Field testing and modeling the effects of treated wastewater for crop irrigation near Dodge City, KS: Minimizing the Nitrogen adverse effects

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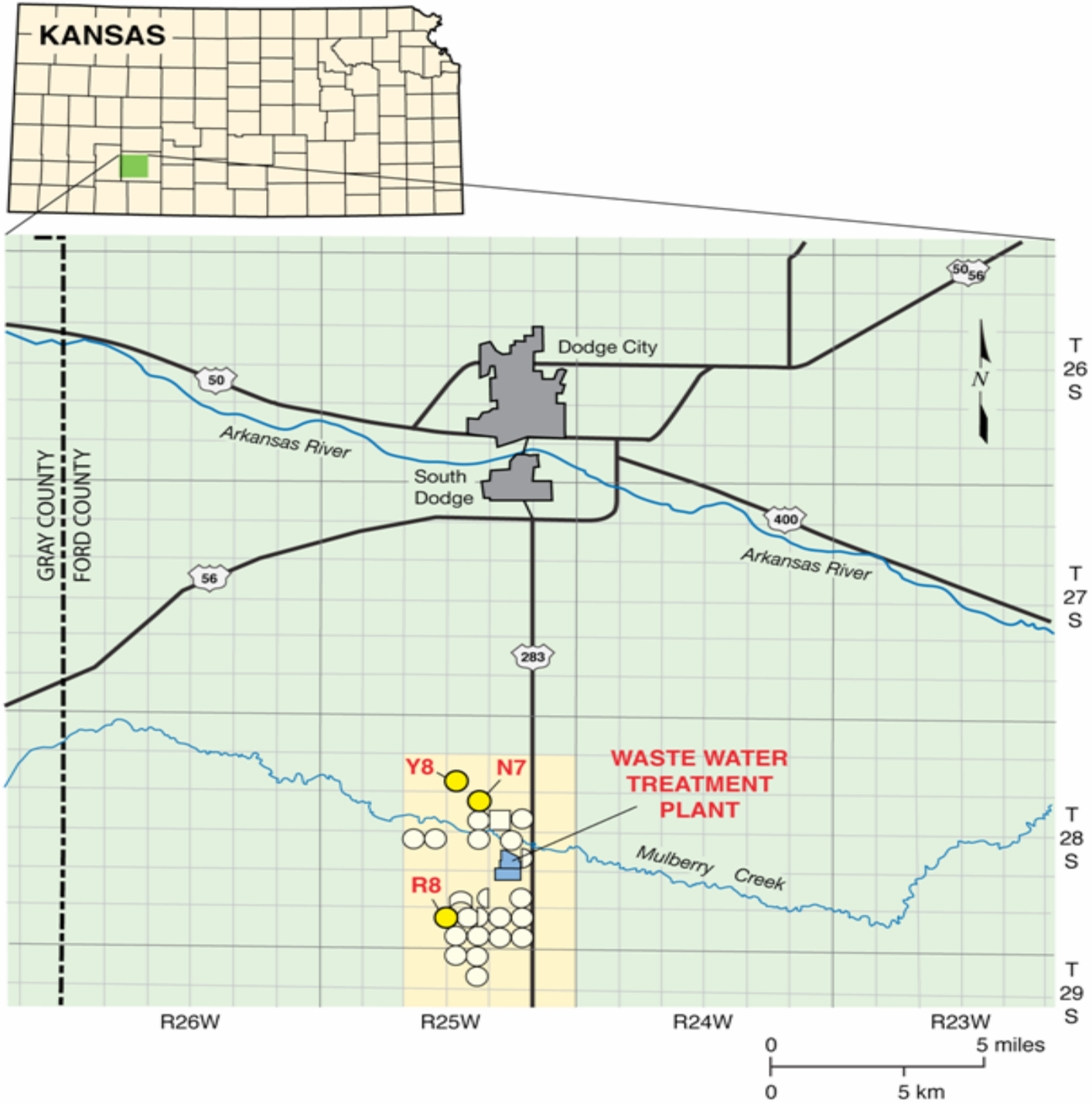
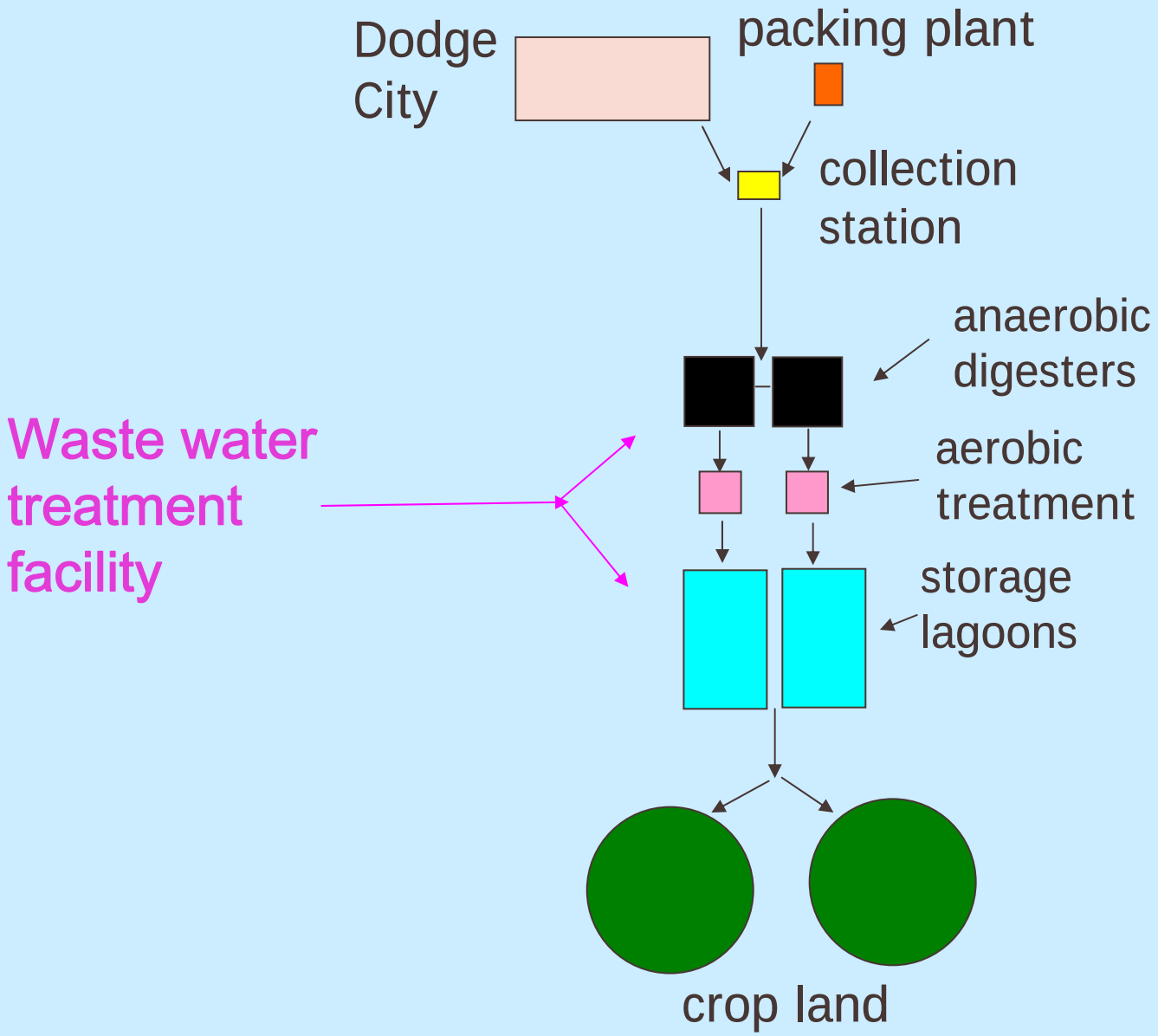
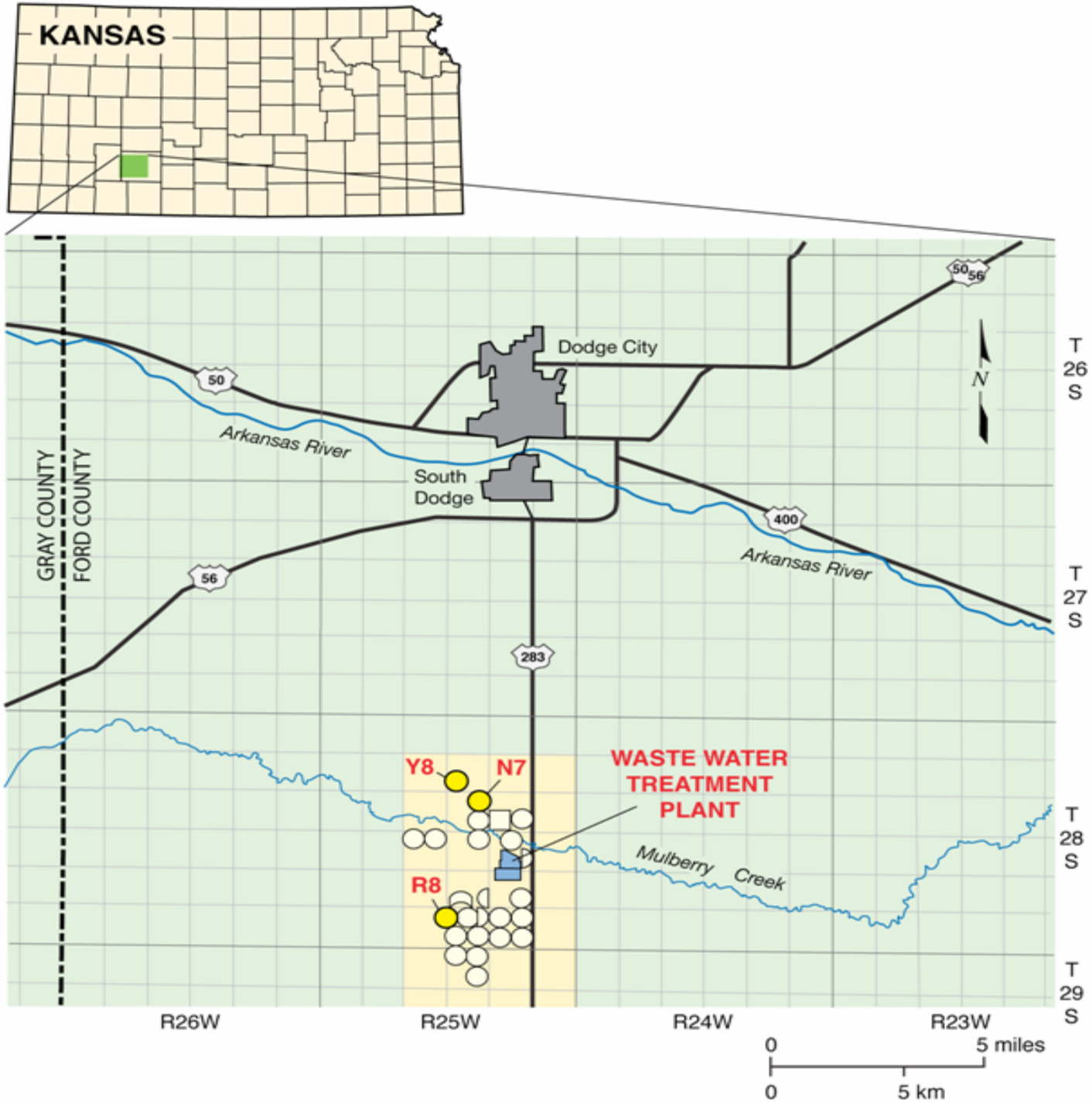

KANSAS
Dodge City
South Dodge
Arkansas River
Arkansas River
Mulberry Creek
GRAY COUNTY
FORD COUNTY
50
56
400
283
N
Y8
N7
R8
WASTE WATER TREATMENT PLANT
T 26 S
T 27 S
T 28 S
T 29 S
R26W
R25W
R24W
R23W
0
5 miles
0
5 km

Dodge City Wastewater Treatment Plant (DCWTP) system schematic

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R24W
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0
5 miles
0
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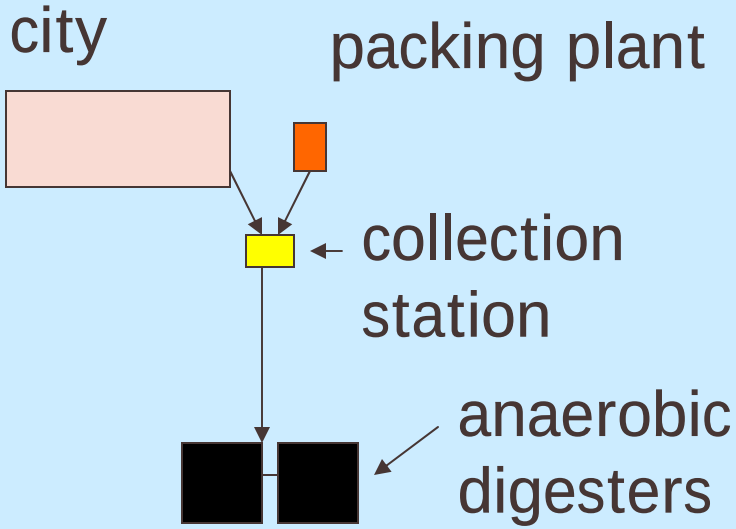
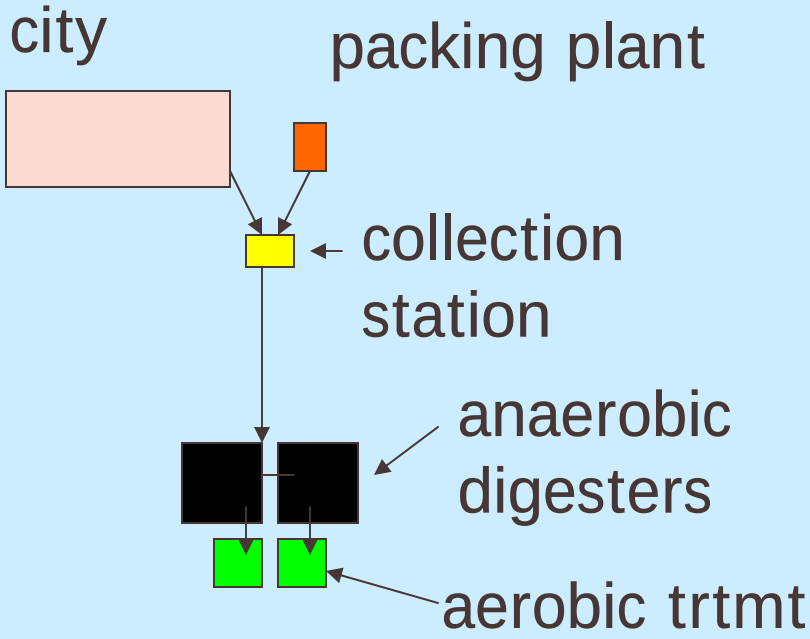
DCWTP system schematic

covered anaerobic digesters, @ 7.5 acres



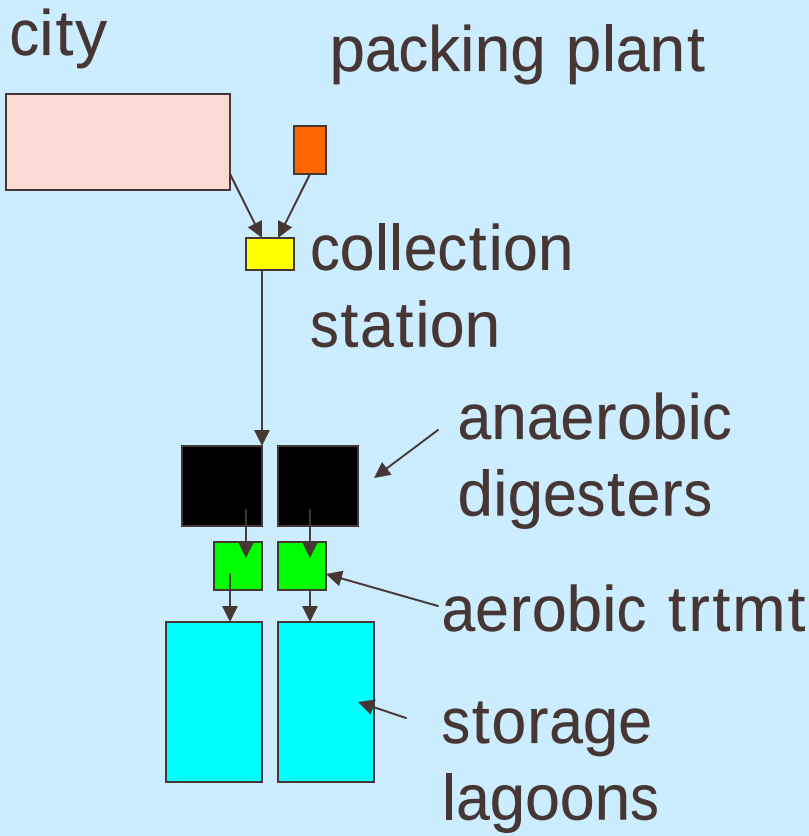
DCWTP system schematic

aerobic treatment



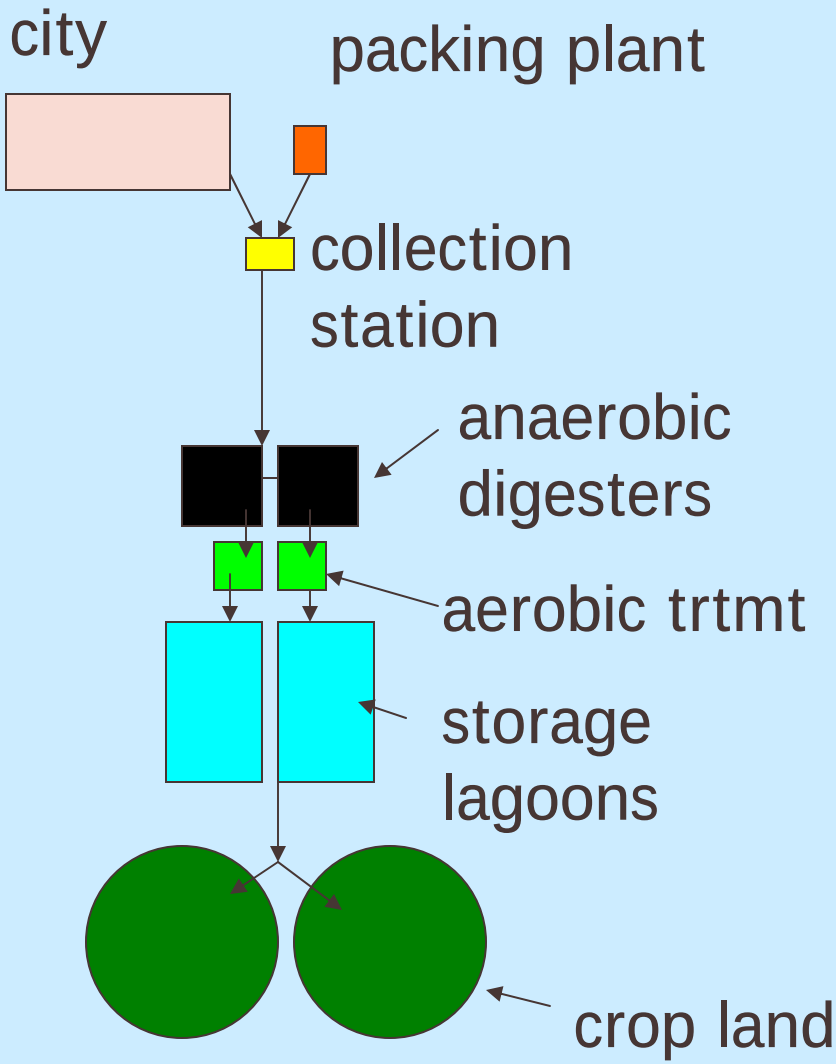
DCWTP system schematic

storage lagoons: 186 acres, 2,829 ac-ft



DCWTP system schematic

total pump capacity ≈ 16,600 gpm



irrigated land
≈ 2,700 acres

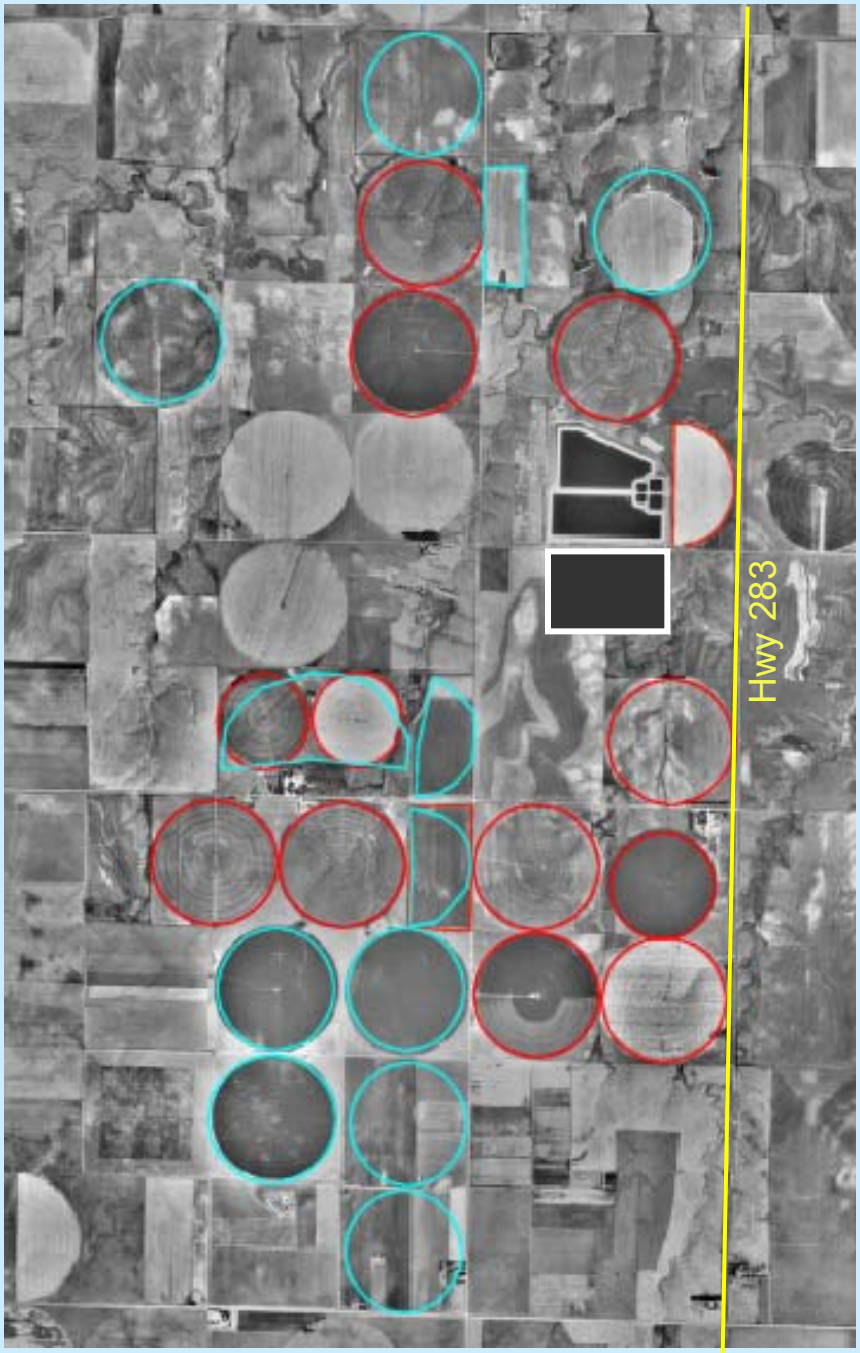
Irrigated acreage

1987

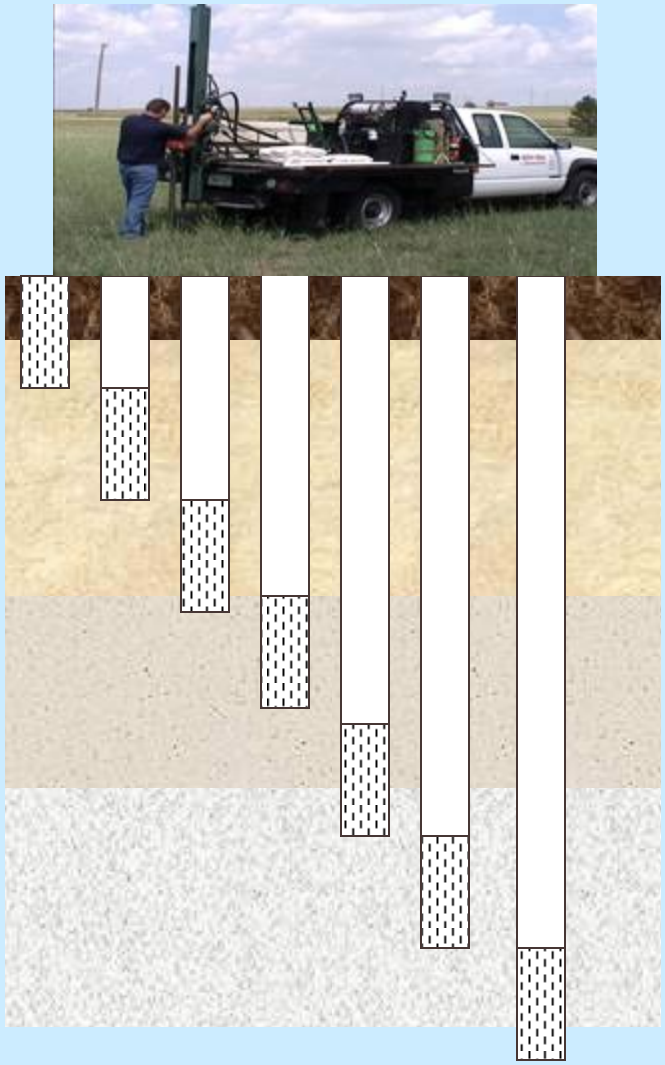
1,430 acres
13 fields

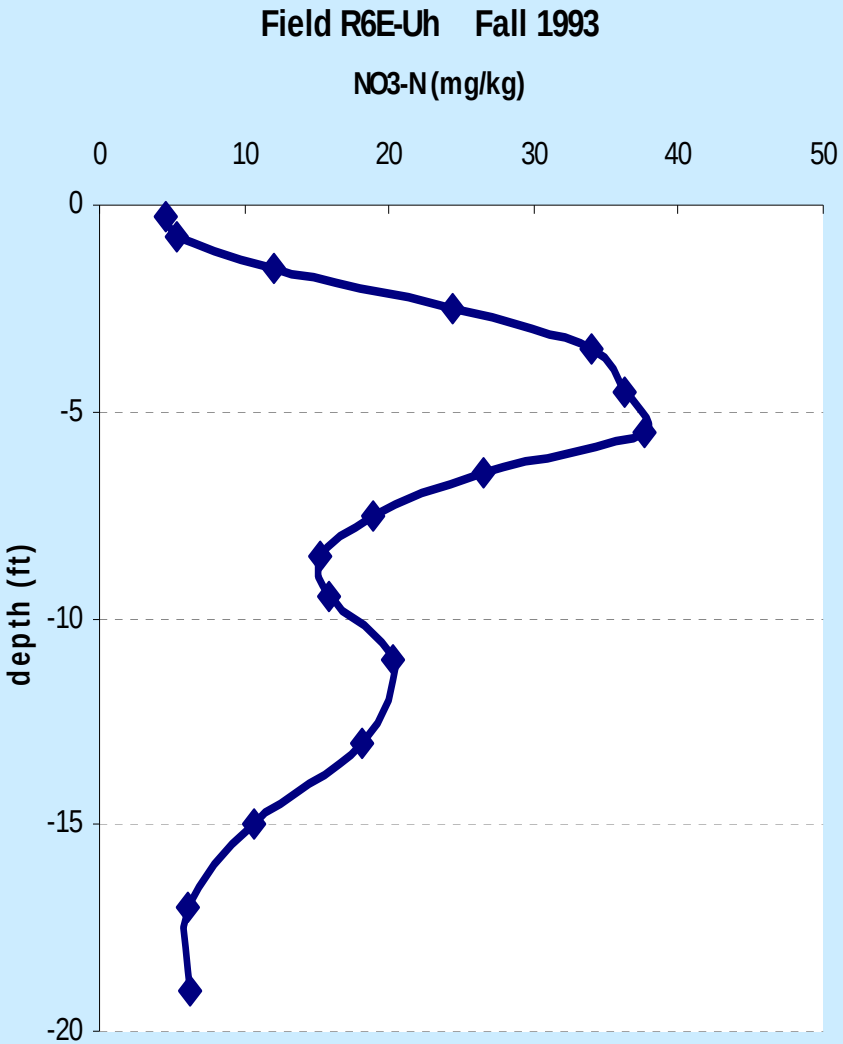
2005

2,730 acres
25 fields



Deep soil monitoring





Objectives

- 1) Conduct field sampling and other analyses to study the impact of treated wastewater irrigation in the area south of Dodge City and the possibility of *N* leaching to groundwater.

- 2) Model the collected data by employing a state-of-the-art numerical model known as *RZWQM* to facilitate evaluation of the environmental impact of different land-use practices and develop recommendations to minimize adverse effects.

Site R8 wastewater-irrigated since 1986

R8 crop history:

Corn—2003-present

Alfalfa—1997-2002

Wheat/Corn prior to 1997

Site N7 wastewater-irrigated since 1998

N7 crop history:

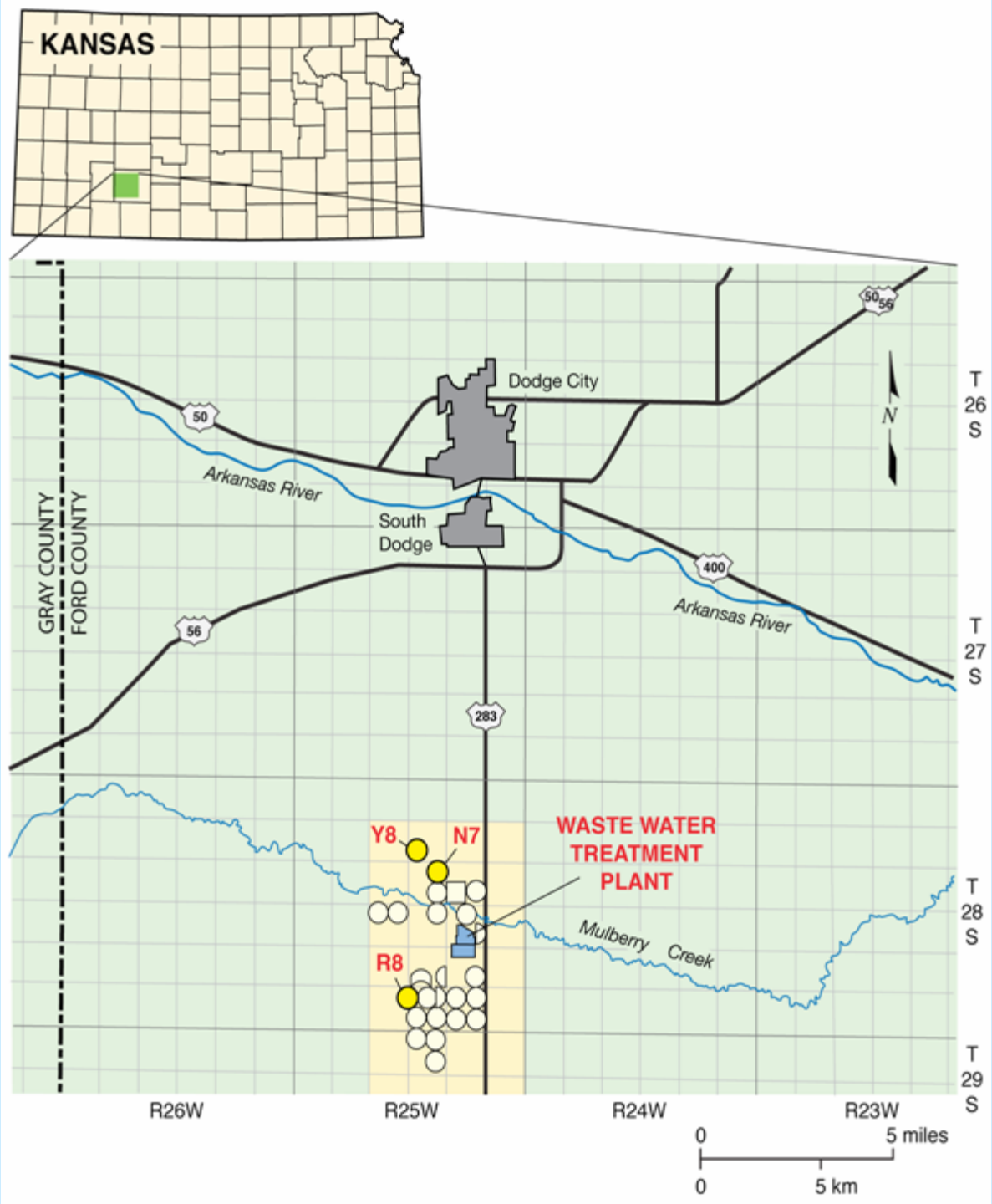
Corn: 1998-present

Site Y8 groundwater-irrigated

Y8 crop history:

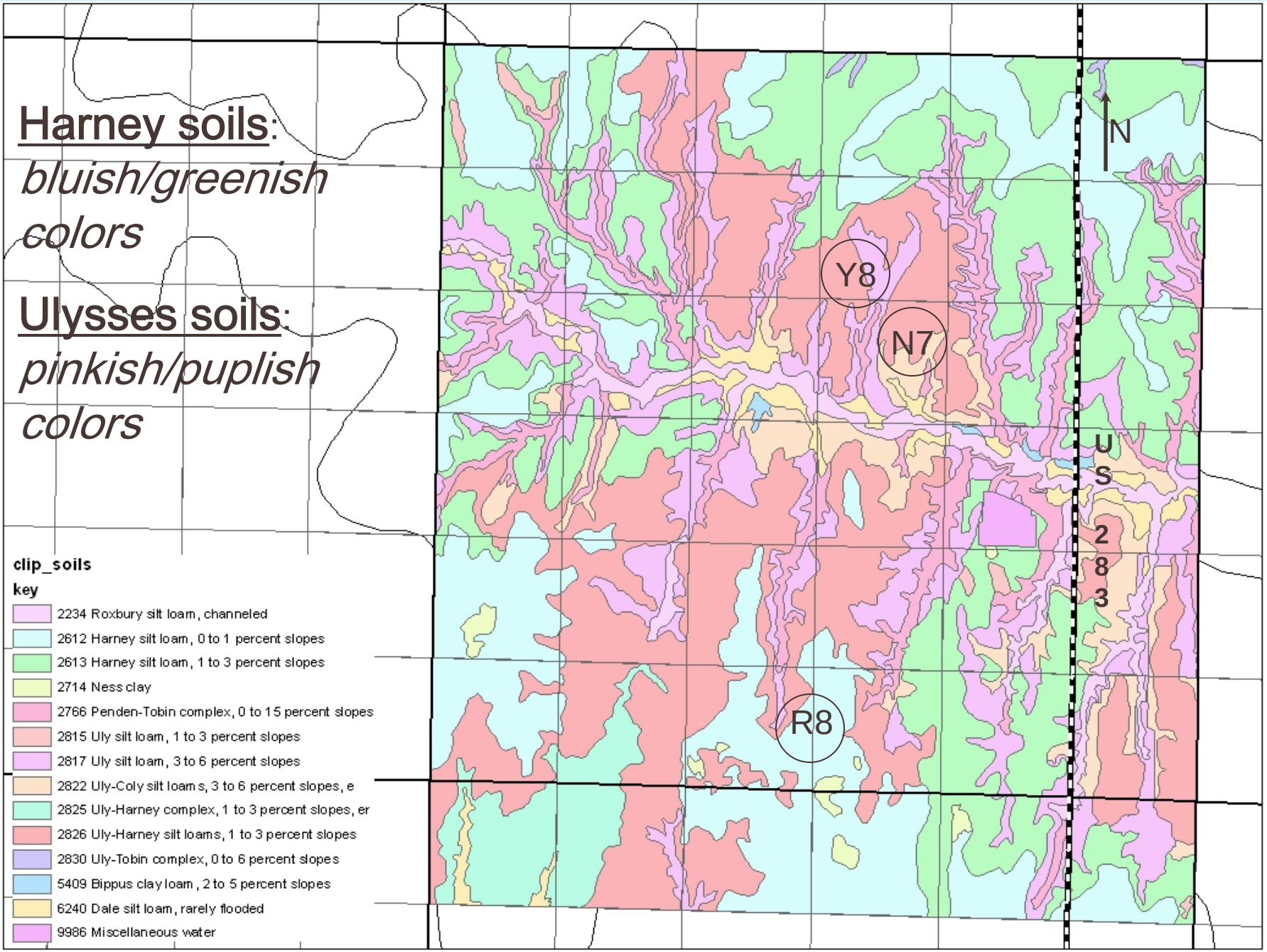
Sorghum: 2005

Corn: 2006



Harney soils:
bluish/greenish colors

Ulysses soils:
pinkish/puplish colors

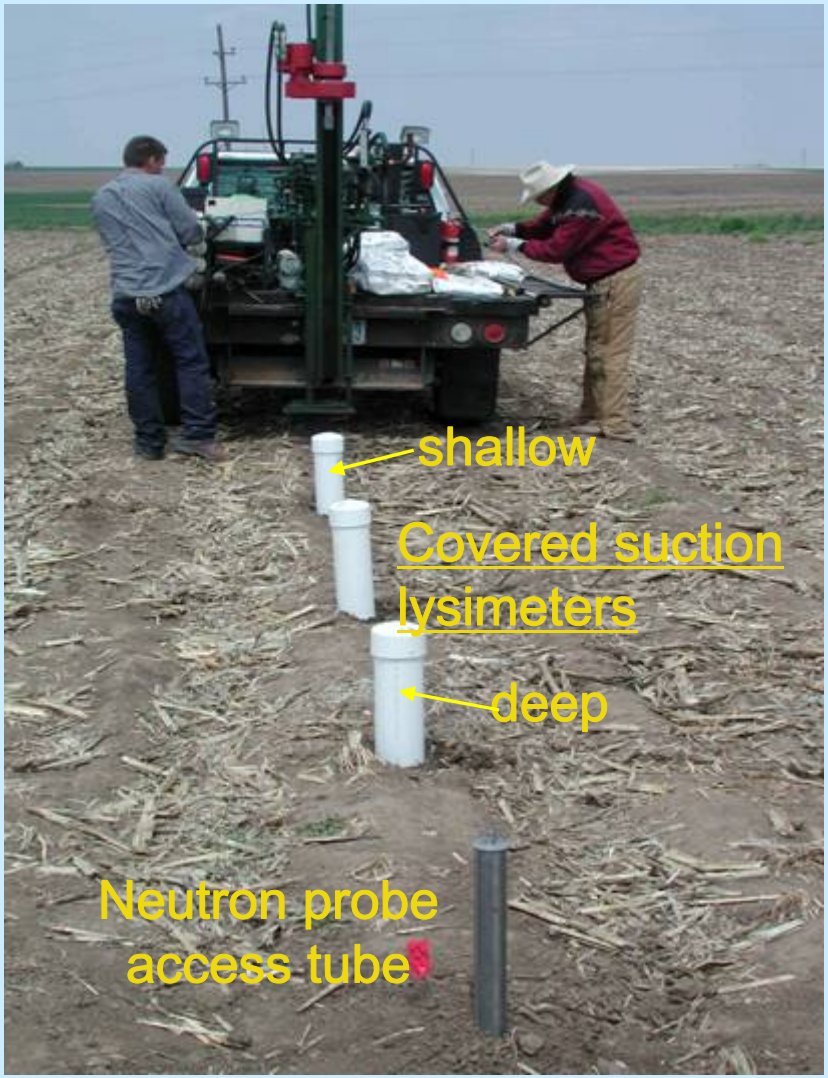


Neutron probe access tube installation

and

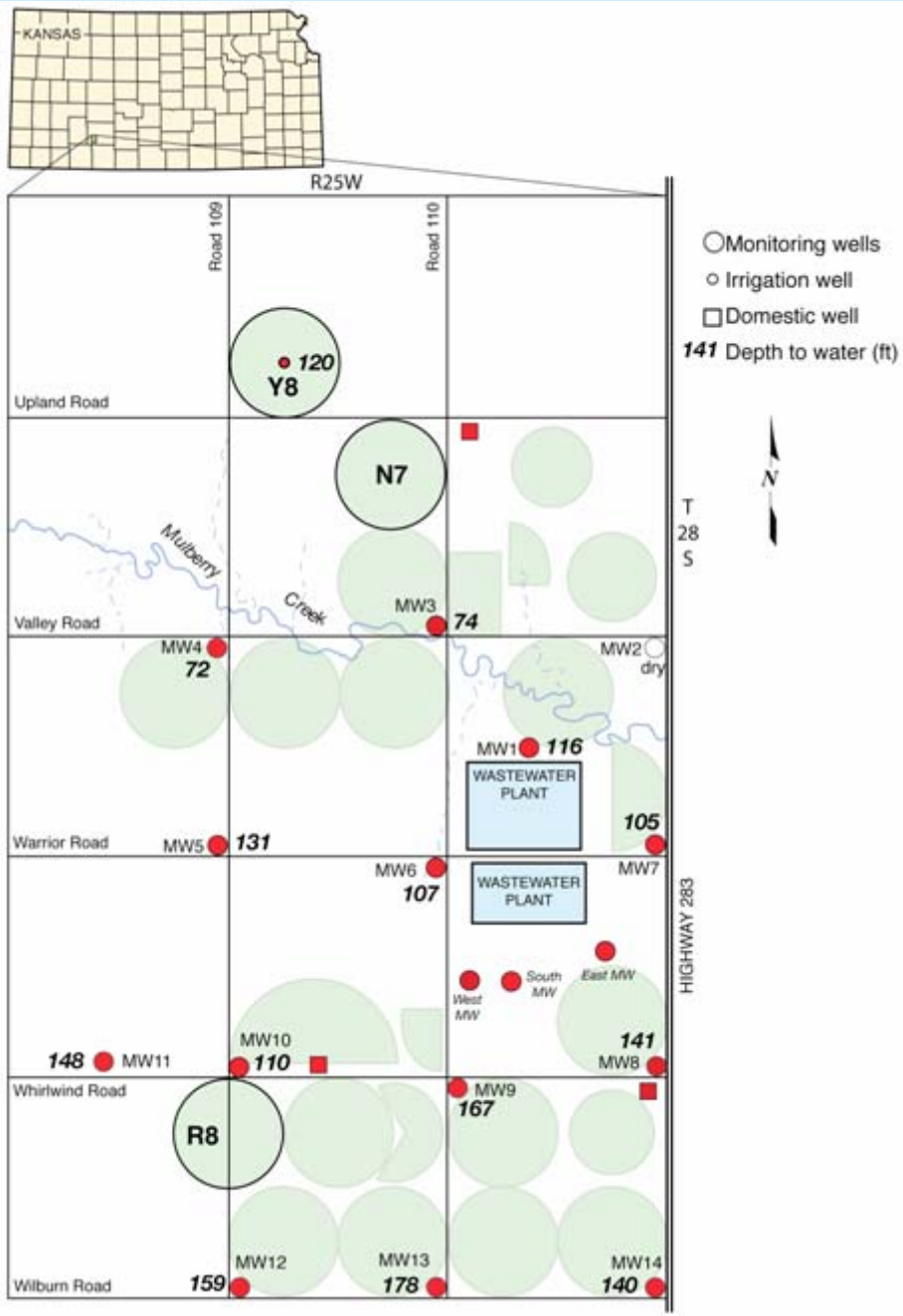
probe calibration

Multi-level suction lysimeters and neutron access tube



Electrical conductivity logging

Depth to water level in wells (ft)



Macropores at various depths

Importance of macropores

- Macropores allow rapid gravitational flow of the free water available at the soil surface or above an impeding soil horizon, thus bypassing the soil matrix
- Short-circuiting to groundwater through macropores is a serious concern because of the possibility of groundwater contamination

Minimum or no tillage practice

- Both pesticides and fertilizer chemicals are applied on the soil surface with minimum incorporation into the soil, thus increasing soluble chemical amounts in surface flow that can enter macropores

- Plant residues on the surface and no tillage enhance worm activity and allow worm holes and other macropore channels to stay open at the surface

ridge tillage - corn

Dye tracer experiments

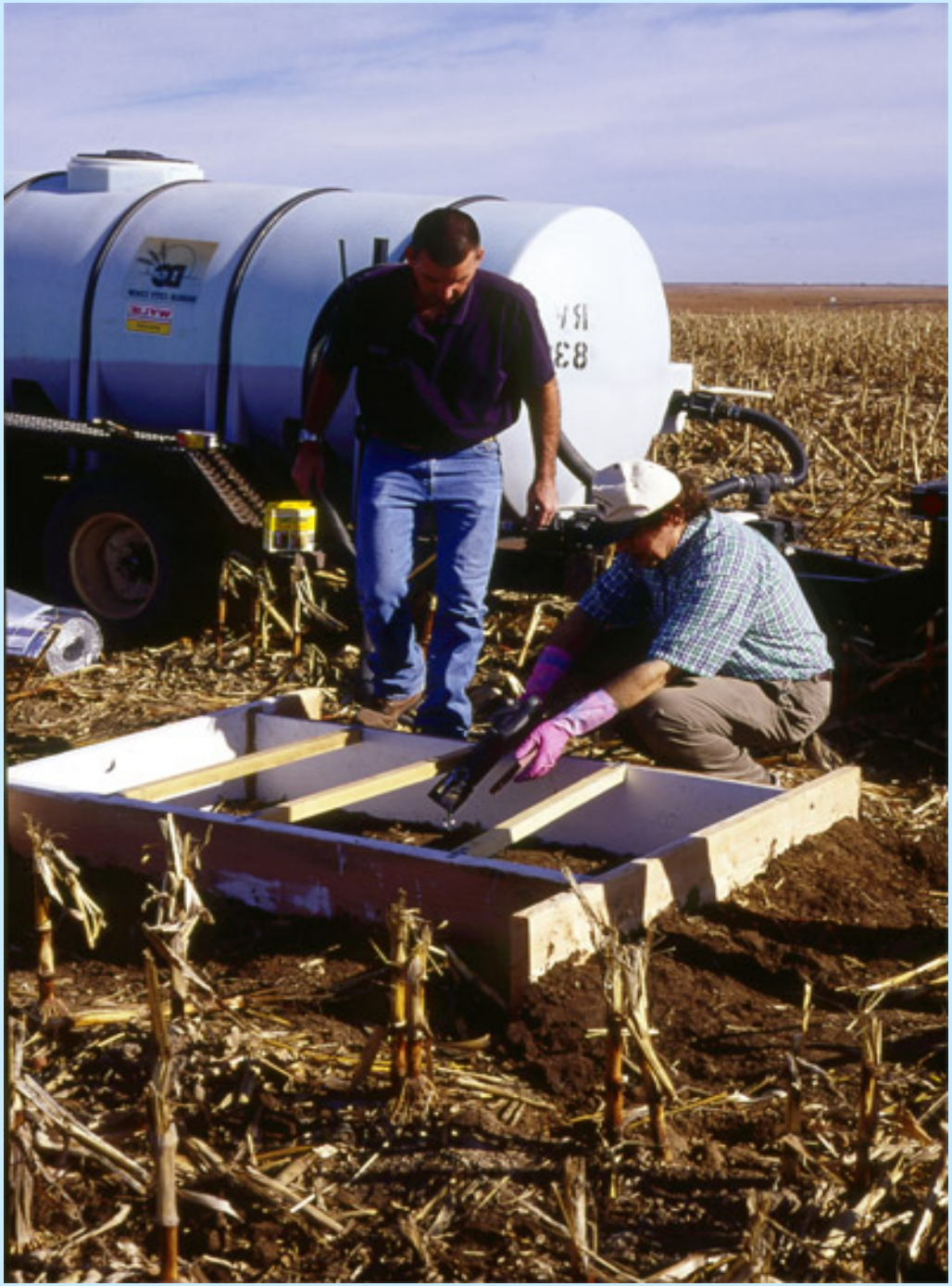
Filling water tank with water …

Weighing appropriate amount of water …

Adding Brilliant Blue powder dye …

Mixing the dye well …

Installing a wooden frame for flooding with dye solution …

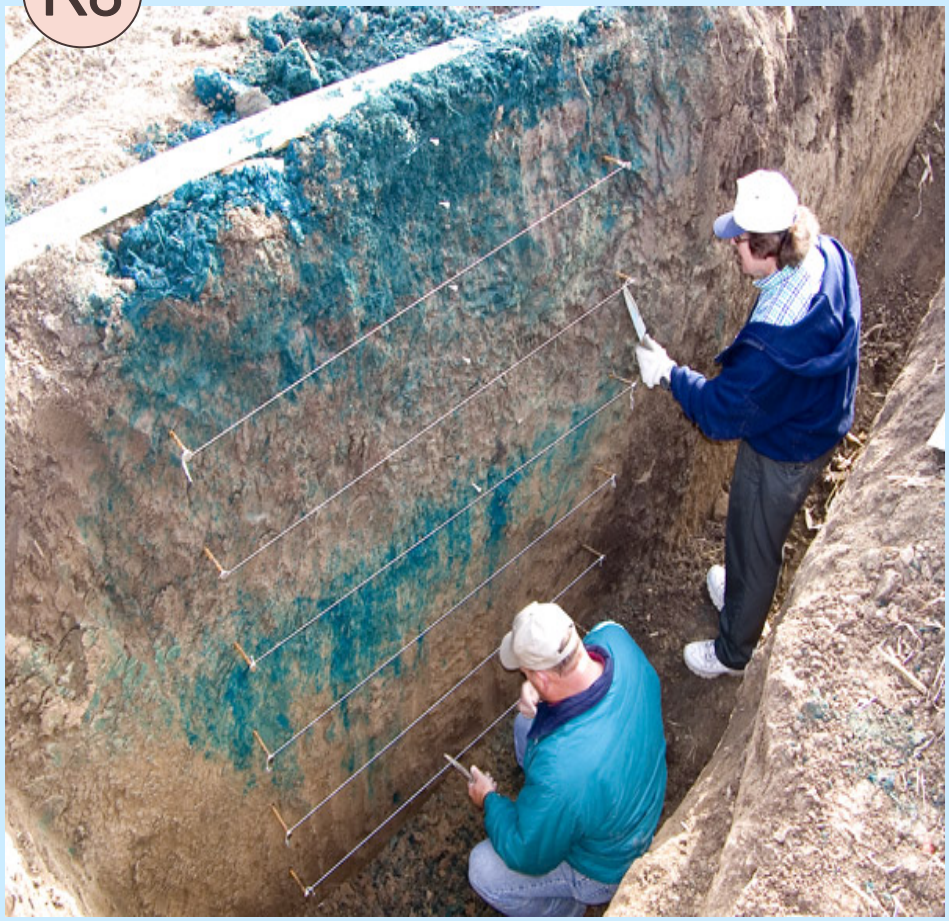


Digging a trench at the flooded site …

R8 dye pattern: Uniform finger front …

N7 dye pattern: Funnel front …

R8

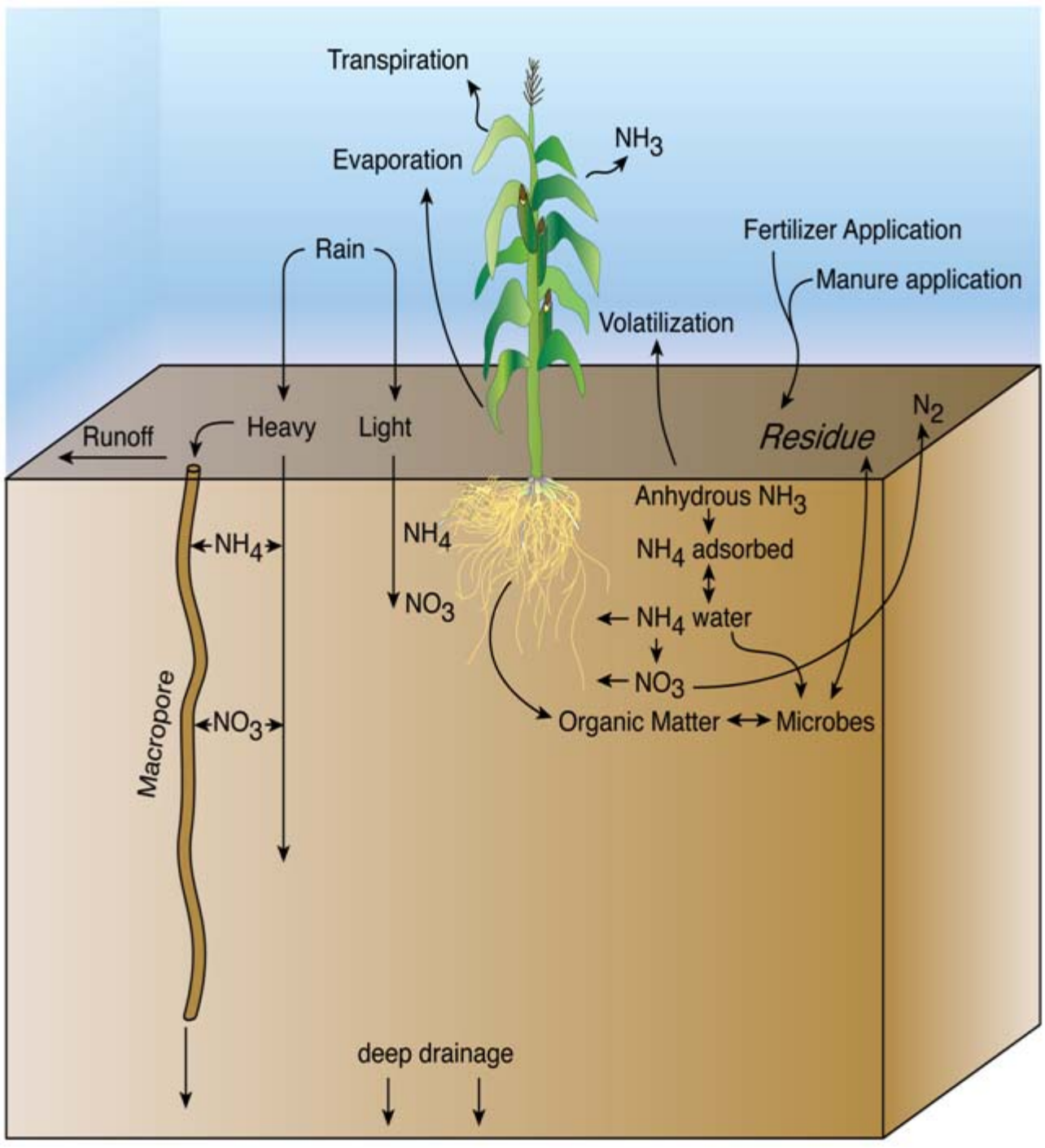


N7

CAUTION

Root Zone Water Quality Model (RZWQM)

is a process-based model that simulates the growth of the plant and the movement of water, nutrients, and agro-chemicals over, within, and below the crop root zone of an agricultural cropping system under a range of common management practices.



Model Calibration Strategy

Calibrate (using 2005 data) for:

1. Soil hydraulic properties
2. N-nutrient properties
3. Plant growth properties

Verify ("validate") using 2006 data

Calibration targets:

1. Measured soil water content profiles
2. Core-sampled nitrate profiles
3. Harvested corn yields

Run sensitivity analyses

Sensitivity analysis

A sensitivity analysis is essential to identify those parameters that have the greatest effect on model output

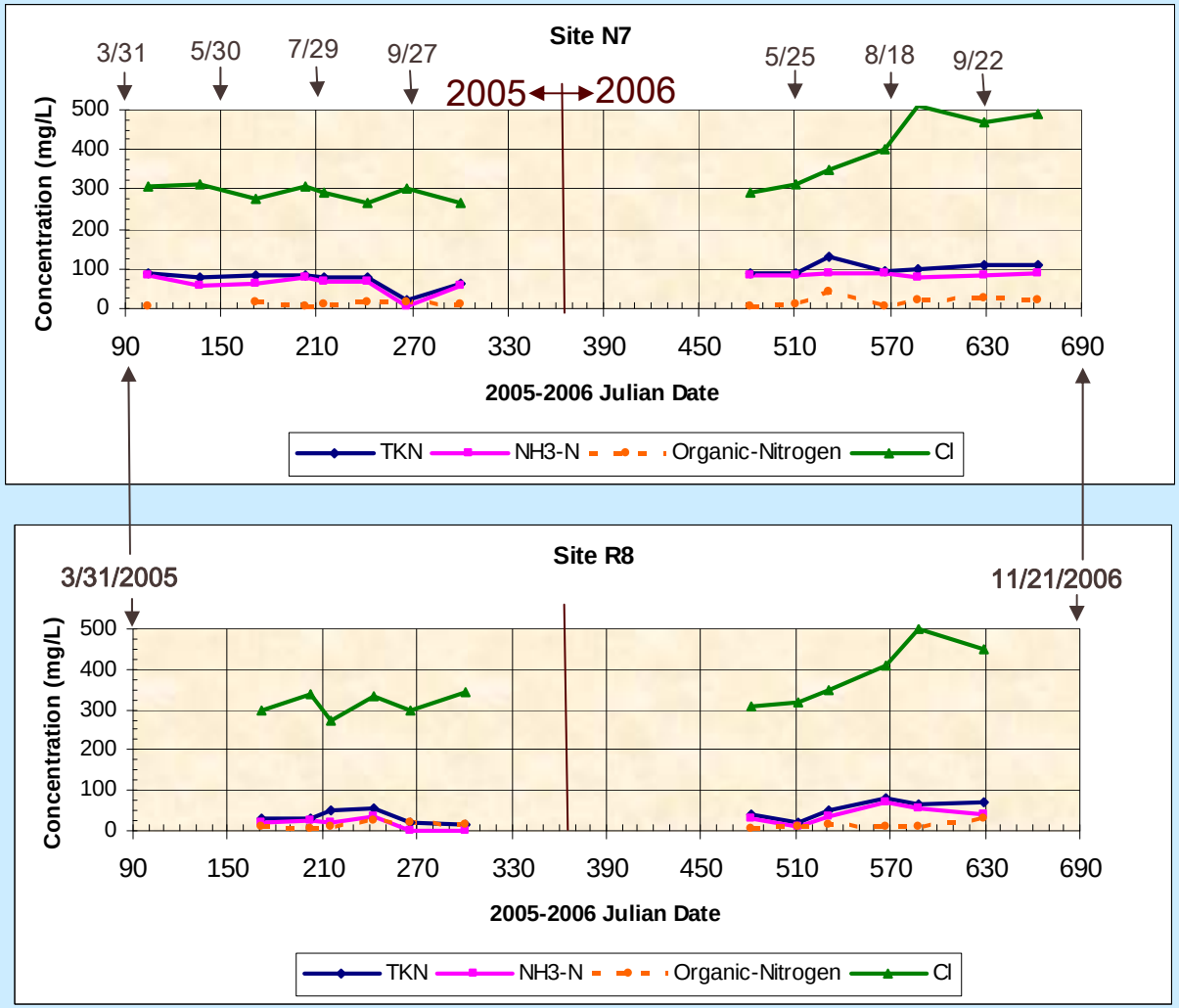
Sensitivity analysis is usually conducted by perturbing model parameter values by a specific percentage around their base values independently

Sensitivity Analysis: Most sensitive parameters

- Hydraulic properties: *bulk density; saturation water content; Brooks & Corey parameters.*
- Organic matter/nitrogen cycling parameters: *aerobic heterotroph microbial population; transitional and fast humus.*
- Corn genetic parameters: P1: *Thermal time from seedling emergence to the end of juvenile phase;* P5: *Thermal time from silking to physiological maturity;* G2: *Max possible number of kernels per plant.*
- Irrigation and fertilization rates

Field Results

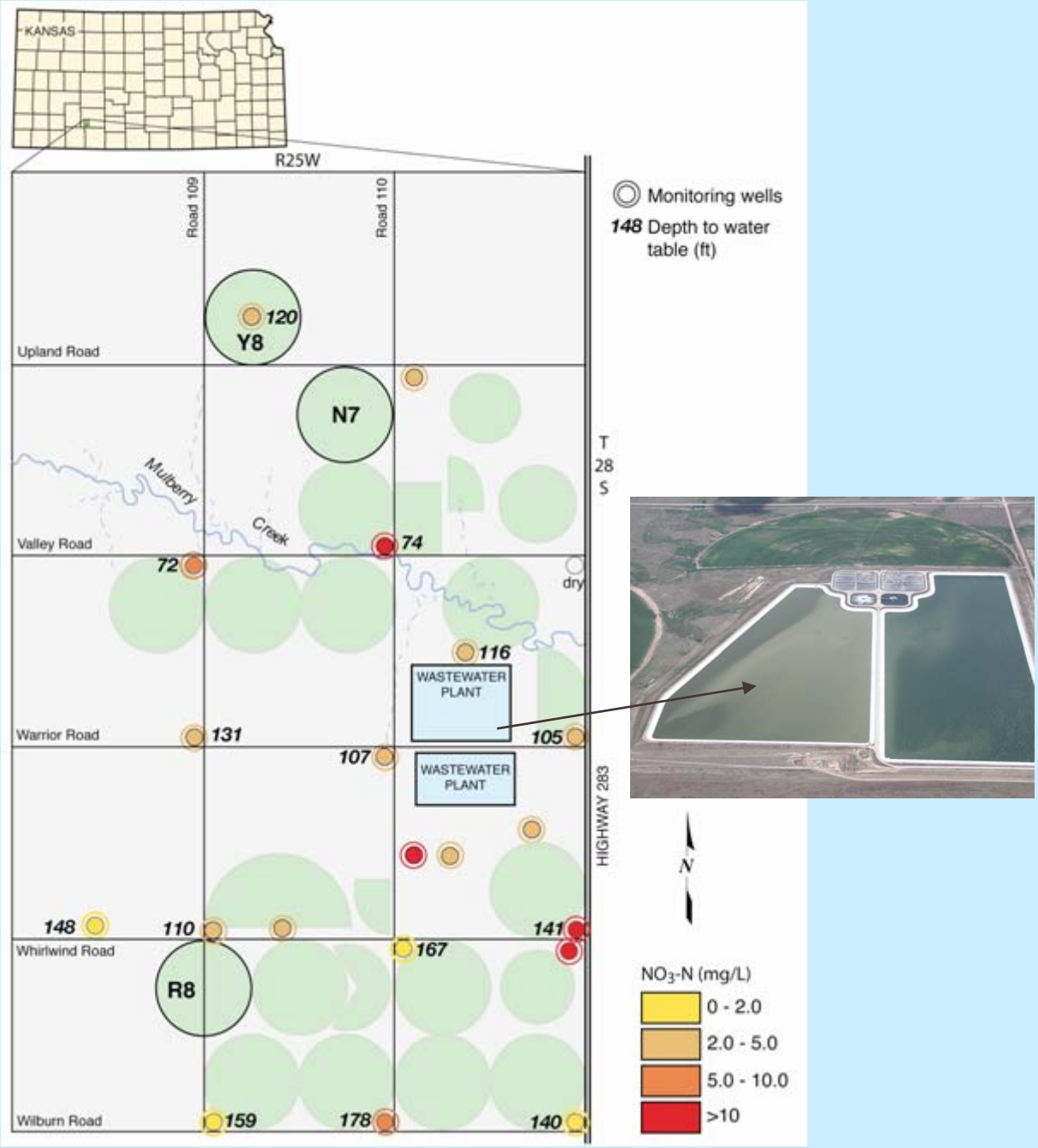
Irrigation water quality during 2005-2006: Sites R8 & N7

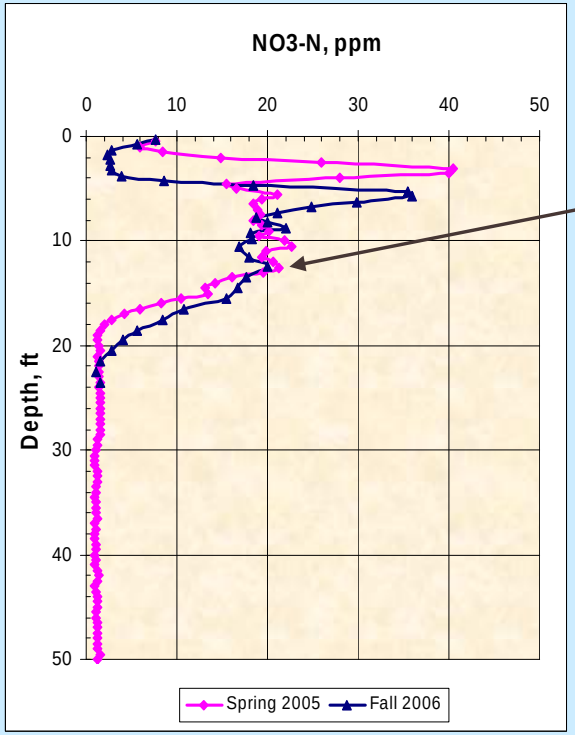


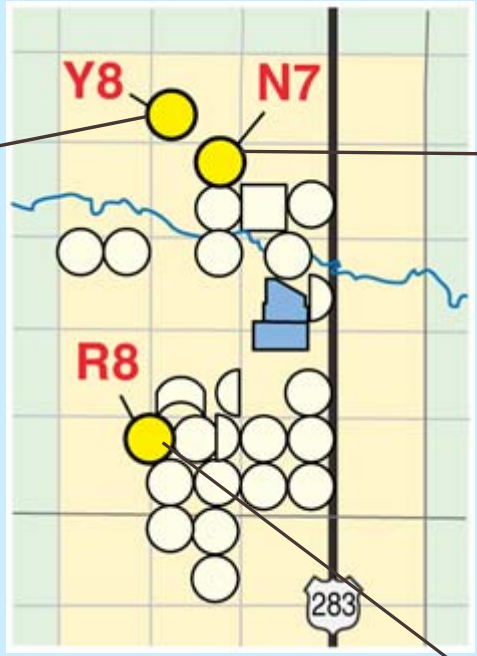
N7 & R8 irrigation effluent salinity

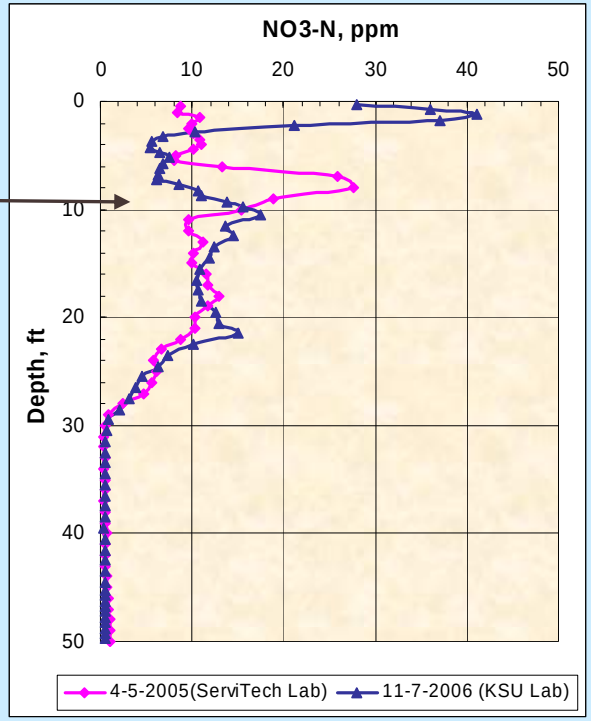
Site	variable	2005	2006	target
N7	EC (mS/cm)	2.11	2.63	≤ 1.5
N7	SAR	5.17	6.34	< 5.0
R8	EC (mS/cm)	2.07	2.43	≤ 1.5
R8	SAR	7.04	5.98	< 5.0

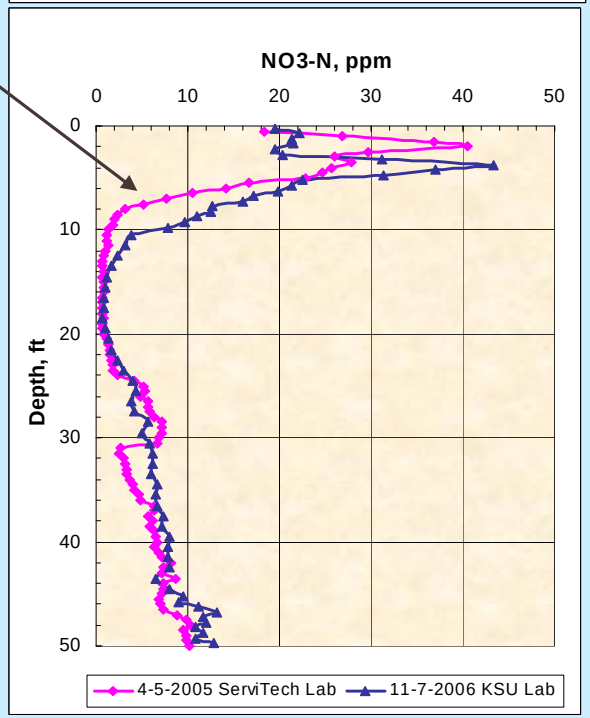
Depth to water table and nitrate (NO_3-N) levels in wells











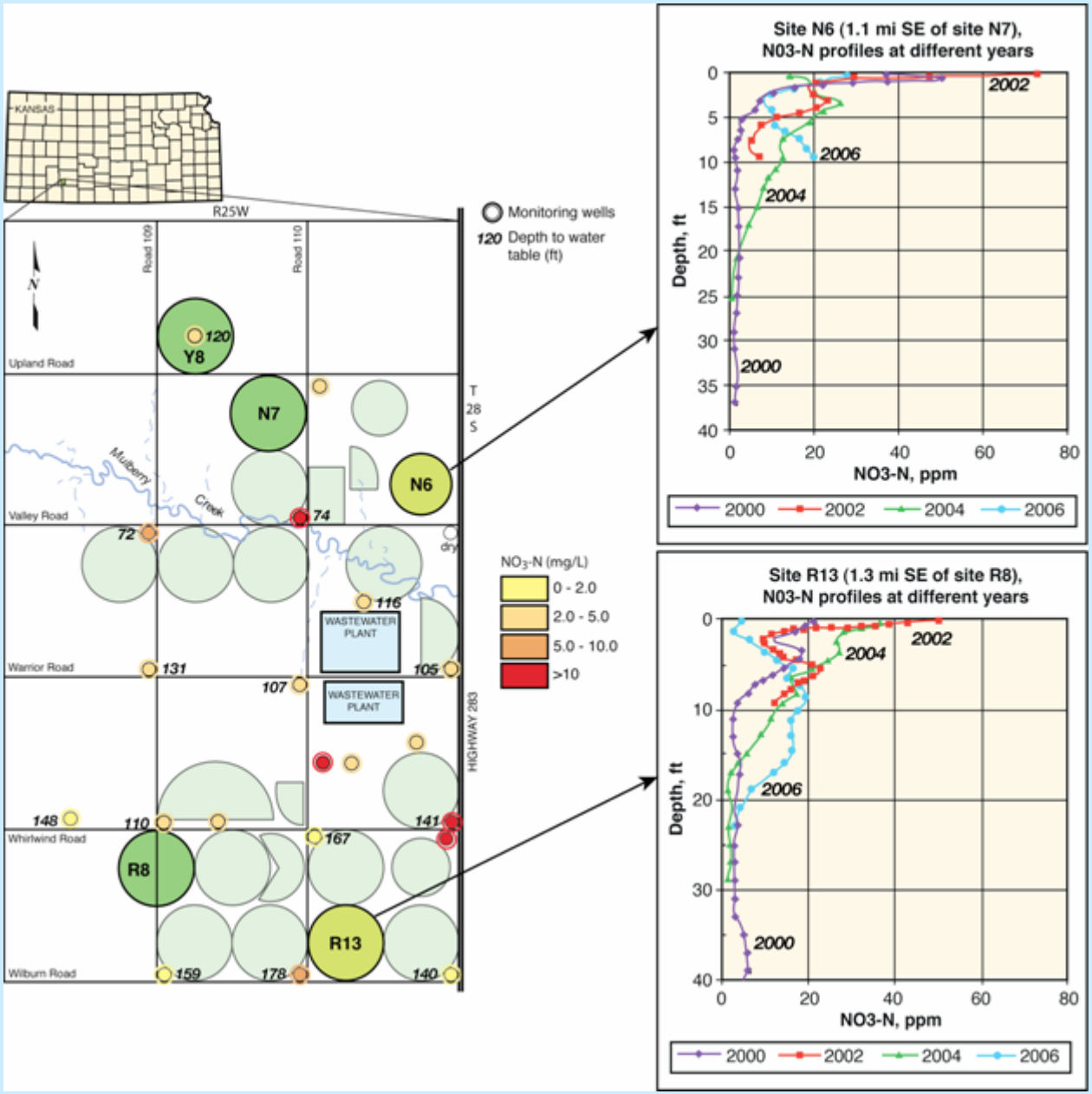
Measured Soil Nitrate (NO3-N)

Symbol Legend

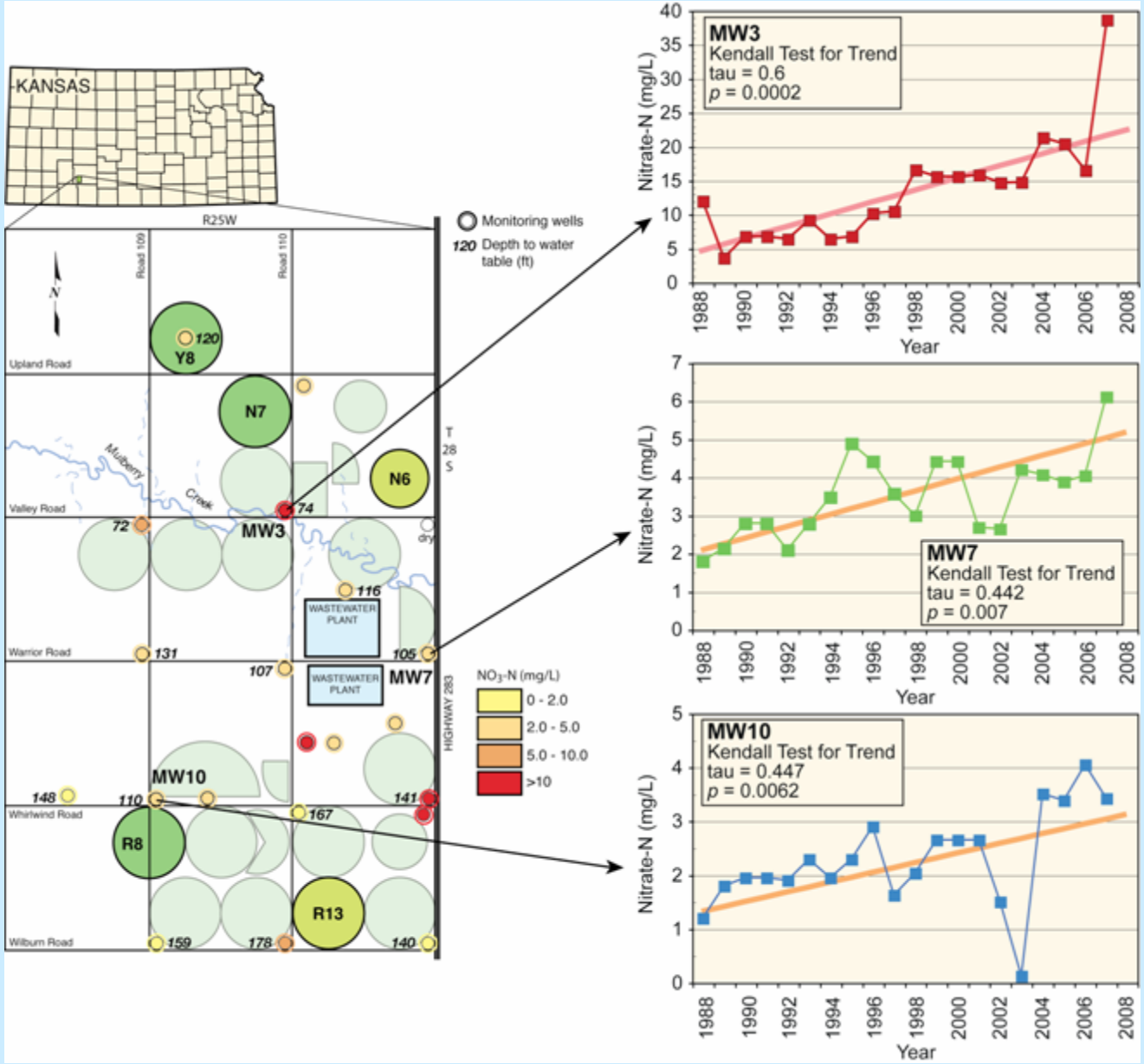
Dark blue — Fall 2006

Magenta — Spring 2005

Progressive increase of vadose zone Nitrate-N storage with time



Progressive increase of ground-water Nitrate-N with time



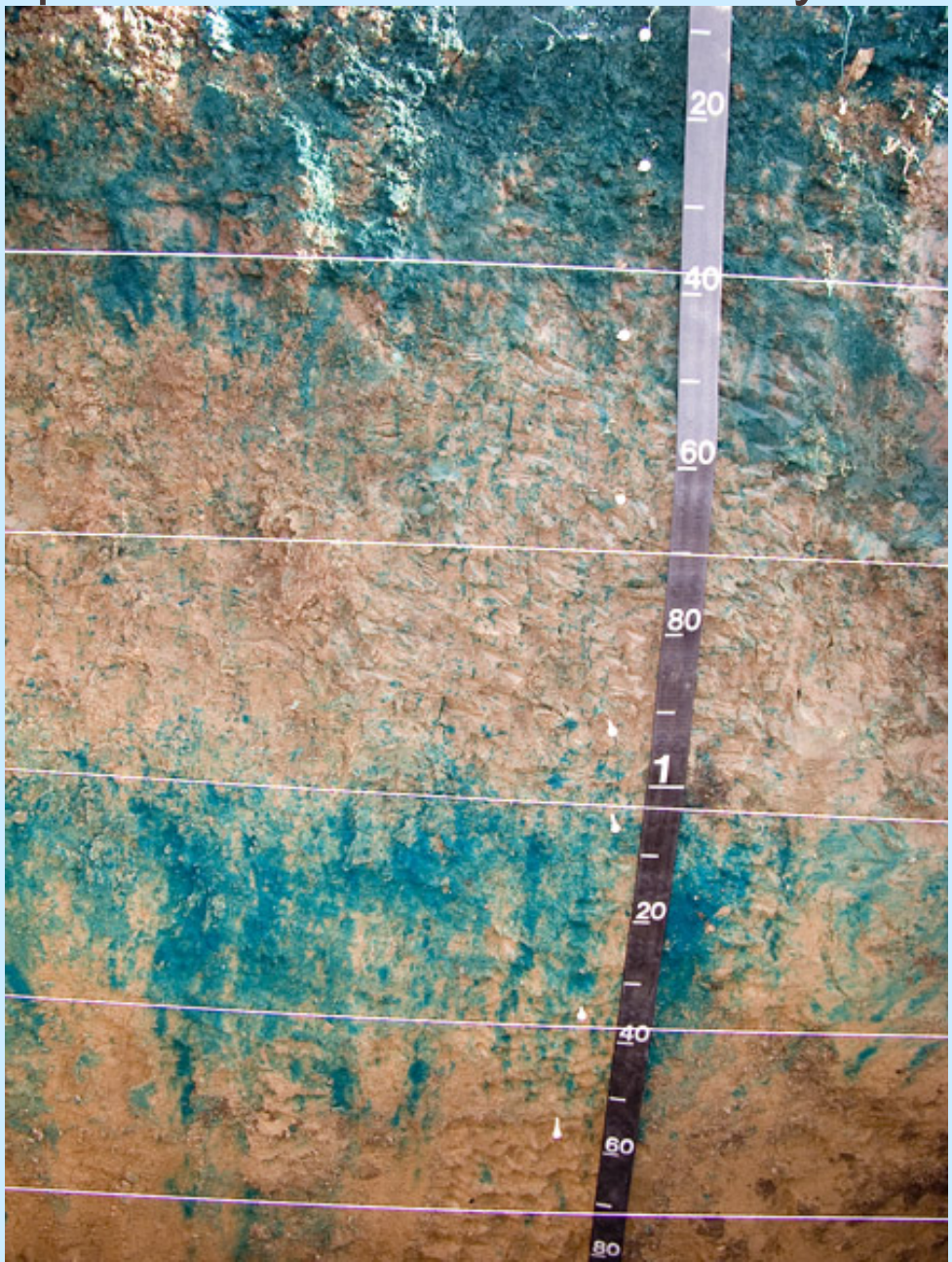
Dye tracer experiments

R8

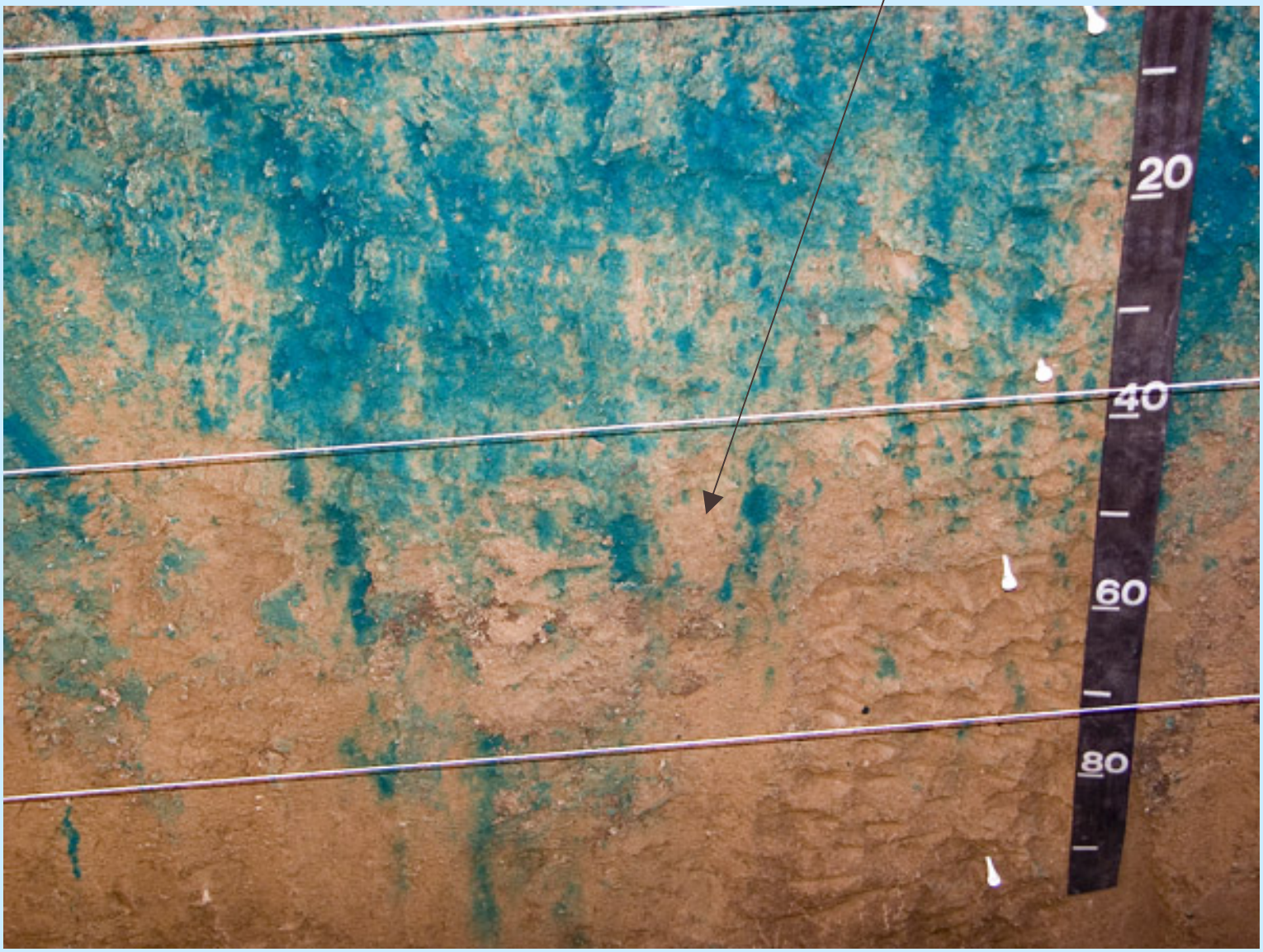
N7

R8 dye pattern: Uniform finger front …

The dye solution in the heavier, blocky-structure soil layer (0.5-1 m) moves along the spaces in-between the blocky soil aggregates …

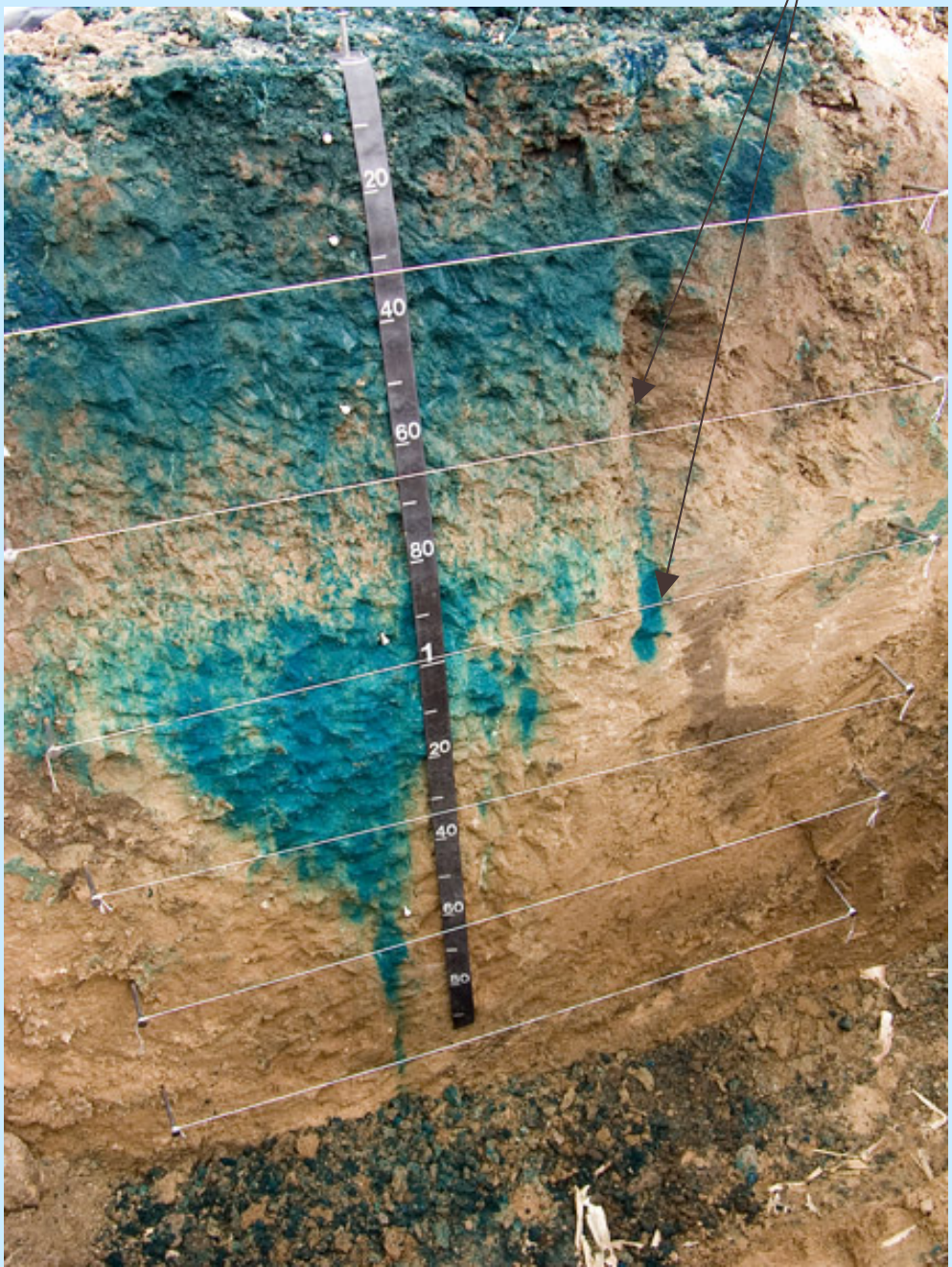


The dye solution is under tension, bypassing coarser texture soil intervals

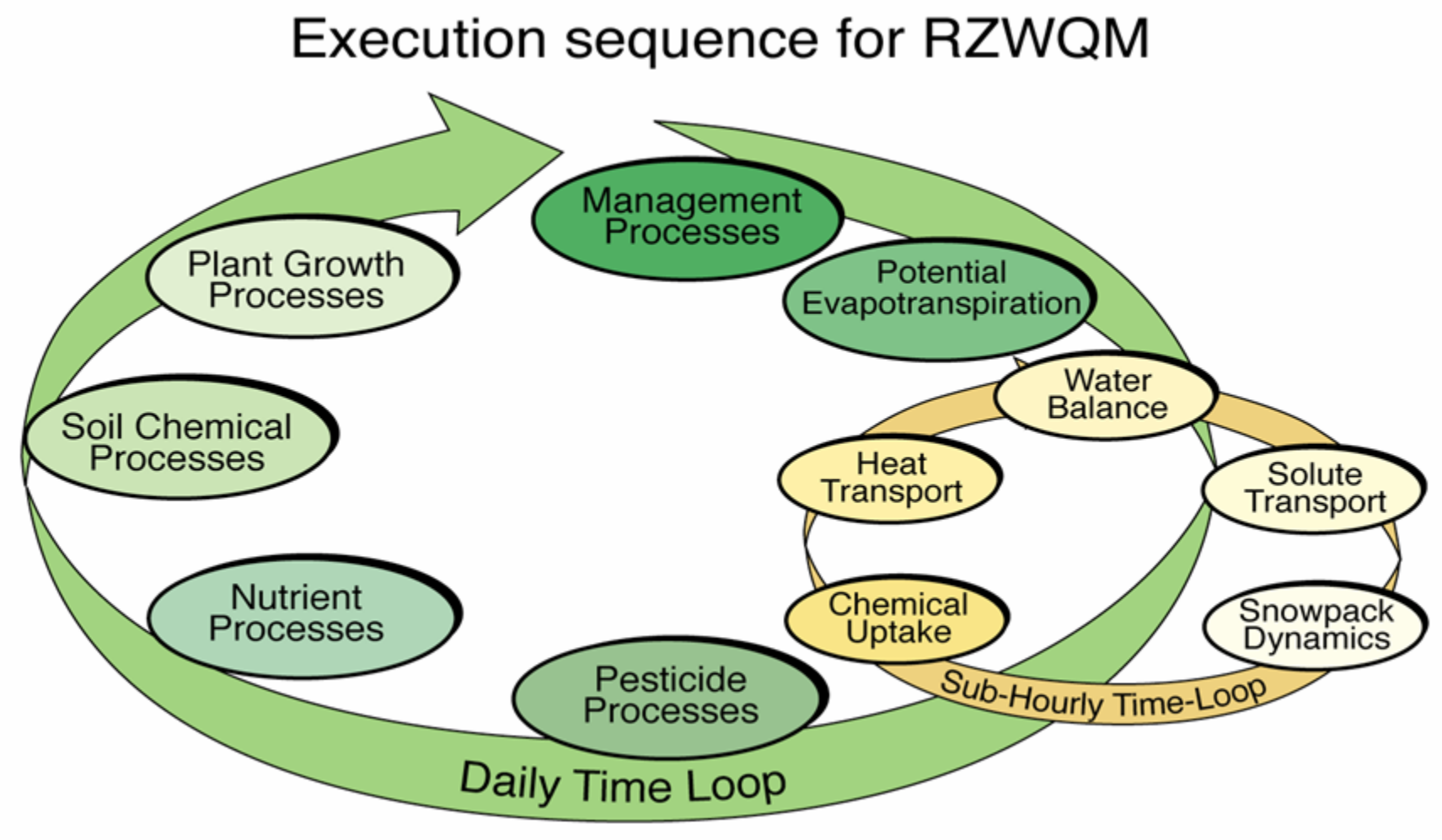


N7 dye pattern: Funnel front …

Dye finger tracing along a root channel



RZWQM Model Evaluation



Error Definitions

S = simulated values; O = observed (measured) values

- Root Mean Square Error (*RMSE*)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2}$$

- Relative Mean Square Error (*RRMSE*)

$$RRMSE = RMSE \times \frac{100\,\%}{O_{avg}}$$

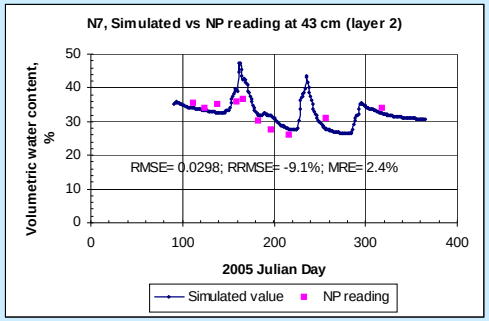
- Mean Relative Error (MRE)

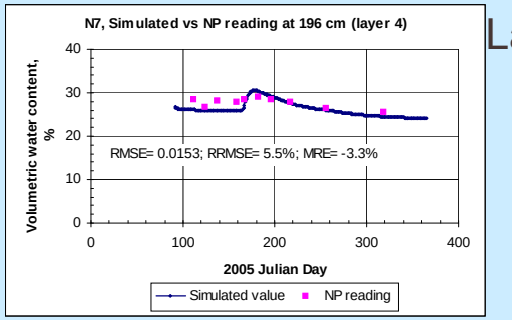
$$MRE = \frac{1}{n}\sum_{i=1}^{n}\frac{(S_i - O_i)}{O_i} \times 100\,\%$$

Comparison of 2005 simulated and measured moisture for different soil layers

Layer bottom (ft)

1.3’

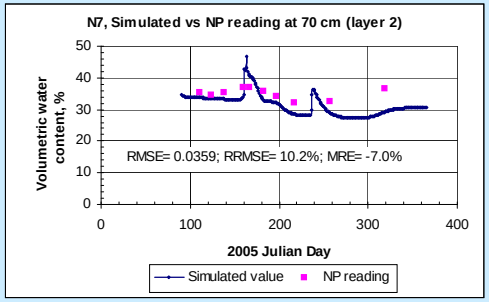


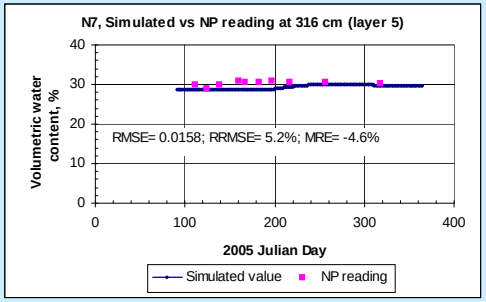


Layer bottom (ft)

6.5’

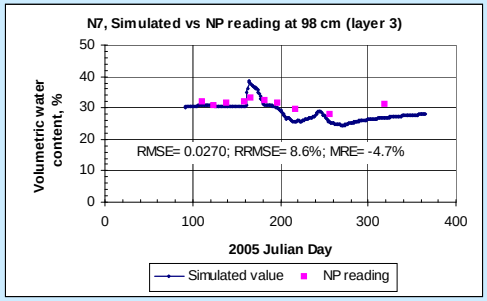
2.3’

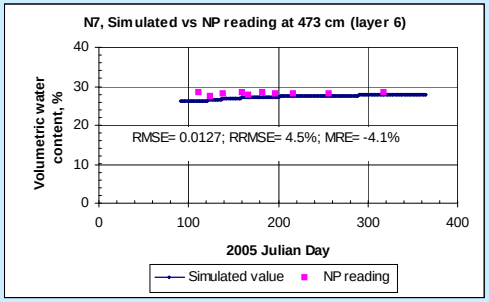




10.5’

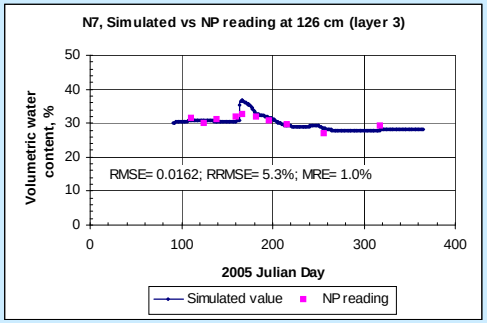
3.2’

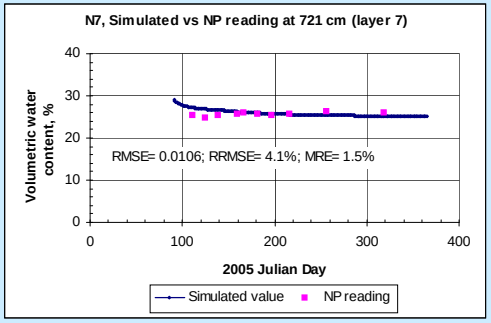




15.5’

4.2’



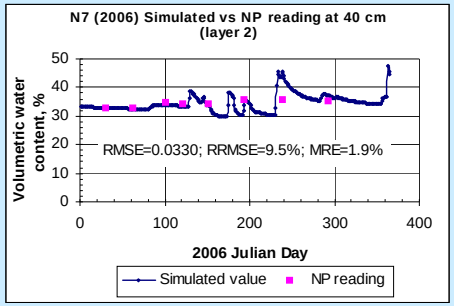


23.5’

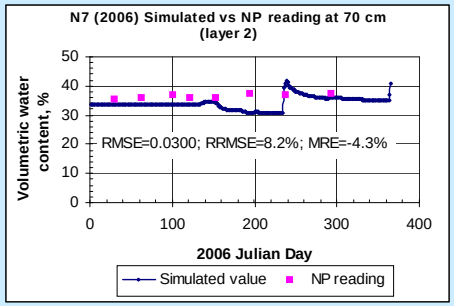
Comparison of 2006 simulated and measured moisture for different soil layers

Layer bottom (ft)

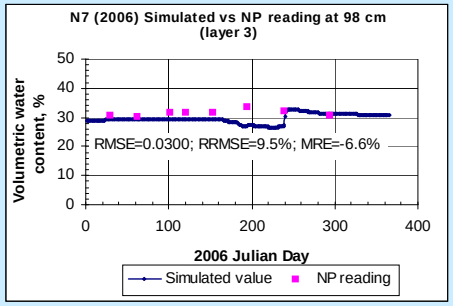
1.3’



2.3’



3.2’



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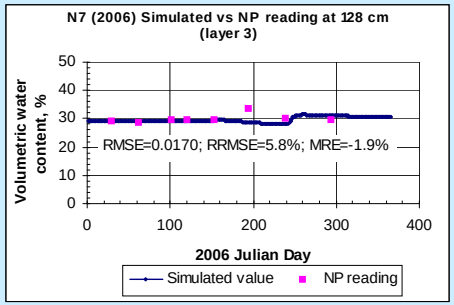
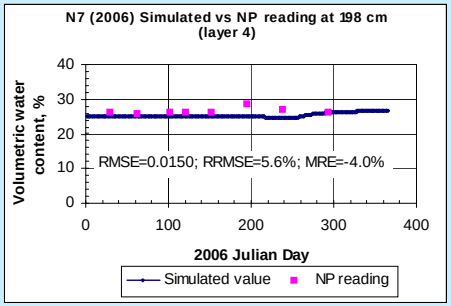
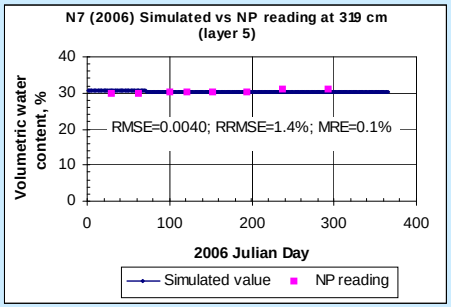


Layer bottom (ft)

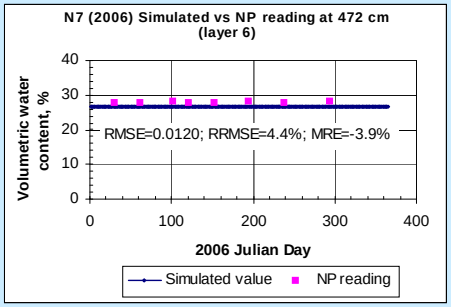
6.5’



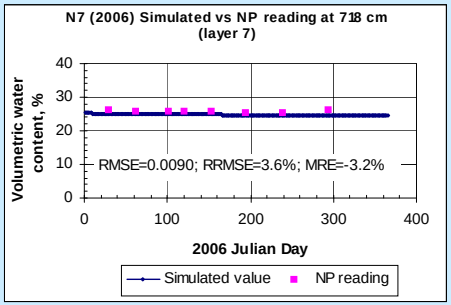
10.5’



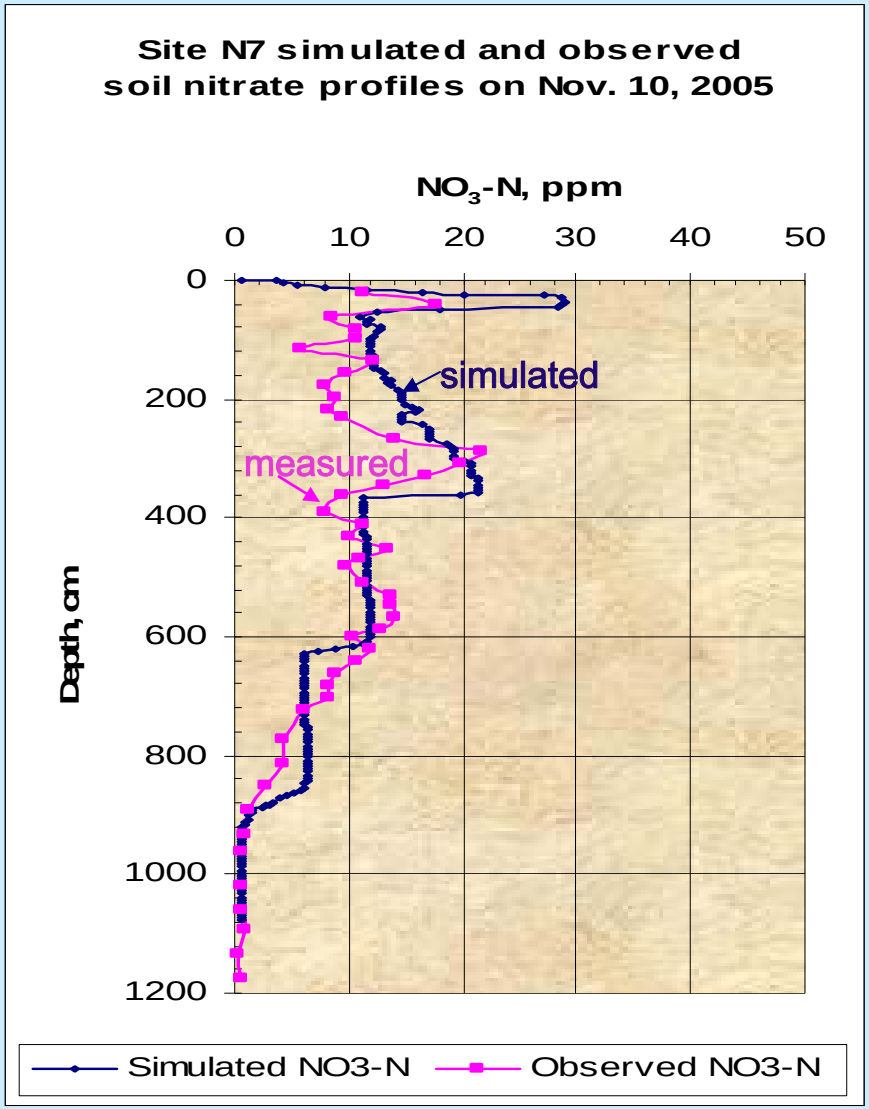
15.5’



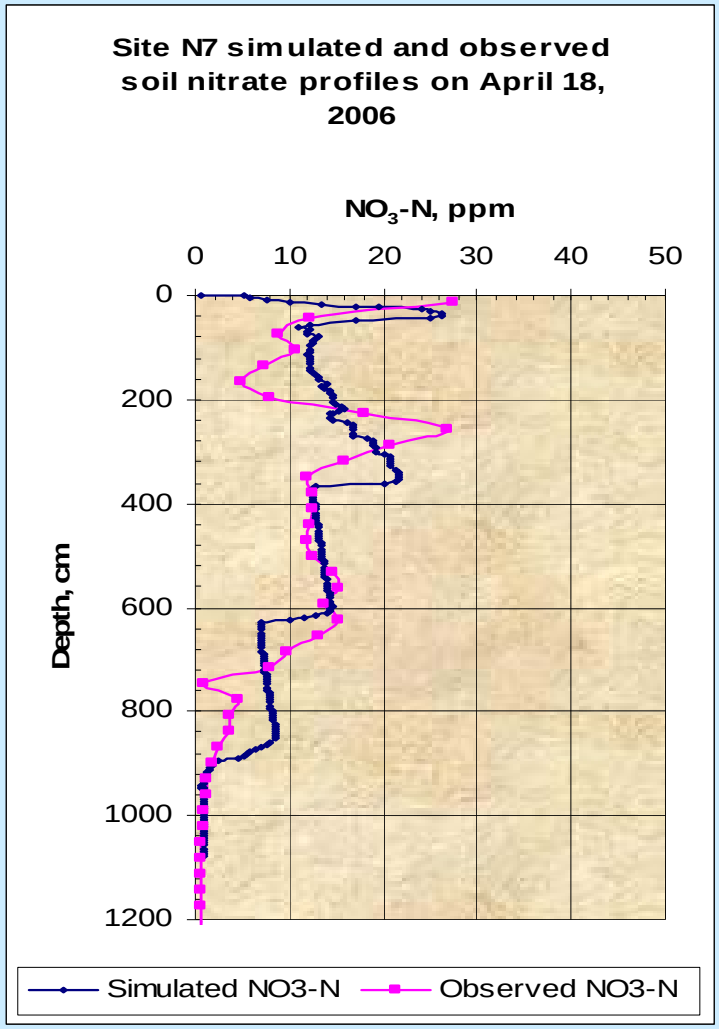
23.5’

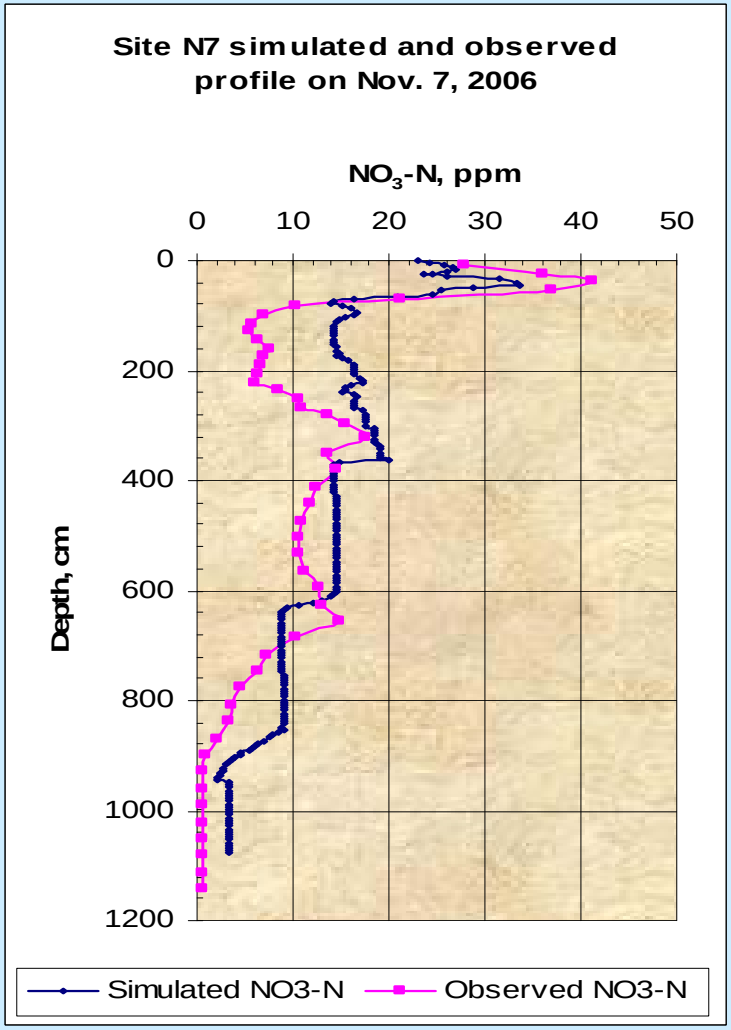


Comparison of measured (Fall 2005) and simulated soil Nitrate-Nitrogen profiles for Site N7



Comparison of measured (Spring & Fall 2006) and simulated soil Nitrate-Nitrogen profiles for Site N7





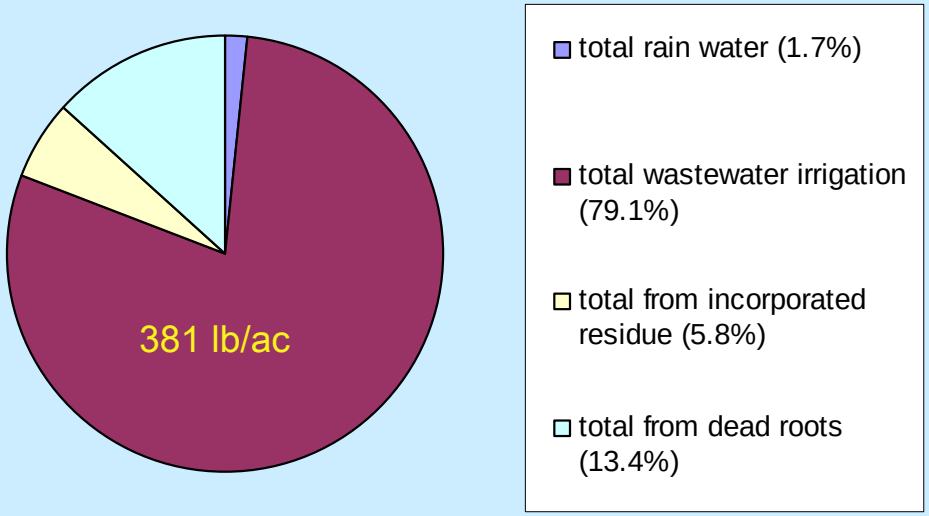
Nitrogen Use Efficiency, Nitrogen Budget, and Management Scenarios

Nitrogen Use Efficiency (NUE)

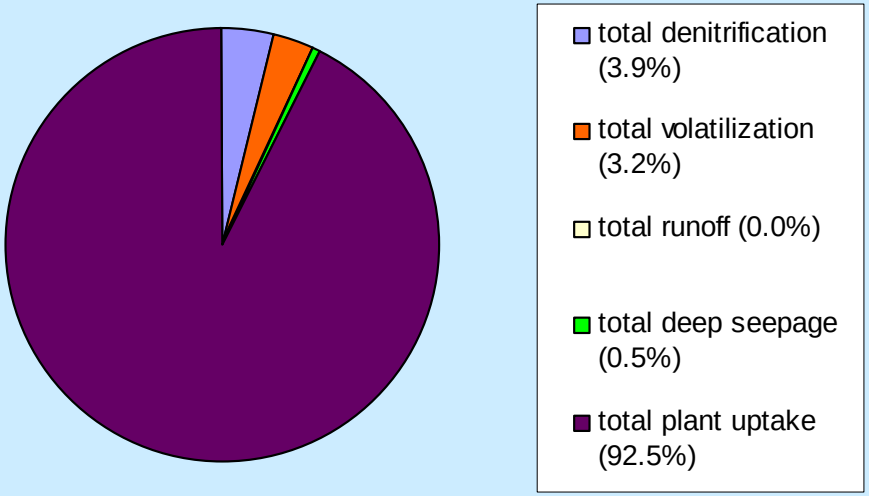
$$\text{NUE} = \frac{(\text{Plant N uptake for a particular N treatment}) - (\text{Plant N uptake for zero-N treatment})}{(\text{Total amount of N applied})}$$

2005 N Budget for Site N7

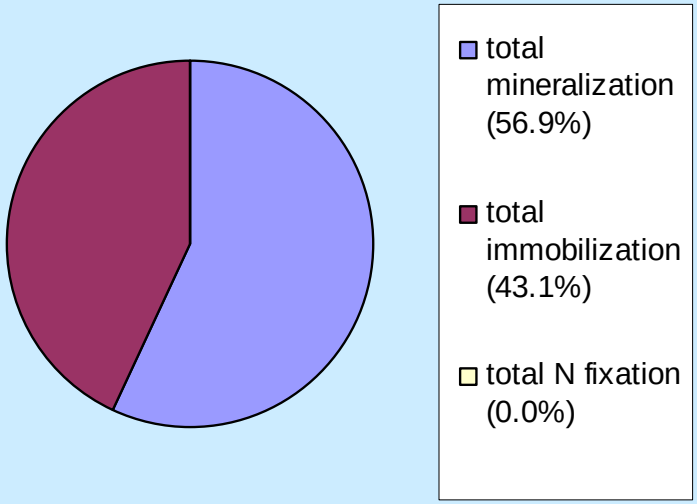
Total sources of N: 482 lb/ac

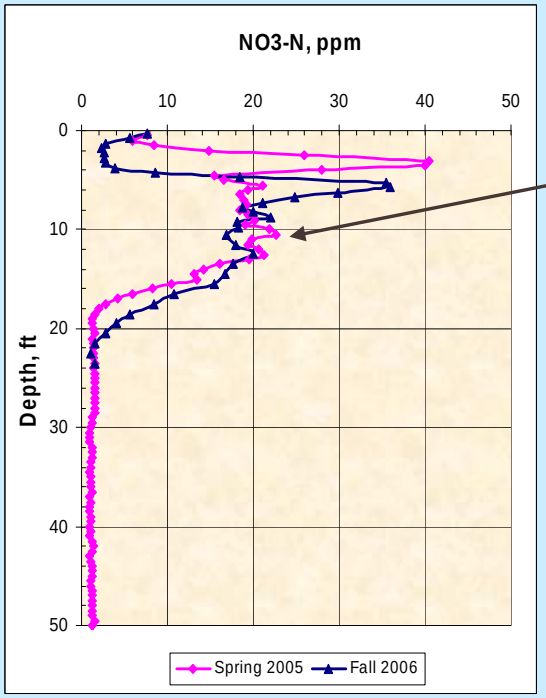


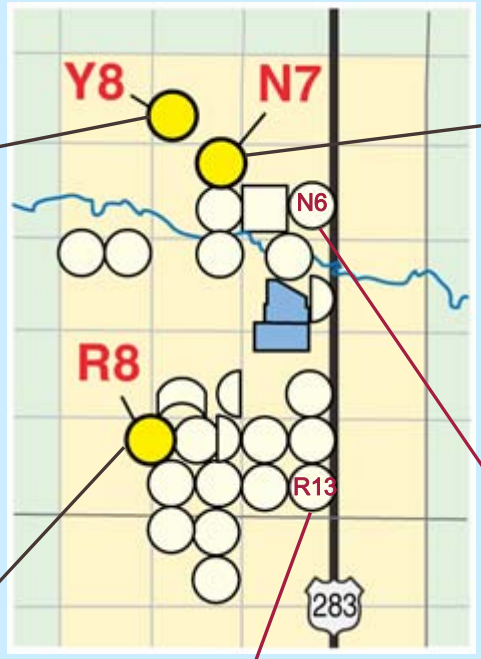
Total losses of N: 348 lb/ac

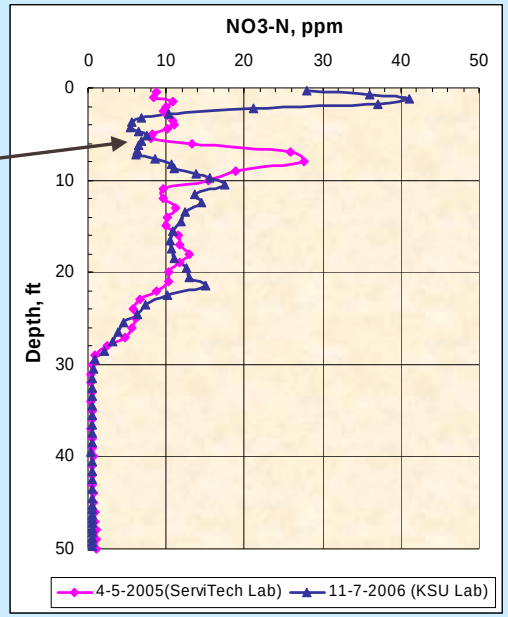


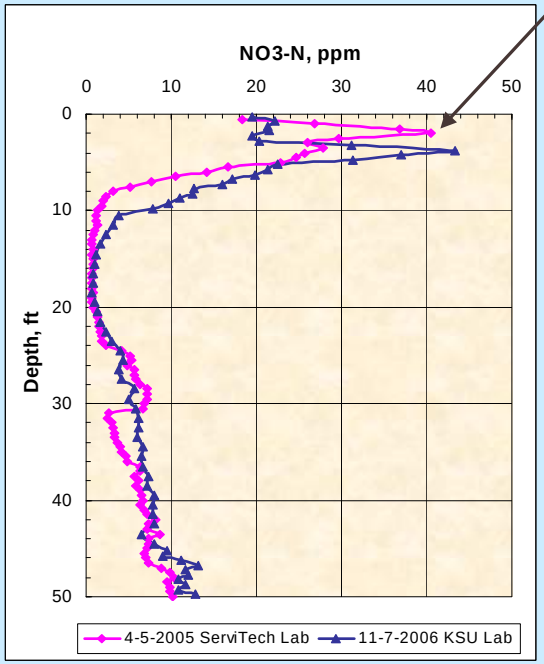
Transformations of N: 65 lb/ac

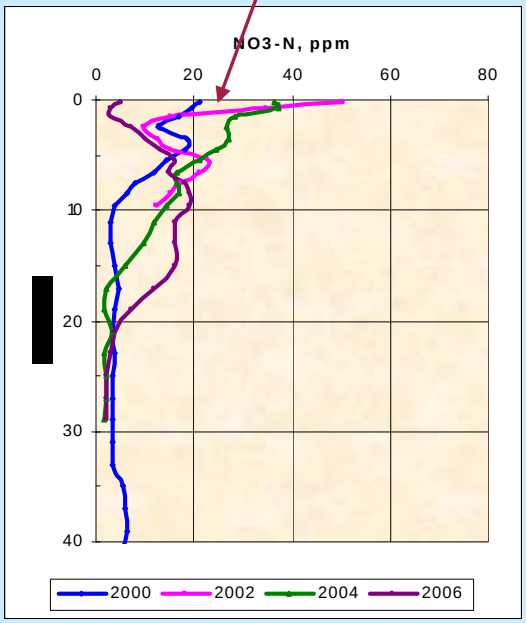


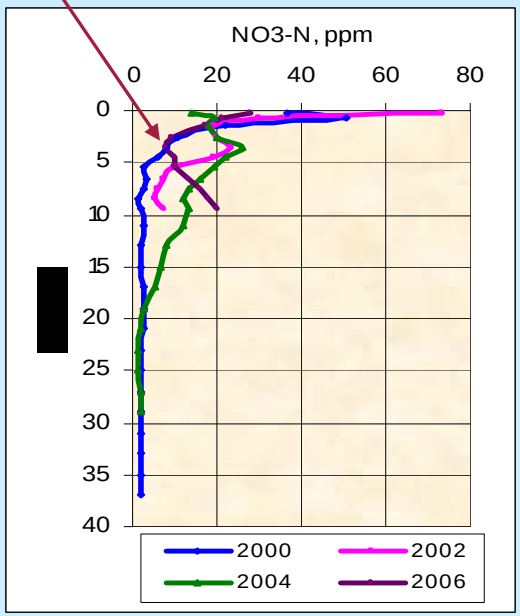

NO3-N, ppm
0
10
20
30
40
50
Depth, ft
Spring 2005
Fall 2006


Y8
N7
N6
R8
R13
283


NO3-N, ppm
0
10
20
30
40
50
Depth, ft
4-5-2005(ServiTech Lab)
11-7-2006 (KSU Lab)


NO3-N, ppm
0
10
20
30
40
50
Depth, ft
4-5-2005 ServiTech Lab
11-7-2006 KSU Lab

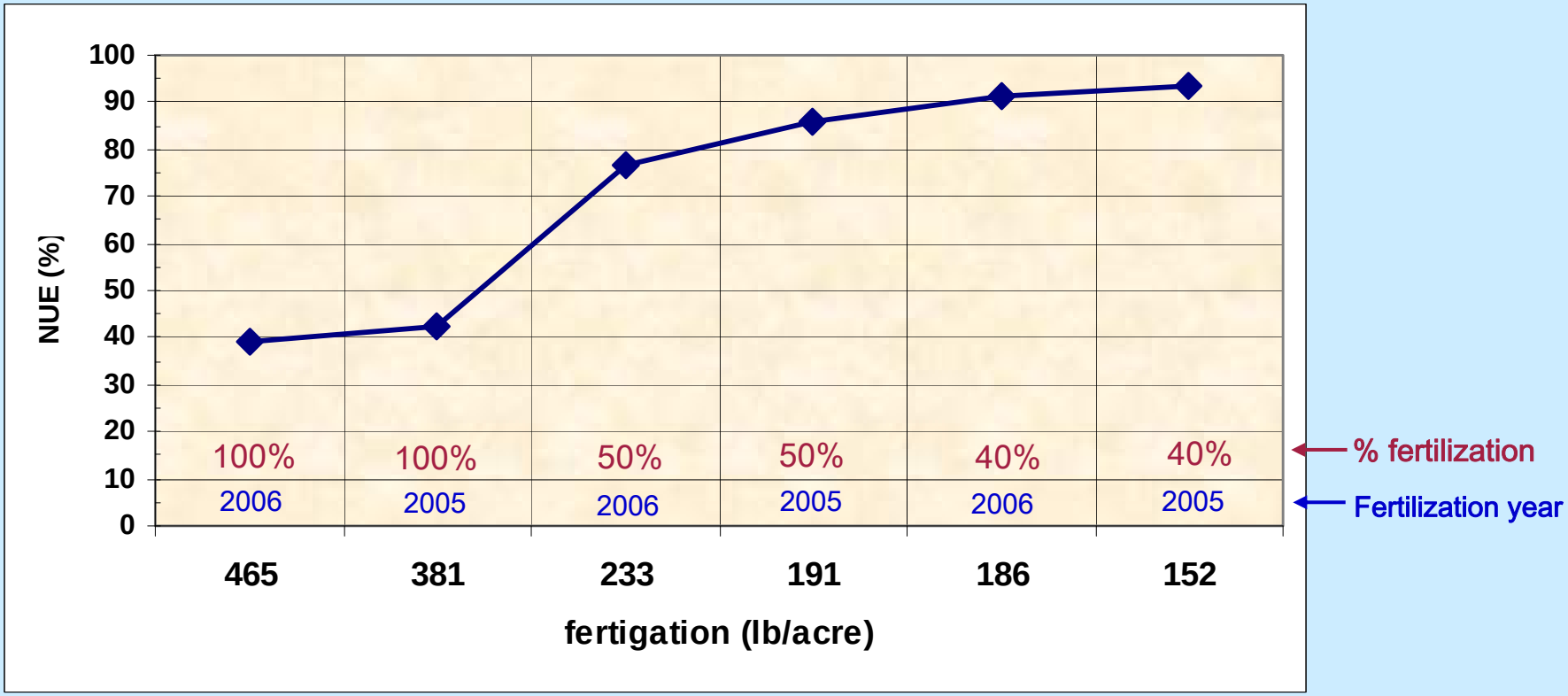

NO3-N, ppm
0
20
40
60
80
2000
2002
2004
2006


NO3-N, ppm
0
20
40
60
80
0
5
10
15
20
25
30
35
40
2000
2002
2004
2006

Management Scenarios

- Reduced fertilization by 50%, 40%
- Reduced irrigation by 50%, 25%, 12%

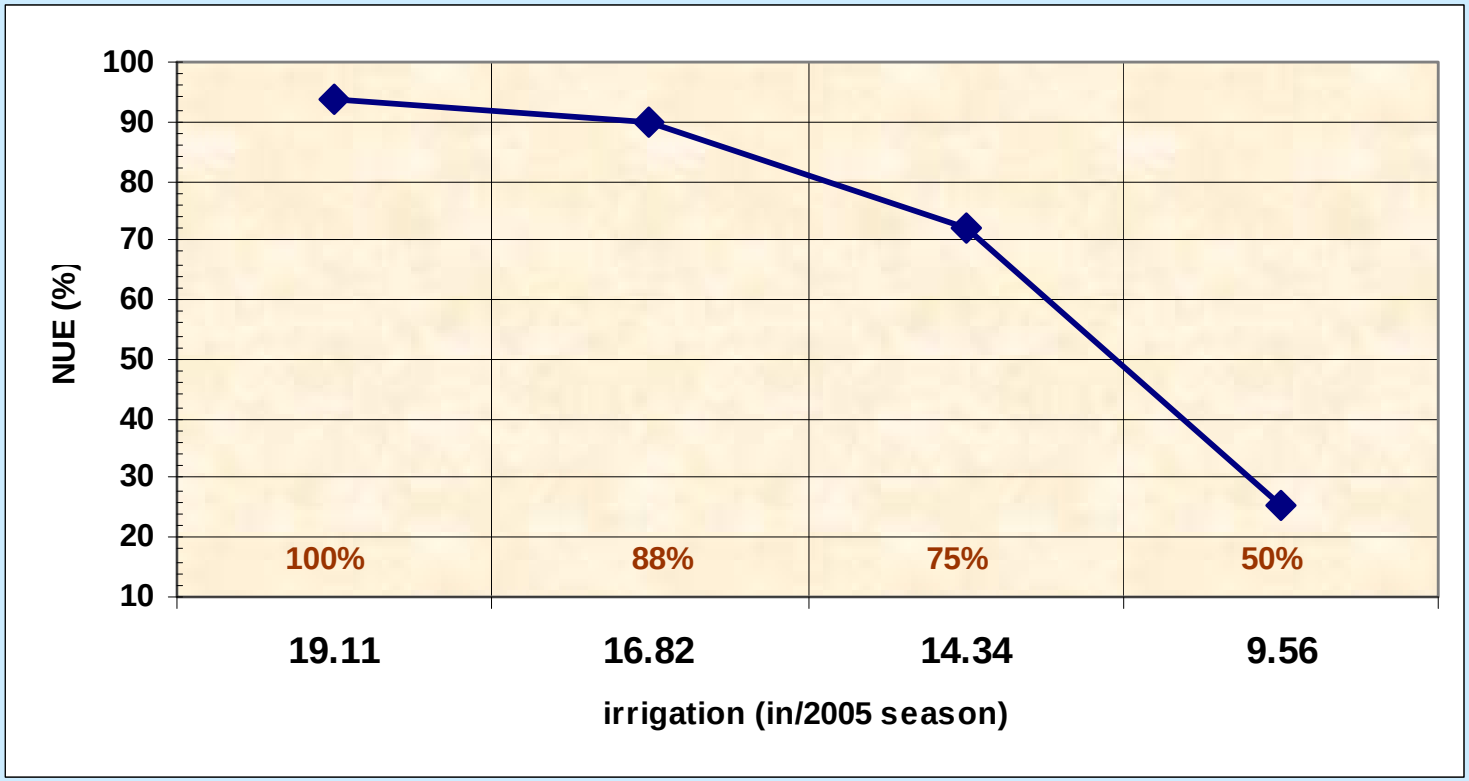
NUE vs fertilization



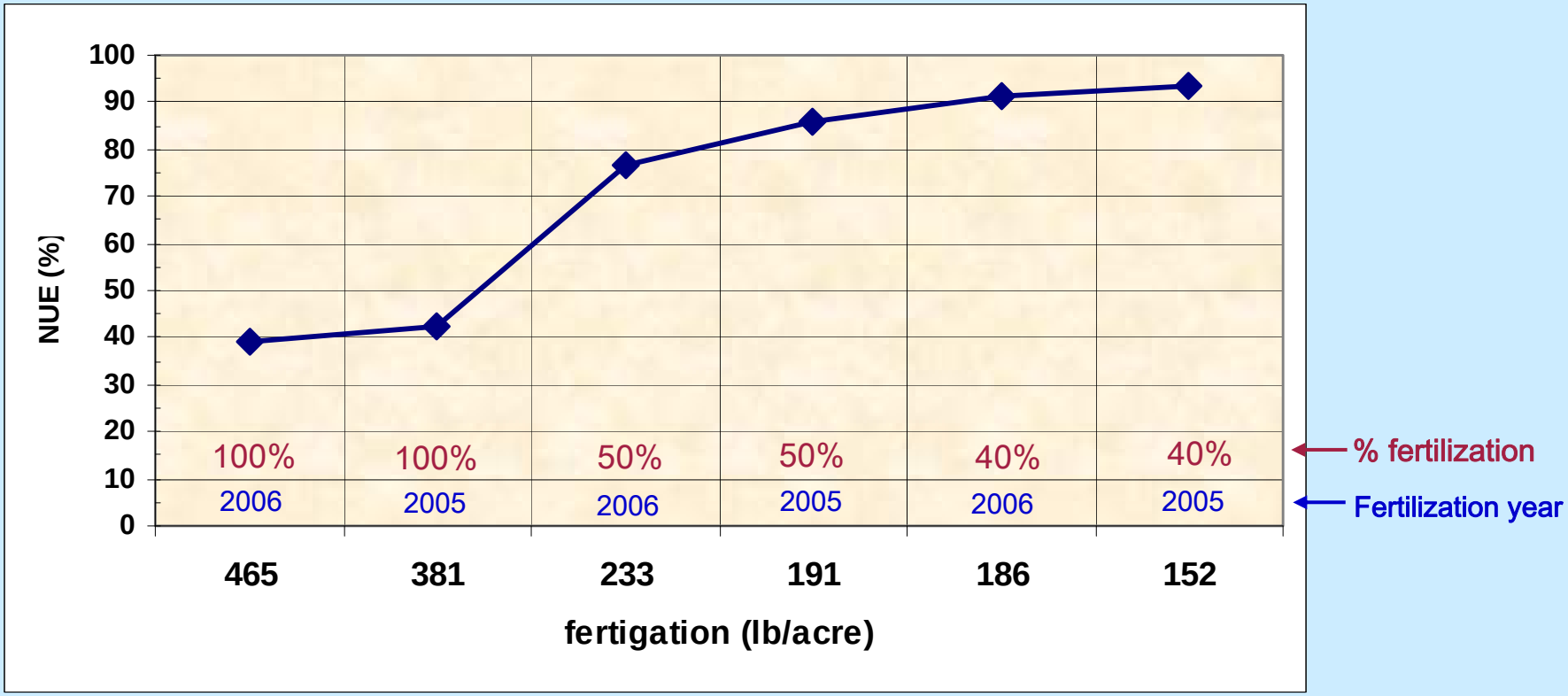
NUE vs irrigation reductions

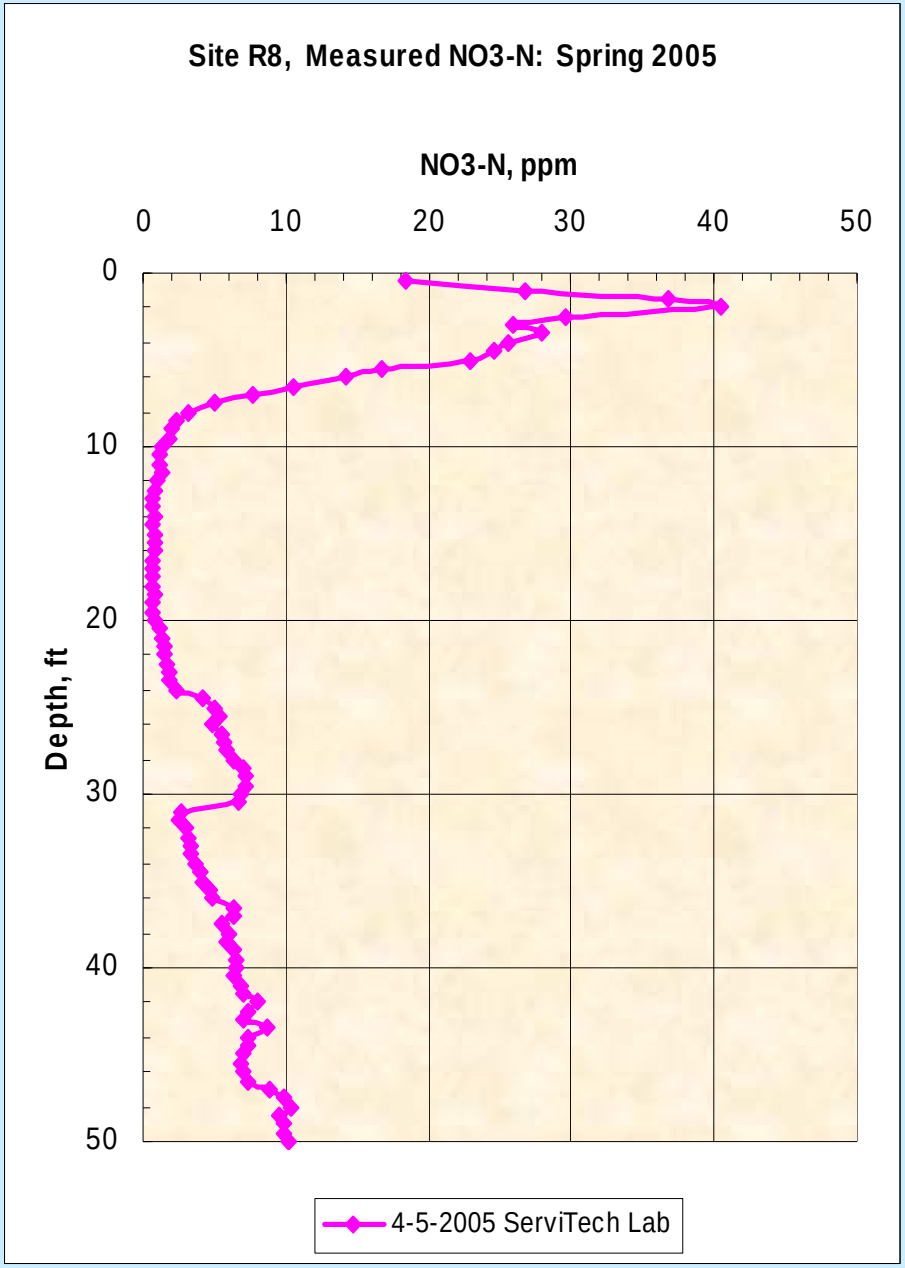
2005 full irrigation = 19.1 in

2005 full N fertilization = 152 lb/acre



NUE vs fertilization





Site R8

Corn: 2003-present

Alfalfa: 1997-2002

Conclusions

1 Our soil coring down to 50 ft and ground-water sampling in the treated wastewater irrigation area south of Dodge City, Kansas indicated that nitrate is accumulating in the vadose zone and has already reached the underlying ground water.

2 Our coring and dye-tracing experiments demonstrated the existence of preferential pathways through macropores from decaying root channels throughout the sampled depths.

3 The residual soil nitrate-nitrogen (NO_3-N) is progressively increasing with depth, and NO_3-N in the underlying ground water is also increasing with time.

Conclusions (cont'd)

4. The RZWQM was calibrated for the 2005 planting season based on limited data and was tested/verified for the 2006 cropping season. The model acceptably approximated the overall patterns of the observed soil water and nitrate profiles but generally overestimated the profile soil nitrate.

5. The RZWQM model showed that reducing the wastewater fertilization rates to around 150 lb/acre increases the Nitrogen Use Efficiency (NUE) significantly while maintaining near-maximal grain yields.

Recommendations

Adopting such measures (i.e. reducing fertilization using wastewater by more than 50%) would reduce the size of residual nitrate stored in the thick vadose zone in the area and slow down its downward migration.

Combining such measures with crop rotations with leguminous plants will most likely further reduce the amounts of residual nitrate in the soil profile.

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