Modelling optimisation of HTO transfer from soil to plants

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PREDRAFT

Owerview

1. Hypothetical scenario conclude that soil pathway is less important than air but night and rain conditions must be elucidated. It is always true?
2. We are interested in HTO and OBT in edible plat part and NOT detailed soil tritium
3. root dynamics
4. potential and actual transpiration
5. water uptake from soil layers
6. HTO profile in soil
7. contamination of leaf water from soil

Plants of interest include pasture, lucerne, rice, wheat, corn, vegetables (leafy and root vegetables), tomatoes, potatoes, apples and citrus fruits, grapes + sunflower and sugar beet

Pasture have roots until 30 cm- permanent pasture
Leafy vegetables also 30 cm but growing from 10. We are interested mostly on few weeks before harvest
Other plants can have deeper roots

Plant characteristics **AQUACROP**

Maize

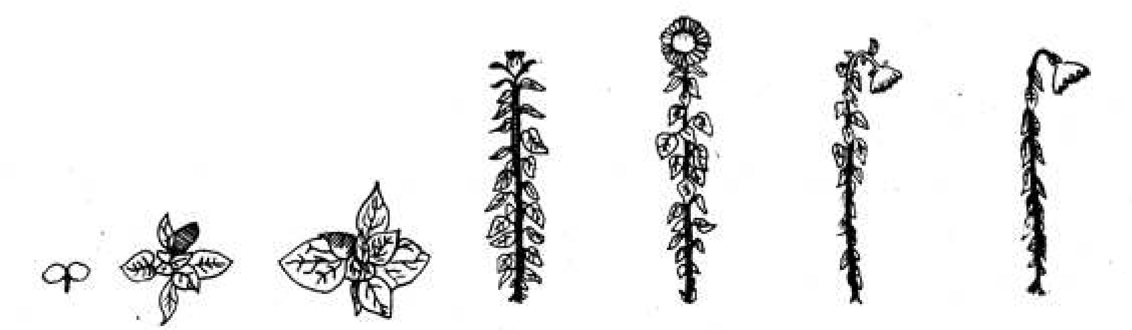
1.4 Development of root zone
Z_n Minimum effective rooting depth (m) Management (3) 0.30
Z_x Maximum effective rooting depth (m) Management (3) Up to 2.80
Shape factor describing root zone expansion Conservative (1) 1.3
Time from sowing to maximum rooting depth (growing degree day) Cultivar (4) Environment (3)
Function of root expansion rate:
1.5 - 2.5 cm/day

Data base for:
Maize potato rice, soybean sugar beet sunflower tomato wheat

SWAP & WOFOST

Faba bean
*
  RDI   =   10.00 ! Initial rooting depth, [0..1000 cm, R]
  RRI   =   0.80 ! Maximum daily increase in rooting depth, [0..100 cm/d, R]
  RDC   = 100.00 ! Maximum rooting depth crop/cultivar, [0..1000 cm, R]
*
Data base for
Faba bean potato sugar beet sun flower winter wheat grain maize spring barley soy bean winter oilseed rape grass

SUNFLOWER



Establishment (0)	Vegetative (1)		Flowering (2)	Yield Formation (3)	Ripening (4)
	early (1a)	late (1b)			
20 days	30 days	25 days	30 days	25 days	15 days

ROOTING ZONE MUST EXTEND MORE THAT 1.5 m !!!

WE NEED apples and citrus fruits, grapes

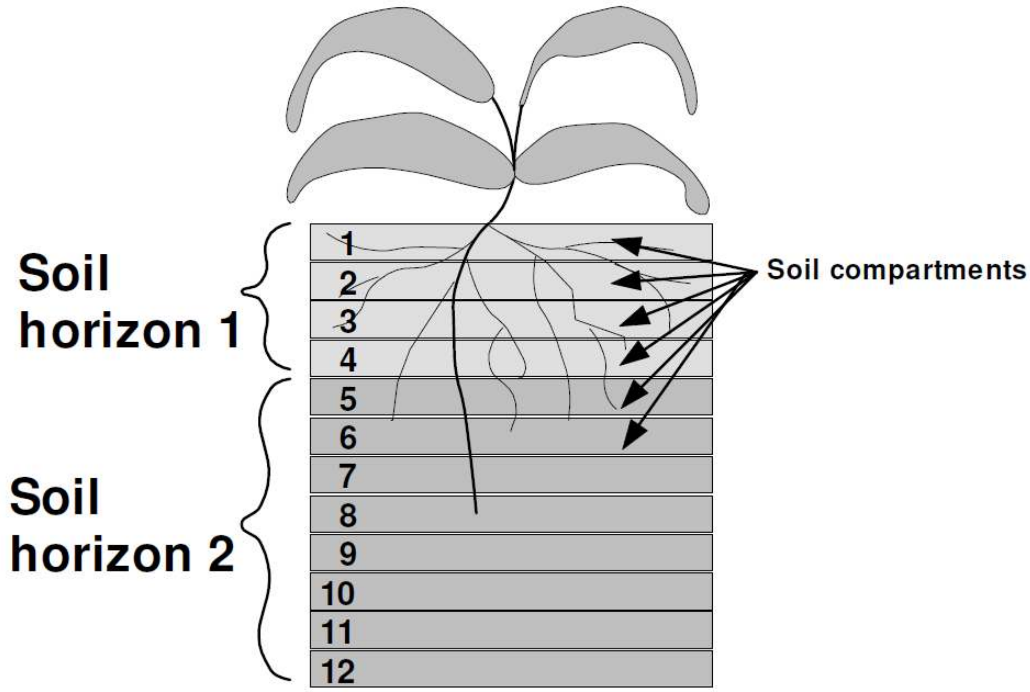


Figure 3.6b
Soil horizons and soil compartments

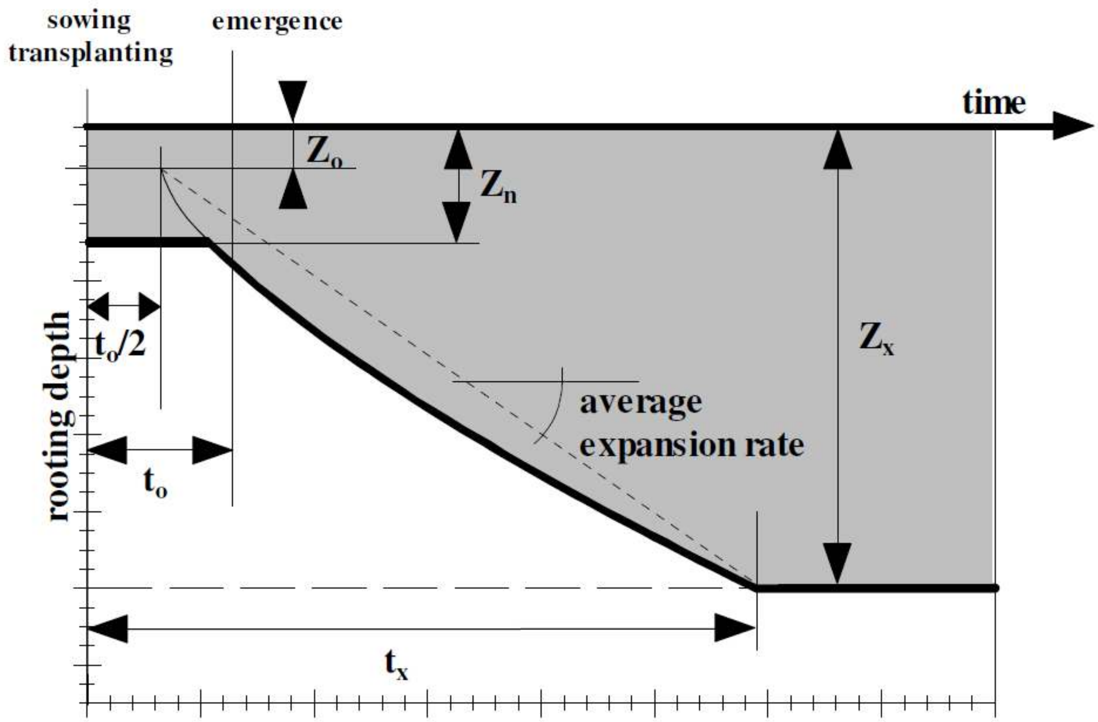


Figure 3.5a
Development of the effective rooting depth (shaded area) from sowing till the maximum effective rooting depth (Z_x) is reached

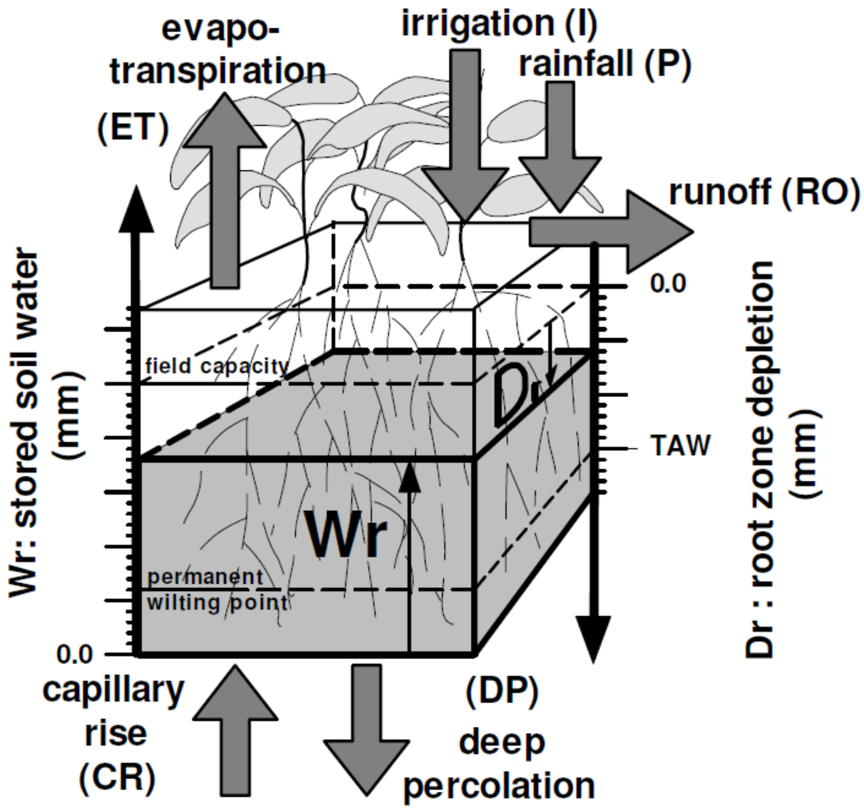


Figure 3.1a
The root zone as a reservoir

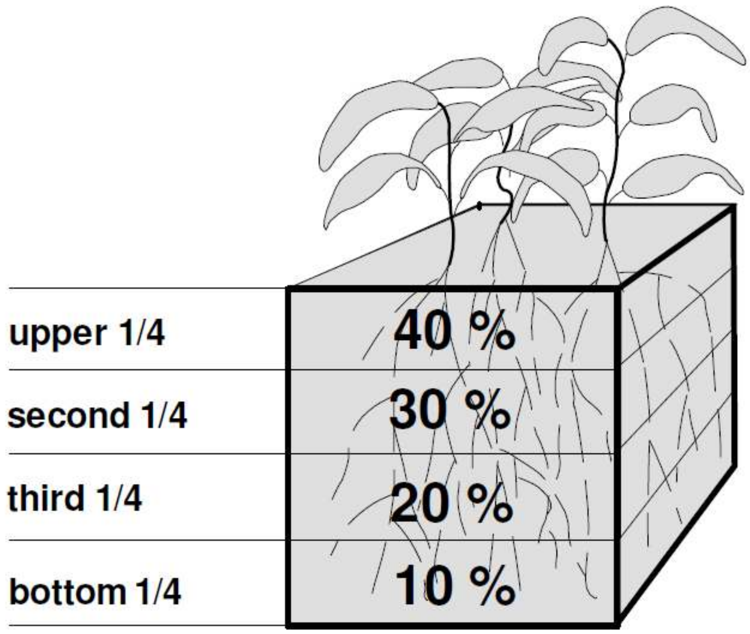


Figure 3.8k
Default extraction pattern in the root zone

POTENTIAL AND ACTUAL TRANSPIRATION

Potential

Comparison of the increasing complexity of the models in terms of number of parameters required

Parameter	Symbol	Units	PT	MB	Penman	PM	SW
Rate of change of vapor pressure with temperature	Δ	$kPa\ K^{-1}$	✓		✓	✓	✓
Total available energy	A	$W\ m^{-2}$	✓		✓	✓	✓
Psychrometric constant	γ	$kPa\ K^{-1}$	✓	✓	✓	✓	✓
Air temperature	T_a	°C	✓	✓	✓	✓	✓
Specific heat at constant pressure	c_p	$J\ kg^{-1}\ K^{-1}$		✓		✓	✓
Air density	ρ	$kg\ m^{-3}$		✓	✓	✓	✓
Vapor pressure deficit	D	kPa		✓	✓	✓	✓
Bulk stomatal resistance of the canopy	r_{cs}	$s\ m^{-1}$		✓		✓	✓
Wind speed	u	$m\ s^{-1}$			✓	✓	✓
Aerodynamic resistance above the canopy	r_{aa}	$s\ m^{-1}$				✓	✓
Bulk boundary layer resistance of the vegetation	r_{ca}	$s\ m^{-1}$					✓
Aerodynamic resistance for substrate and canopy	r_{sa}	$s\ m^{-1}$					✓
Surface resistance of the substrate	r_{ss}	$s\ m^{-1}$					✓
Available soil energy	A_s	$W\ m^{-2}$					✓

PT, Priestley–Taylor; MB, McNaughton–Black; PM, Penman–Monteith; SW, Shuttleworth–Wallace.

The Penman–Monteith model (Monteith, 1965) expanded upon the Penman model:

$$\lambda E = (\Delta A + c_p \rho D / r_{aa}) / (\Delta + \gamma + \gamma(r_{cs}/r_{aa}))$$

where r_{aa} is the aerodynamic resistance above the canopy, and r_{cs} is stomatal resistance of the canopy.

SW

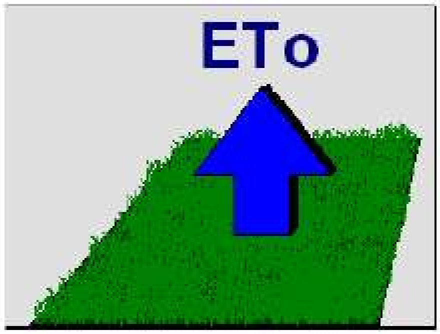
$$\lambda E_s = (\Delta A_s + \rho c_p D_0 / r_{sa}) / (\Delta + \gamma(1 + r_{ss}/r_{sa}))$$

$$\lambda E_c = (\Delta(A - A_s) + \rho c_p D_0 / r_{ca}) / (\Delta + \gamma(1 + r_{cs}/r_{ca}))$$

where A_s is available soil energy, and D_0 is vapor pressure deficit in the canopy; r_{sa} is the aerodynamic resistance between the substrate and canopy source height, r_{ca} is the boundary layer resistance of the vegetation, and r_{ss} is soil resistance. The aerodynamic resistance above the canopy (r_{aa}) and the aerodynamic resistance between the substrate and canopy source height (r_{sa}) are functions of leaf area index, eddy diffusivity decay constant, roughness length of the vegetation (function of vegetation height), zero plane displacement (function of vegetation height), a reference height above the canopy where meteorological measurements are available, wind speed, von Karman's constant, and roughness length of the substrate. D_0 is derived from the Ohm's law electrical analog for the vapor pressure and temperature difference between the canopy and the reference height above the canopy where fluxes out of the vegetation are measured. D_0 is a function of the measurable vapor pressure deficit at the reference height, D:

$$D_0 = D + (\Delta A - r_{aa} \lambda E_c (\Delta + \gamma)) / \rho c_p$$

The ETo Calculator



Evapotranspiration
from a reference surface

Reference Manual

Version 3.1
January, 2009

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3.8.7 Actual crop transpiration (Tr)

- **Thresholds for stomatal closure**

The actual rate of crop transpiration depends on the amount of water available in the root zone (Figure 3.8g). Crop transpiration is reduced below its maximum value as soon as the soil water content in the root zone (Wr) drops below the upper threshold for stomatal closure:

$$Wr_{sto,upper} = [\theta_{FC} - p_{sto}\ (\theta_{FC} - \theta_{PWP})]\,1000\,Z \qquad \text{(Eq. 3.8p)}$$

or the root zone depletion (Dr) exceeds:

$$Dr_{sto,upper} = p_{sto}\ TAW \qquad \text{(Eq.3.8q)}$$

where
- $Wr_{sto,upper}$ upper threshold expressed as an equivalent depth [mm];
- $Dr_{sto,upper}$ upper threshold expressed as root zone depletion [mm];
- p_{sto} fraction of TAW at which stomata start to close;
- θ_{FC} soil water content at field capacity [m^3(water)/m^3(soil)];
- θ_{PWP} soil water content at permanent wilting point [m^3(water)/m^3(soil)];
- Z effective rooting depth [m];
- TAW total available soil water in the root zone [mm].

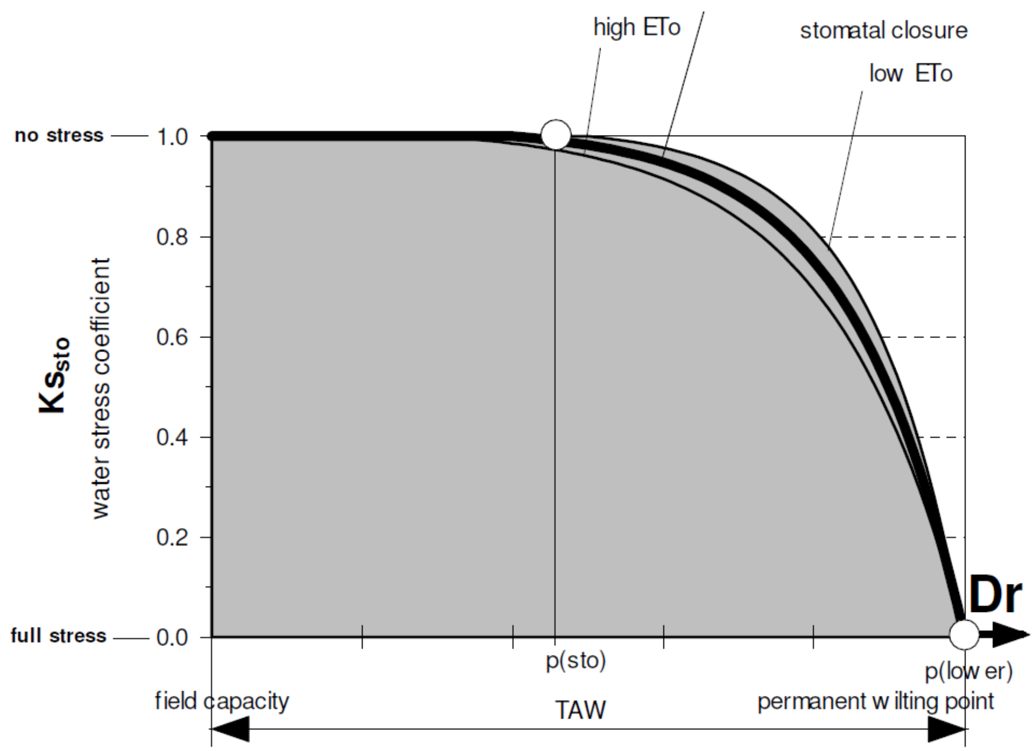

Figure 3.8h
The water stress coefficient for stomatal closure (Ks_{sto}) for various degrees of root zone depletion (Dr)

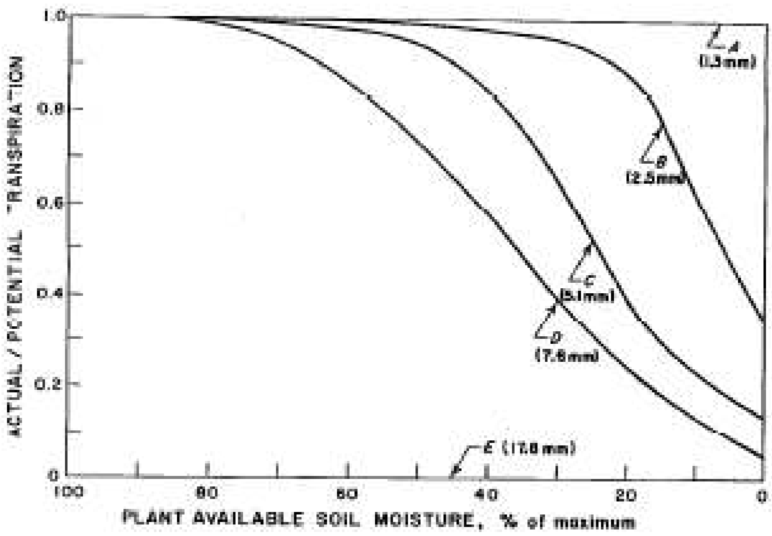

Figure 17.5: Actual over potential transpiration as a function of plant available water and daily PET.

The maximum possible root water extraction rate, integrated over the rooting depth, is equal to T_p (cm d^{-1}), which is governed by atmospheric conditions and plant characteristics. Taking into account the root length density distribution (Bouten, 1992), the potential root water extraction rate at a certain depth, $S_p(z)$ (d^{-1}) is calculated by:

$$S_p(z) = \frac{\ell_{root}(z)}{\int_{-D_{root}}^{0} \ell_{root}(z)\,dz} T_p \qquad (2.67)$$

where D_{root} is the root layer thickness (cm).

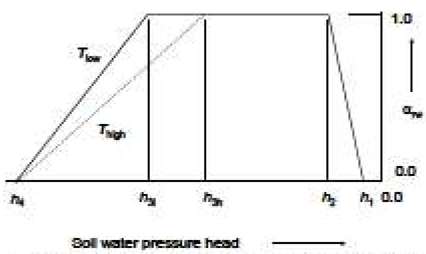

Figure 3.4 Reduction coefficient for root water uptake, α_{rw}, as function of soil water pressure head h and potential transpiration rate T_p (after Feddes et al., 1978).

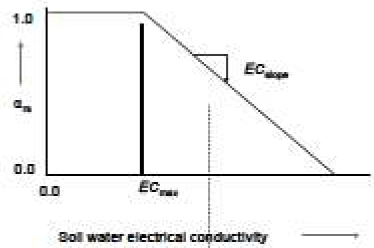

Figure 3.5 Reduction coefficient for root water uptake, ars, as function of soil water electrical conductivity EC (after Maas and Hoffman, 1977).

Appendix 8 Critical pressure head values for root water extraction

After Taylor and Ashcroft (1972)

Crop	h_{3h}	h_{3l}	Crop	h_{3h}	h_{3l}
Vegetative crops			Deciduous fruit	-500	-800
Alfalfa	-1500	-1500	Avocadoes	-500	-500
Beans (snap and lima)	-750	-2000	Grapes		
Cabbage	-600	-700	early season	-400	-500
Canning peas	-300	-500	during maturity	-1000	-1000
Celery	-200	-300	Strawberries	-200	-300
Grass	-300	-1000	Cantaloupe	-350	-450
Lettuce	-400	-600	Tomatoes	-800	-1500
Tobacco	-300	-800	Bananas	-300	-1500
Sugar cane					
tensiometer	-150	-500	***Grain crops***		
blocks	-1000	-2000	Corn		
Sweet corn	-500	-1000	vegetative period	-500	-500
Turfgrass	-240	-360	during ripening	-8000	-12000
			Small grains		
Root crops			vegetative period	-400	-500
Onions			during ripening	-8000	-12000
early growth	-450	-550			
bulbing time	-550	-650	***Seed crops***		
Sugar beets	-400	-600	Alfalfa		
Potatoes	-300	-500	prior to bloom	-2000	-2000
Carrots	-550	-650	during bloom	-4000	-8000
Broccoli			during ripening	-8000	-15000
early	-450	-550	Carrots		
after budding	-600	-700	at 60 cm depth	-4000	-6000
Cauliflower	-600	-700	Onions		
			at 7 cm depth	-4000	-6000
Fruit crops			at 15 cm depth	-1500	-1500
Lemons	-400	-400	Lettuce		
Oranges	-200	-1000	during productive phase	-3000	-3000

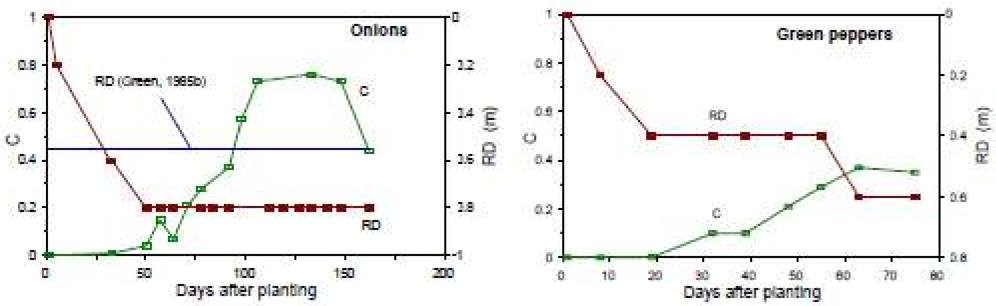

Figure 1
Measured values of canopy cover (C) and estimated root depth (RD, depth at which 90% of weekly soil-water depletion occurred) during the growing season of onions and green peppers. Root depth recommended by Green (1985b) is also presented for onions

TABLE 2
MAXIMUM ROOT DEPTH (RD) AND CROP HEIGHT (Hc_{MAX}), AND 90% OF MAXIMUM CANOPY COVER (C) FOR 6 WINTER AND 19 SUMMER VEGETABLE CULTIVARS

Crop	Maximum RD (m)	Hc_{max} (m)	90% of maximum C
Onions	0.8	0.5	0.60
Cabbage	0.8	0.3	0.90
Carrots	0.8	0.3	0.90
Beetroot	0.8	0.4	0.90
Lettuce	0.6	0.3	0.88
Swisschard	0.8	0.4	0.90
Sweet-corn (cv. Cabaret)	1.0	1.7	0.81
Sweet-corn (cv. Jubilee)	0.6	2.1	0.83
Sweet-corn (cv. Paradise)	0.6	2.1	0.80
Sweet-corn (cv. Dorado)	0.8	1.7	0.61
Bush beans (cv. Provider)	0.4	0.5	0.74
Bush beans (cv. Bronco)	0.8	0.5	0.71
Runner beans	0.6	2.3	0.81
Pumpkin (cv. Miniboer)	0.8	0.6	0.75
Pumpkin (cv. Minette)	0.8	0.7	0.76
Marrow (cv. President)	1.0	0.6	0.61
Marrow (cv. Long White Bush)	0.8	0.65	0.74
Squash (cv. Table Queen)	0.8	0.4	0.47
Squash (cv. Waltham)	0.8	0.3	0.55
Tomato (cv. Zeal)	0.6	0.6	0.48
Tomato (cv. P747)	0.8	0.65	0.69
Tomato (cv. HTX14)	0.8	0.45	0.53
Eggplant	0.6	0.6	0.45
Green peppers	0.6	0.5	0.31
Chilli peppers	0.6	0.6	0.29

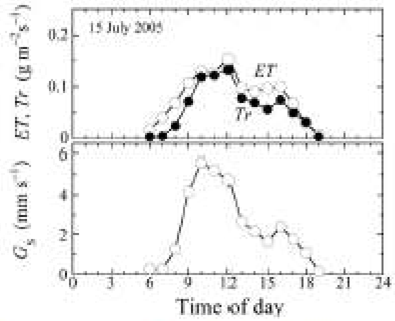

Fig. 12 Diurnal changes in evapotranspiration rate (ET), transpiration rate (Tr) and stomatal conduciance (G_s) of the canopy in the cornfield on 15 July in the crop development stage in 2005, respectively.