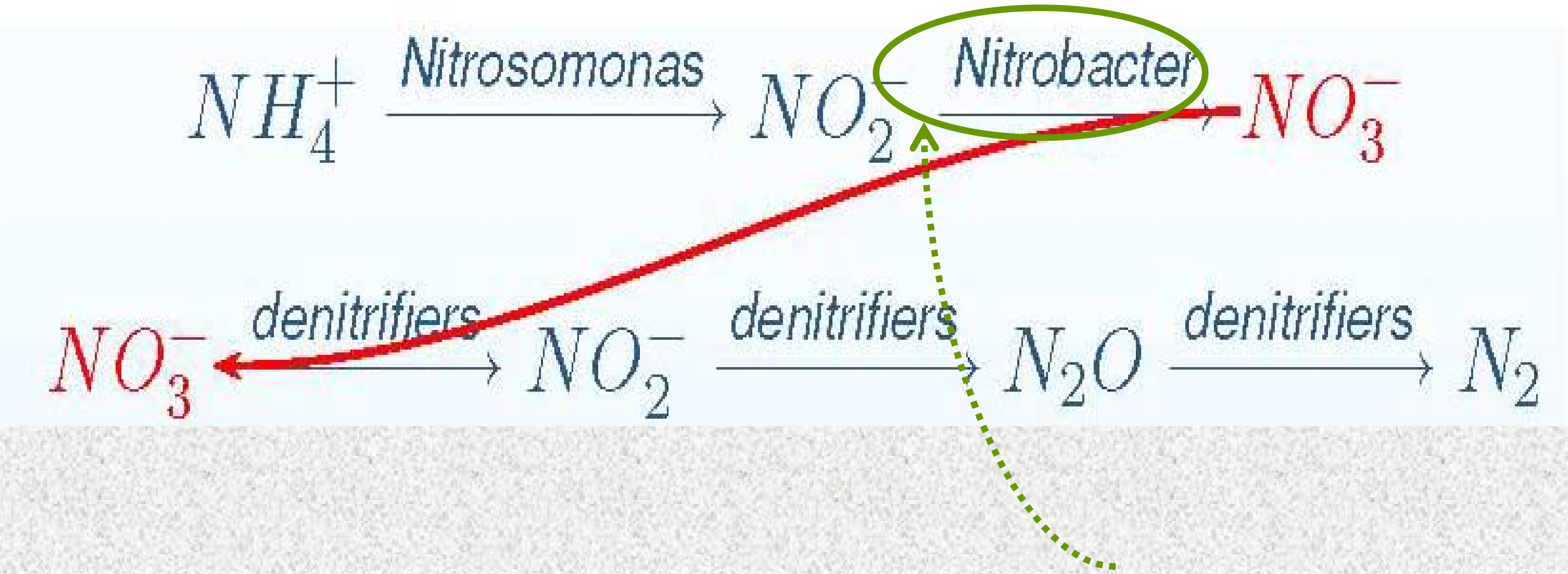
k_{NH4} = 0.4 1/d

k_{NH4} = 0.6 1/d

Averaged Decrease of O2 Saturation

Coupled Nitrification/Denitrification Pathway,

Nitrate derived from Nitrification, is directly available for Denitrification

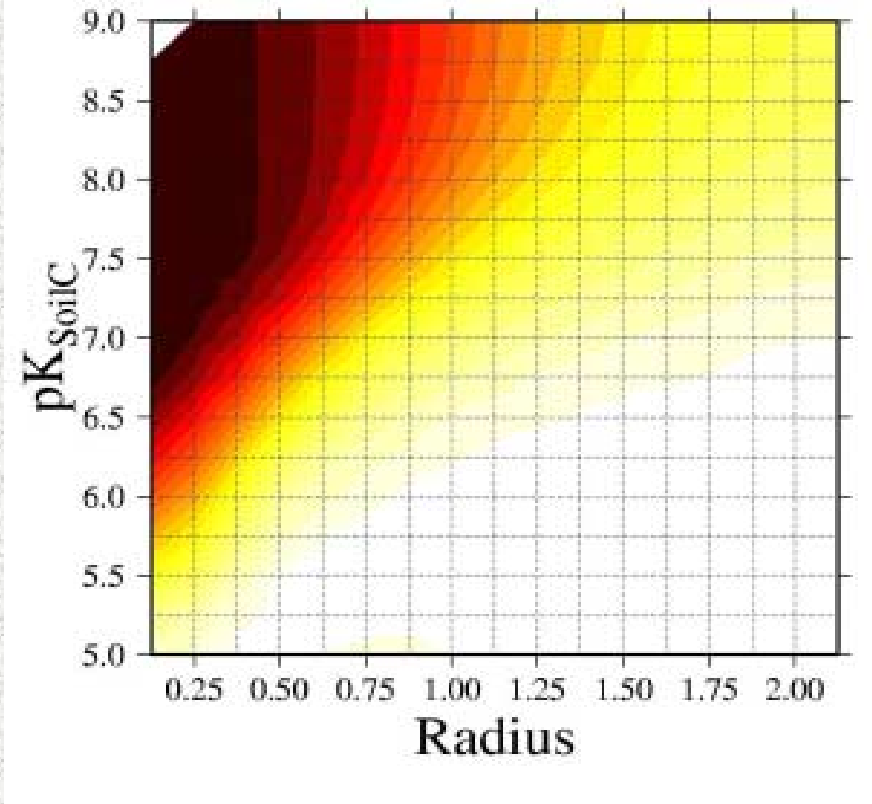


$$NH_4^+ \xrightarrow{\text{Nitrosomonas}} NO_2^- \xrightarrow{\text{Nitrobacter}} NO_3^-$$

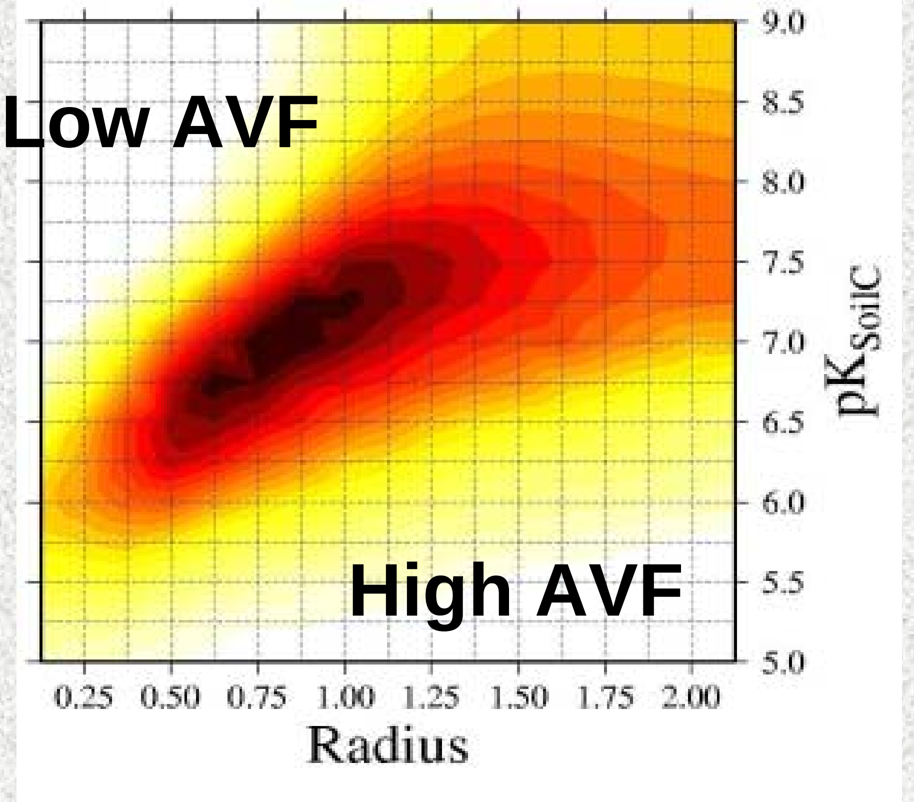
$$NO_3^- \xrightarrow{\text{denitrifiers}} NO_2^- \xrightarrow{\text{denitrifiers}} N_2O \xrightarrow{\text{denitrifiers}} N_2$$

Effluent inhibition

Coupled Nitrification/Denitrification in Aggregates

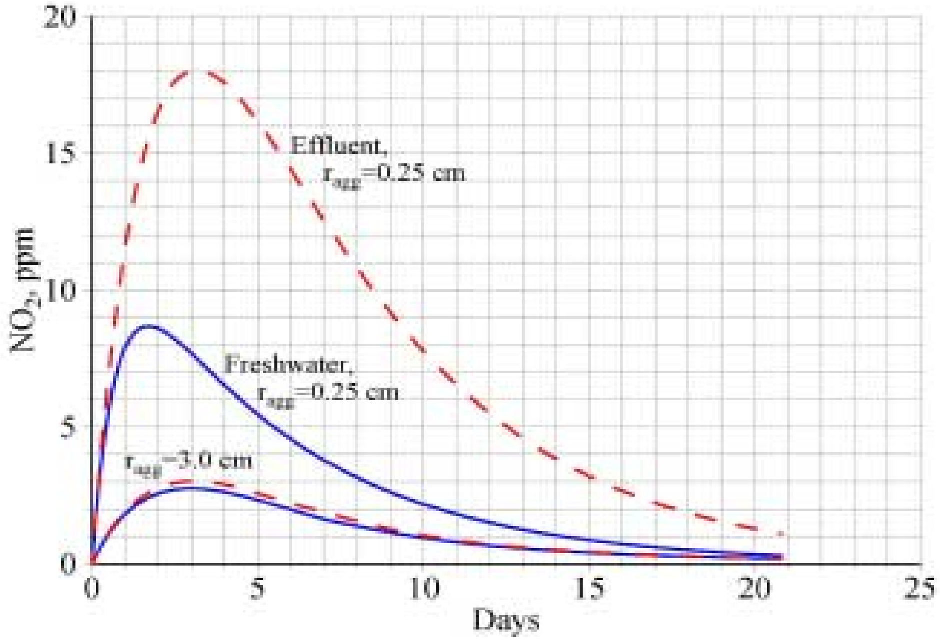


(a) Nitrate



(b) Di-Nitrogen

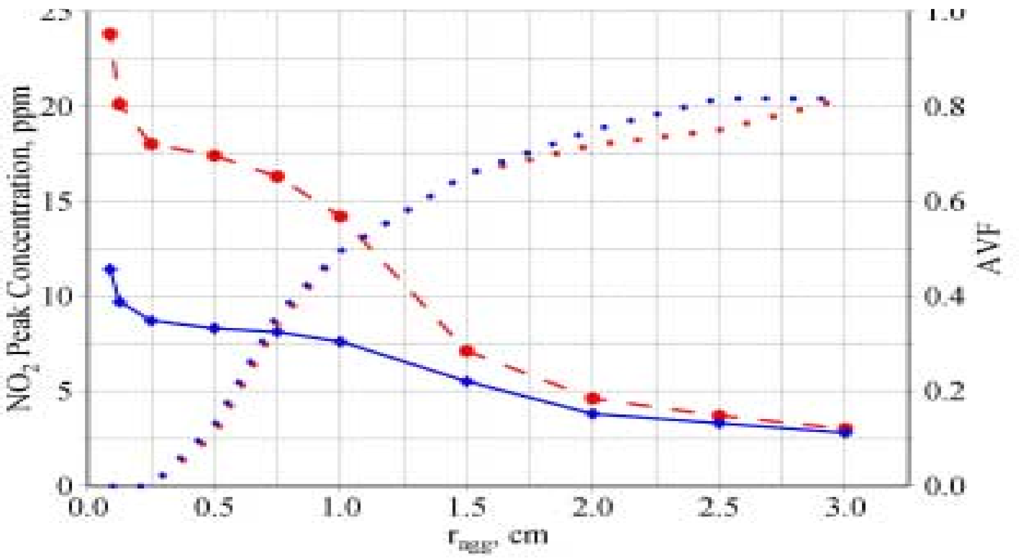
Nitrite Accumulation



Freshwater – blue, solid line;

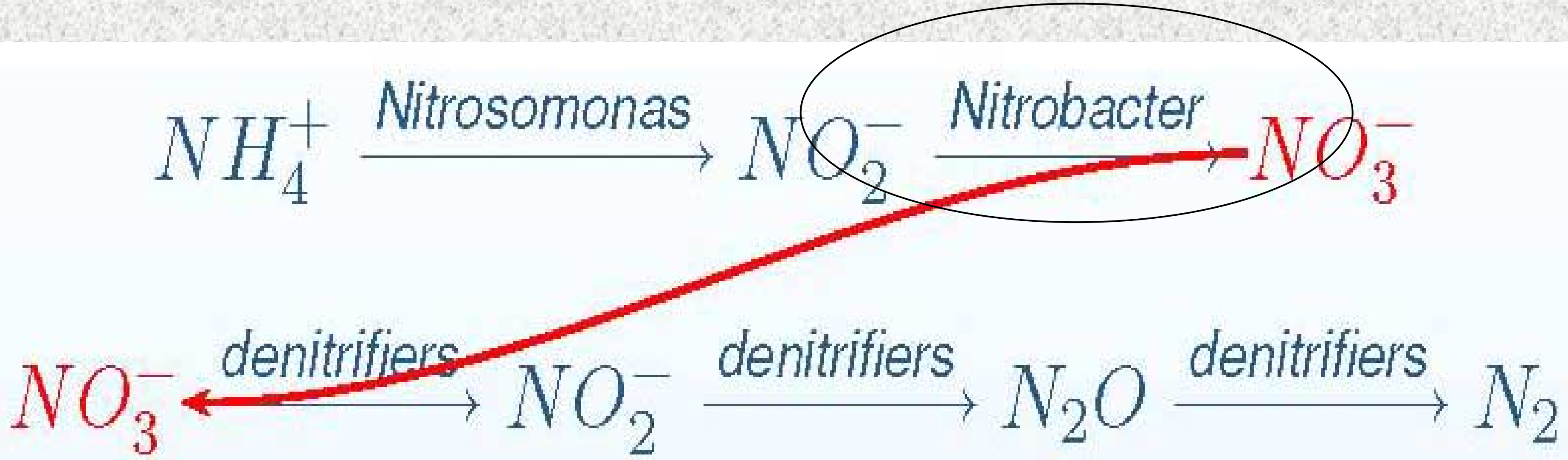
Effluent – red, dashed line;

AVF – dotted lines



Peak Conc in Aggregates

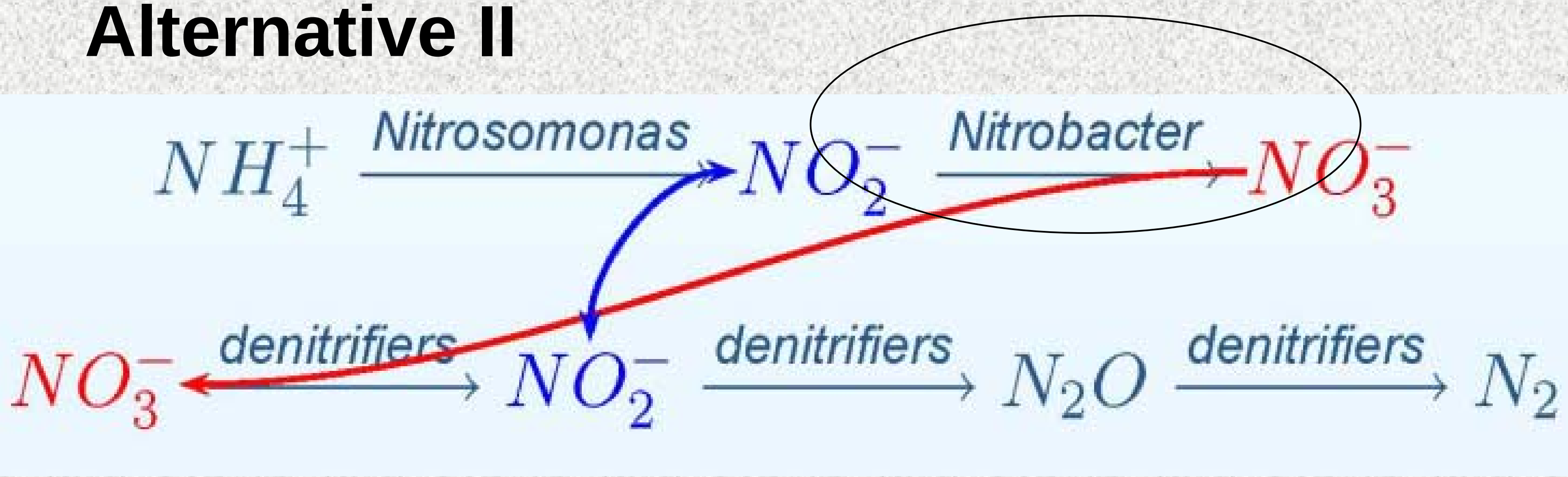
Alternative I



$$NH_4^+ \xrightarrow{\text{Nitrosomonas}} NO_2^- \xrightarrow{\text{Nitrobacter}} NO_3^-$$

$$NO_3^- \xrightarrow{\text{denitrifiers}} NO_2^- \xrightarrow{\text{denitrifiers}} N_2O \xrightarrow{\text{denitrifiers}} N_2$$

Alternative II



$$NH_4^+ \xrightarrow{\text{Nitrosomonas}} NO_2^- \xrightarrow{\text{Nitrobacter}} NO_3^-$$

$$NO_3^- \xrightarrow{\text{denitrifiers}} NO_2^- \xrightarrow{\text{denitrifiers}} N_2O \xrightarrow{\text{denitrifiers}} N_2$$

Summary and conclusions

- Aggregates in structured soils explain the occurrence of anaerobic processes in otherwise aerobic soils

- Ammonium application to aggregates subject to oxygen limitations may result in CND

- BOD marginally affects aggregate O2 status

- The effect ammonium is more pronounced

Di-nitrogen production under CND requires anaerobic and aerobic conditions for Nitrate production of ➔ Optimal at intermediate r_{ag}

Nitrite production enhanced by effluent (pH)

Under CND part of the nitrite directly reduced to N_2 (short cut)

In small aggregates enough Nitrite is produced via nitrification

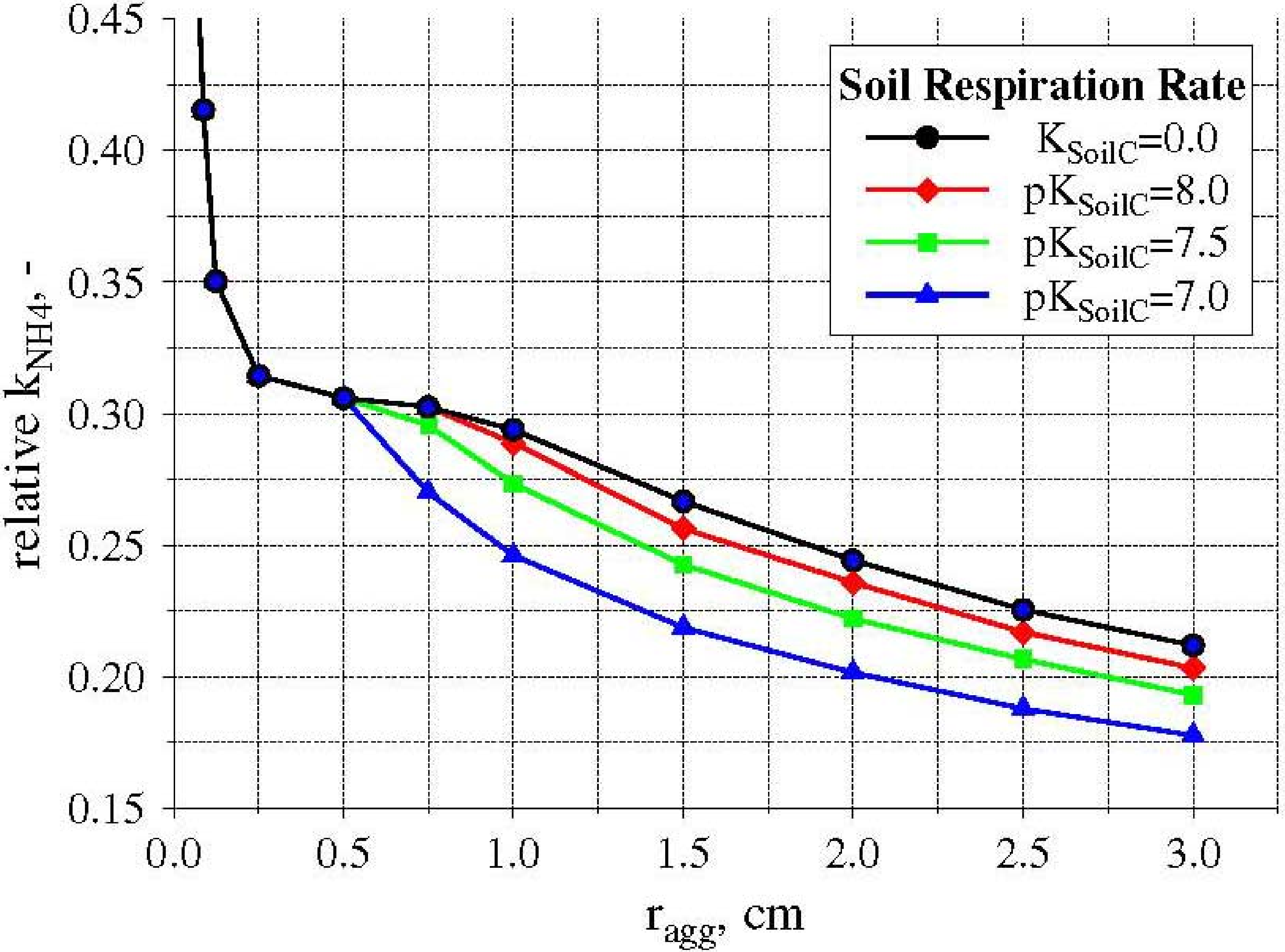
Effluent enhances Nitrite → N_2

But in large aggregates AVF dominates the

Dinitrification differences → no effluent effect

Who said that Size Does not Matter ?

Thanks

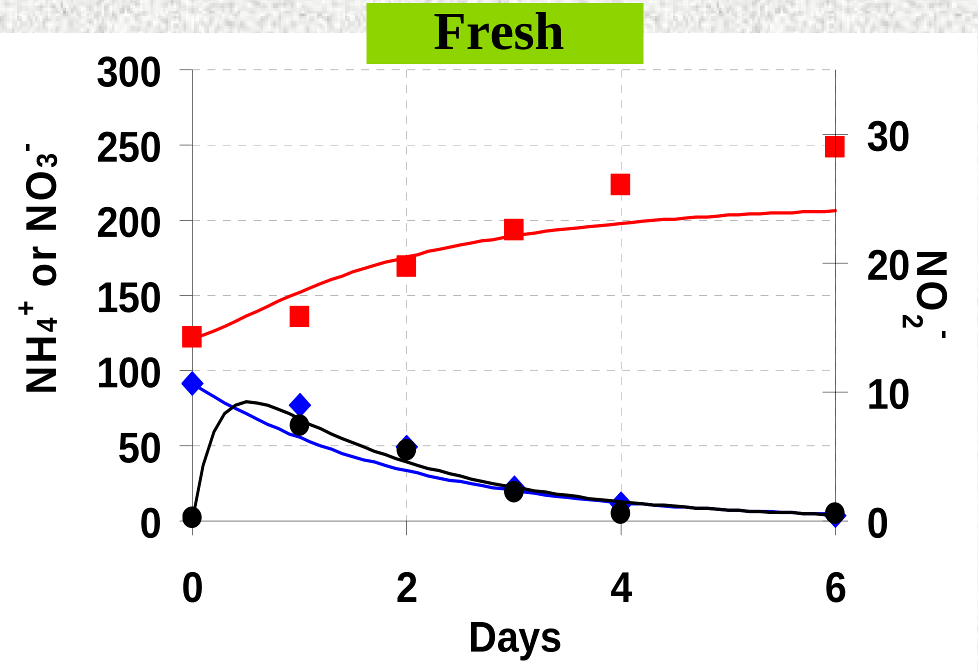


Soil Respiration Rate
K_{SoilC}=0.0
pK_{SoilC}=8.0
pK_{SoilC}=7.5
pK_{SoilC}=7.0
relative k_{NH4}, -
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.0
0.5
1.0
1.5
2.0
2.5
3.0
r_{agg}, cm

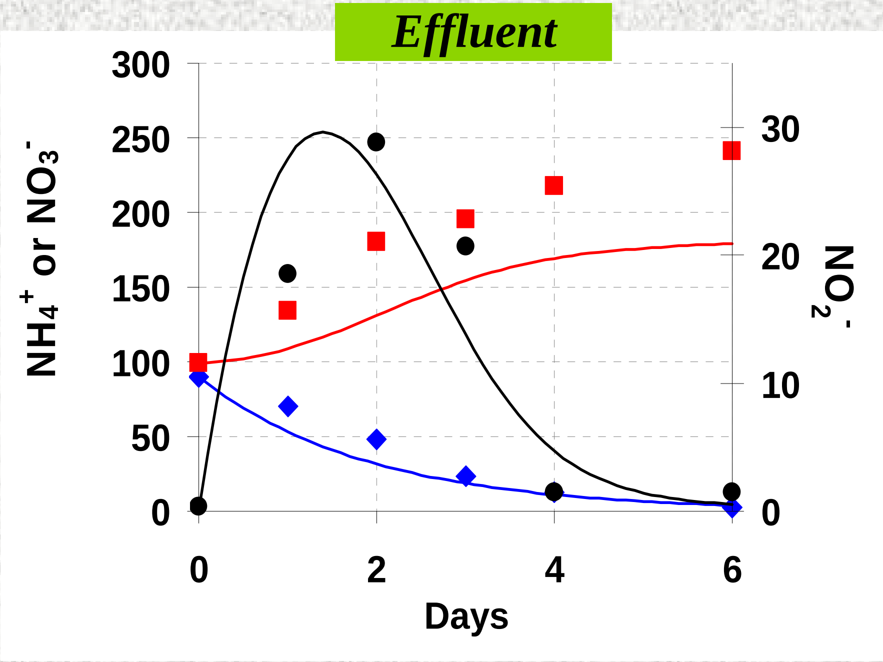
Experimental vs. Modeled

$$\chi = \chi(t)$$

Time Dependent Inhibition



Fresh



Effluent

Nitrification

Gross vs. Net rates

Nitrification period	Gross rate mg N-NO_3^- kg^{-1} day^{-1}	Net (observed) rate mg N-NO_3^- kg^{-1} day^{-1}
0-2	18.4	4.0
2-5	14.0	19.6
5-10	8.5	0.9
10-14	0.3	2.5
Total N nitrified in 14 days	**122.6**	**81**

14.4 mg N-NO_3^- kg^{-1} day^{-1}

Immobilization, Denitrification, Conversion to NH_4^+

Effluent effect not significant -- Tendency of increased Nitrification rates!