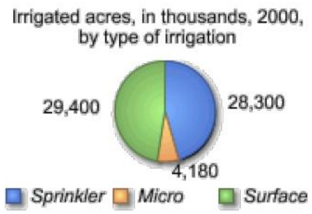
Irrigation background & modeling

Jan W Hopmans – UC Davis

United States

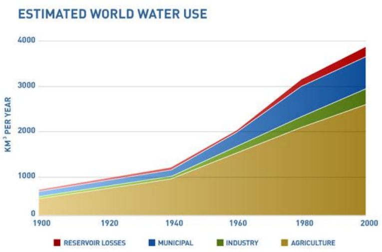


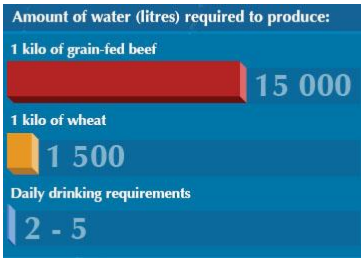
Why increasingly more relevant ?

- Globally, about 80% of water use is for irrigation;
- Interest in improving irrigation water use efficiency;
- Groundwater quality concerns regarding nitrate, and GHG emissions by denitrification to N_2O;
- Therefore, optimize nitrate use efficiency

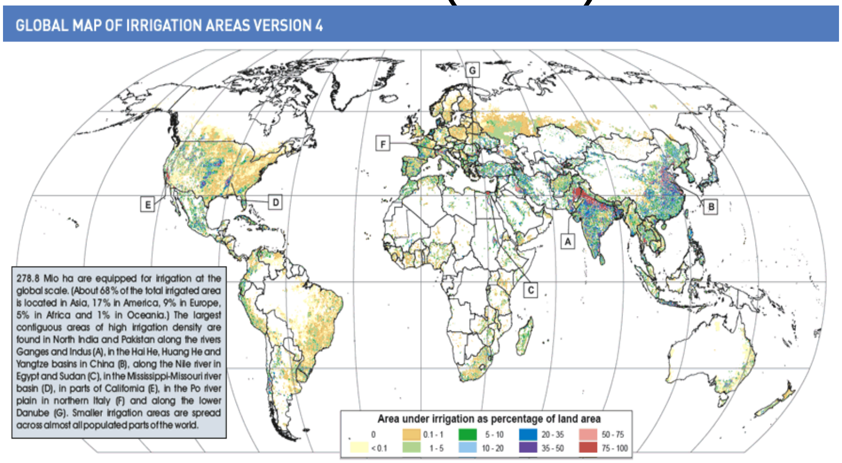
FACTS: Water for food Water for life

- **Is there enough water to produce food for a growing population over the next 50 years?**
- **It takes about 1L of water per calorie of food (daily dietary needs is about 3,000L/day;**
- **Global agricultural crop production takes about 70% of developed freshwater, of which about 30% is groundwater;**
- **Whereas currently about 15% of agriculture is irrigated, it produces about 45 % of global food production;**
- **About 1/3 of irrigated land is salt-affected**;





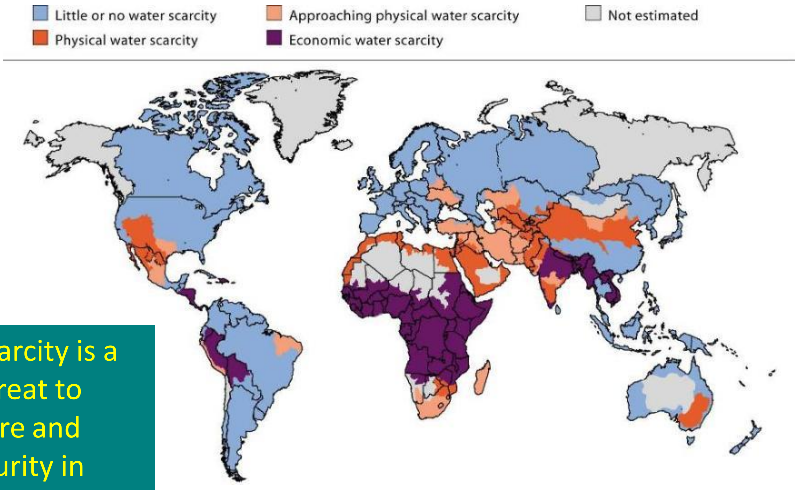
Global Map of Irrigated Areas (FAO)



278.8 Mio ha are equipped for irrigation at the global scale. (About 68% of the total irrigated area is located in Asia, 17% in America, 9% in Europe, 5% in Africa and 1% in Oceania.) The largest contiguous areas of high irrigation density are found in North India and Pakistan along the rivers Ganges and Indus (A), in the Hai He, Huang He and Yangtze basins in China (B), along the Nile river in Egypt and Sudan (C), in the Mississippi-Missouri river basin (D), in parts of California (E), in the Po river plain in northern Italy (F) and along the lower Danube (G). Smaller irrigation areas are spread across almost all populated parts of the world.

Food – Water – Climate Change

GRAND CHALLENGES – Water Scarcity



Water scarcity is a major threat to agriculture and food security in developing countries

www.iwmi.org

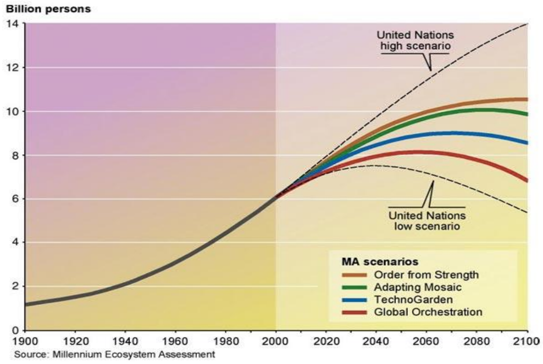
Water for a food-secure world

Key Drivers of Water Scarcity

- Population growth

(6.7 billion now to
9 billion by 2050)

- Dietary changes
- Urbanization
- Globalization
- Climate Change



Source: Millennium Ecosystem Assessment

- Biofuels/hydropower competing for land and water

The Paradox and the Challenge

Feeding another

c.2.5 billion people with

less water for

agriculture than we

have now

'NEW AGRICULTURE' : DO MORE WITH LESS-

MINIMIZE YIELD LOSSES WHILE KEEPING ENVIRONMETNAL EFFECTS OF CROP PRODUCTION IN CHECK

(maximize application efficiency by minimizing losses)

EXAMPLES (of strategic applications):

- Micro irrigation and Fertigation
- Deficit Irrigation and Partial root zone drying
- Agroforestry
- Bioremediation and Phytoremediation

Type of irrigation systems

- Gravity systems:
  - basin and border irrigation
  - furrow irrigation
  - flood irrigation
- Micro-irrigation (pressurized)
  - sprinkler (large and small systems)- fan jet
  - center pivot and linear move systems
  - drip irrigation: surface and subsurface

Basin & Border Irrigation

Laser Leveling and Surface Flood Irrigation

Furrow Irrigation

Flood irrigation, Fremont County, Wyomi
Credit: Jeff Vanuga, USDA NRCS

Improving Irrigation Efficiency

- Land smoothing and laser grading
  - Helps to improve uniformity
- Surge irrigation
  - Alternate on-off periods for applying water
  - Achieve higher efficiencies and uniformities in some soils
  - Lends itself to semi-automation

Sprinkler Irrigation

Linear move

Water gun

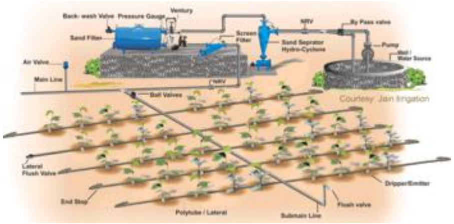
Center Pivot

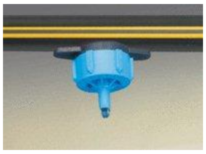
Drop tube

Wheel Line

Wheel line Sprinkler System

Micro sprinkler and Drip Irrigation

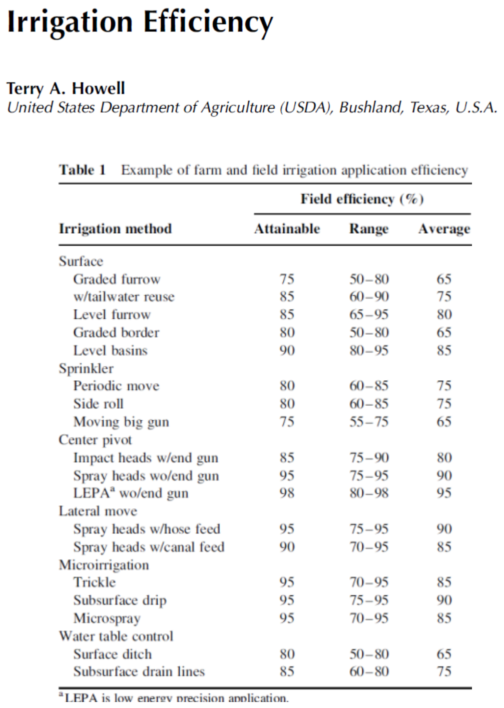




Almond Irrigation- Fan jet

Differences in water application uniformity & efficiency between irrigation systems

- Gravity systems typically have the lowest water application efficiency, as irrigation water moves down the irrigated field, with water infiltration varying across the wetted field/furrow/border – **Non Uniform**
- Micro irrigation systems typically show highest water application efficiency.



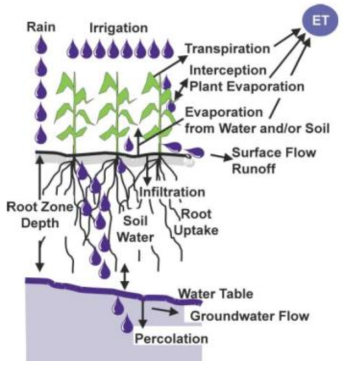
Irrigation Efficiency

Terry A. Howell
United States Department of Agriculture (USDA), Bushland, Texas, U.S.A.

Table 1 Example of farm and field irrigation application efficiency

	Field efficiency (%)		
Irrigation method	**Attainable**	**Range**	**Average**
Surface			
Graded furrow	75	50–80	65
w/tailwater reuse	85	60–90	75
Level furrow	85	65–95	80
Graded border	80	50–80	65
Level basins	90	80–95	85
Sprinkler			
Periodic move	80	60–85	75
Side roll	80	60–85	75
Moving big gun	75	55–75	65
Center pivot			
Impact heads w/end gun	85	75–90	80
Spray heads wo/end gun	95	75–95	90
LEPA[a] wo/end gun	98	80–98	95
Lateral move			
Spray heads w/hose feed	95	75–95	90
Spray heads w/canal feed	90	70–95	85
Microirrigation			
Trickle	95	70–95	85
Subsurface drip	95	75–95	90
Microspray	95	70–95	85
Water table control			
Surface ditch	80	50–80	65
Subsurface drain lines	85	60–80	75

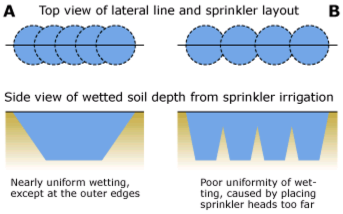
[a] LEPA is low energy precision application.

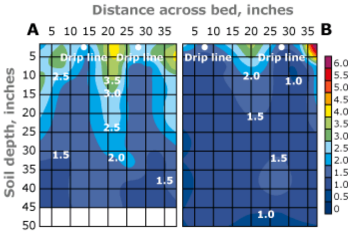


Processing tomatoes in CA is highly profitable crop

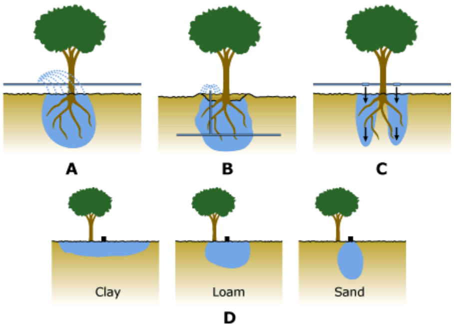
Subsurface Drip-irrigated

Wetting Patterns

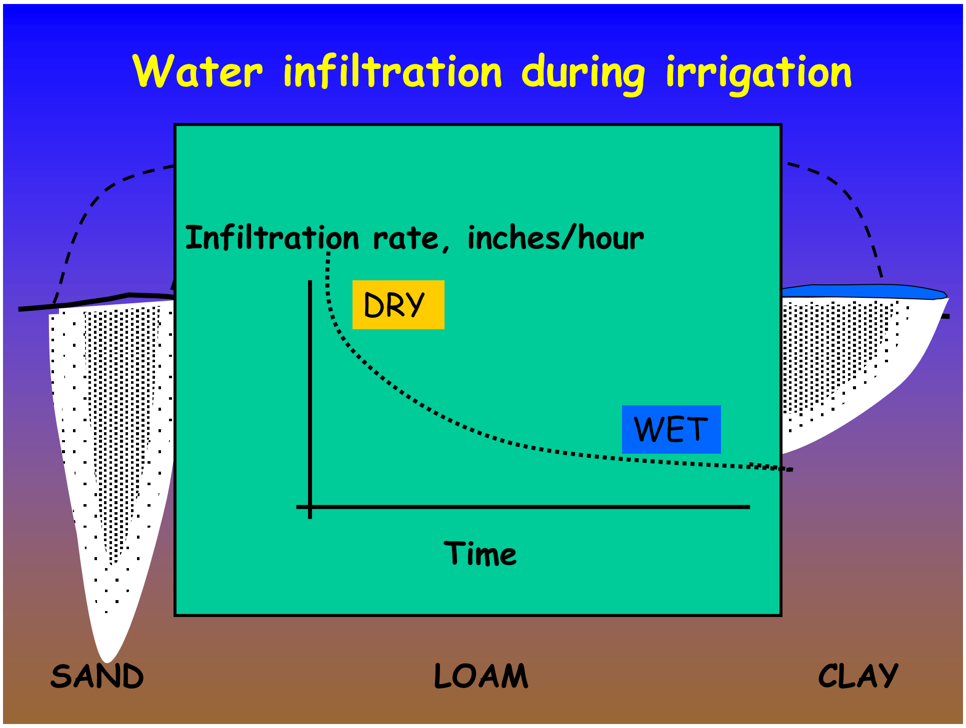




Pattern of salinity for soil wetted by a dual-drip irrigation system at relatively low (a) and high (b) leaching fraction. The vertical scale at right shows the value of EC_e associated with each color.

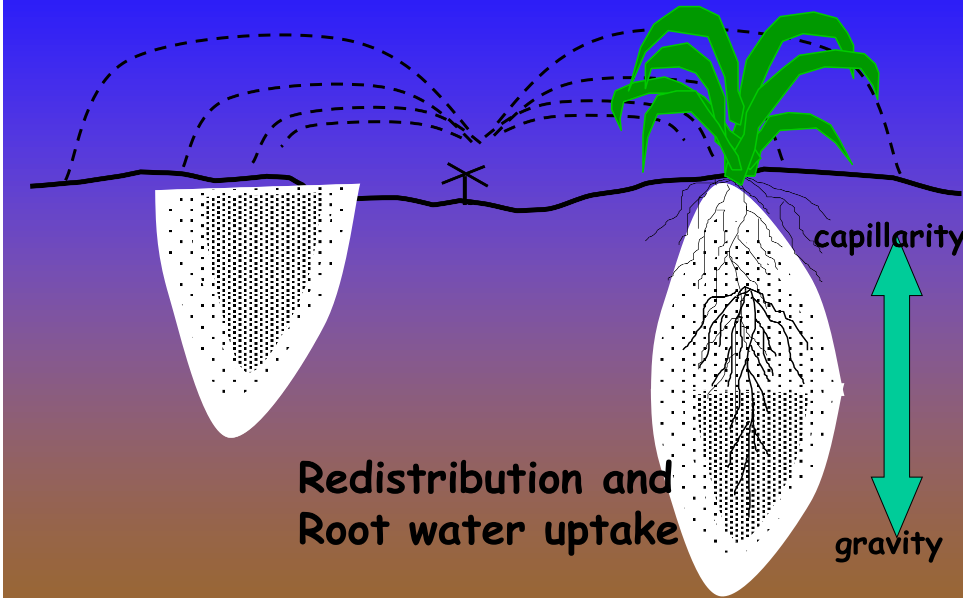


Water and Salinity distribution during/after irrigation



Water infiltration during irrigation

Water flow after irrigation



Redistribution and Root water uptake

Leaching Requirement

Minimum fraction of the total amount of applied water that must pass through the soil root zone to prevent reduction of crop yield from an excess accumulation of salts

Advances in irrigation technology such as micro irrigation and sprinkling irrigation provide opportunities to irrigate with very low LF values, however, this might lead to soil salinization and crop yield reduction, especially if groundwater table is shallow

Leaching Fraction (LF)

Field Water Balance Method: Amount of water that drains below the root zone divided by the amount of water applied

OR

$$\frac{\text{Water Applied} - \text{EvapoTranspiration (ET)}}{\text{Water Applied}}$$

Typically, LF is determined assuming that water is uniformly applied across the field, as by flooding, furrow or sprinkling irrigation.

Also, the common approach to compute field-wide LF, is to use seasonal amount of applied water and potential ET, negating temporal variations in leaching during and between irrigation cycles.

We note that drip irrigation only partly wets the soil zone, thus we expect that localized leaching will occur if Applied Water is equal or even less that ET.

Soil Salinity in Drip-Irrigated Tomatoes

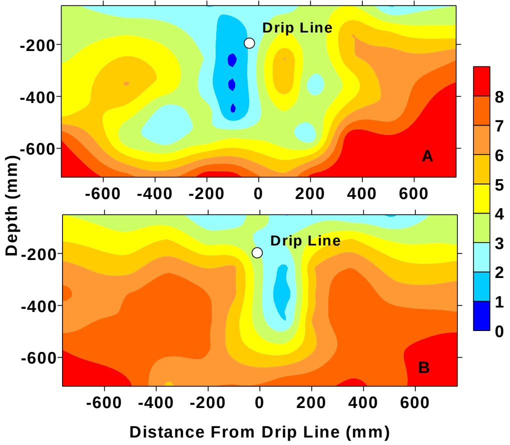


Fig. 2. Soil salinity/electrical conductivity (EC) around drip line for water depth of about 18 to 24 inches, EC irrigation water = 0.5 dS/m, EC groundwater = 8 to 10 dS/m, for water applications of (A) 23.2 and (B) 15.6 inches.

Soil salinity near drip lines is controlled by:

1. Depth of saline groundwater
2. Irrigation water salinity
3. Amount of applied irrigation water, relative to ET
4. Crop root distribution
5. Irrigation frequency
6. Soil type

Salt tolerance function tomatoes:

Threshold: 2.5 dS/m

Slope: 9.9%

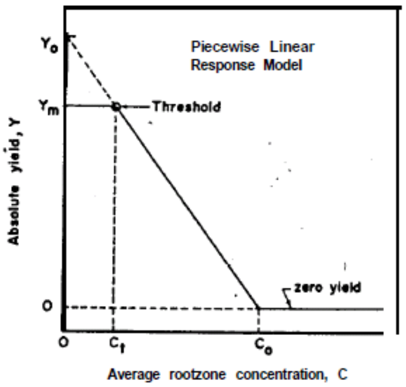


Fig.1. Graphical representation of the piece-wise linear crop and salt tolerance response function (Eq.1)

Moderately sensitive to salts, hence reduced yields may occur if not managed properly

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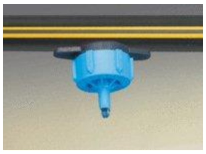
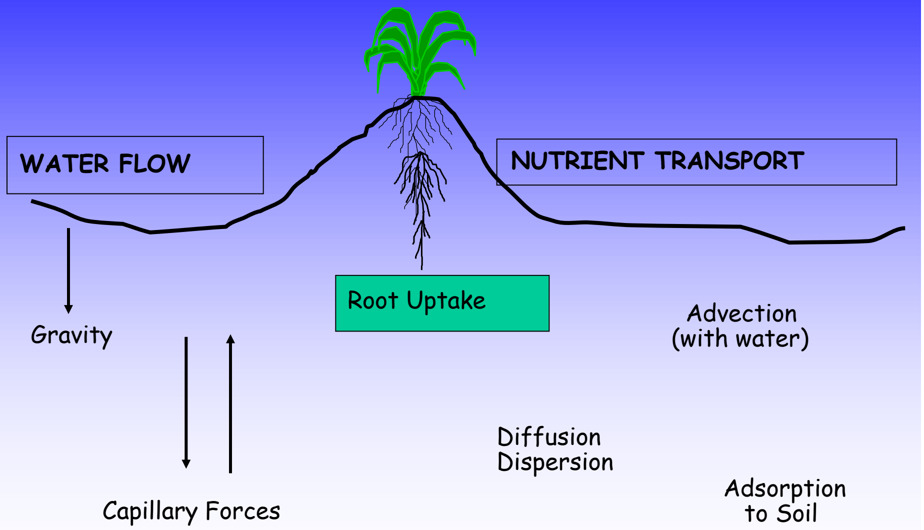
Soil solution nitrate distribution during and between irrigation events



Movement of Nutrients in Soils



WATER FLOW

Gravity

Capillary Forces

Root Uptake

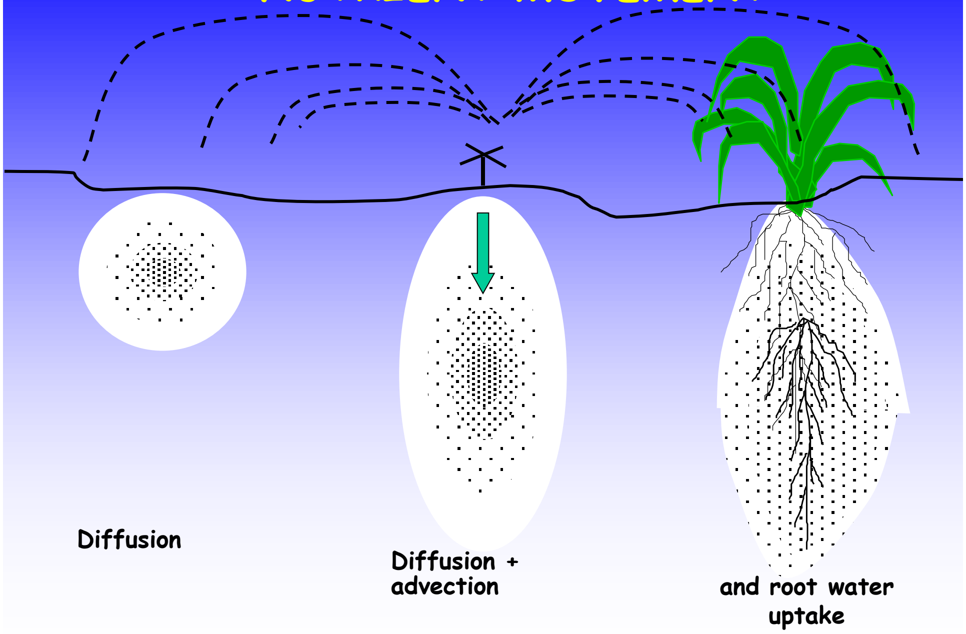
NUTRIENT TRANSPORT

Advection
(with water)

Diffusion
Dispersion

Adsorption
to Soil

NUTRIENT MOVEMENT

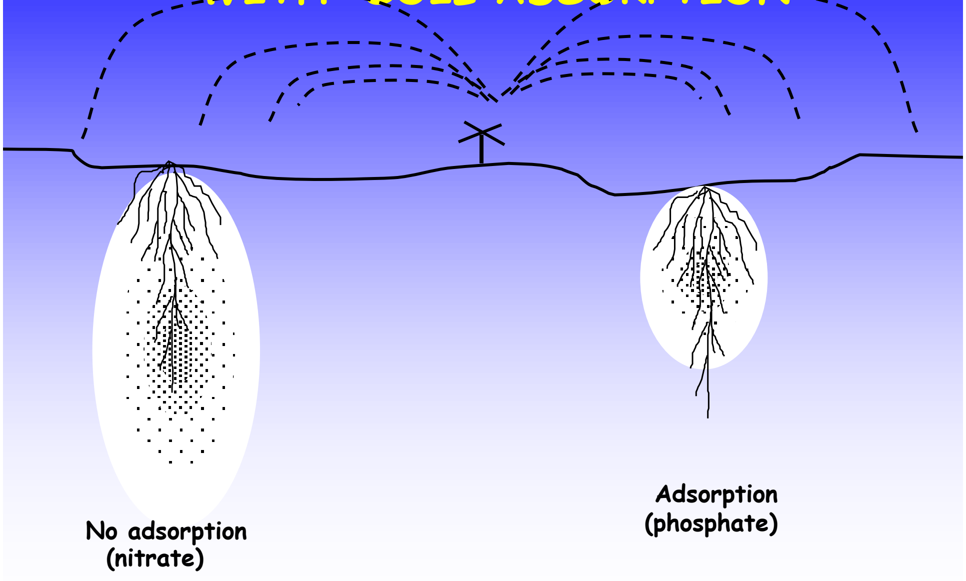


Diffusion

Diffusion + advection

and root water uptake

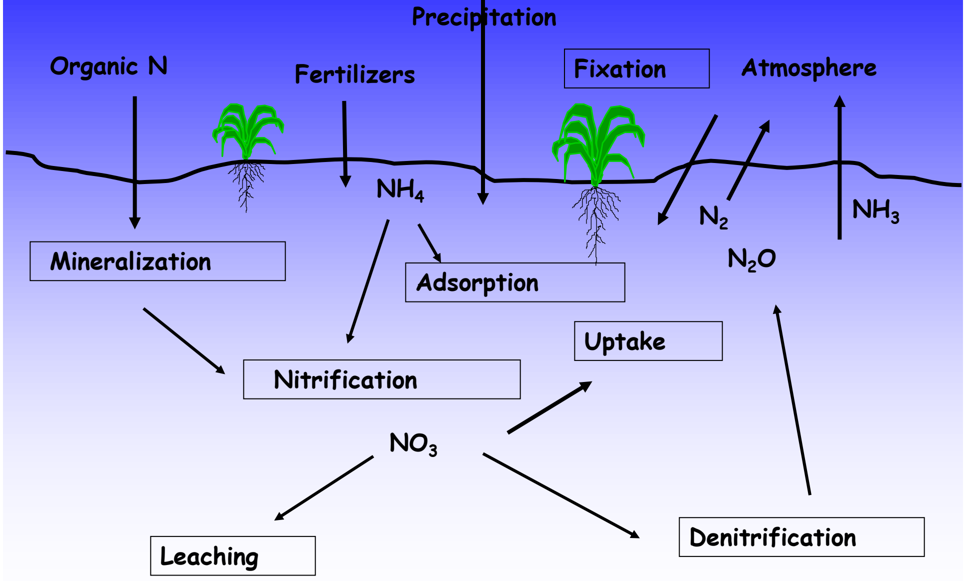
NUTRIENT MOVEMENT WITH SOIL ADSORPTION



No adsorption (nitrate)

Adsorption (phosphate)

NITROGEN CYCLE



Precipitation

Organic N

Fertilizers

Fixation

Atmosphere

NH_4

N_2

NH_3

Mineralization

Adsorption

N_2O

Uptake

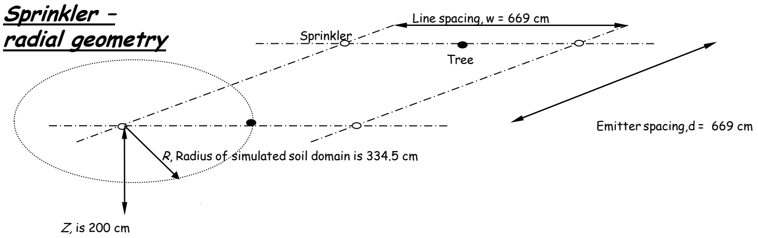
Nitrification

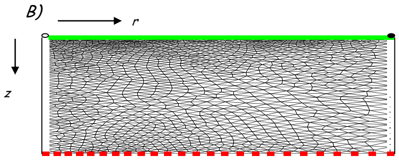
NO_3

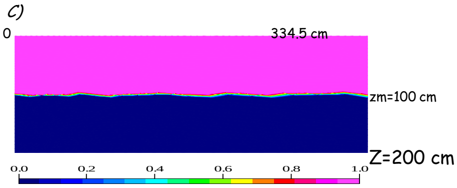
Leaching

Denitrification

Sprinkler – radial geometry



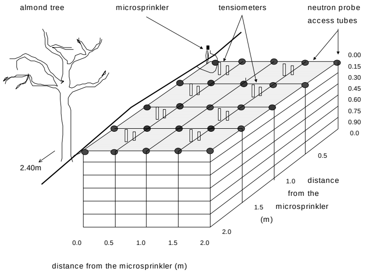


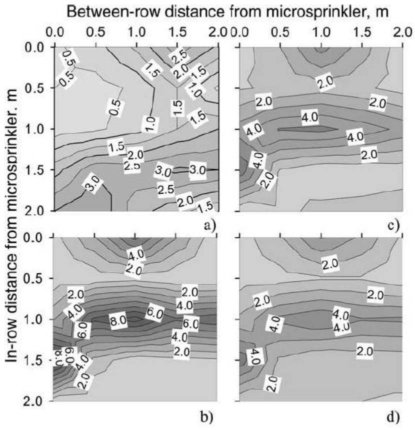


Non-uniform water application rate is likely

Define boundary conditions . . . .

Fig. 2 Patterns of sprinkling application rate (mm h^{-1}) obtained from the catch cans on August 18 (**a**), August 21 (**b**), August 23, 1995 (**c**), and for the three irrigation events combined (**d**)

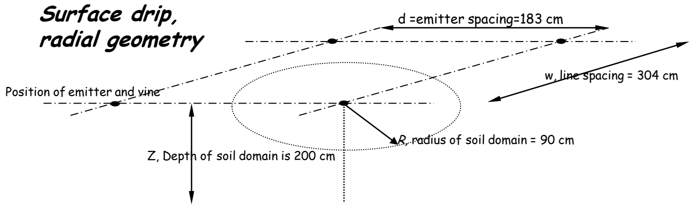


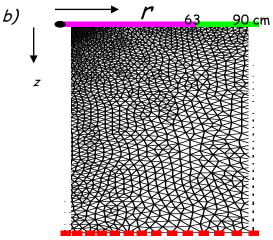


Kouman S. Koumanov · Jan W. Hopmans
Larry W. Schwankl

Spatial and temporal distribution of root water uptake of an almond tree under microsprinkler irrigation

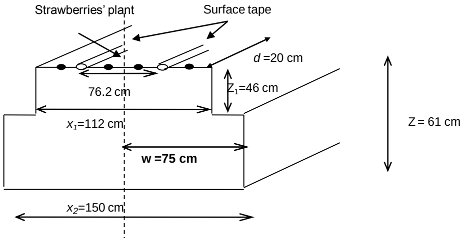
Surface drip, radial geometry

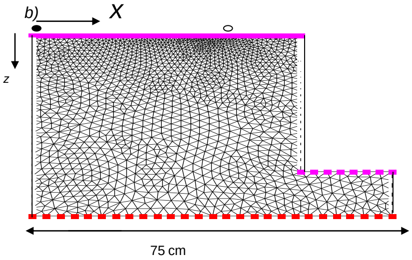


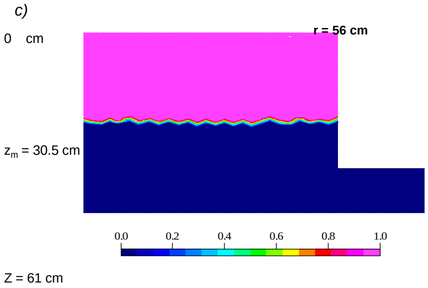


- Point irrigation water source: axy-symmetrical & radial geometry
- Must allow for model to compute increase in wetted surface area, as emitter application rate becomes higher than infiltration rate……
- Transition from flux to head boundary condition
- Smallest element size near drip emitter

Surface Drip Tape – Two-dimensional domain

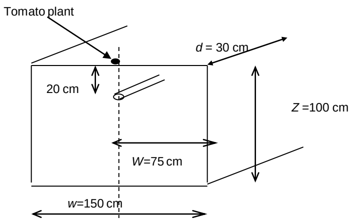


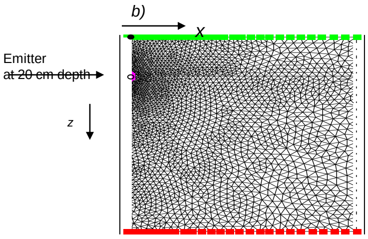


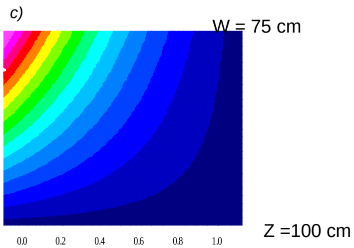


- Must allow for model to switch from surface boundary flux to positive head boundary condition in the furrow
- Infinite line source

Subsurface Drip – Two-dimensional geometry







- **Rectangular symmetry, smallest elements near emitter**
- **Emitter is source term in Richards's equation**

•Must allow for model to compute positive soil water pressure if the flow rate of the dripper is larger than the rate at which discharged water can move into the wetted soil.

Model parameters, to be defined

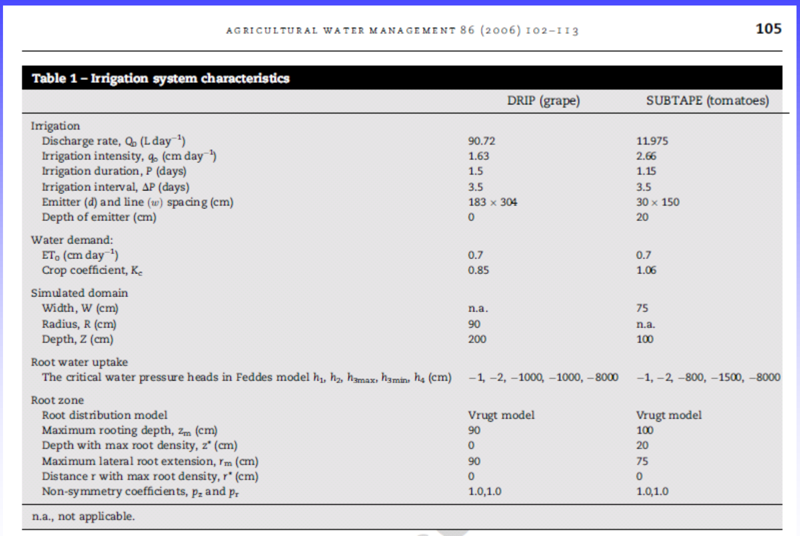


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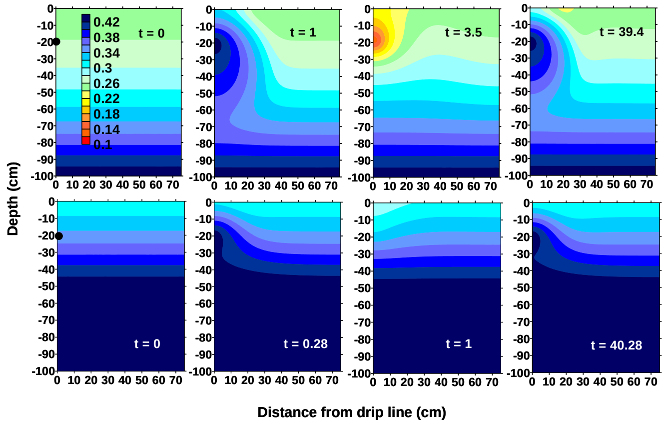
Table 1 – Irrigation system characteristics

	DRIP (grape)	SUBTAPE (tomatoes)
Irrigation		
Discharge rate, Q_0 (L day^{-1})	90.72	11.975
Irrigation intensity, q_0 (cm day^{-1})	1.63	2.66
Irrigation duration, P (days)	1.5	1.15
Irrigation interval, ΔP (days)	3.5	3.5
Emitter (d) and line (w) spacing (cm)	183 × 304	30 × 150
Depth of emitter (cm)	0	20
Water demand:		
ET_0 (cm day^{-1})	0.7	0.7
Crop coefficient, K_c	0.85	1.06
Simulated domain		
Width, W (cm)	n.a.	75
Radius, R (cm)	90	n.a.
Depth, Z (cm)	200	100
Root water uptake		
The critical water pressure heads in Feddes model h_1, h_2, h_{3max}, h_{3min}, h_4 (cm)	−1, −2, −1000, −1000, −8000	−1, −2, −800, −1500, −8000
Root zone		
Root distribution model	Vrugt model	Vrugt model
Maximum rooting depth, z_m (cm)	90	100
Depth with max root density, z^* (cm)	0	20
Maximum lateral root extension, r_m (cm)	90	75
Distance r with max root density, r^* (cm)	0	0
Non-symmetry coefficients, p_z and p_r	1.0,1.0	1.0,1.0

n.a., not applicable.

Simulated water content distributions for water table depths at 100 cm (top) and 50 cm (bottom) – **subsurface drip with irrigation every 3.5 days**

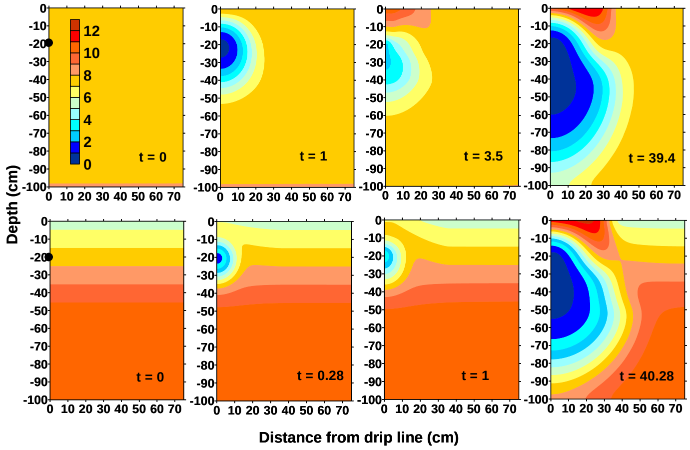


100 cm

50 cm

Water application is 100% ET and EC_{iw} = 0.3 dS/m

Simulated soil salinity distributions for water table depths at 100 cm (top) and 50 cm (bottom)

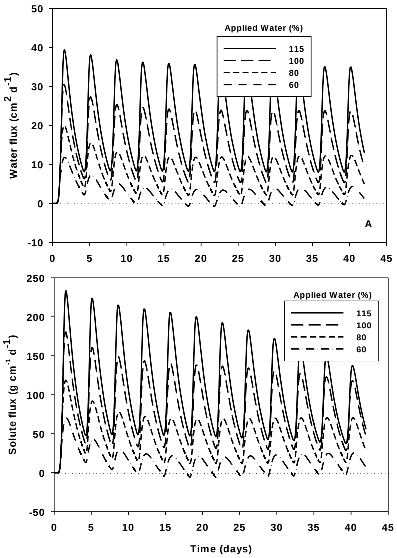


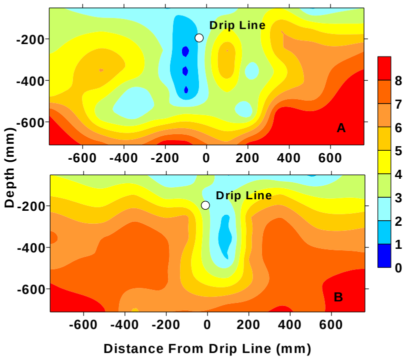
100 cm

50 cm

Water application is 100% ET and EC_{iw} = 0.3 dS/m (EC_{gw} is 8 or 10 dS/m)

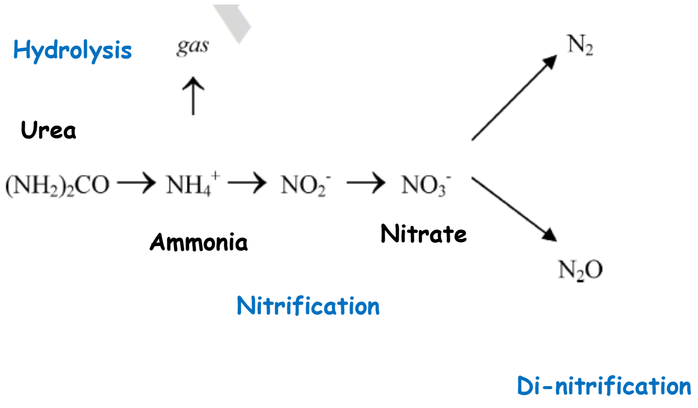
Water (top) and salinity (bottom) fluxes at the bottom of the root zone, for different water applications





Effect of applied irrigation water on soil salinity

Fertigation studies



Hydrolysis

gas

Urea

$(NH_2)_2CO \rightarrow NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$

N_2

N_2O

Ammonia

Nitrate

Nitrification

Di-nitrification

Non-equilibrium chemical transport (first-order decay chain, by which chemicals (k) are removed and/or produced)

$$\frac{\partial \theta c_1}{\partial t} + \rho \frac{\partial s_1}{\partial t} = \frac{\partial}{\partial x_i}\left(\theta D_{ij,1}\frac{\partial c_1}{\partial x_j}\right) - \frac{\partial q_i c_1}{\partial x_i} - \mu_{w,1}\theta c_1 - \mu_{s,1}\rho s_1 - S c_{r,1} \qquad (2)$$

$$\frac{\partial \theta c_k}{\partial t} + \rho \frac{\partial s_k}{\partial t} = \frac{\partial}{\partial x_i}\left(\theta D_{ij,k}\frac{\partial c_k}{\partial x_j}\right) - \frac{\partial q_i c_k}{\partial x_i} - \mu_{w,1}\theta c_k - \mu_{s,k}\rho s_k + \mu_{w,k-1}\theta c_{k-1} + \mu_{s,k-1}\rho s_{k-1} - S c_{r,k}, \quad k\,\varepsilon\,(2, n_s) \qquad (3)$$

- **Transformation reactions depend on first-order rate constants, μ, for hydrolysis, nitrification and de-nitrification.**
- **Adsorption isotherm controls adsorption of chemical species to the solid phase:**

$$s_k = K_{d,k} c_k \qquad (4)$$

where $K_{d,k}$ [$L^3 M^{-1}$] is the distribution coefficient of species k.

Fate of Urea/Ammonium/Nitrate fertilizer, as applied by surface drip system