Controlled Release Fertilizers

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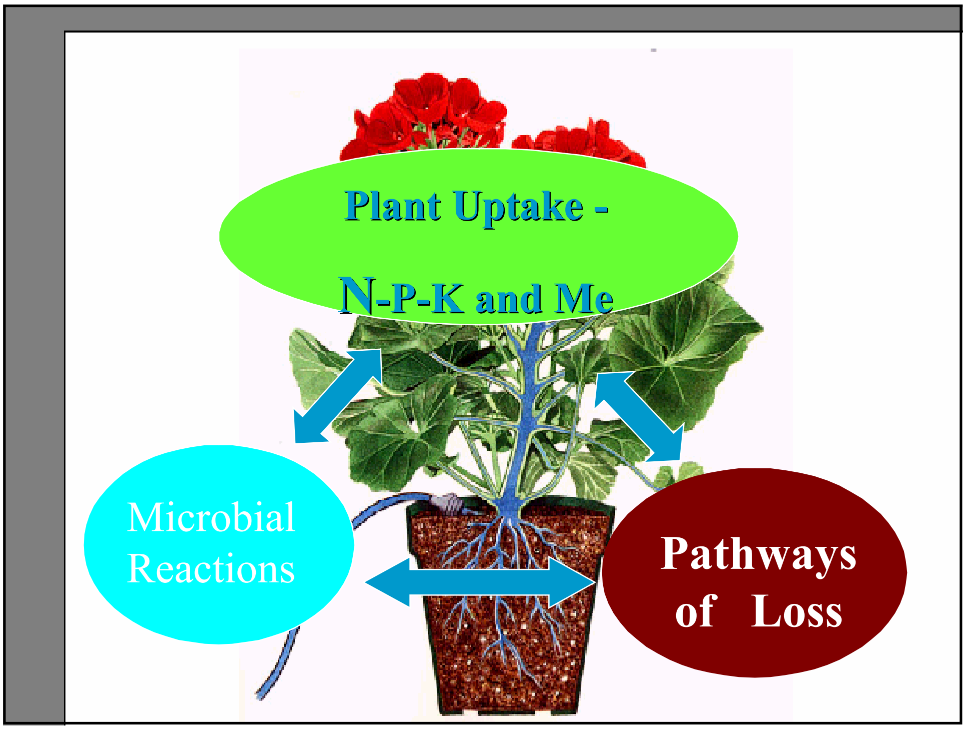
CRF's - "High Agronomic Use Efficiency while minimizing Environmneta l Impact ,,, in one single application"

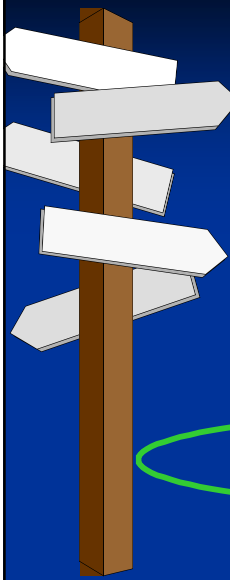
Conventional fertilization goes with high N (and other) losses to GW (NO_3) and to air (NH_3, N_2O ,,No_x)

➔ *Great efforts to develop approaches, techniques and Fertilizers to minimize damage and sustain agriculture (soil, water, production potential)*

➔ *Increasing awareness to fertilizer impact on Environment*



- SYNCRONIZATION- ..Plant Demand vs. Nutrients Supply
- SUPPLY: Preferred & Bio-Available Nutrient Compositions
  - ammonium/nitrate;
  - NH_4^+ /P
  - NH_4^+ or K / Microelements



Improve Application Methods or Modify Fertilizers

- **Positioning:** Banding, nesting,,, Super Granules (high NH_4 conc. To reduce nitrification)
- **Bio-Inhibitor** Amendments (NI's)
- **Controlled Release** Fertilizers
- **Targeted Delivery** Fertigation, Precision Agriculture

CRF vs. SRF

SRF ➔ UF, MEU, SCU, PSCU?

CRF➔ Polymer coated

One single application,,, provides prolonged supply of nutrients

Matches (better) plant demand…

(level, proportions, timing)

The closer the synchrony

higher **NUE** and lower **LOSSES**

CRF vs. SRF

- Release less sensitive to:

Soil/medium type, moisture, pH, microbial activity

- Minimizes:

losses to environment,

application cost,

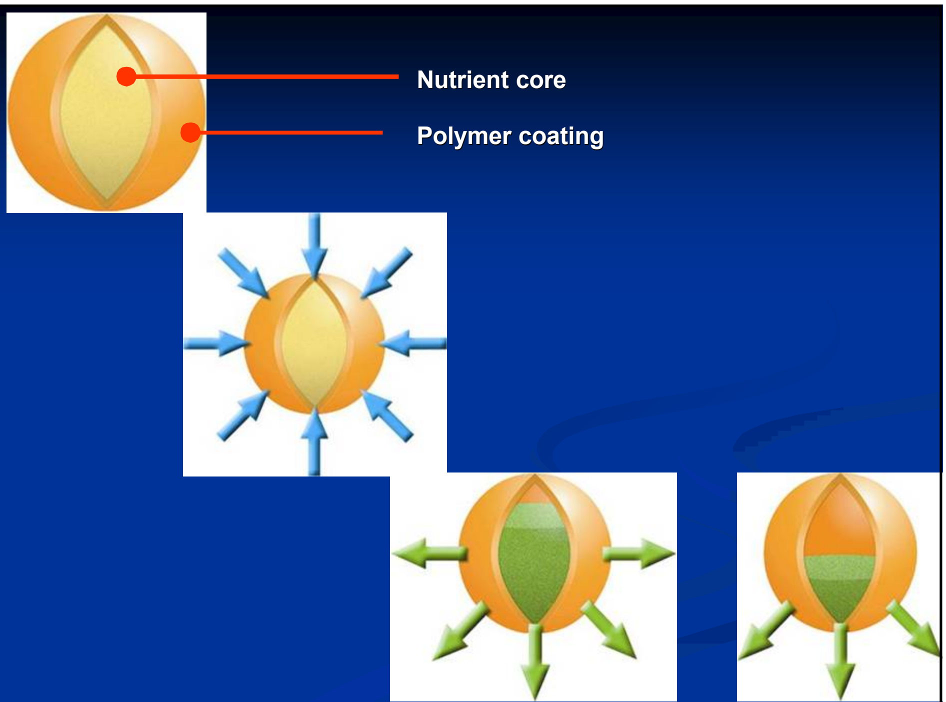
stress on plants,

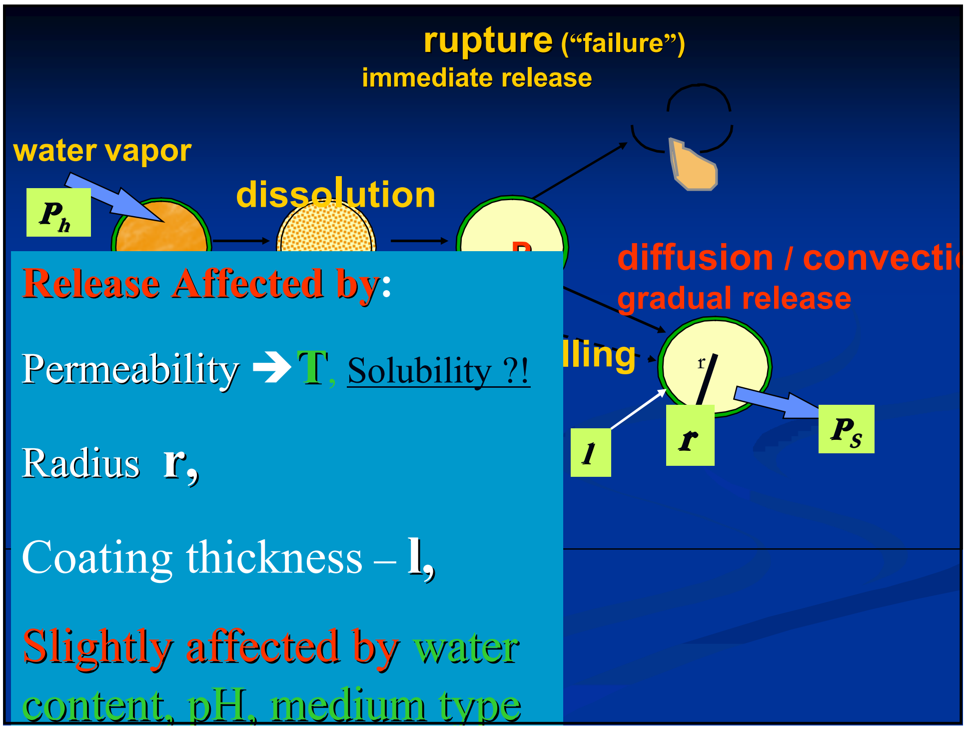
- Ensures: -

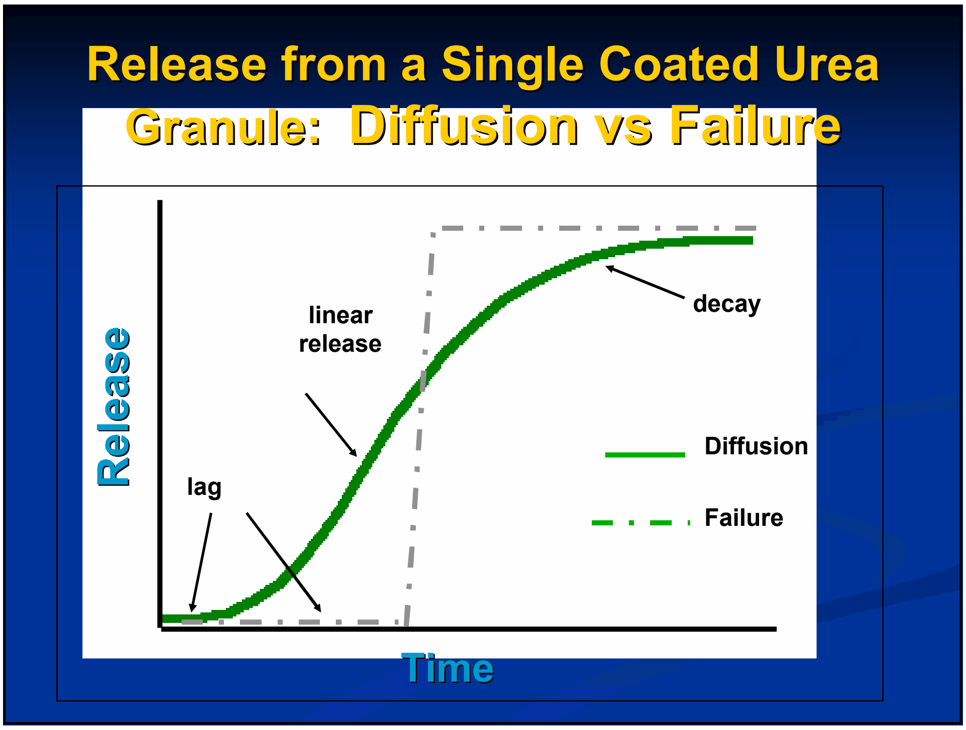
better growth & yields,

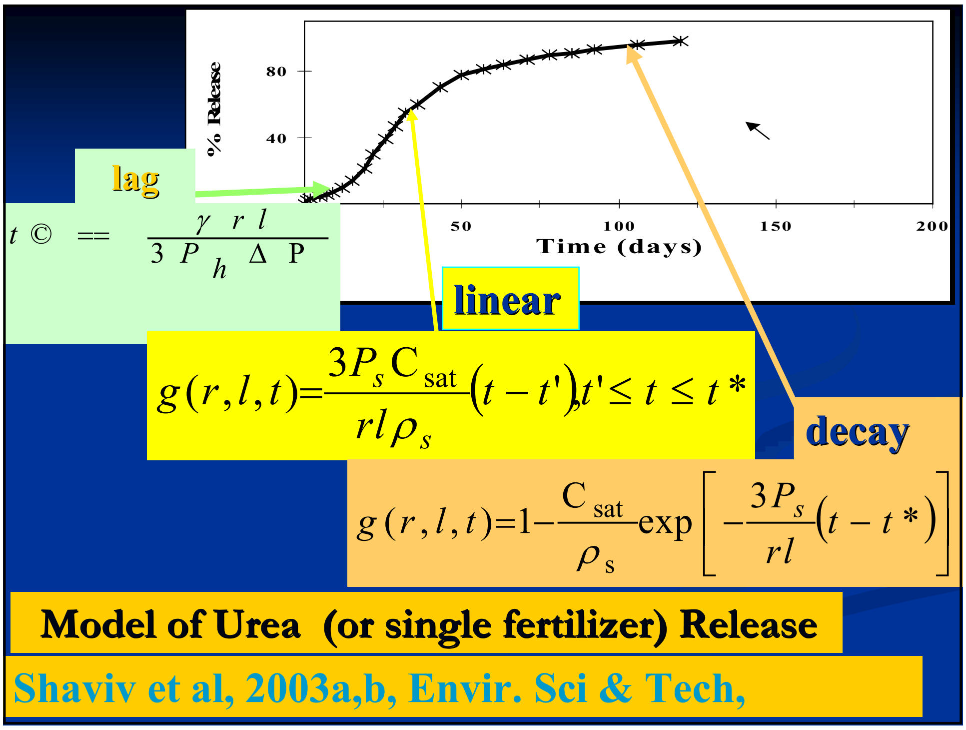
high quality food/product

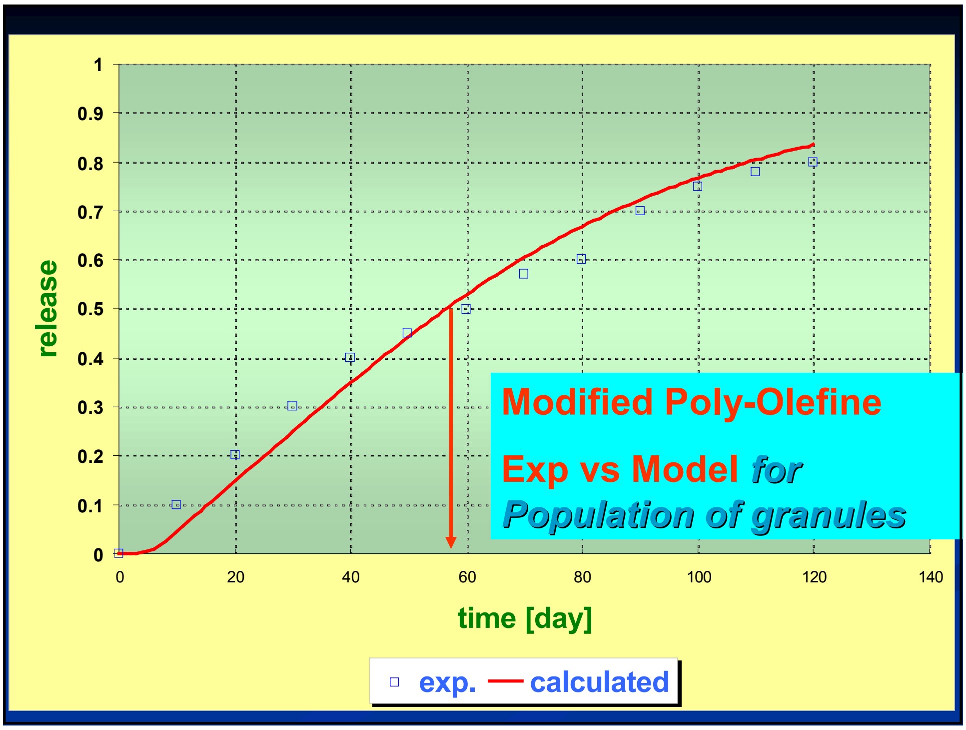
- ,,,,,,,,,,,,,,,,,,,,,,,,,,YET - CRF COST is A LIMIT

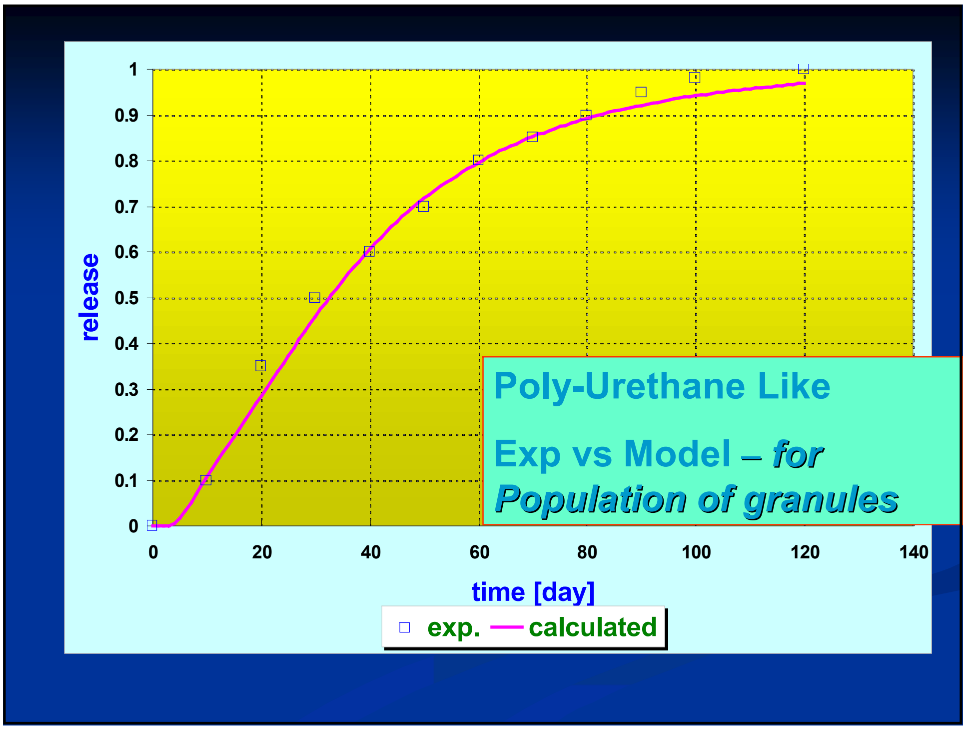



rupture ("failure")
immediate release
water vapor
P_h
dissolution
diffusion / convecti
gradual release
lling
r
l
r
P_S
Release Affected by:
Permeability → T, Solubility ?!
Radius r,
Coating thickness – l,
Slightly affected by water content, pH, medium type


Release from a Single Coated Urea Granule: Diffusion vs Failure
linear release
decay
lag
Diffusion
Failure
Release
Time


% Release
80
40
50
100
150
200
Time (days)
lag
t © == γ r l / 3 P h Δ P
linear
g(r,l,t)= 3P_s C_sat / rlρ_s (t − t'), t' ≤ t ≤ t*
decay
g(r,l,t)=1− C_sat / ρ_s exp[−3P_s / rl (t − t*)]
Model of Urea (or single fertilizer) Release
Shaviv et al, 2003a,b, Envir. Sci & Tech,


release
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
time [day]
Modified Poly-Olefine
Exp vs Model for
Population of granules
exp.
calculated



Energy of Activation for Release helps in Modeling Temperature effect

$$R_{linear} \sim C_{sat} \times P_S = C_{sat}^0 \exp(-EA_C/RT) \times P_S^0 \exp(-EA_{Ps}/RT)$$

$$R_{linear} \sim C_{sat}^0 \times P_S^0 \exp[-(EA_C + EA_{Ps})/RT]$$

$\text{Log } R_{linear}$ vs $1/RT$ ➔ $EA = EA_C + EA_{Ps}$

or,,,,,, the concept of **Cumulative Rate of N release** (Gandeza et al., 1991)

$$CRN = a + b\,(CT) + c\,(CT)^2$$

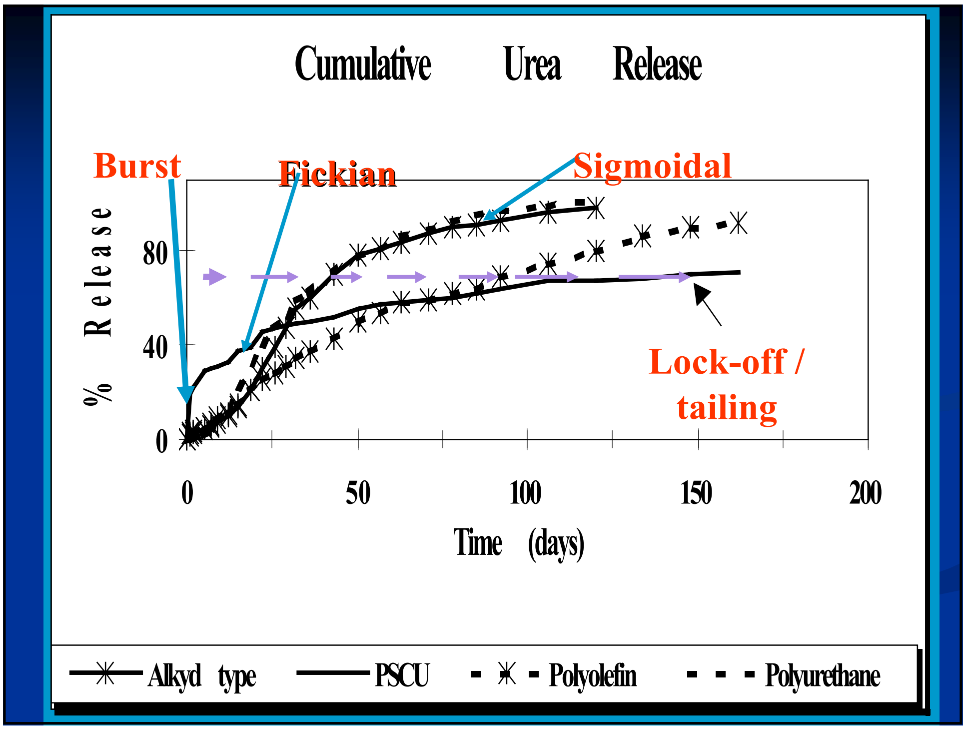
Important Release Features

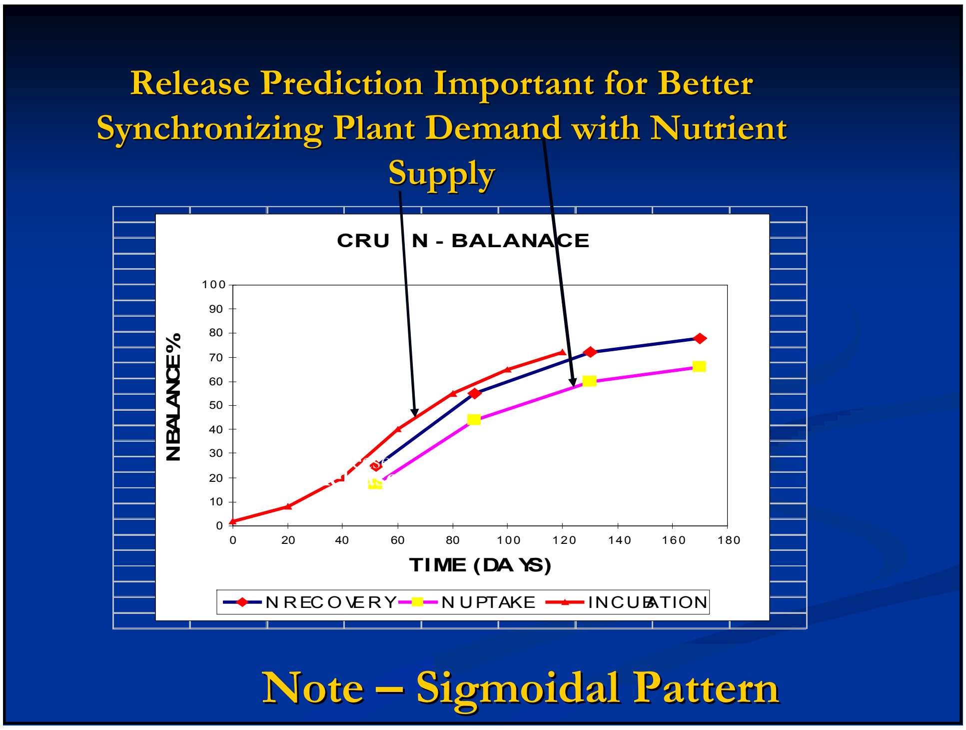
- **Pattern:**
- **Fickian (parabolic), linear, sigmoidal, bi-modal**
- **Duration:**

Time of release of content (*75%, 80%?)*

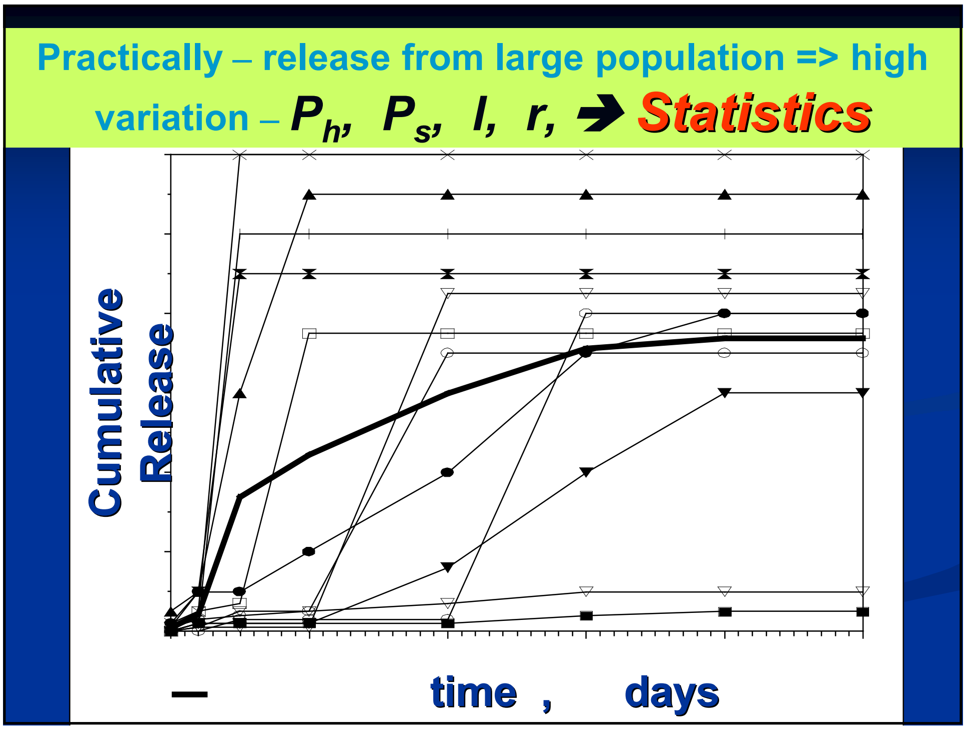
at given temperature, 21^0C or 25^0C (?)

- **Burst (initial release < few %)**
- **Tailing - Lockoff (non utilised nutrient)**





Release Prediction Important for Better Synchronizing Plant Demand with Nutrient Supply
CRU N - BALANACE
NBALANCE%
TIME (DAYS)
N RECOVERY
N UPTAKE
INCUBATION
Note – Sigmoidal Pattern



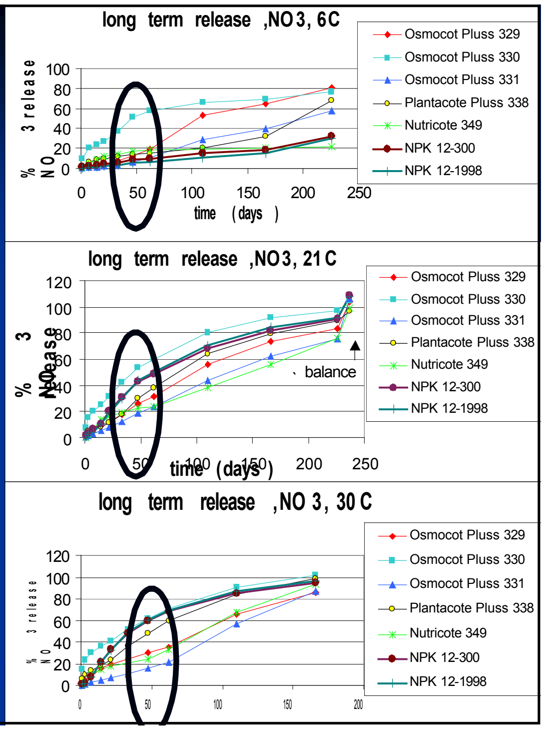
Practically – release from large population => high variation – P_h, P_s, l, r, ➔ Statistics
Cumulative Release
time , days

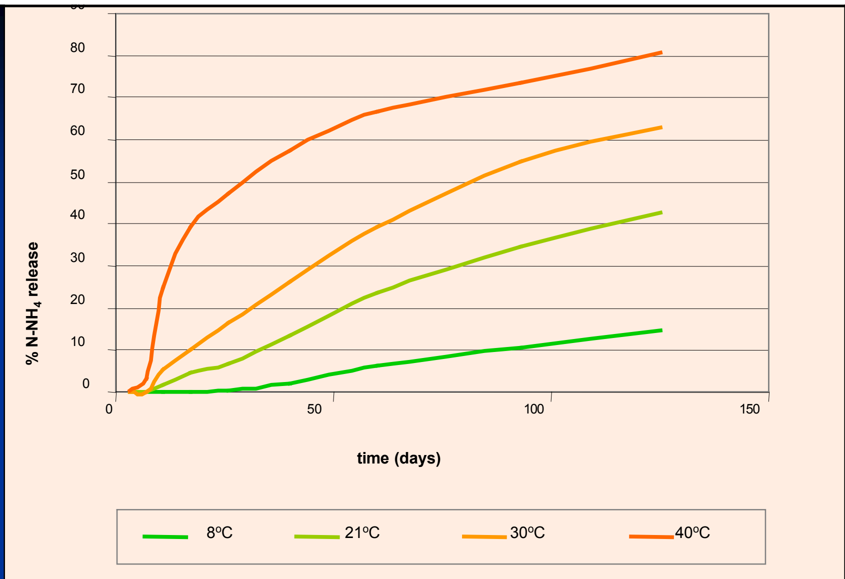
Temperature Effect

Various CRFs

~ 1.5 –2.0 increase

for 10^0C



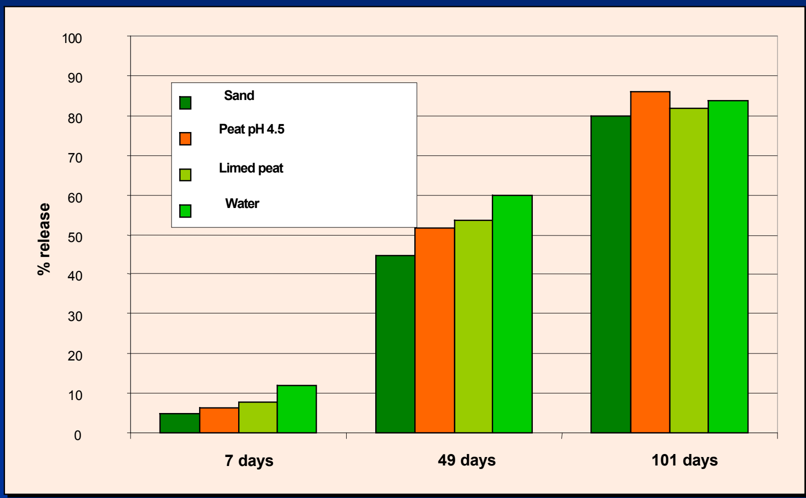


~ 1.5 –2.0 fold increase for each 10^0C

~ ? ~ Q10 factor

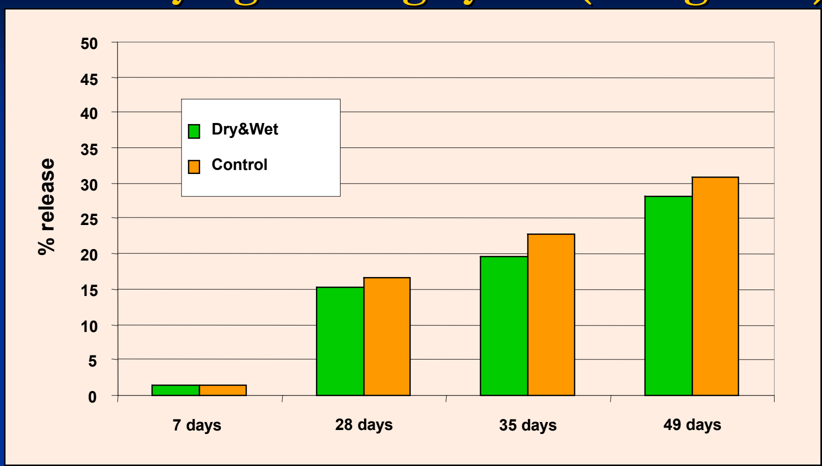
Effect of soil/medium properties (or water status?)

Release at 30°C



⇨ Release **only SLIGLTY** affected by soil type and soil pH

Effect of drying-wetting cycles (=irrigation)



- **Important** -Drying-wetting cycles do not damage the coating
- The release is slowed down when the soil is dry –

(this prevents salt accumulation and root scorching)

Release from a compound CRF

more complicated

- Different Solubilities of NO_3 , NH_4 , P , K
- Limited amount of WATER for dissolution
- Moisture content Changes:

  Free Water,

  Saturated Soil

  Unsaturated Soil

- Temperature Changes

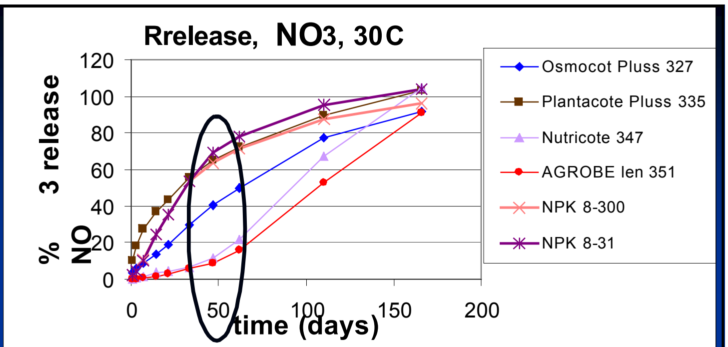
Different

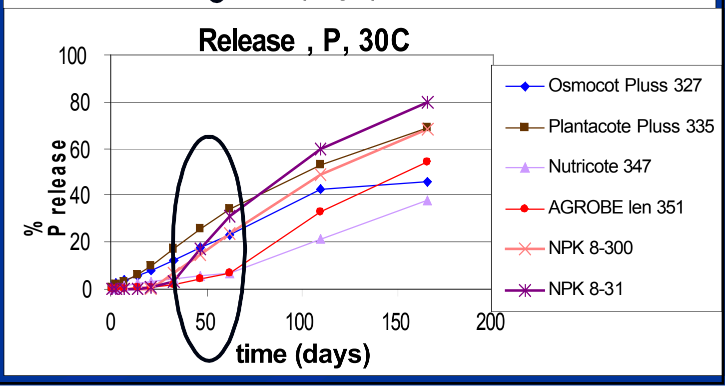
Release Patterns/

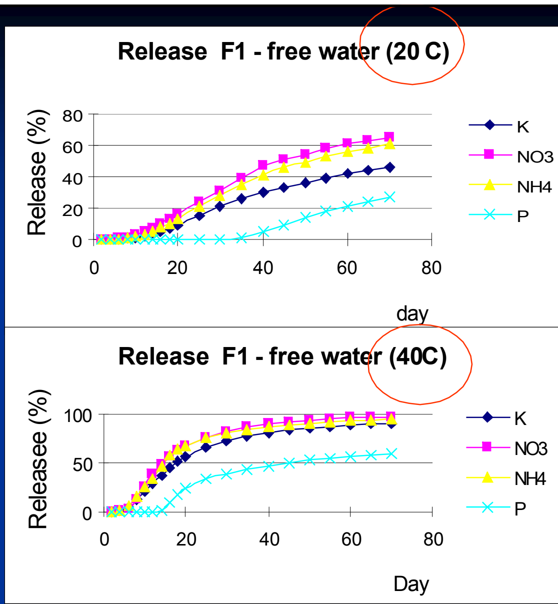
Rate

Typical

For All single Ferts. basis CRFs



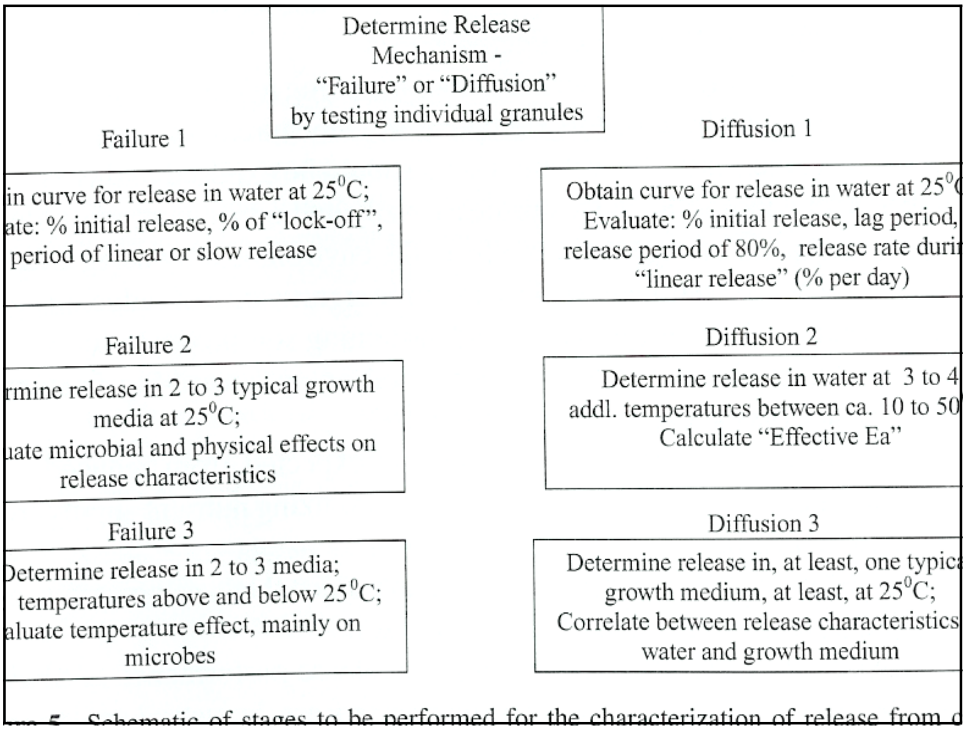


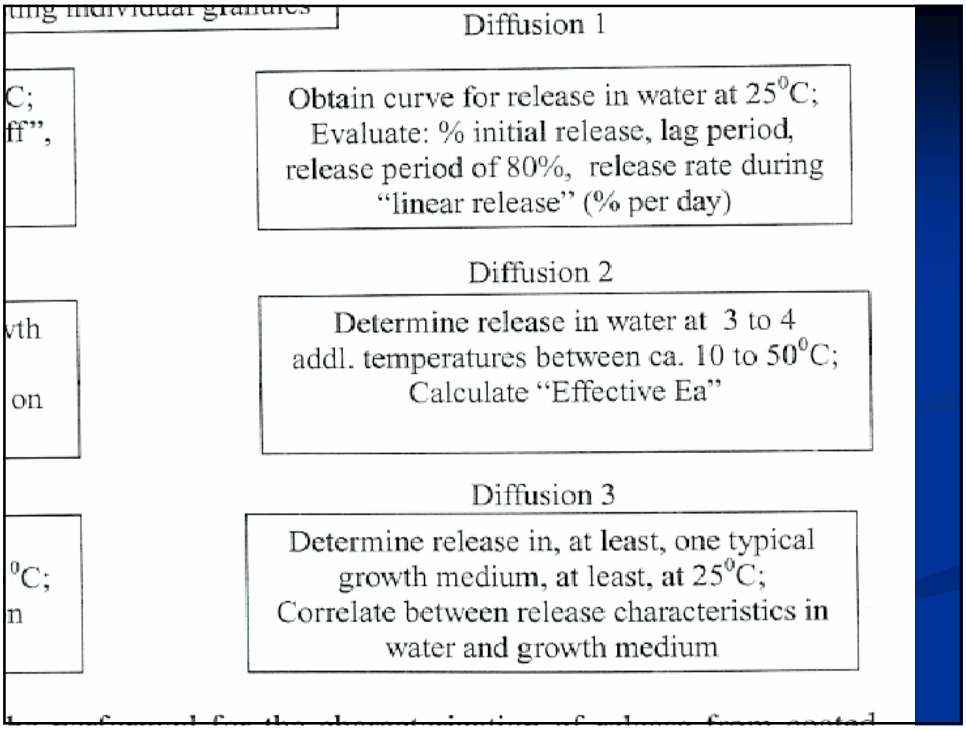


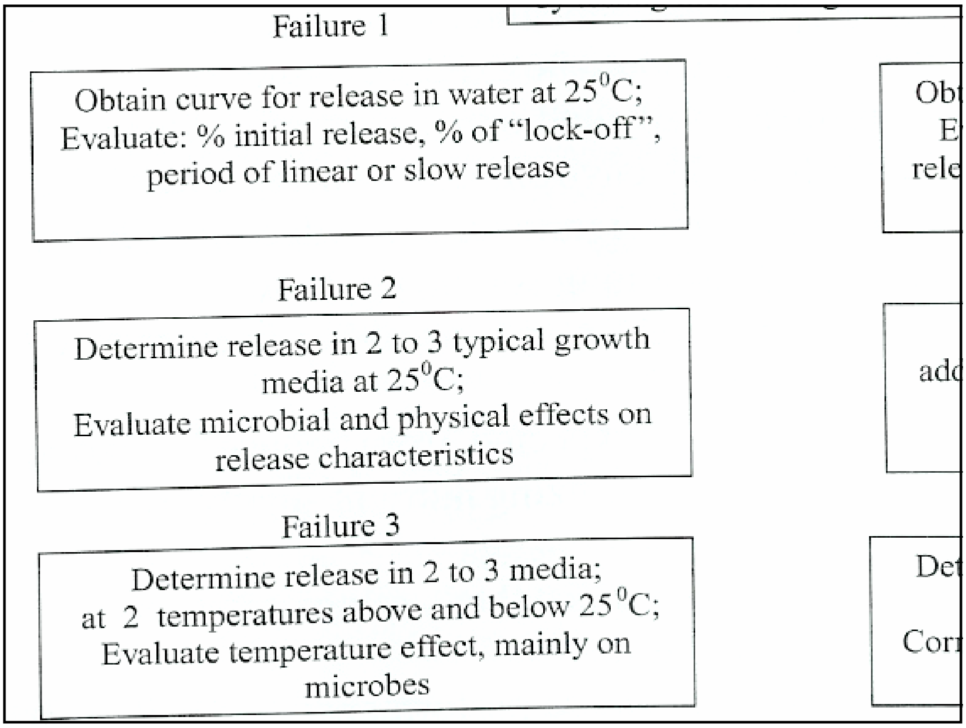
$NO_3 \sim NH_4 > K > P$

Characteristic Coated CRF – **limited** water amount in **granule**

- **Characterization,,,,,,,,,,,,**
- **Testing,,,,,,,,,,,,**
- **Performance Evaluation**


Determine Release
Mechanism -
"Failure" or "Diffusion"
by testing individual granules
Failure 1
in curve for release in water at 25⁰C;
ate: % initial release, % of "lock-off",
period of linear or slow release
Diffusion 1
Obtain curve for release in water at 25⁰
Evaluate: % initial release, lag period,
release period of 80%, release rate duri
"linear release" (% per day)
Failure 2
rmine release in 2 to 3 typical growth
media at 25⁰C;
uate microbial and physical effects on
release characteristics
Diffusion 2
Determine release in water at 3 to 4
addl. temperatures between ca. 10 to 50
Calculate "Effective Ea"
Failure 3
Determine release in 2 to 3 media;
temperatures above and below 25⁰C;
aluate temperature effect, mainly on
microbes
Diffusion 3
Determine release in, at least, one typic
growth medium, at least, at 25⁰C;
Correlate between release characteristics
water and growth medium


Diffusion 1
Obtain curve for release in water at 25⁰C;
Evaluate: % initial release, lag period,
release period of 80%, release rate during
"linear release" (% per day)
Diffusion 2
Determine release in water at 3 to 4
addl. temperatures between ca. 10 to 50⁰C;
Calculate "Effective Ea"
Diffusion 3
Determine release in, at least, one typical
growth medium, at least, at 25⁰C;
Correlate between release characteristics in
water and growth medium



Experiments in Different Planting Systems

- Pots, low volume
- Containers (detached media), 30 Liter
- Lysimeters , 130 liter (to mimic field conditions „„ACAP)
- Real soil experiments, complicated/difficult when Mass Balance & Environmnetal Impact needed

Ryegrass Experiment – to test the effect of

Urea Release Pattern on Growth and Leaching

4 cuttings (each 4-5 weeks)

Leaching before each cutting

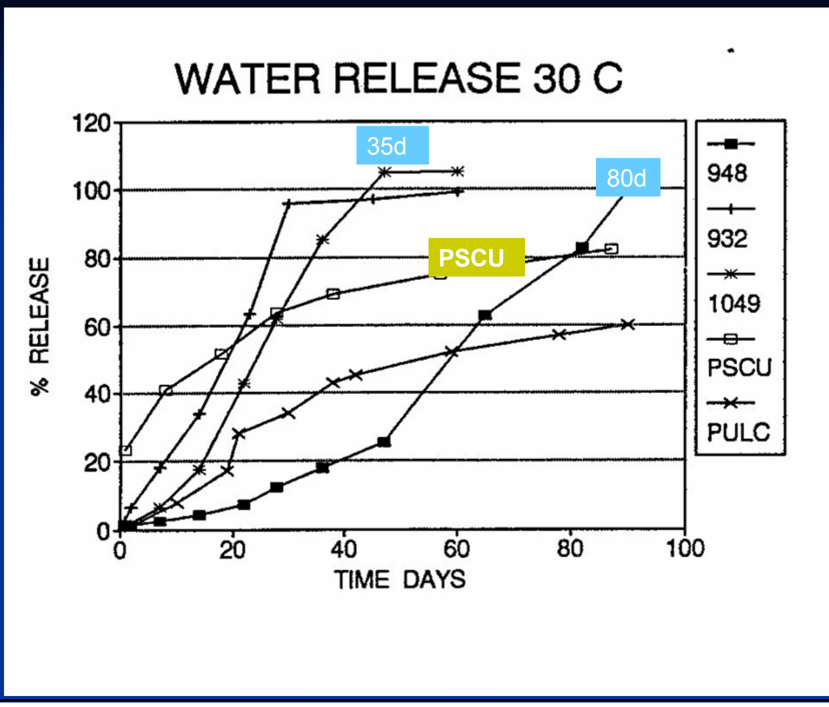
CRFs –

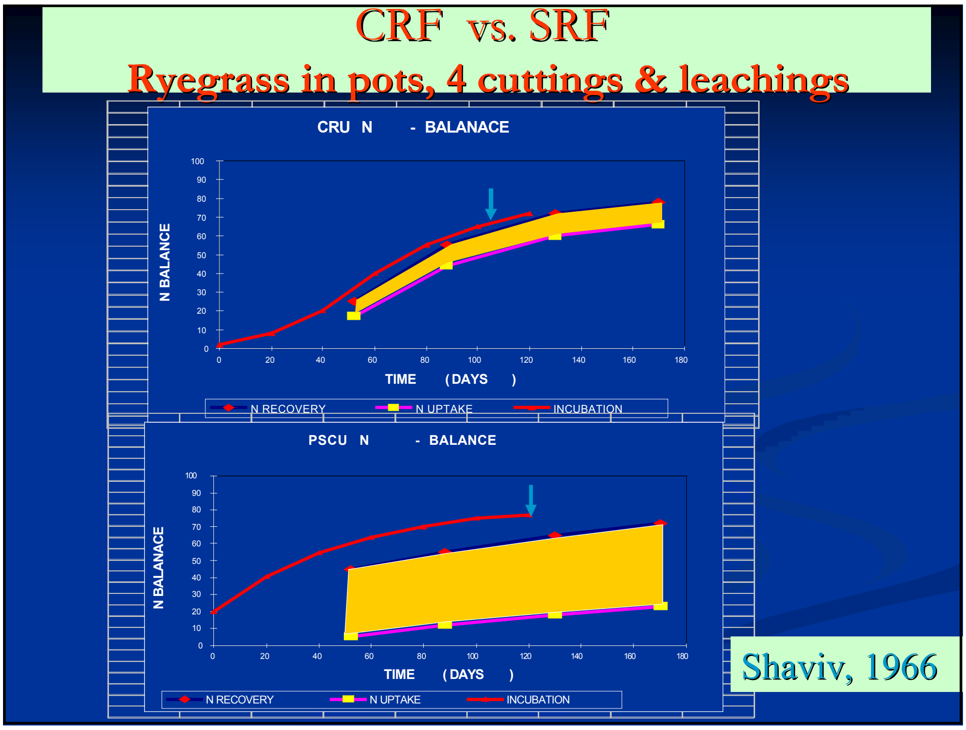
Three N levels 0.8, 1.2, 1.6 gN/pot

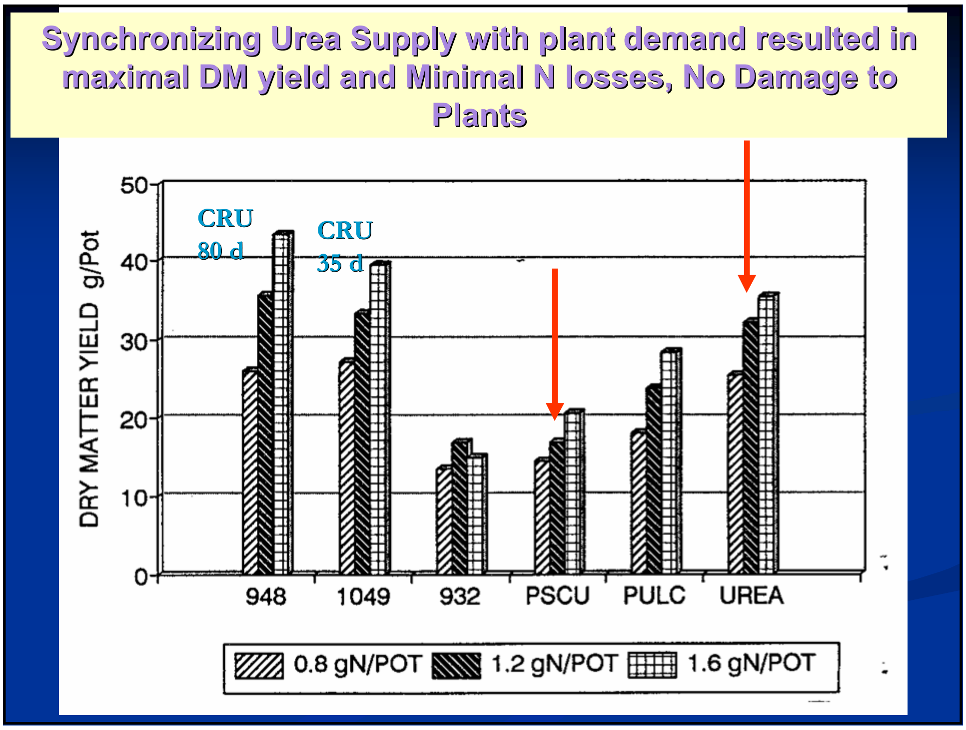
Special CRU 932; CRU 948; CRU 1049 with different SIGMOIDAL N release patterns and Durations

PSCU – Polymer sulphur Coated Urea - with "burst" and "lockoff"

Compared to urea application 1/3 at start (solid) 1/3 after 1st harvest (liquid); 1/3 after 2nd harvest,




CRF vs. SRF
Ryegrass in pots, 4 cuttings & leachings
CRU N - BALANACE
N BALANCE
TIME (DAYS)
N RECOVERY
N UPTAKE
INCUBATION
PSCU N - BALANCE
N BALANACE
TIME (DAYS)
N RECOVERY
N UPTAKE
INCUBATION
Shaviv, 1966


Synchronizing Urea Supply with plant demand resulted in maximal DM yield and Minimal N losses, No Damage to Plants
DRY MATTER YIELD g/Pot
CRU 80 d
CRU 35 d
948
1049
932
PSCU
PULC
UREA
0.8 gN/POT
1.2 gN/POT
1.6 gN/POT

Container Experiments:
Volcanic Tuff - 1999, Perlite - 2000

Red Volcanic Tuff, 0-8 mm (porous)

CEC 15 meq/100g, Qsat 50%

(Amorphous Clay, Volcanic Glass, Primary Min., Iron Min.)

Perlite, 2-3mm (porous)

low CEC, Qsat 65%

Basil - 4 Harvestes (30 days)

3-5 fertigations/days

continuos leaching + collection

monitoring : fertigation, leachate,

assay: plants => nutrient uptake

Experimental setup, Tuff, 1999.

Treatment Description

B	Control A	D
D	C	B

A- Fertigation: First 1/3 irrigation only, 2/3 with 100% of reference

Total applied- 65% of reference

A	C	D
Control C	B	A

B- 20% fertigation and 45% as banded CRF.

Total applied - 65% of reference

D	C	B
B	A	Control D

C- Fertigation with 65% of reference level, no leaching period

Total applied- 65% of reference

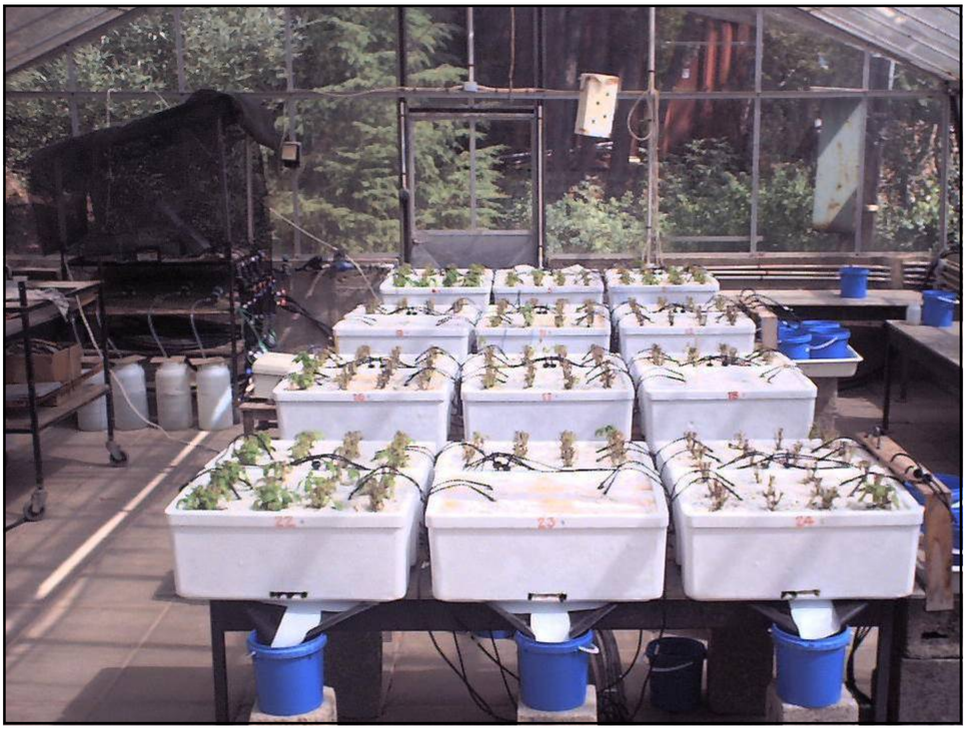
C	D	A
A	Control B	C

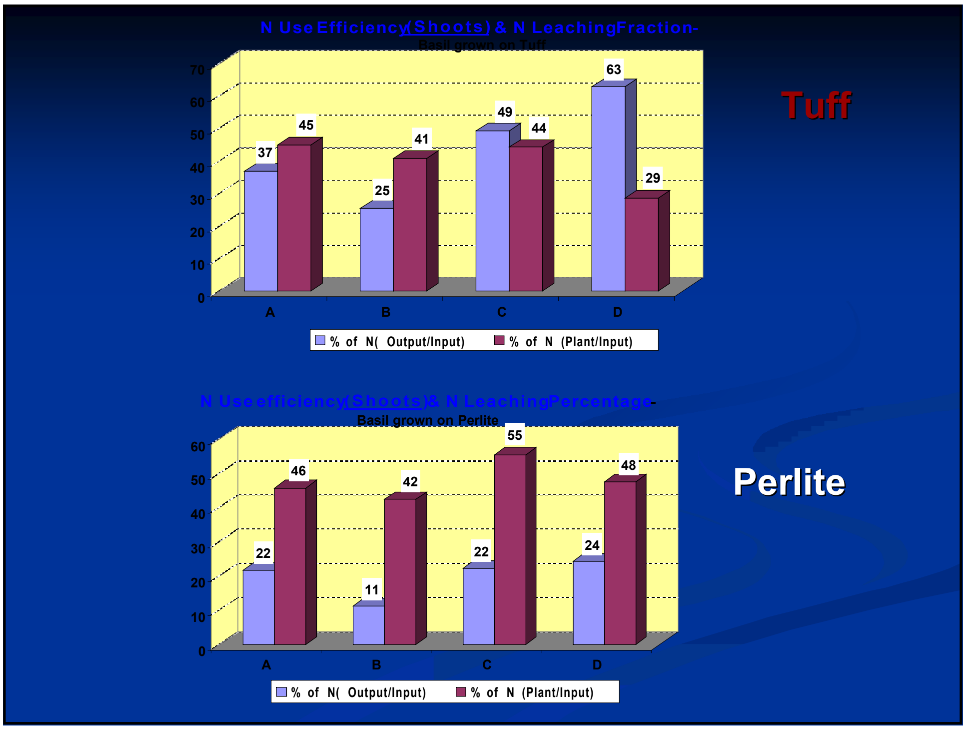
D- Fertigation according to commercial recommendations, Reference treat

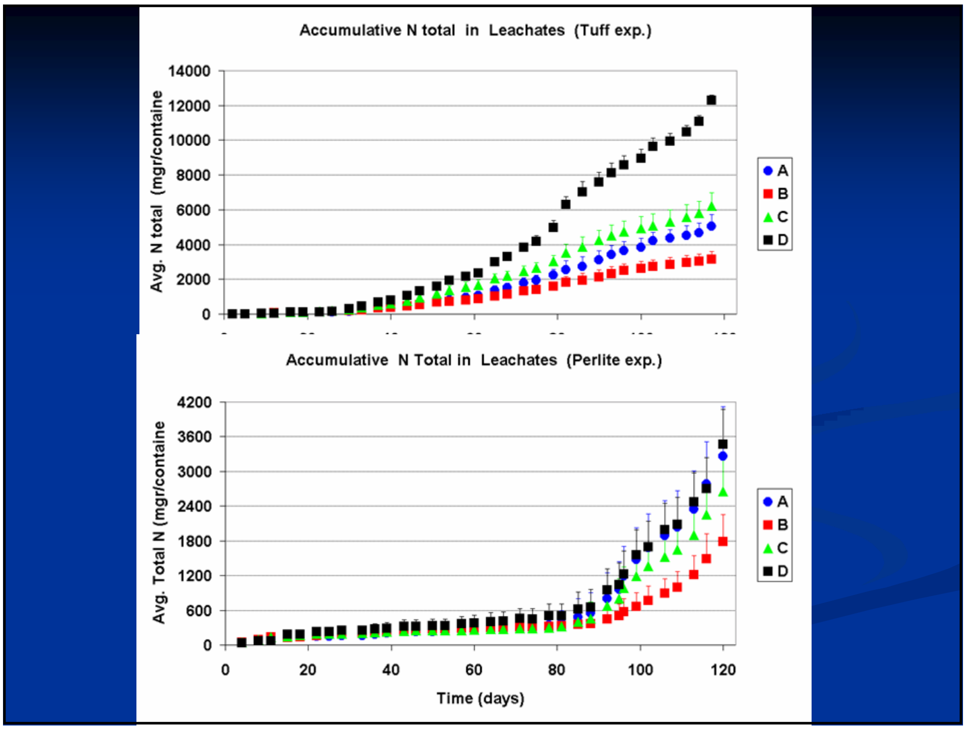
Total applied - 100% (reference)

Reference Treatment: 70 ppm N after planting, raising to 120 after 2 weeks

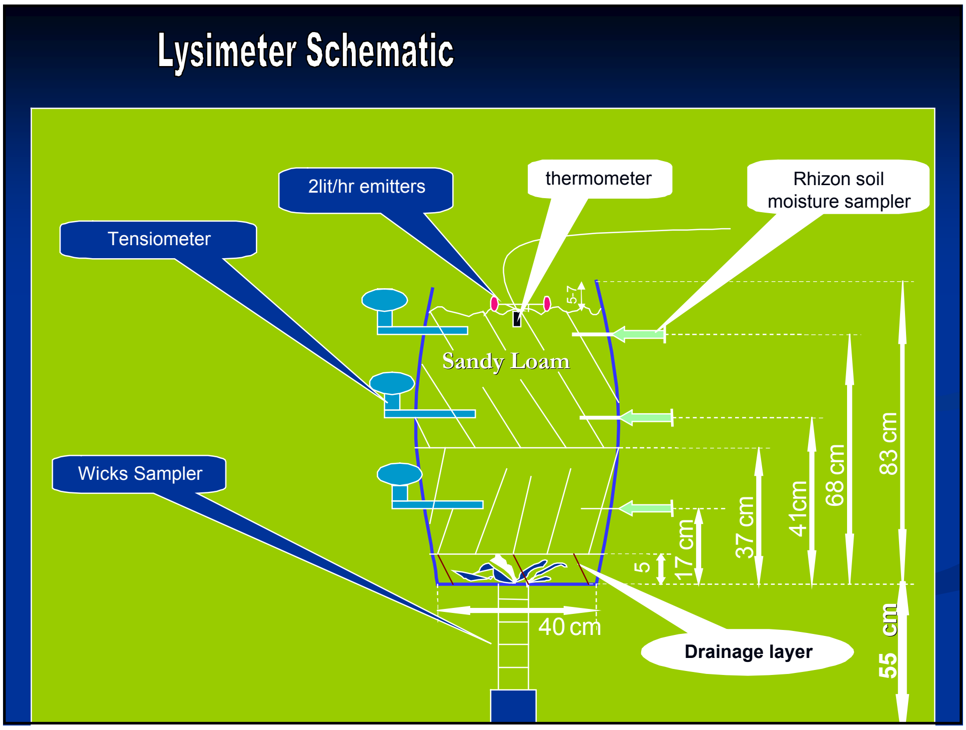
1. Fertilizer used for fertigation: 6-3-6 +6ME (Deshen Gat), ammonium/nitrate - 60:40
2. Applied controlled release fertilizer (CRF) "Multicote" (Haifa Chemicals), with a "tailor made" composition of : 16.5-8.5-16.5



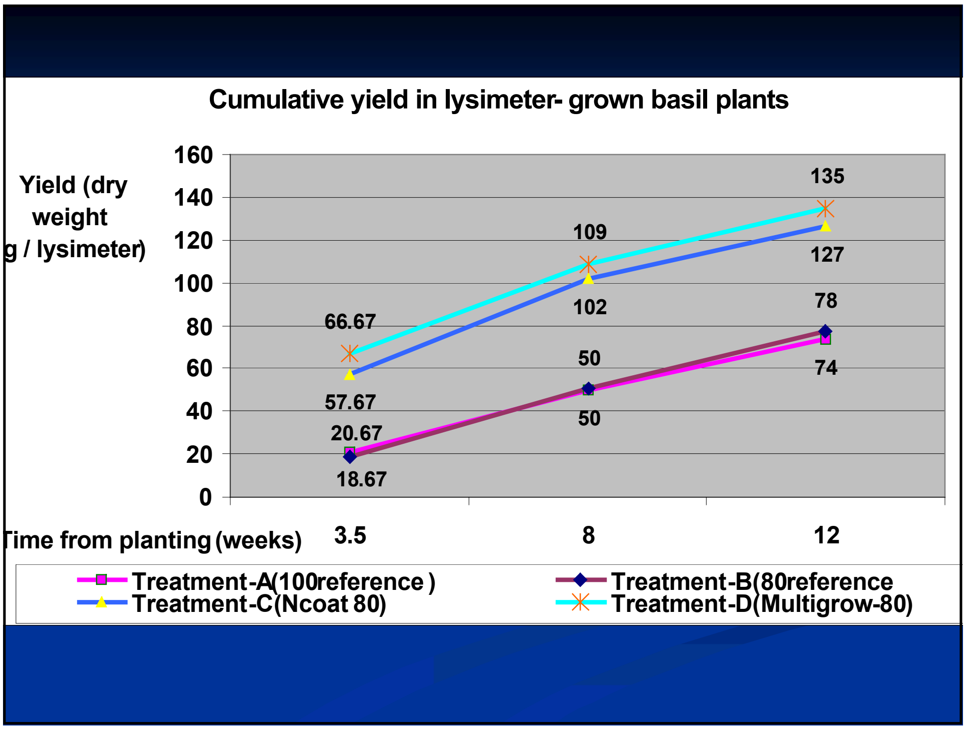

N Use Efficiency (Shoots) & N Leaching Fraction-
Basil grown on Tuff
70
60
50
40
30
20
10
0
37
45
25
41
49
44
63
29
A
B
C
D
% of N(Output/Input)
% of N (Plant/Input)
Tuff
N Use efficiency (Shoots) & N Leaching Percentage-
Basil grown on Perlite
60
50
40
30
20
10
0
22
46
11
42
22
55
24
48
A
B
C
D
% of N(Output/Input)
% of N (Plant/Input)
Perlite



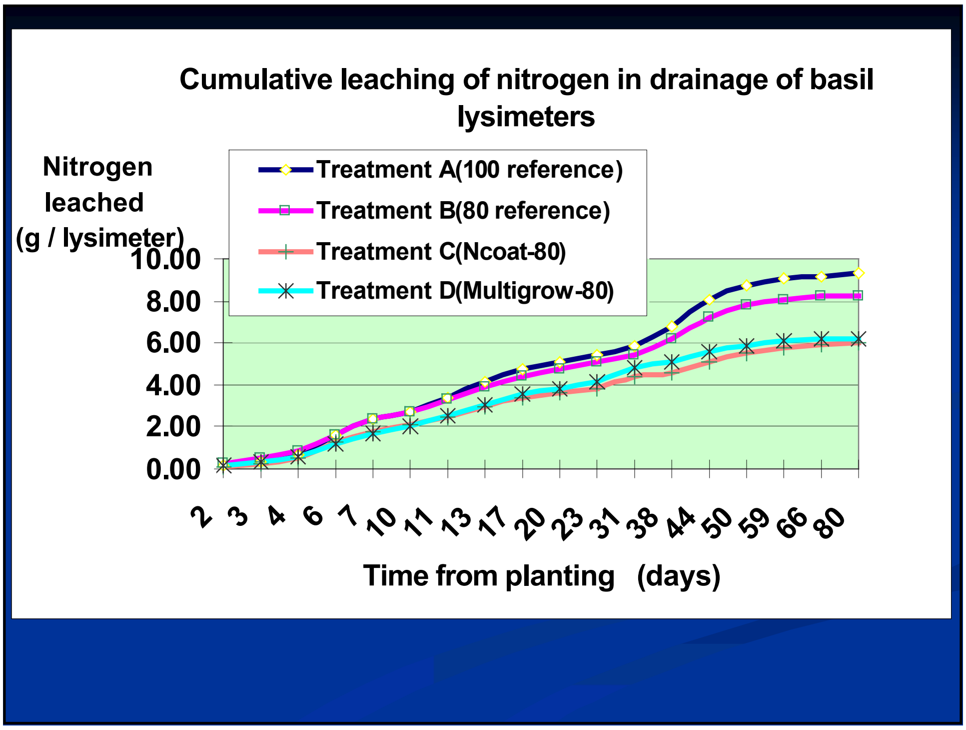
Lysimeters (substitute experiment in "real" soil)

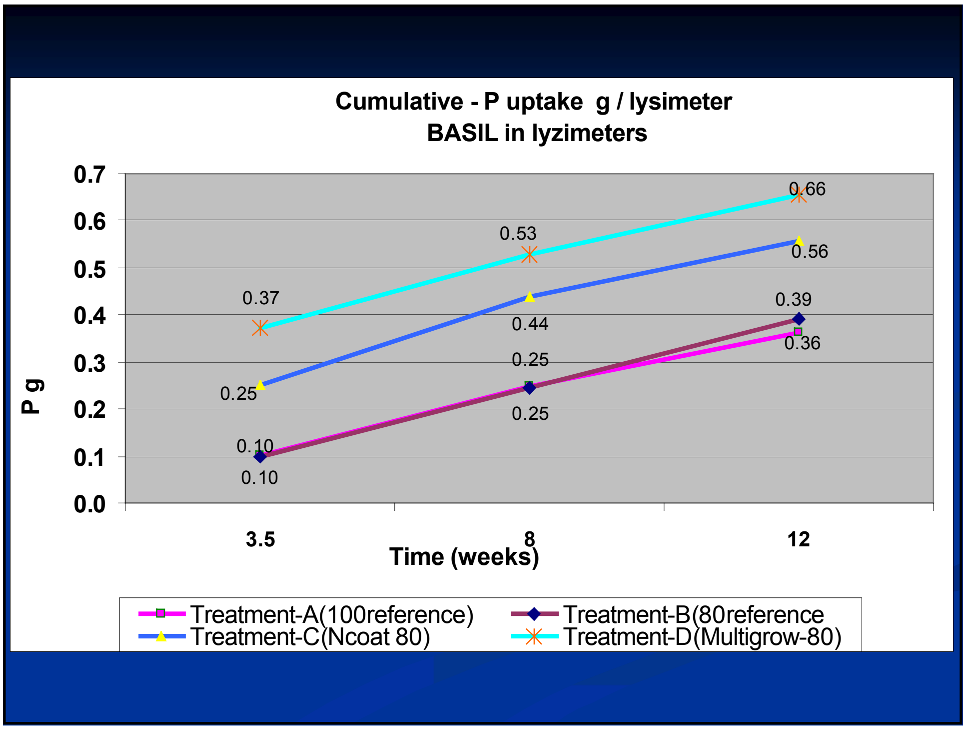


Lysimeter Schematic
2lit/hr emitters
thermometer
Rhizon soil moisture sampler
Tensiometer
Sandy Loam
Wicks Sampler
40 cm
Drainage layer
5
17 cm
37 cm
41cm
68 cm
83 cm
55 cm



Cumulative yield in lysimeter- grown basil plants
Yield (dry weight g / lysimeter)
160
140
120
100
80
60
40
20
0
Time from planting (weeks)
3.5
8
12
66.67
57.67
20.67
18.67
109
102
50
50
135
127
78
74
Treatment-A(100reference)
Treatment-B(80reference
Treatment-C(Ncoat 80)
Treatment-D(Multigrow-80)


Cumulative leaching of nitrogen in drainage of basil lysimeters
Nitrogen leached (g / lysimeter)
Treatment A(100 reference)
Treatment B(80 reference)
Treatment C(Ncoat-80)
Treatment D(Multigrow-80)
10.00
8.00
6.00
4.00
2.00
0.00
2 3 4 6 7 10 11 13 17 20 23 31 38 44 50 59 66 80
Time from planting (days)


Cumulative - P uptake g / lysimeter
BASIL in lyzimeters
P g
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.66
0.53
0.56
0.37
0.39
0.44
0.25
0.36
0.25
0.25
0.10
0.10
3.5
8
12
Time (weeks)
Treatment-A(100reference)
Treatment-B(80reference
Treatment-C(Ncoat 80)
Treatment-D(Multigrow-80)

Important Features Summary

- Release Pattern, (shape, lag, lock off)
- Release Duration
- Differential Release N-P-K
- Temperature effect on Release
- Medium/Env. Cond. effect on Release

Additional points for consideration ……

- Microelements release (??)
- Ammonium/Nitrate Ratio
- Urea in the CRF (?)
- Degrability (erodibility)/Bio-degrability of coating

When are "real" advantages of the CRF vs. "More Conventional" alternative expected?

Depends on factors such :

- Culturing Conditions: field (row, whole bulk, orchard), greenhouse (soil or detached media), potting media (small, large)
- Medium or soil type: Light? Heavy? CEC? OM?
- Leaching: (irrigation system, rain-fed,),
- Nutrient loss mechanisms
- Balanced/Imbalanced nutrient supply (availability problems)
- Environmnetal aspects
- pH, Ec, Eh constrains
- Special needs: e.g. ionic species combinations of

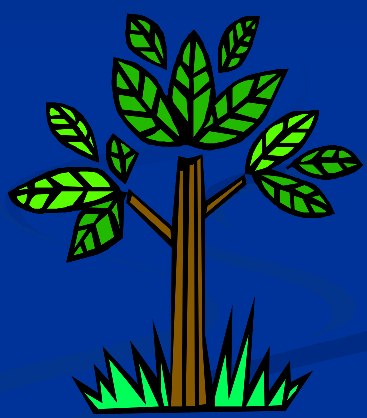
ammonium-nitrate,, ammonium-P,

Future Needs,,,,,,, or Improvements

- **Improved utilization of advanced technologies , development of new concepts for preparing more cost-effective CRFs**
- Better **Quantification of the agronomic and economic advantages**
- **Better assessment of expected benefits to the environment**
- **Development/Standardization of tests for characterizing the release performance of SRF/CRFs to improve**
  - **user's decision-making process,**
  - **industrial quality control,**
  - **assist legislation efforts.**
- **Utilization of mechanistic-mathematical models for predicting release of nutrients under laboratory and field conditions, and as a design tool for technologists**

- Knowledge Integration to result in:
    - Better Use Instructions,
    - Proper definitions of products
    - Improved/Relevant Performance Information
- Users should be exposed to this knowledge to help them choose SRF/CRFs professionally and on quantitative basis
- Agronomists, Environmentalists should be exposed to this knowledge to help them in better advising from both Agronomic (&economic) and Environmnetal points of view

Thanks



Specific Points in Case of Questions

Urea hydrolysis increases soil pH and losses of Ammonia

$(NH_2)_2CO + H^+ + 2H_2O \Rightarrow 2NH^+_4 + HCO^-_3$

$(NH_4)_2CO_3 \Leftrightarrow NH_3 + H_2CO_3$

High pH and Ammonia reduce activity of Nitrobacter and hence cause accumulation of "toxic" Nitrite during nitrification

Nitrification - FIRST STEP - inhibited by:
specific inhibitors

$2NH^+_4 + 3\ O_2 \Rightarrow 2NO^-_2 + 2H_2O + 4\ H^+$ (Nitrosomonas, Nitrosospira)

$2NO^-_2 + O_2 \Rightarrow 2NO^-_3$ (Nitrobacter) (high pH, NH_3)

Application of local high urea concentrations (e.g., basal placement) may cause:

1. Increased pH (due to formation of ammonium carbonate)
2. Increased ammonia levels due to the decomposition of the ammonium carbonate and high pH. In calcareous soils the effect is dramatically enhanced!!
3. In containers, with restricted volume – the local concentration of applied urea may be high (if not carefully applied) and may stimulate processes like in 1 and 2.
4. High pH and ammonia may damage roots and also affect the fast oxidation of nitrite into nitrate and cause accumulation of Toxic levels of Nitrite

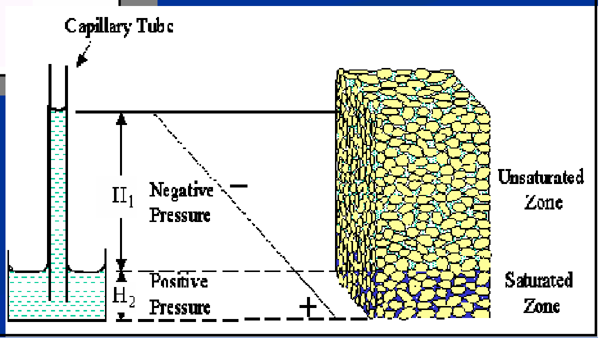
Any system providing metered supply or controlled supply of urea has a great potential to reduce the above effects.

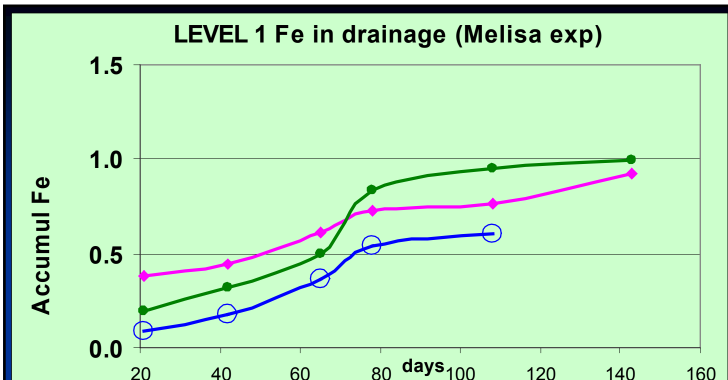
Too high (local) levels of applied urea may turn soon into Ammonium after urea the hydrolysis (~half a day).

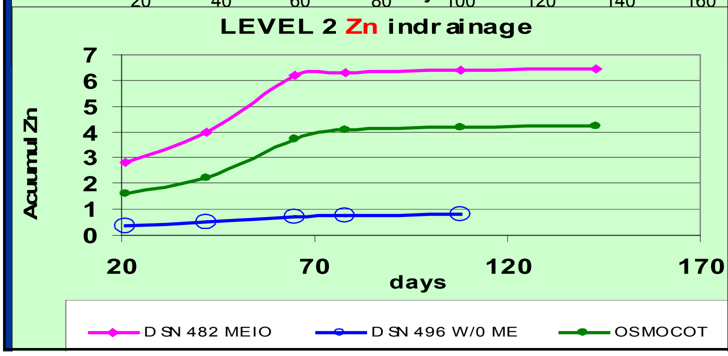
Exposing plants to high loads of ammonium and particularly in containers (detached media) with restricted volume and neutral to slightly acidic pH, may induce further acidification due to nitrification or ammonium uptake by plants.

Metered or Controlled Supply of the ammoniacal source (including urea) is not expected to cause dramatic acidification, particularly when a balanced supply of urea/ammonium and nitrate is given.

Potting media







Accumulating **Fe** with leaching time

ccumulating **Zn** with leaching time

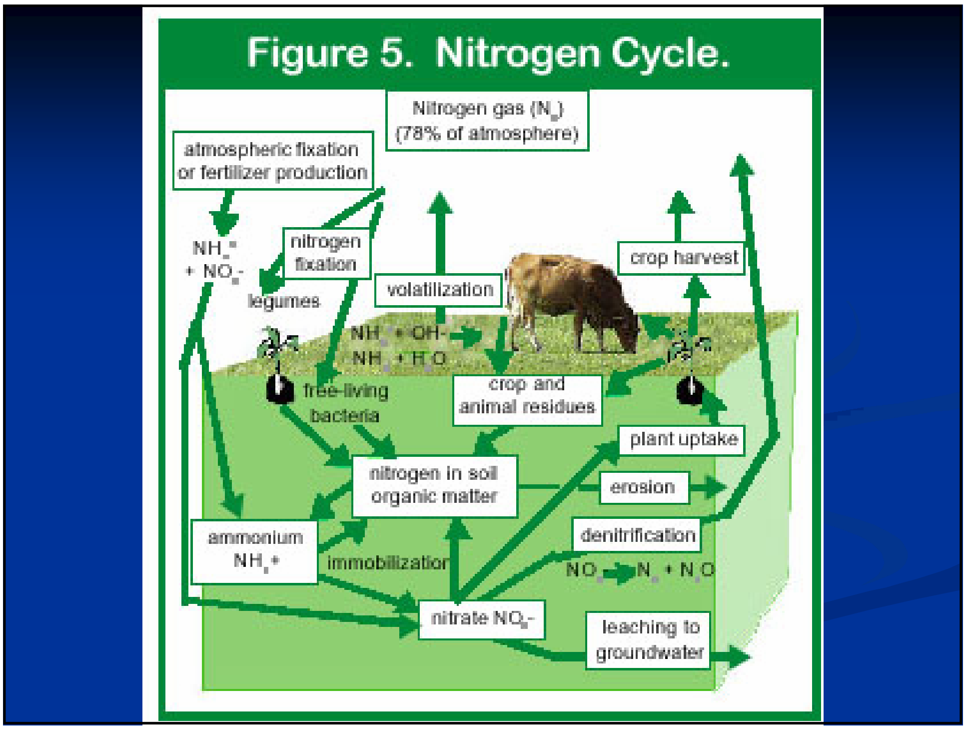


Figure 5. Nitrogen Cycle.
Nitrogen gas (N2)
(78% of atmosphere)
atmospheric fixation
or fertilizer production
nitrogen
fixation
legumes
volatilization
crop harvest
free-living
bacteria
crop and
animal residues
plant uptake
nitrogen in soil
organic matter
erosion
ammonium
NH4+
immobilization
denitrification
nitrate NO3-
leaching to
groundwater