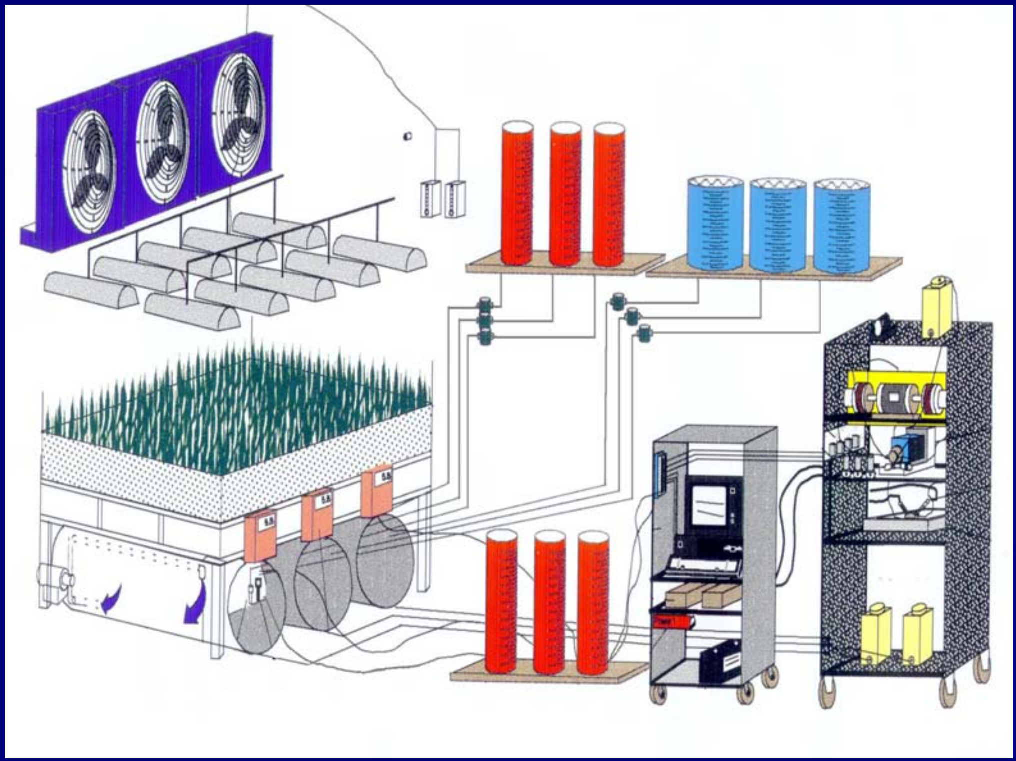
Long-Term Effects of NH_4^+/NO_3^- Ratios on Growth and Nitrification in Hydroponic Culture



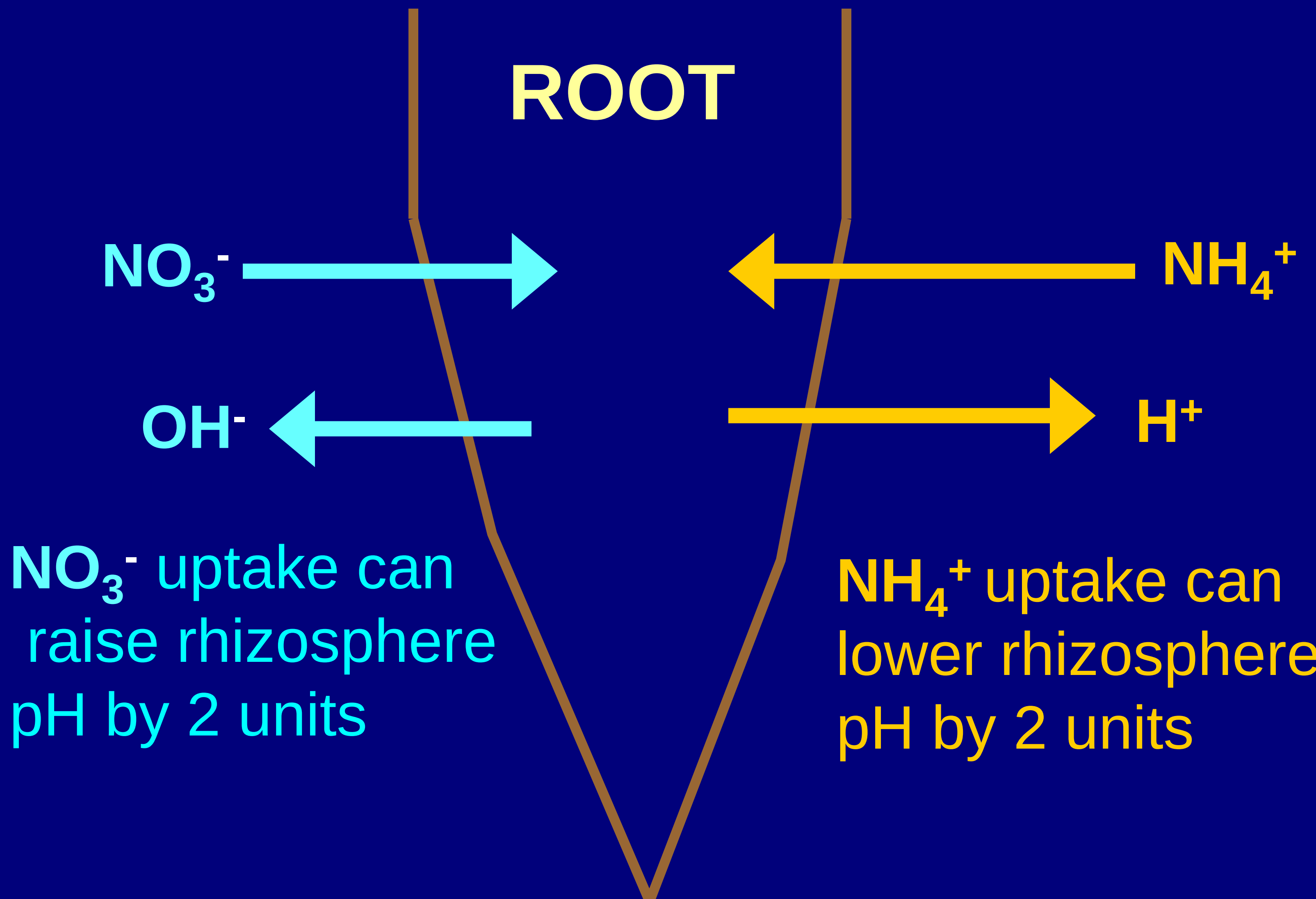
Bruce Bugbee
Crop Physiology Lab
Utah State University

Review
of plant nutrition principles

theory ⇄ measurement

The principle of charge balance:

All Cells Must Maintain Charge Balance



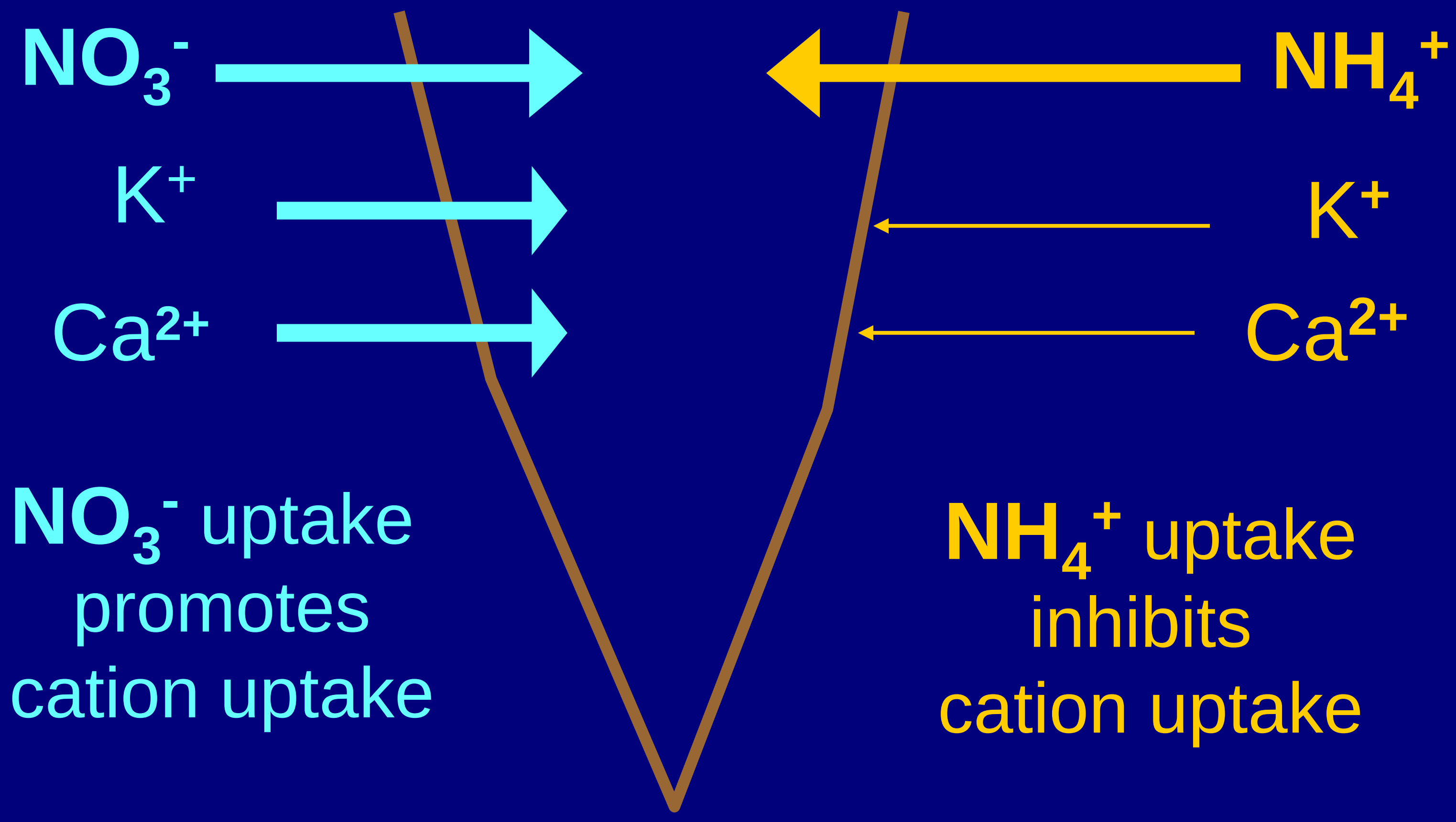
Techniques for preventing NH_4^+ Toxicity

1. Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)

The principle of mutual antagonism:

Like charges repel

& opposite charges attract

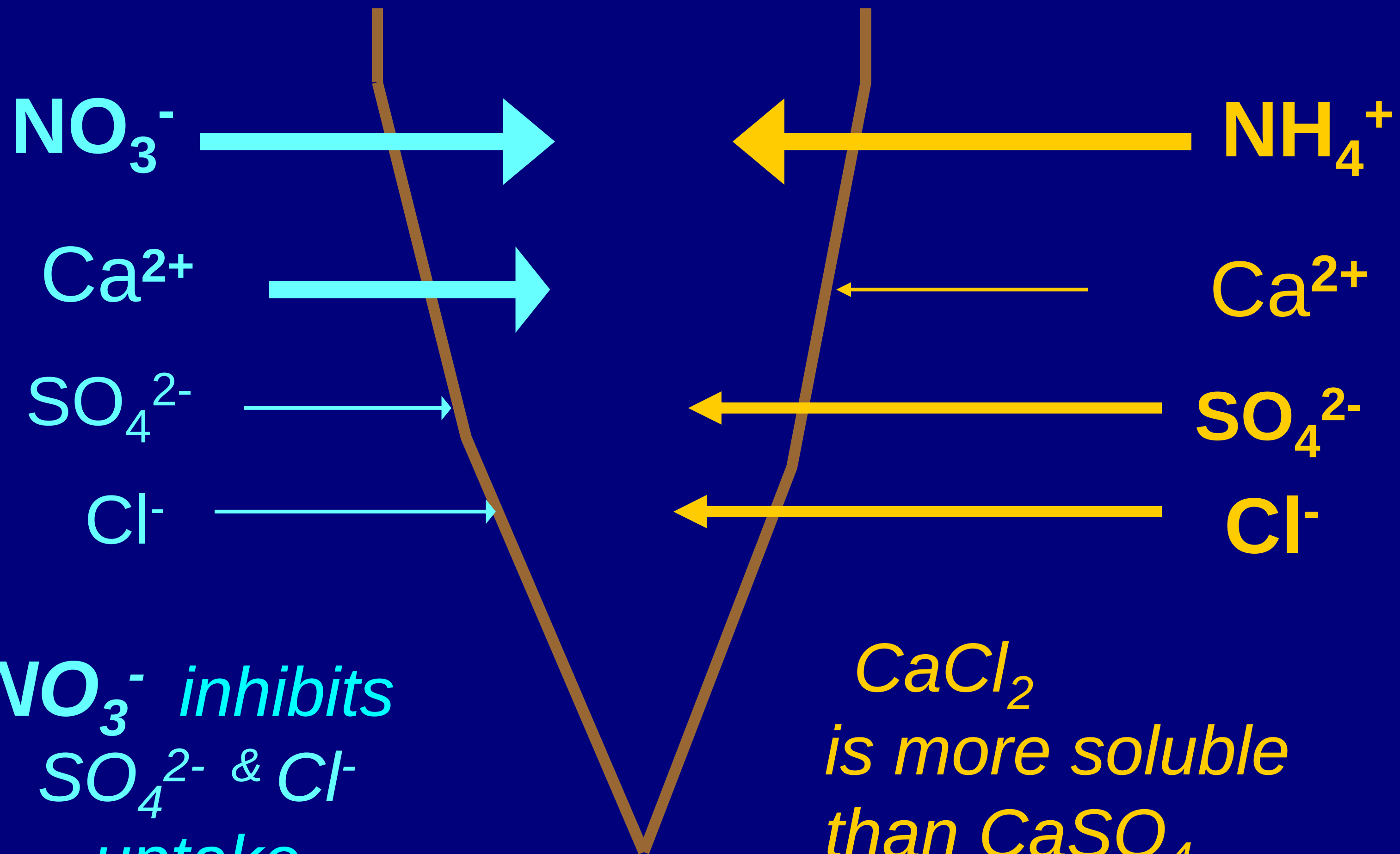


Techniques for preventing NH_4^+ Toxicity

1. Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
2. Alleviate K^+ deficiencies by adding excess K^+ (Ajayi *et al*., 1970)

Hypothesis:

Sulfate and chloride have different effects on calcium uptake

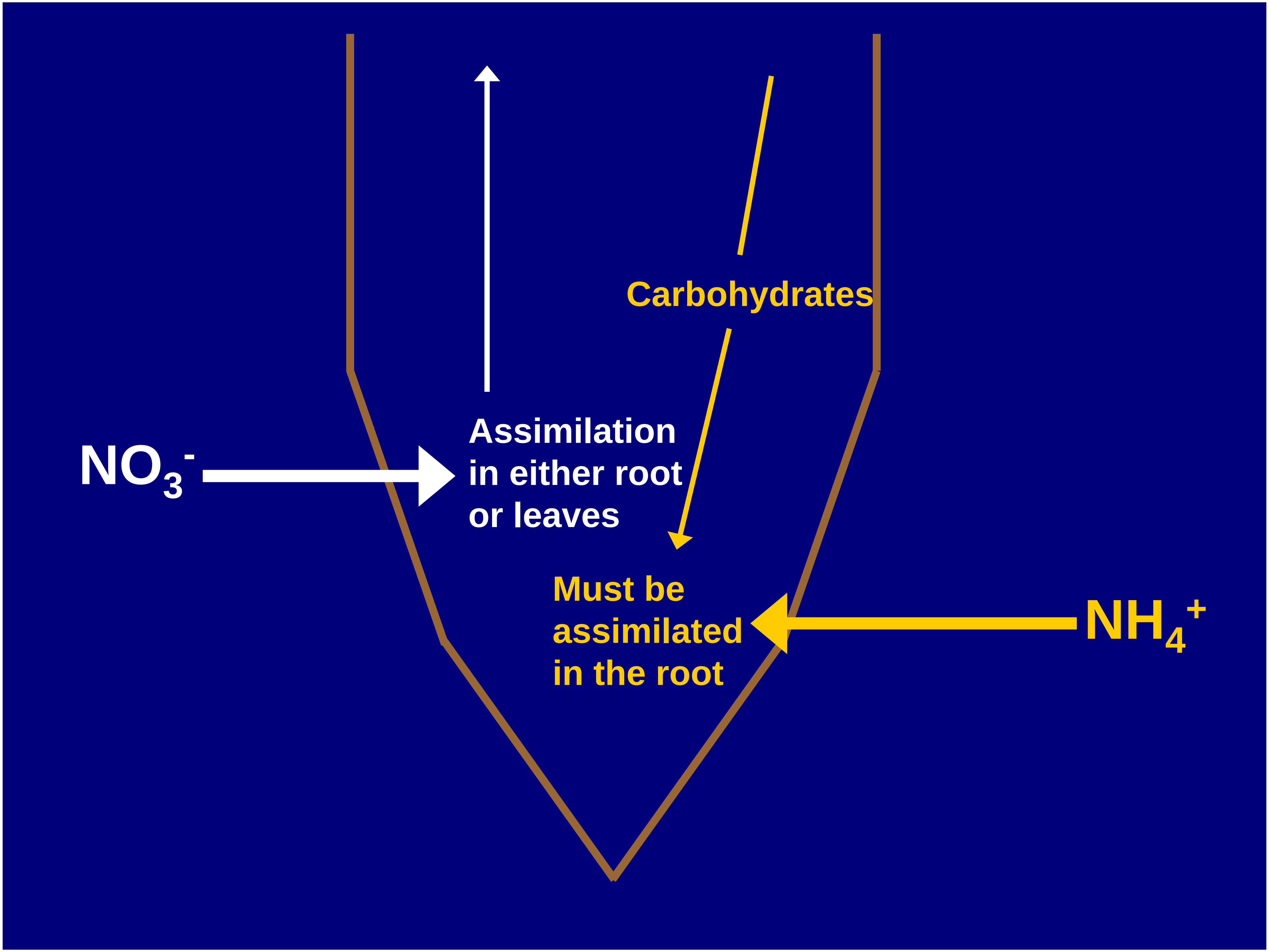


***NO_3^-* inhibits SO_4^{2-} & Cl^- uptake**

$CaCl_2$ is more soluble than $CaSO_4$

Techniques for preventing NH_4^+ Toxicity

1. Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
2. Alleviate K^+ deficiencies by adding excess K^+ (Ajayi *et al*., 1970)
3. Using $CaCl^-$ may increase Ca^{2+} uptake compared to $CaSO_4$ (Koenig and Pan, 1996)


Carbohydrates
Assimilation in either root or leaves
NO_3^-
Must be assimilated in the root
NH_4^+

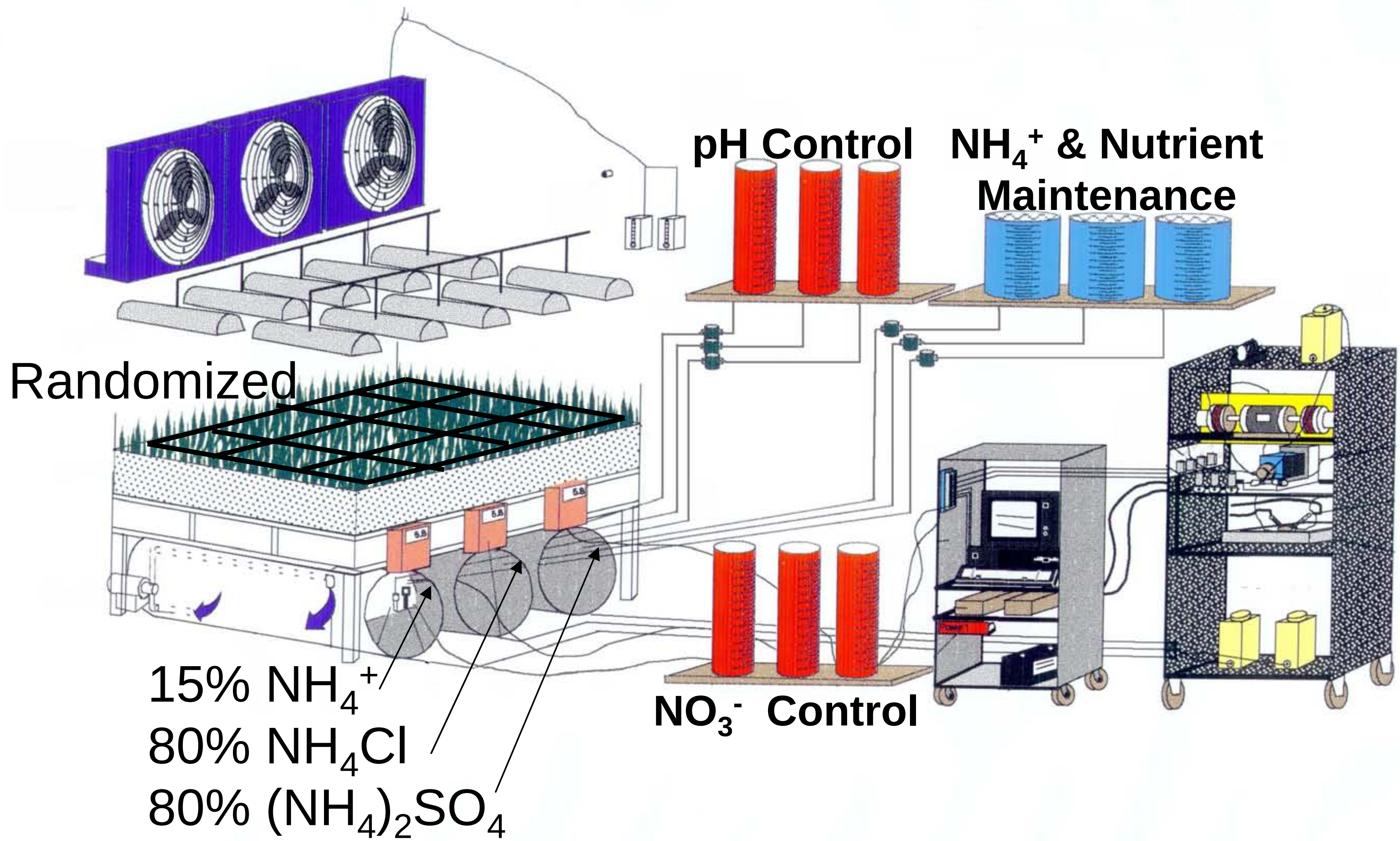
Techniques for preventing NH_4^+ Toxicity

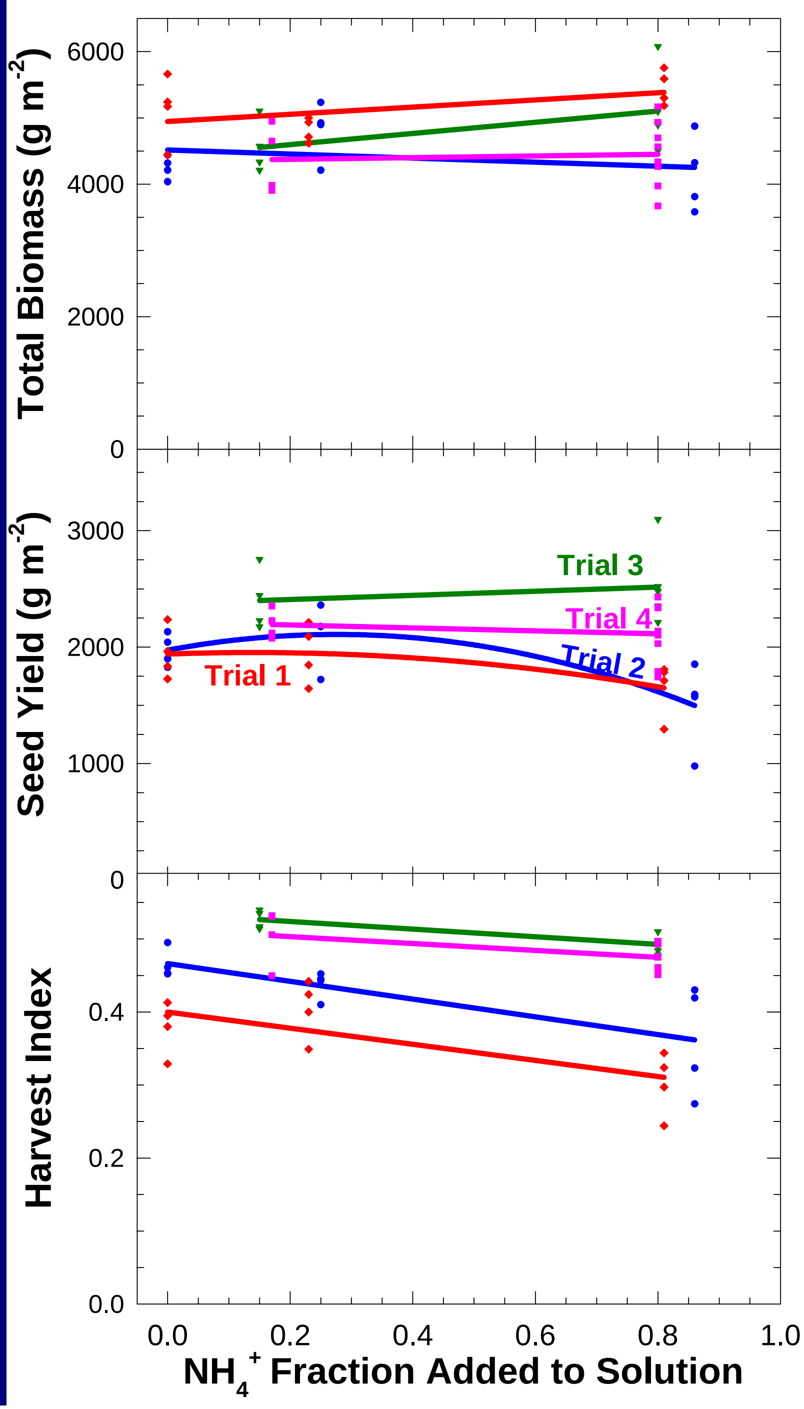
1. Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
2. Alleviate K^+ deficiencies by adding excess K^+ (Ajayi *et al*., 1970)
3. Providing Cl^- (counter ion) may increase Ca^{2+} uptake (Koenig and Pan, 1996)
4. Prevent carbohydrate deficiencies by maintaining constant temperature and light levels (Lavoie *et al*., 1992)

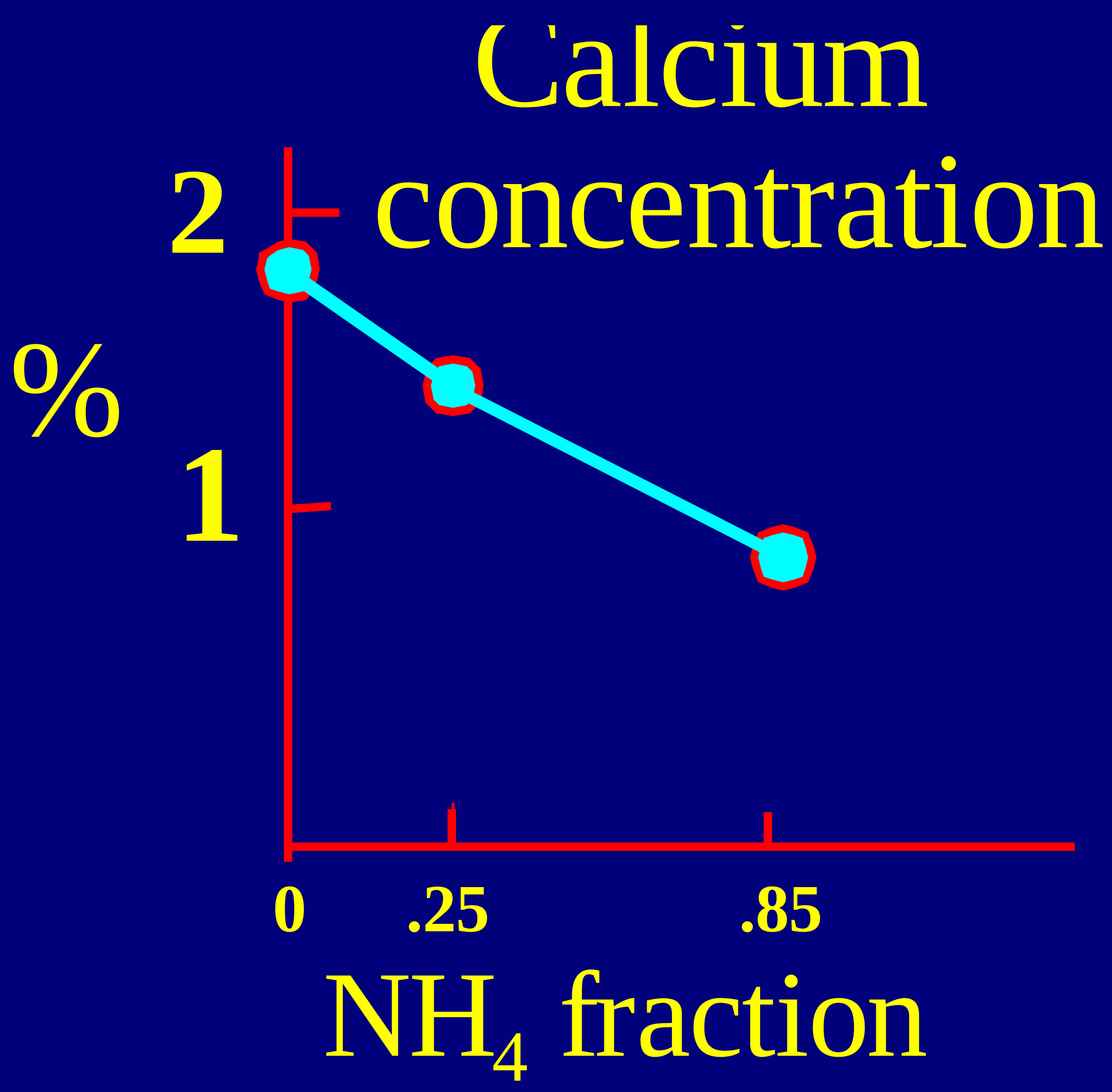
Objectives

- Determine the long-term effects of high NH_4^+ on growth, yield, and nutrient uptake
- Determine the importance of SO_4^{2-} vs. Cl^- as counterbalancing ions with NH_4^+
- Quantify nitrification

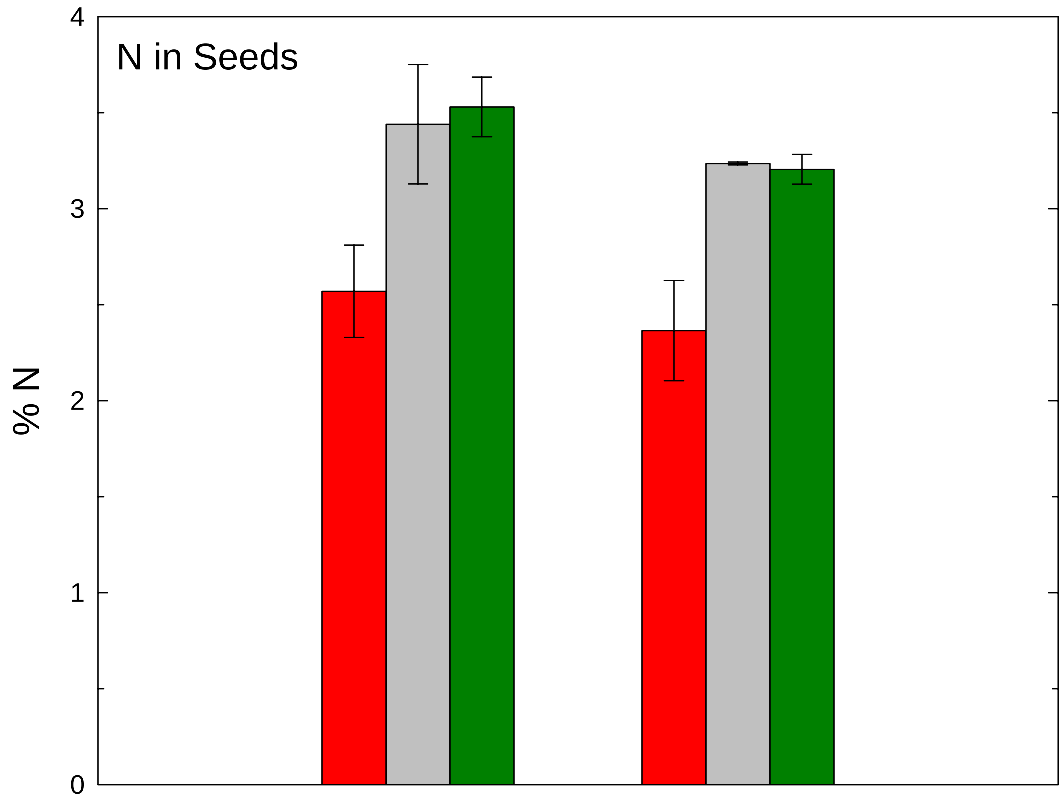
Automated Nutrient Control System




Total Biomass (g m^{-2})
6000
4000
2000
0
Seed Yield (g m^{-2})
3000
2000
1000
0
Trial 1
Trial 2
Trial 3
Trial 4
Harvest Index
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
NH_4^+ Fraction Added to Solution


Calcium
concentration
%
2
1
0
.25
.85
NH4 fraction

Ammonium increases protein in seeds



Nitrification

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

Ammonium oxidizers such as *Nitrosomonas*

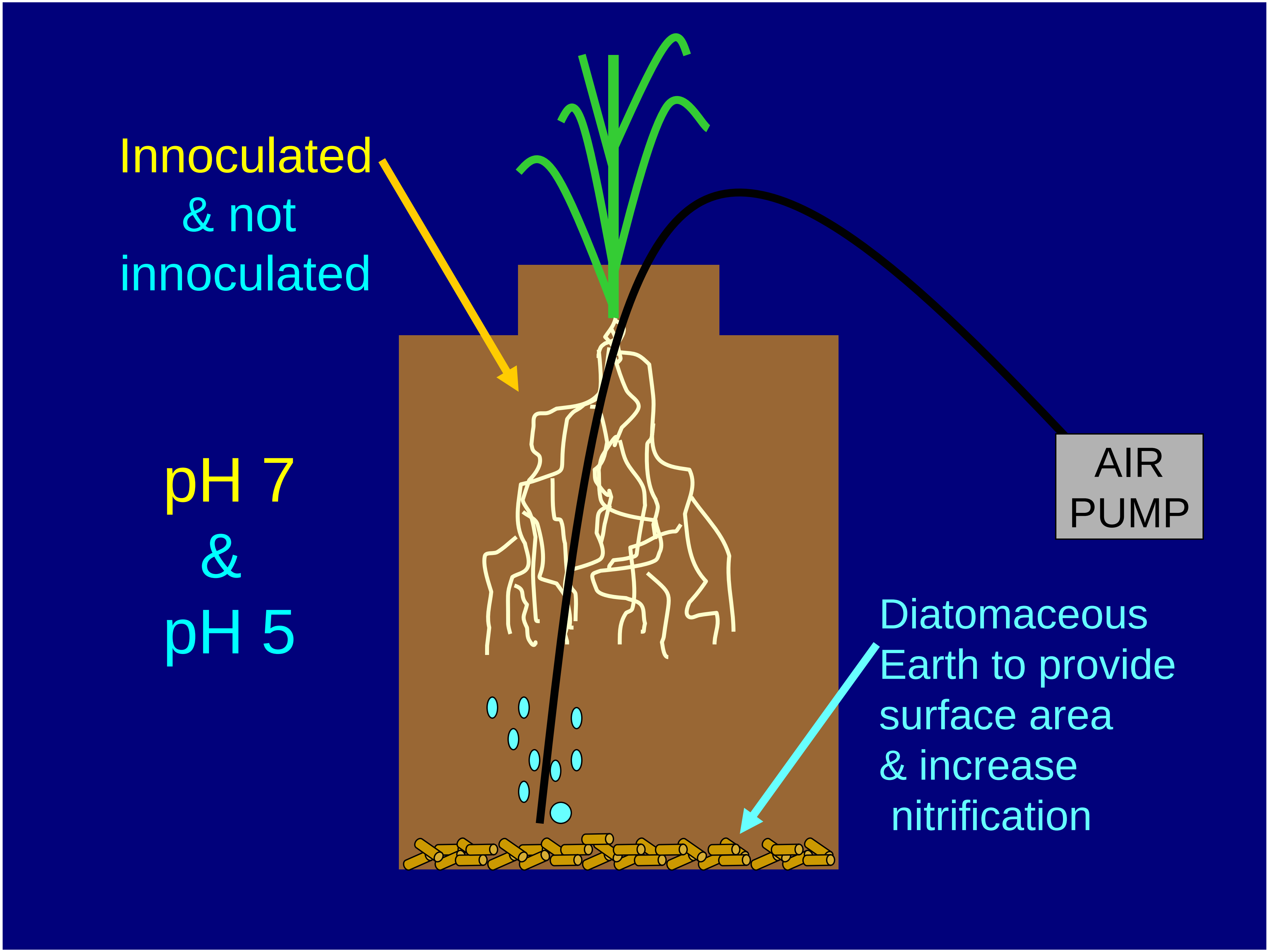
Nitrite oxidizers such as *Nitrobacter*

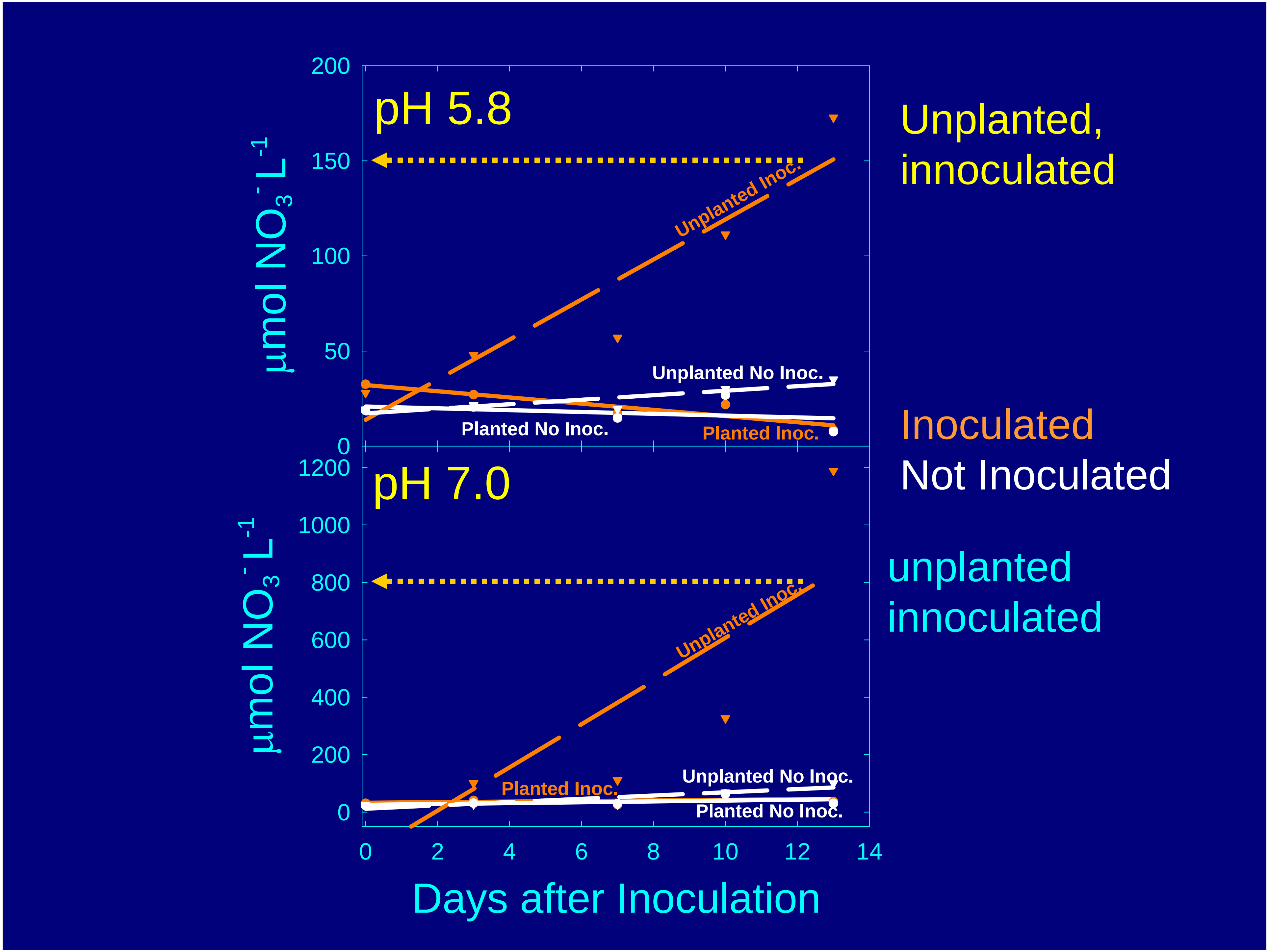
- Microbial optimum pH 6.6-8.0
- Plant optimum pH 5.8

Nitrification in Hydroponics

- Padgett and Leonard reported that conversion of NH_4^+ to NO_3^- by nitrifying organisms is significant in NH_4^+ based hydroponic solutions

Plant Physiology (1993)


Innoculated
& not
innoculated
pH 7
&
pH 5
AIR
PUMP
Diatomaceous
Earth to provide
surface area
& increase
nitrification

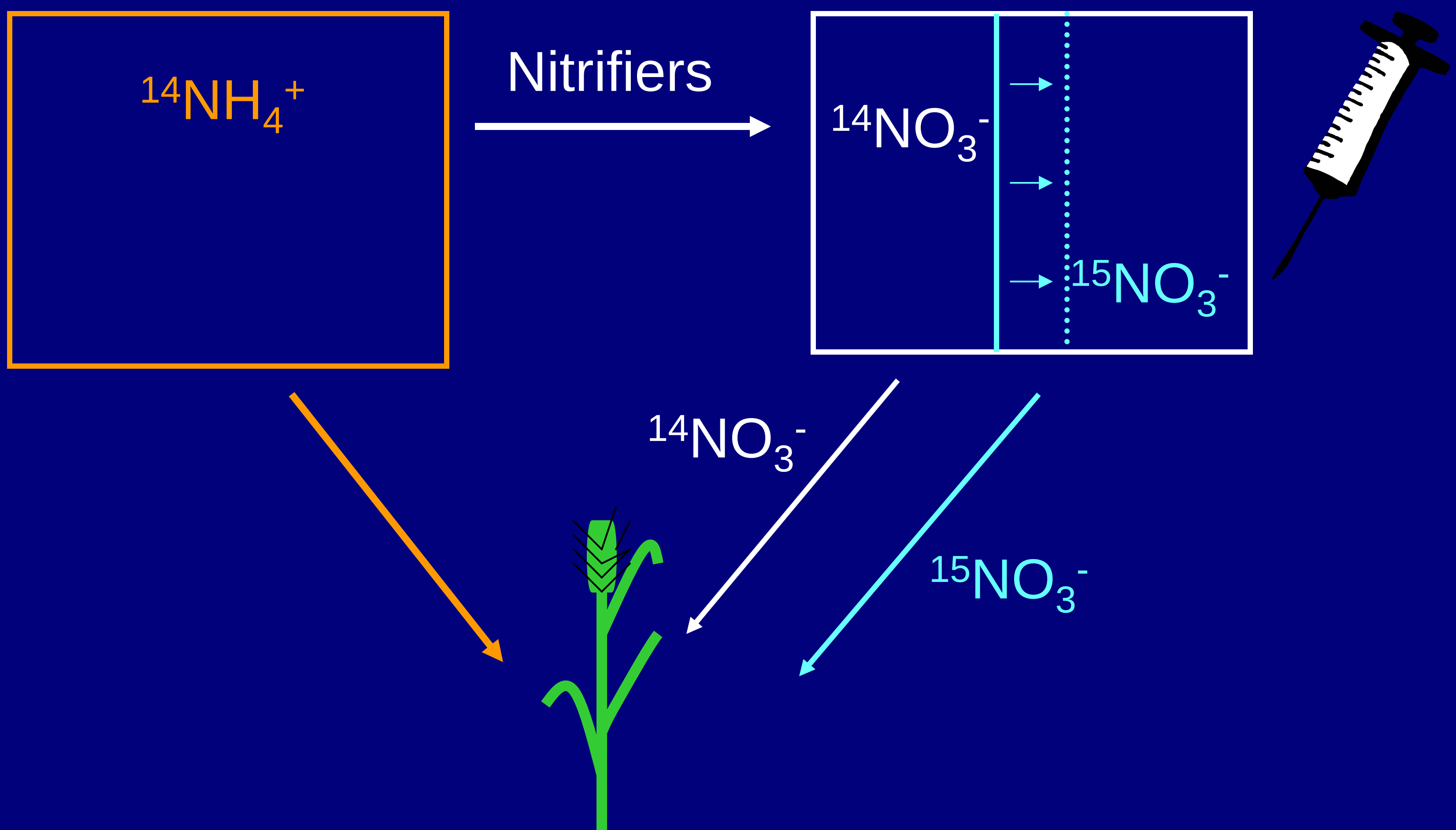


pH 5.8
pH 7.0
Unplanted Inoc.
Unplanted No Inoc.
Planted No Inoc.
Planted Inoc.
200
150
100
50
0
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
µmol NO_3^- L^{-1}
Days after Inoculation
Unplanted,
innoculated
Inoculated
Not Inoculated
unplanted
innoculated

Hypothesis:

Nitrifying microorganisms are more active in the rhizosphere than on inert substrates

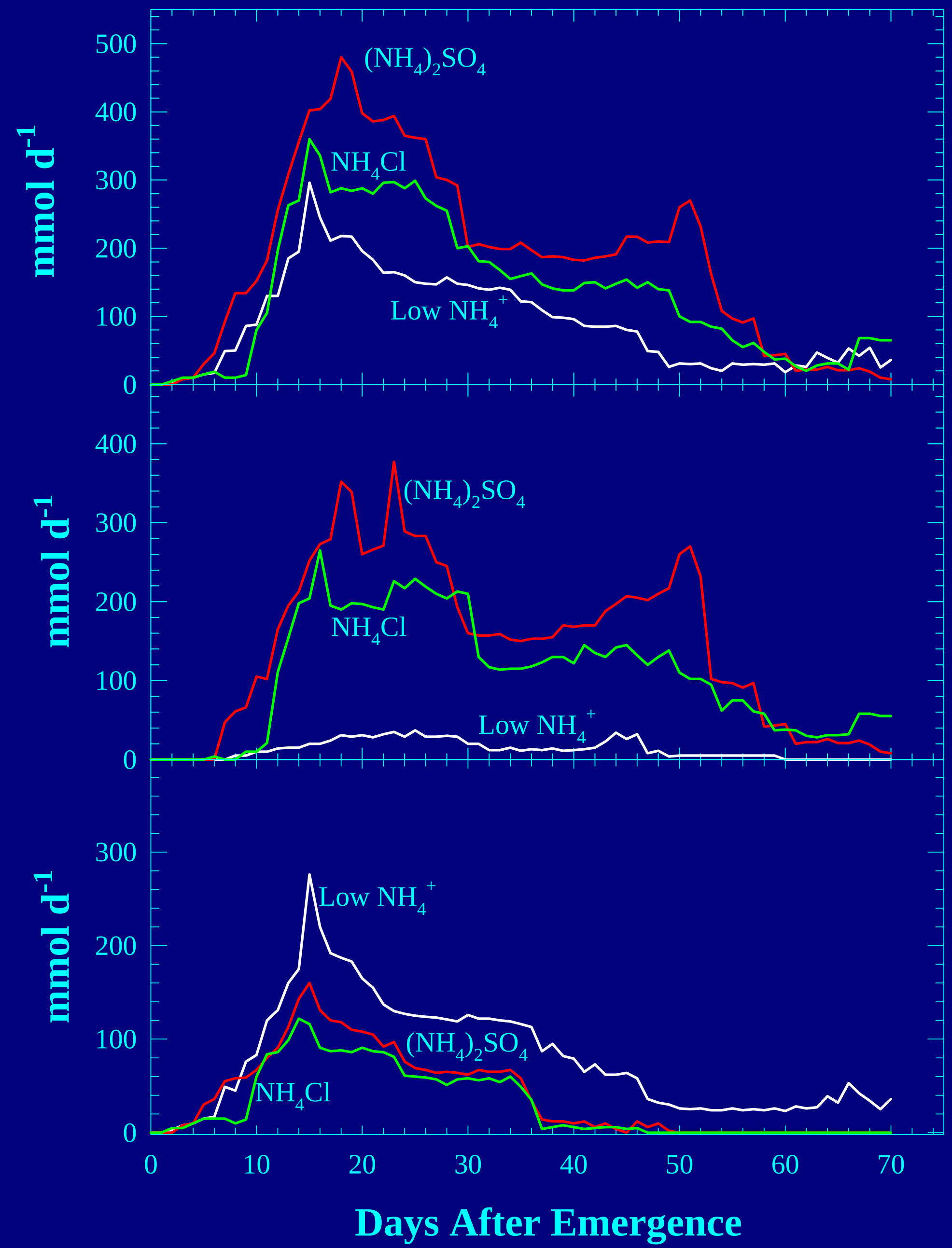
Isotopic Dilution



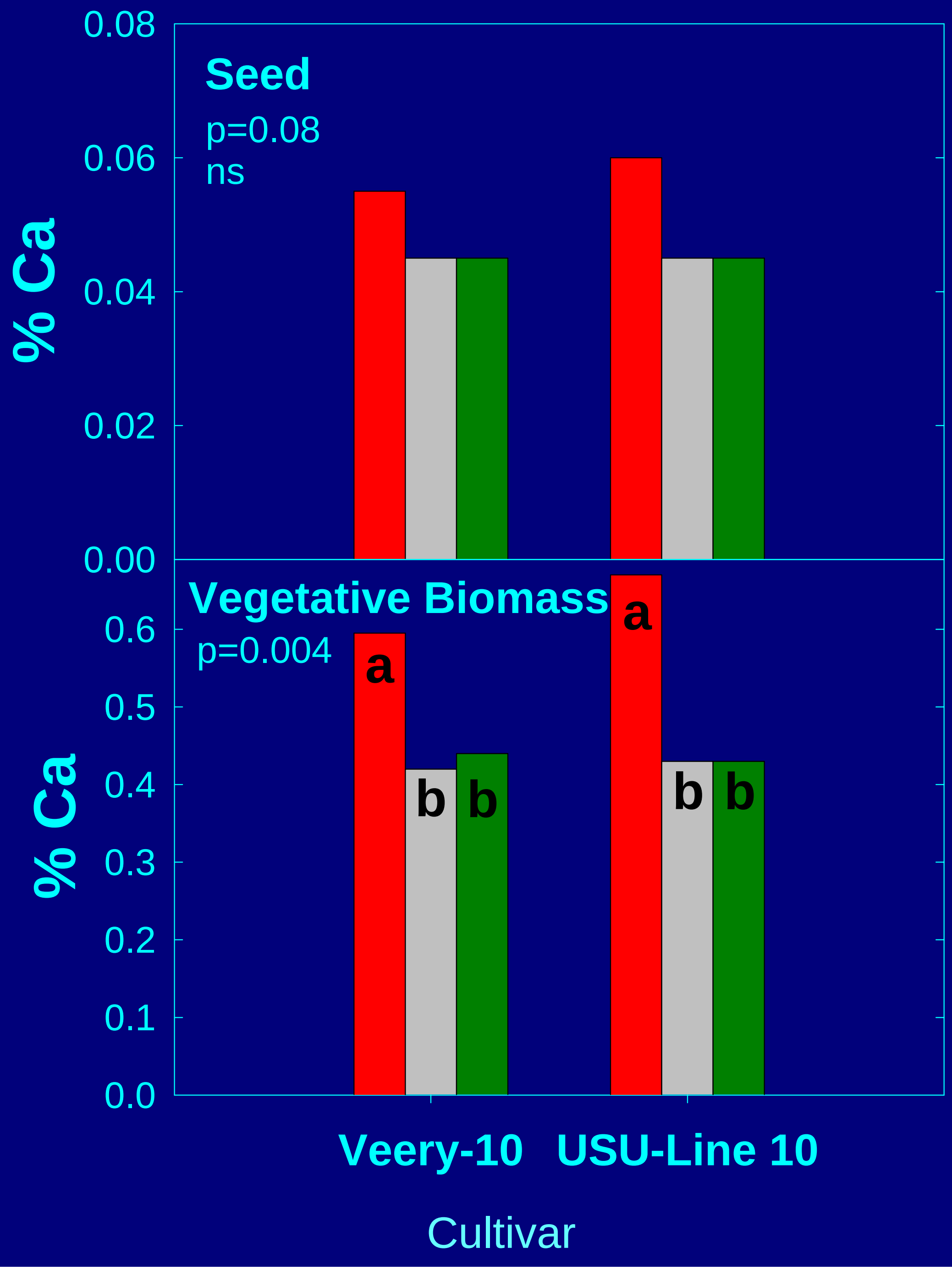
			GPR (μmol L^{-1} hr^{-1})	GCR (μmol L^{-1} hr^{-1})
pH 5.8	Planted	Inoculated	9.10 (SD = 0.20)	15.09 (SD = 6.85)
		Not Inoculated	8.80 (SD = 0.38)	14.98 (SD = 7.92)
	Not Planted	Inoculated	18.83 (SD = 2.89)	11.39 (SD = 3.65)
		Not Inoculated	17.13 (SD = 3.51)	6.70 (SD = 7.09)
pH 7.0	Planted	Inoculated	8.66 (SD = 3.05)	17.94 (SD = 4.73)
		Not Inoculated	7.33 (SD = 0.50)	25.60 (SD = 11.27)
	Not Planted	Inoculated	28.58 (SD = 2.34)	10.70 (SD = 10.11)
		Not Inoculated	22.87 (SD = 3.69)	14.96 (SD = 11.80)

Conclusions

- Wheat can be grown in high NH_4^+ with little effect on growth and yield
- Counter ion had no effect on Ca^{2+} uptake in these studies
- Inoculation with nitrifying microorganisms may help alleviate high NH_4^+ problems



mmol d-1
500
400
300
200
100
0
(NH4)2SO4
NH4Cl
Low NH4+
mmol d-1
400
300
200
100
0
(NH4)2SO4
NH4Cl
Low NH4+
mmol d-1
300
200
100
0
Low NH4+
(NH4)2SO4
NH4Cl
0
10
20
30
40
50
60
70
Days After Emergence



2 Replicate Trials

Root Zone Treatments

15% NH_4^+

80% NH_4Cl

80% $(NH_4)_2SO_4$

Materials And Methods
(Nitrification Study)

- 3 x 2 Factorial (4 Reps)
  - pH 5.8 or 7.0
  - Inoculated or not inoculated
  - Planted or not planted

- $^{15}NO_3^-$ addition to quantify nitrification rates (isotopic dilution)

2 Replicate Trials

Root Zone Treatments

15% NH_4^+

80% NH_4Cl

80% $(NH_4)_2SO_4$

Do high levels of NH_4 in hydroponic solut ion reduce yield?