Modeliranje rasta korijena i primanja nitrata u heterogenom tlu

Zed Rengel

Univ Western Australia
Perth

Ukupna kolicina nitrata u tlu

- u 1.5-m profilu tla -

	Lupina	psenica	pasnjak
Kolicina nitrata	----------------------------	kg/ha	----------------------------
21 srpnja	74	46	35
27 rujna	33	13	4
29 studenog	44	24	17

Ukupna kolicina ispranog nitrata, kg/ha

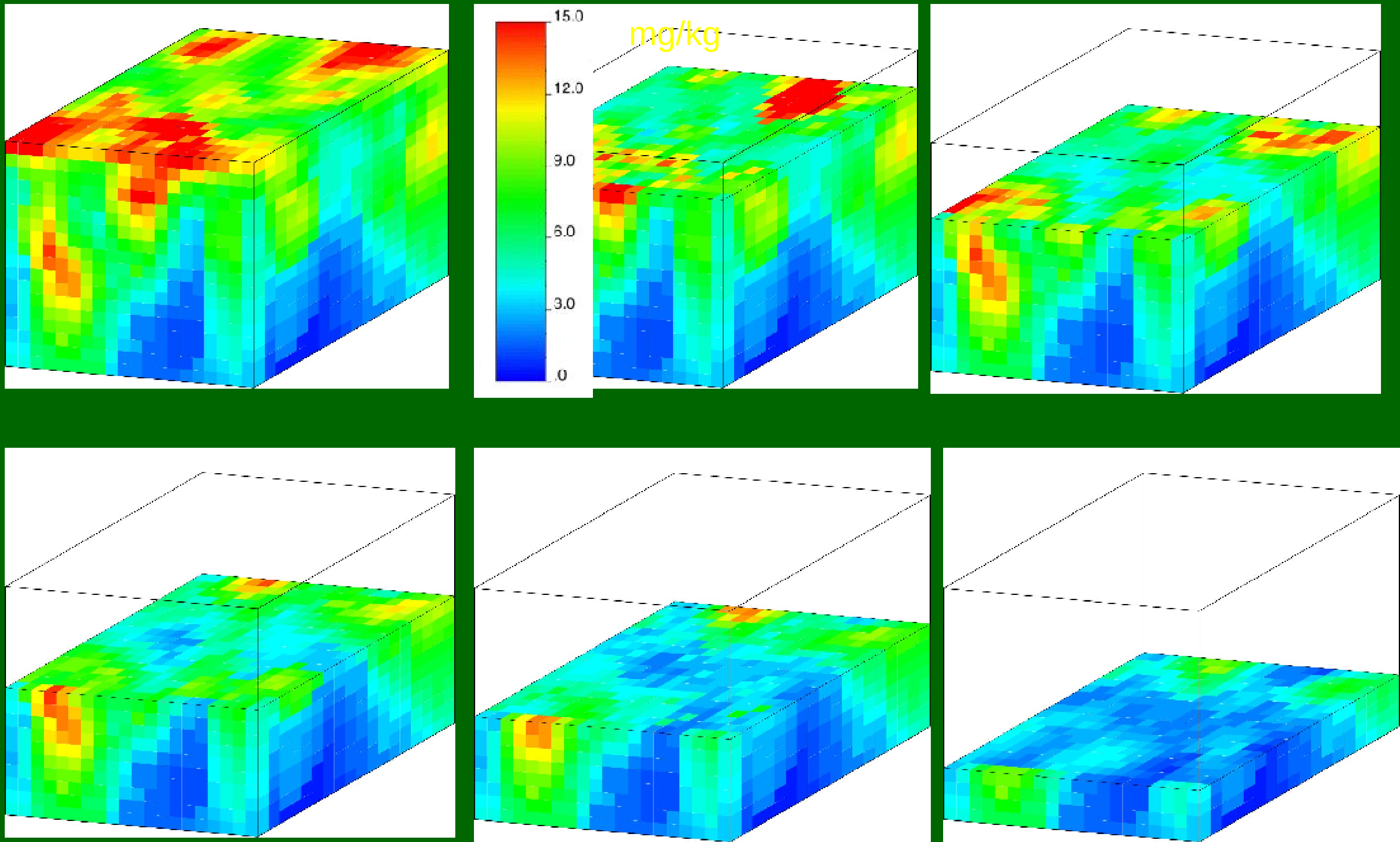
- dolje do 1 m u profilu tla -

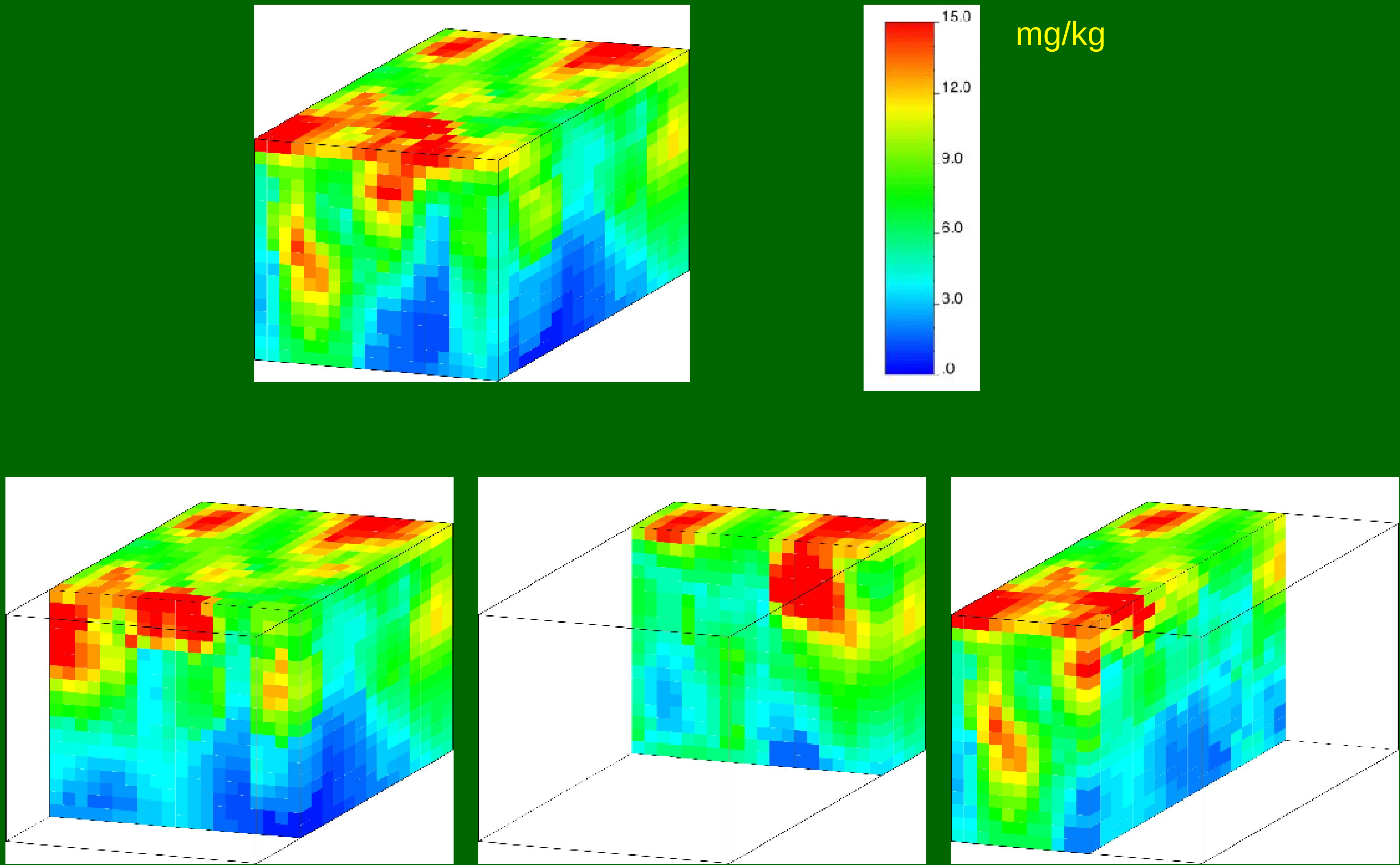
21 lipnja – 26 rujna	24	20	3

Dolling et al. 1995

Heterogenost concentracije nitrata u tlu

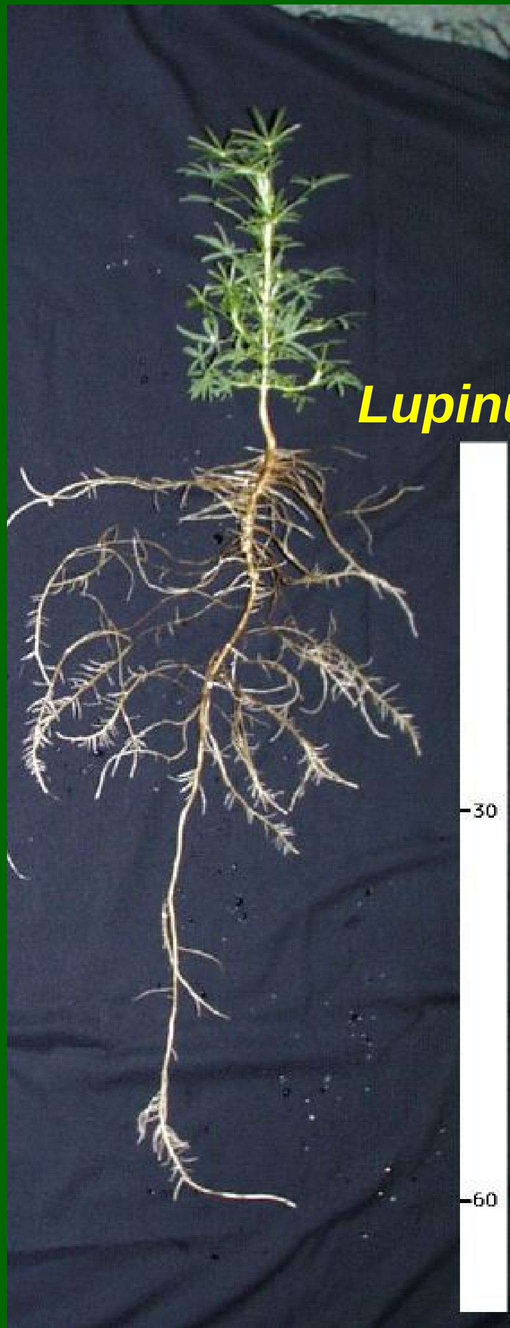
- blok 5 m × 5 m × 5 m, mali blok od 25 cm x 25 cm x 25 cm -




15.0
12.0
9.0
6.0
3.0
.0
mg/kg

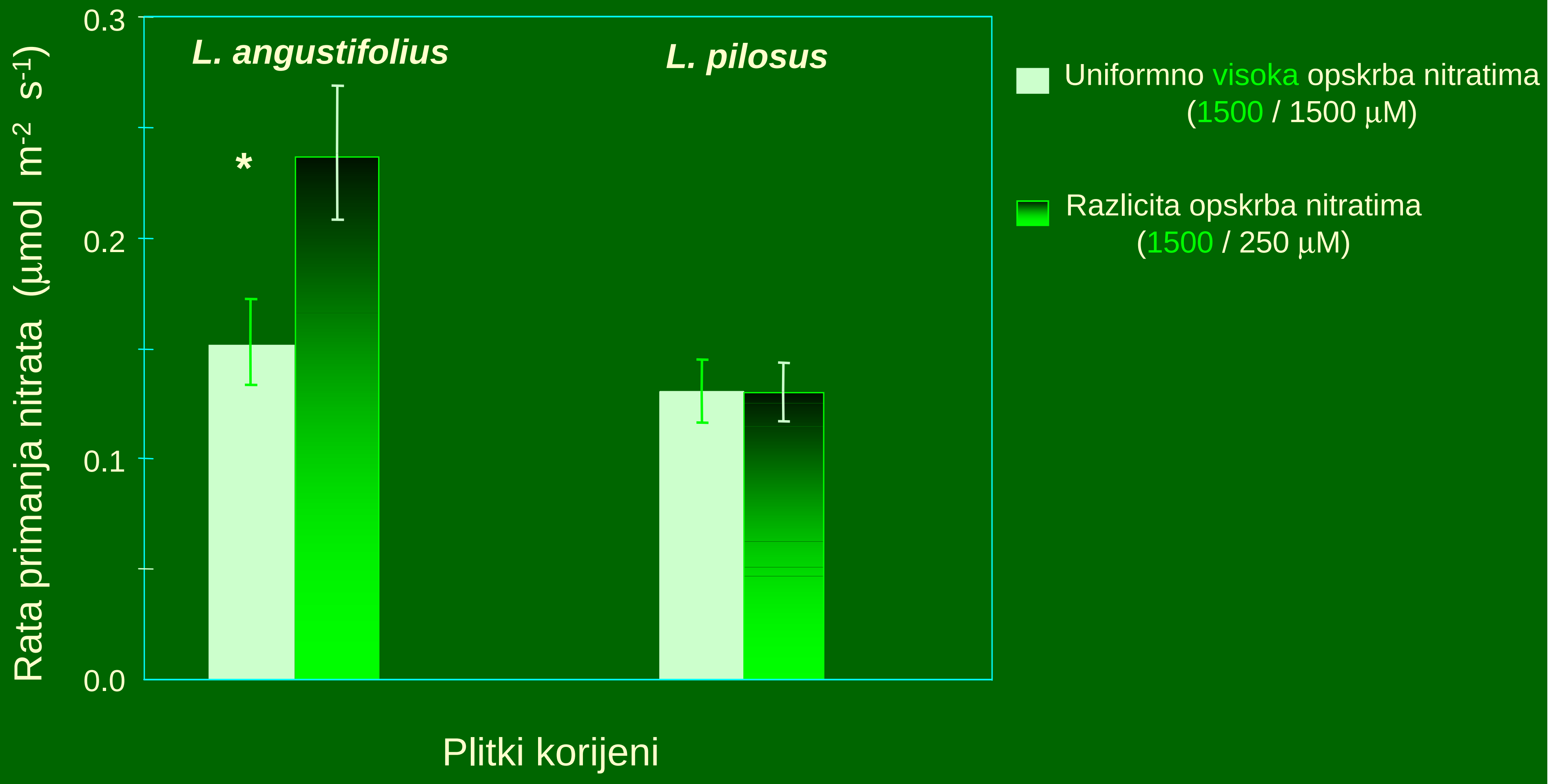
Nakon 41 dana rasta

Lupinus angustifolius



Kompenzacija u primanju nitrata, *L. angustifolius*

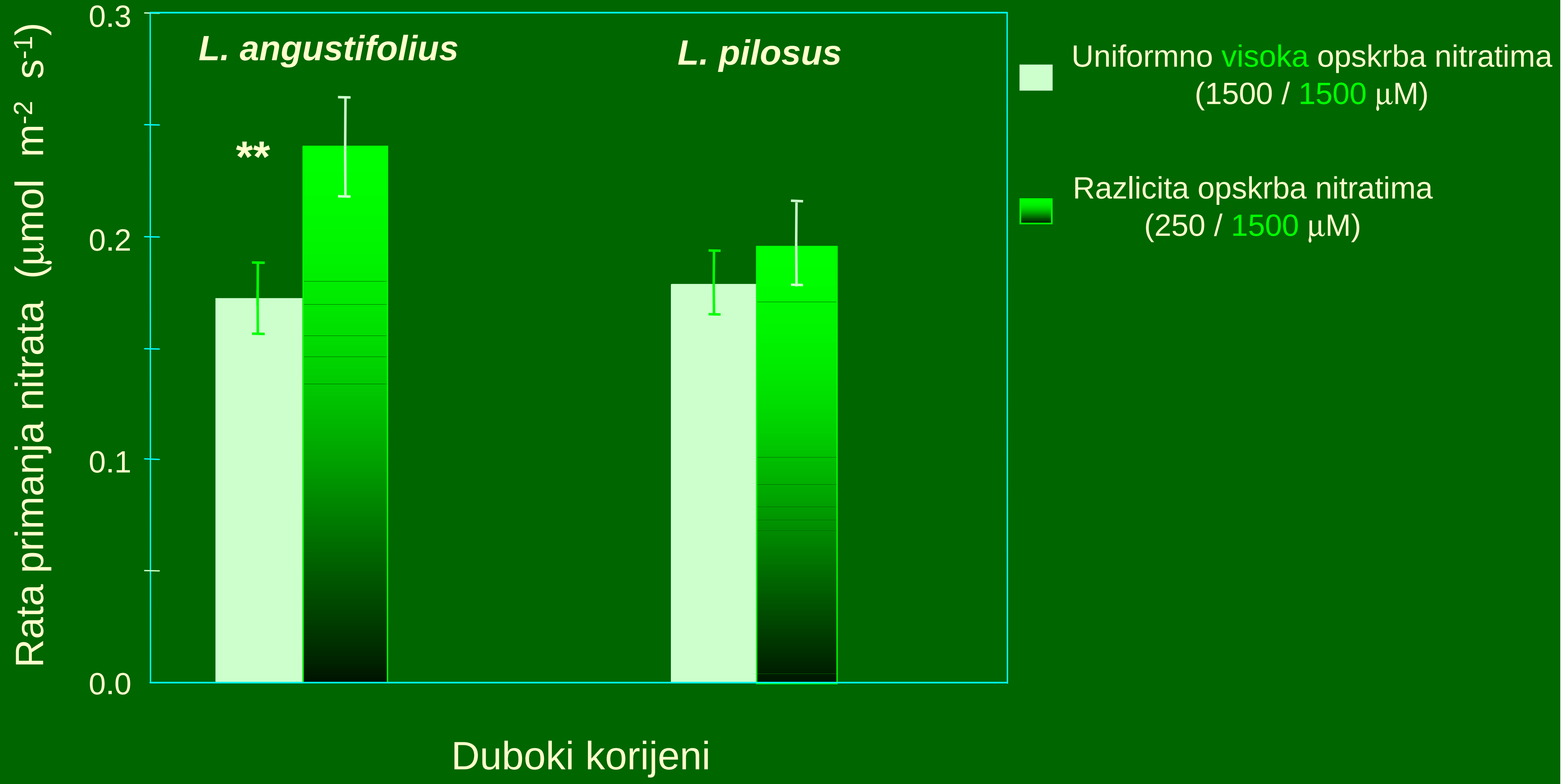
- rata primanja plitkim korijenima opskrbljenih visokom koncentracijom nitrata -



Dunbabin, Rengel & Diggle 2001 Aust J Agric Res 52, 505-512.

Kompenzacija u primanju nitrata, *L. angustifolius*

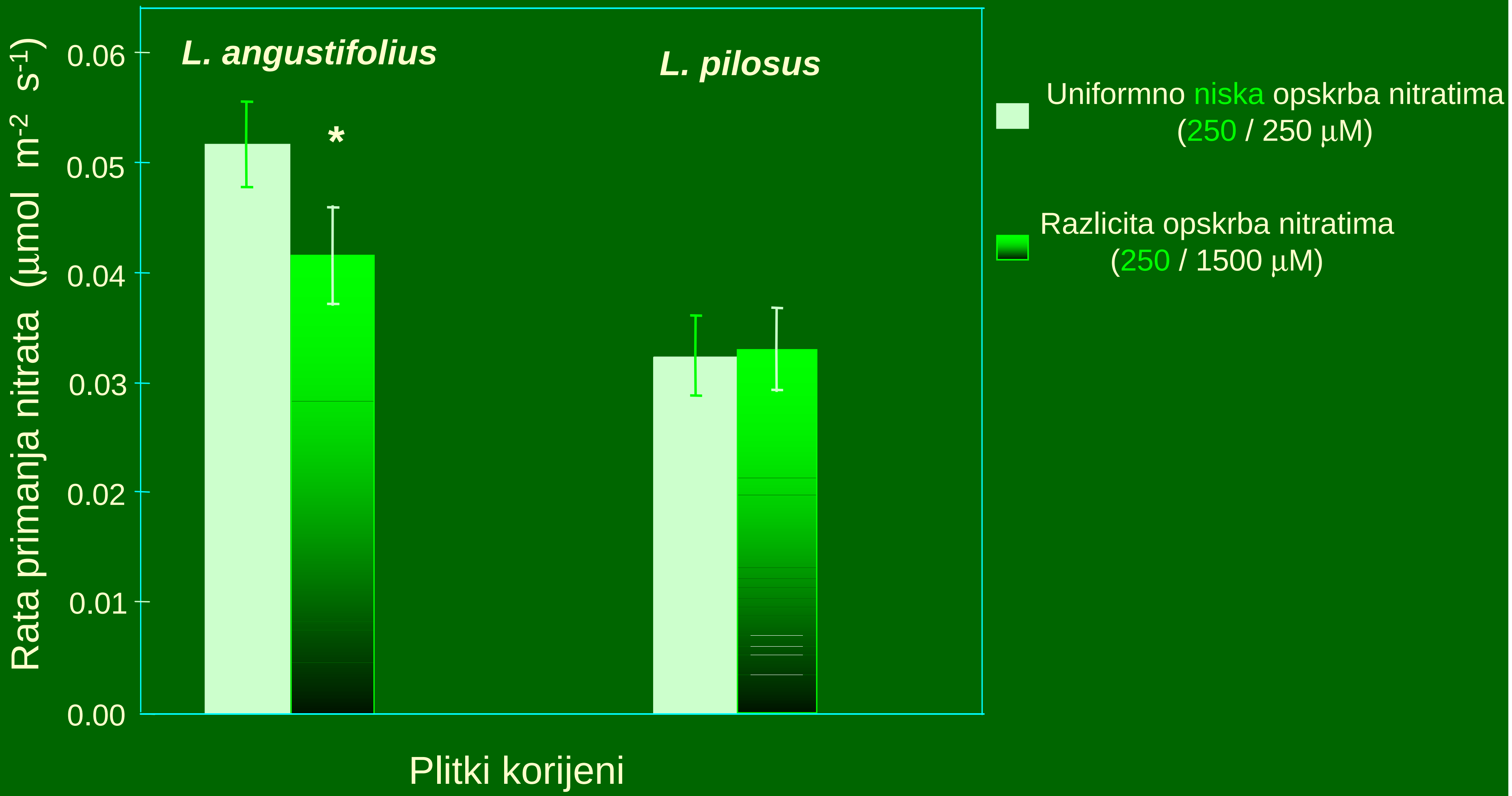
- rata primanja dubokim korijenima opskrbljenih visokom koncentracijom nitrata -



Dunbabin, Rengel & Diggle 2001 Aust J Agric Res 52, 505-512.

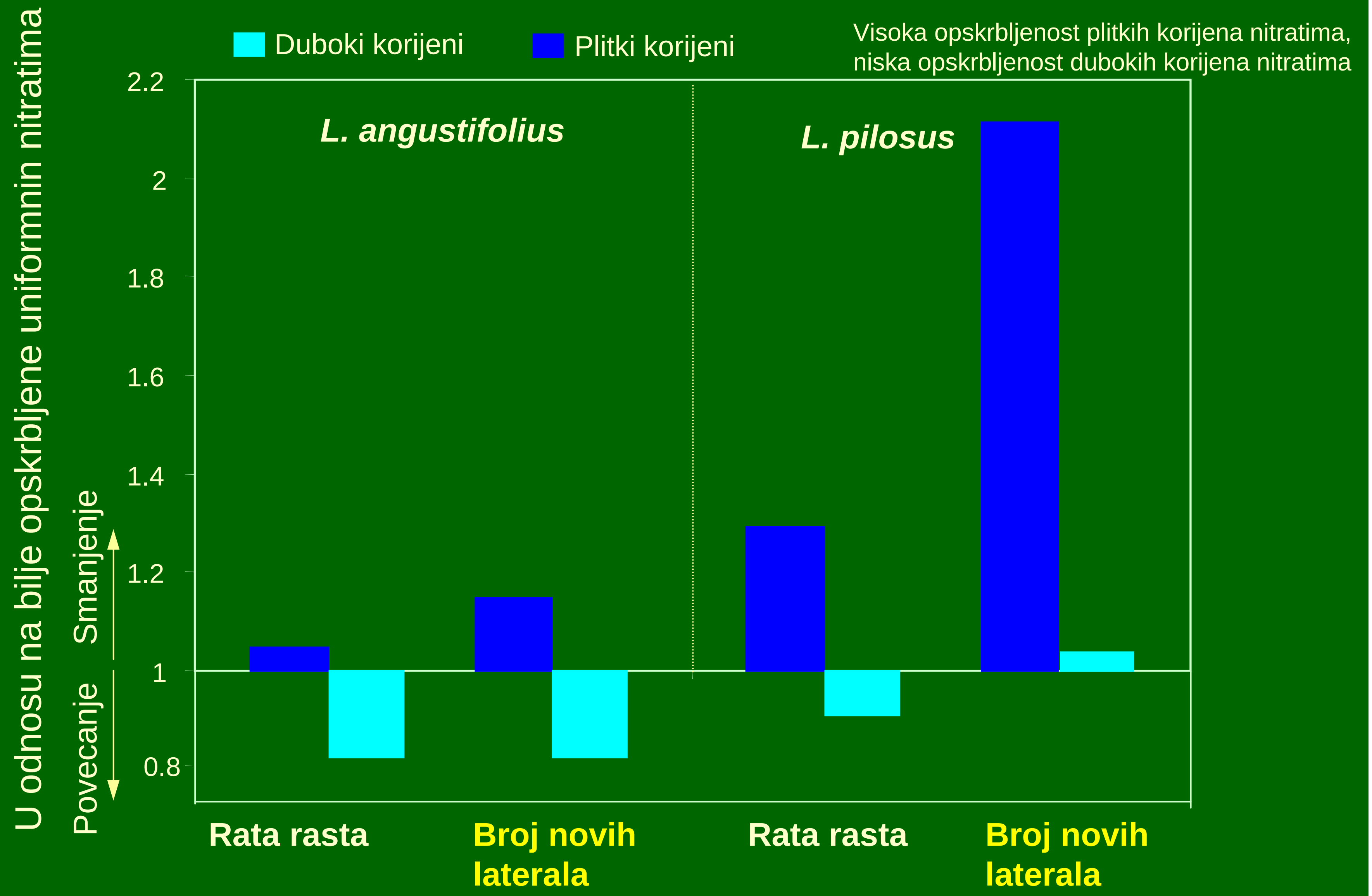
Kompenzacija u primanju nitrata, *L. angustifolius*

- rata primanja plitkim korijenima opskrbljenih niskom koncentracijom nitrata -



Dunbabin, Rengel & Diggle 2001 Aust J Agric Res 52, 505-512.

Kompenzacija rasta korijena, *L. pilosus*



Biljke su bile stare 21 dan na pocetku tretmana,
Rast nakon 9 dana

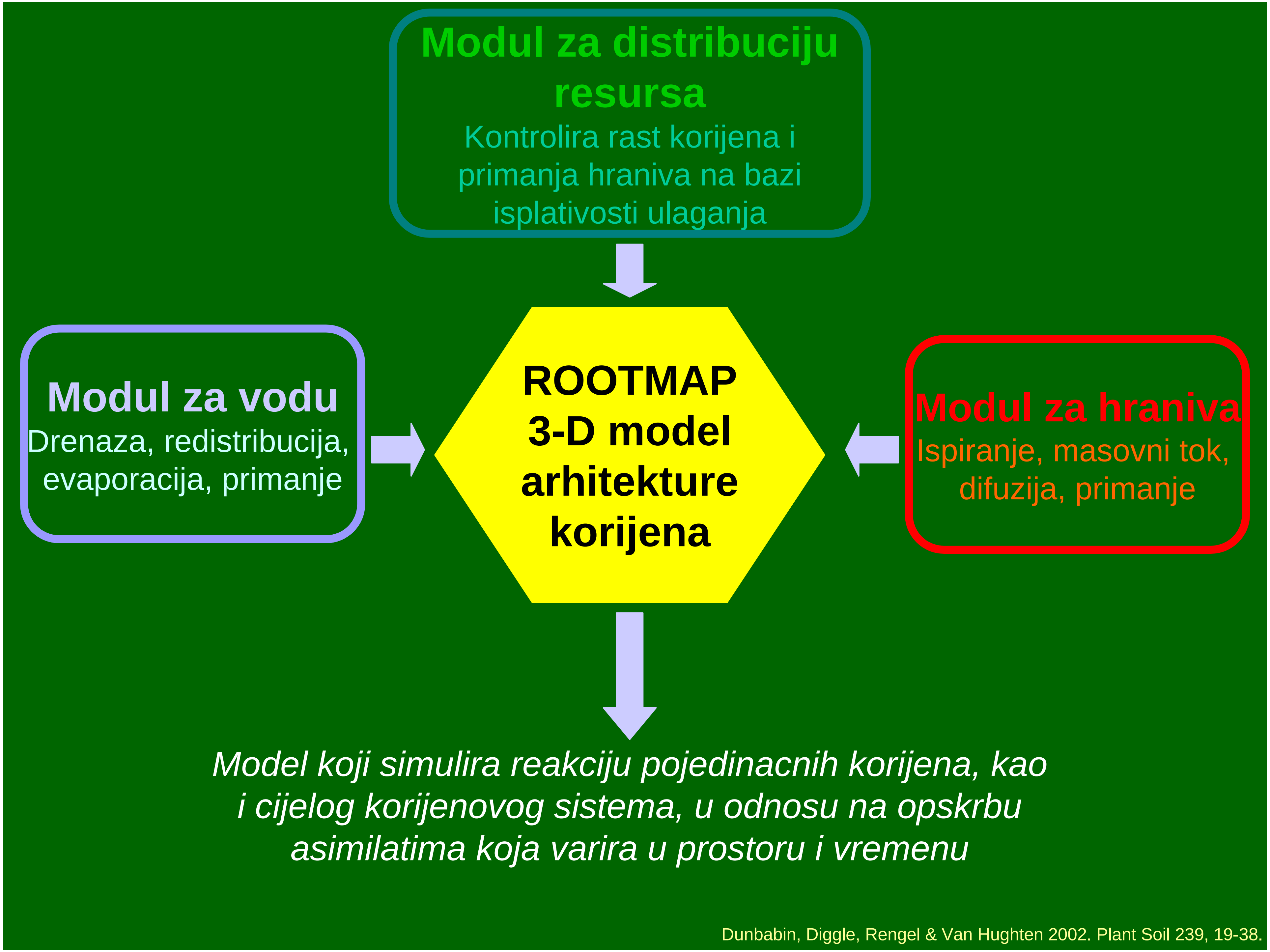
Dunbabin, Rengel & Diggle 2001 Aust J Agric Res 52, 495-503.

Kratak opis modela

Komponenta modela za reakciju korijena

Koristenje modela u simulaciji poljskih pokusa

Koristenje modela za istrazivanje rasta korijena i primanja nitrata u heterogenom tlu


Modul za distribuciju resursa
Kontrolira rast korijena i primanja hraniva na bazi isplativosti ulaganja
Modul za vodu
Drenaza, redistribucija, evaporacija, primanje
ROOTMAP 3-D model arhitekture korijena
Modul za hraniva
Ispiranje, masovni tok, difuzija, primanje
Model koji simulira reakciju pojedinacnih korijena, kao i cijelog korijenovog sistema, u odnosu na opskrbu asimilatima koja varira u prostoru i vremenu
Dunbabin, Diggle, Rengel & Van Hughten 2002. Plant Soil 239, 19-38.

Osnovna metodologija modela

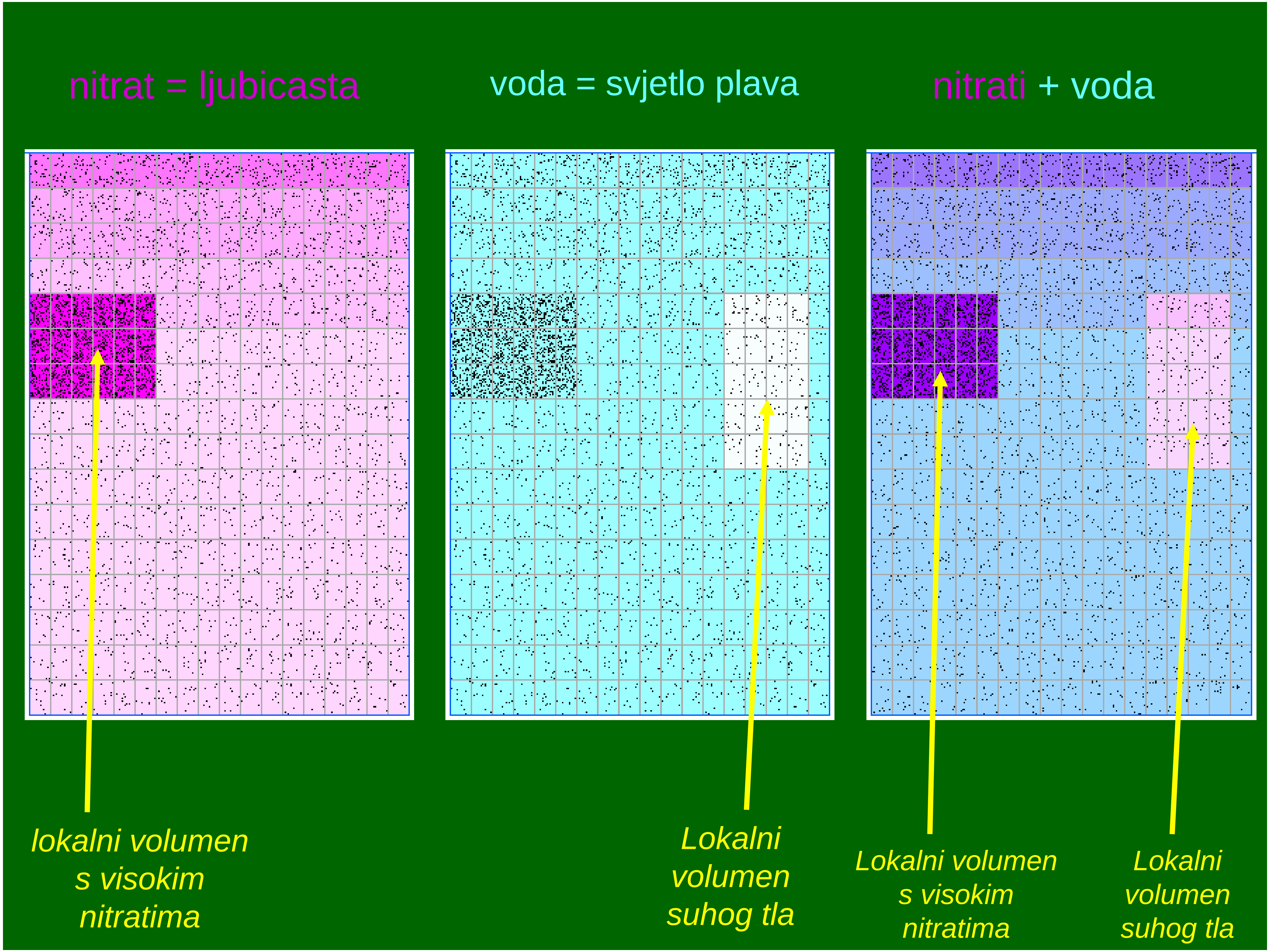
Dunbabin, Diggle, Rengel & Van Hughten 2002. Plant Soil 239, 19-38.

Kratak opis modela

Komponenta modela za reakciju korijena

Koristenje modela u simulaciji poljskih pokusa

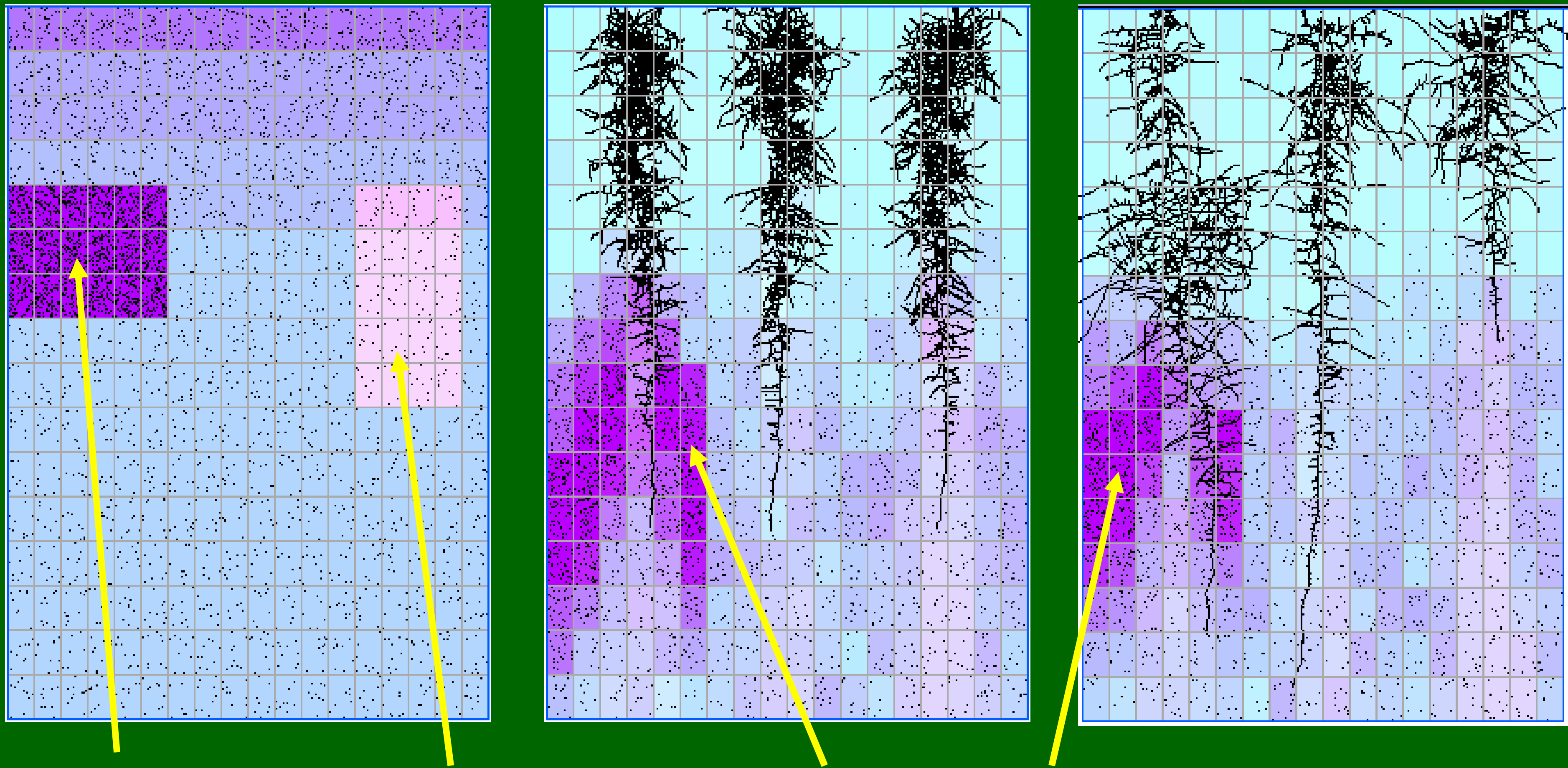
Koristenje modela za istrazivanje rasta korijena i primanja nitrata u heterogenom tlu


nitrat = ljubicasta
voda = svjetlo plava
nitrati + voda
lokalni volumen s visokim nitratima
Lokalni volumen suhog tla
Lokalni volumen s visokim nitratima
Lokalni volumen suhog tla

Pocetni profil tla

Ne-reagirajuci korijenov sistem koji raste na osnovu pre-definiranih pravila

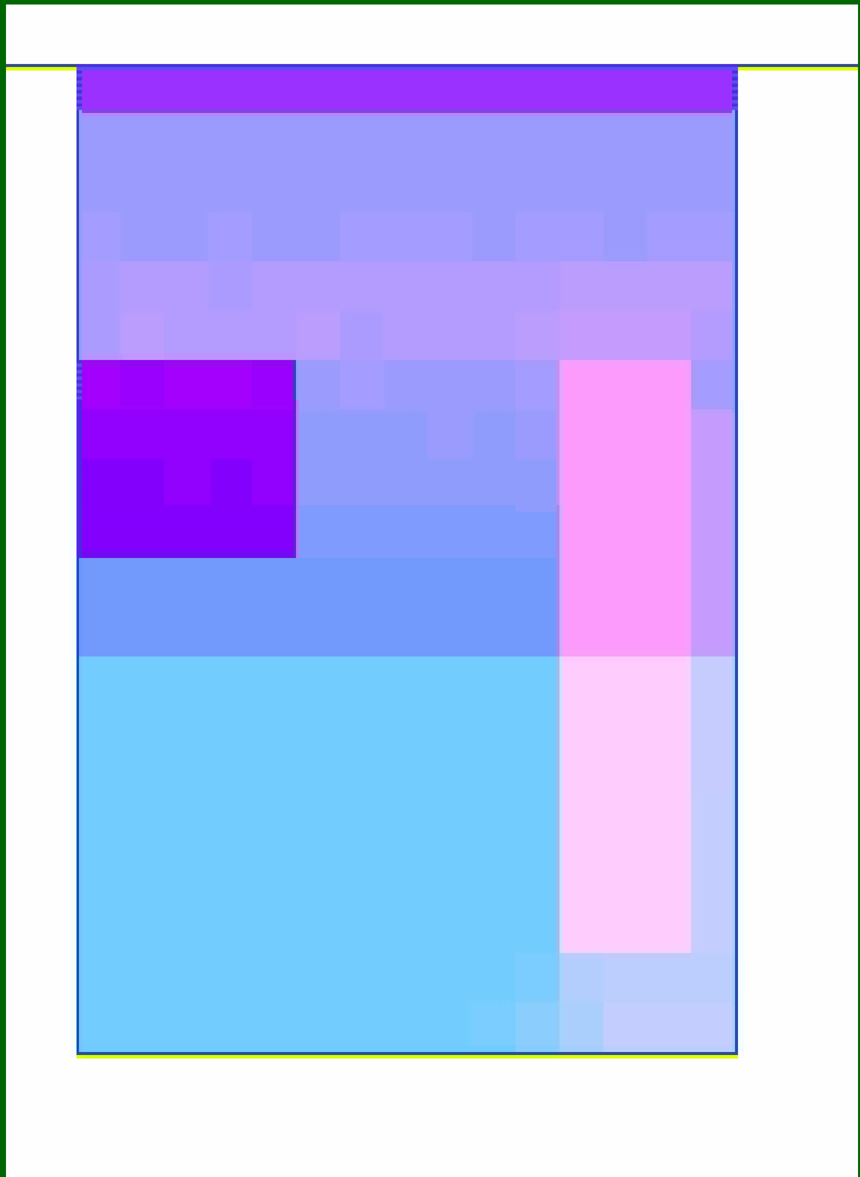
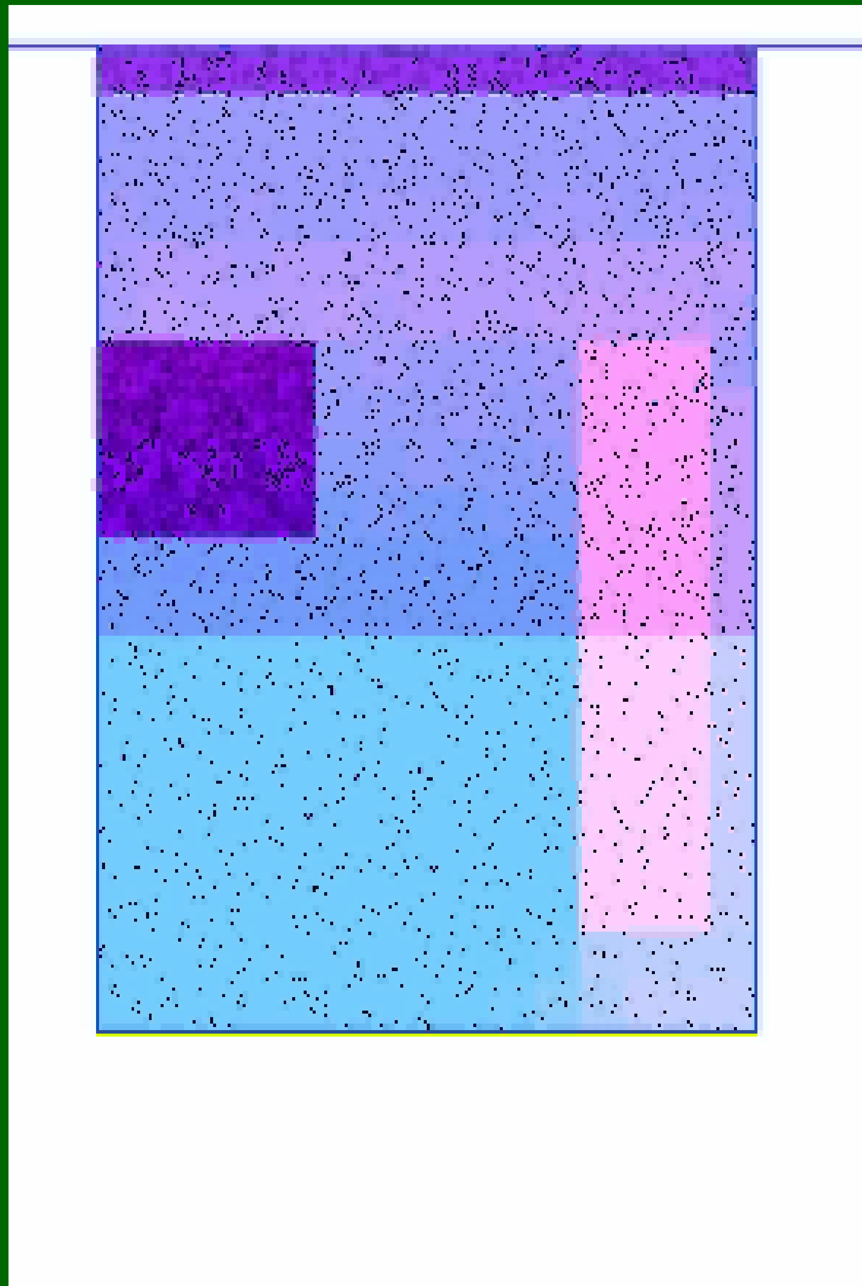
Korijenovi sistem koji reagira na lokalni okolis



Lokalni volumen s visokim nitratima

Lokalni volumen suhog tla

Ispiranje nitrata u profilu tla nakon uzastopnih kisa

Kratak opis modela

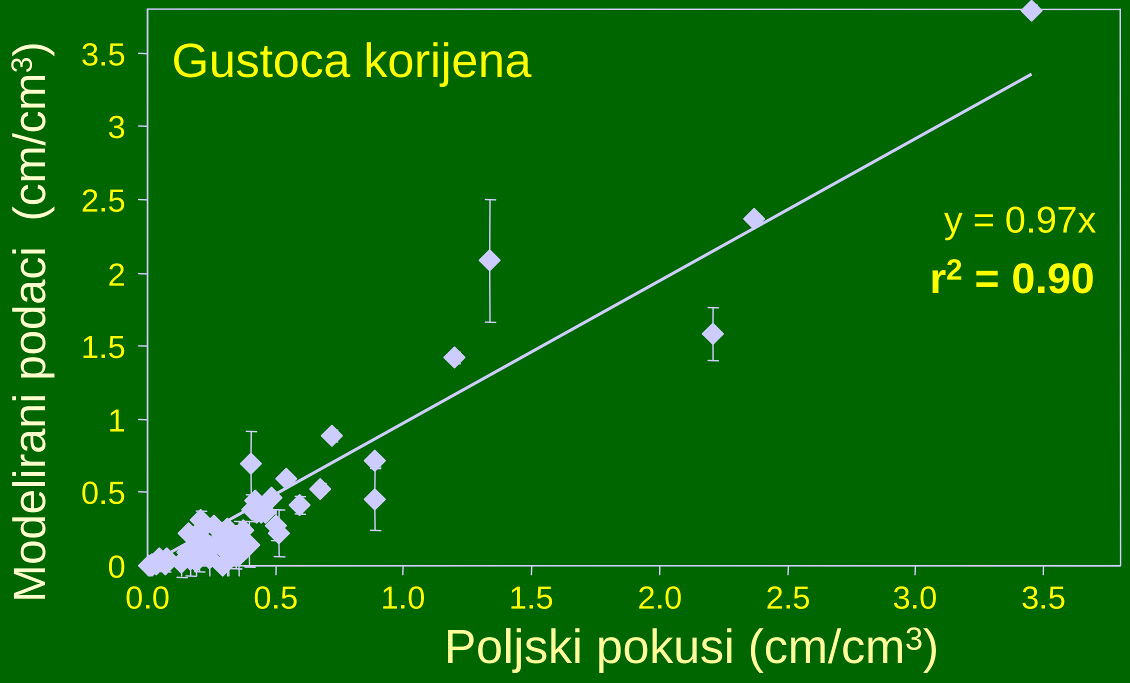
Komponenta modela za reakciju korijena

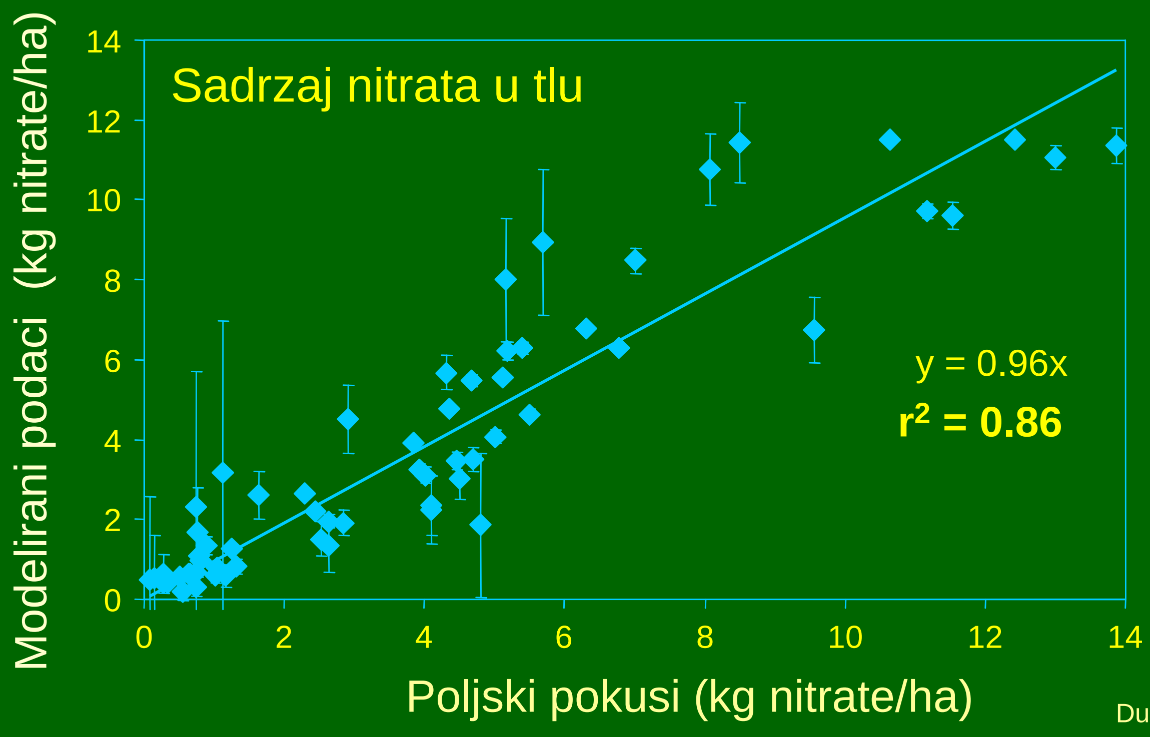
Koristenje modela u simulaciji poljskih pokusa

Koristenje modela za istrazivanje rasta korijena i primanja nitrata u heterogenom tlu

Korelacija izmedju modeliranih i poljskih podataka

L. angustifolius je rasla na polju 1995 i 1996

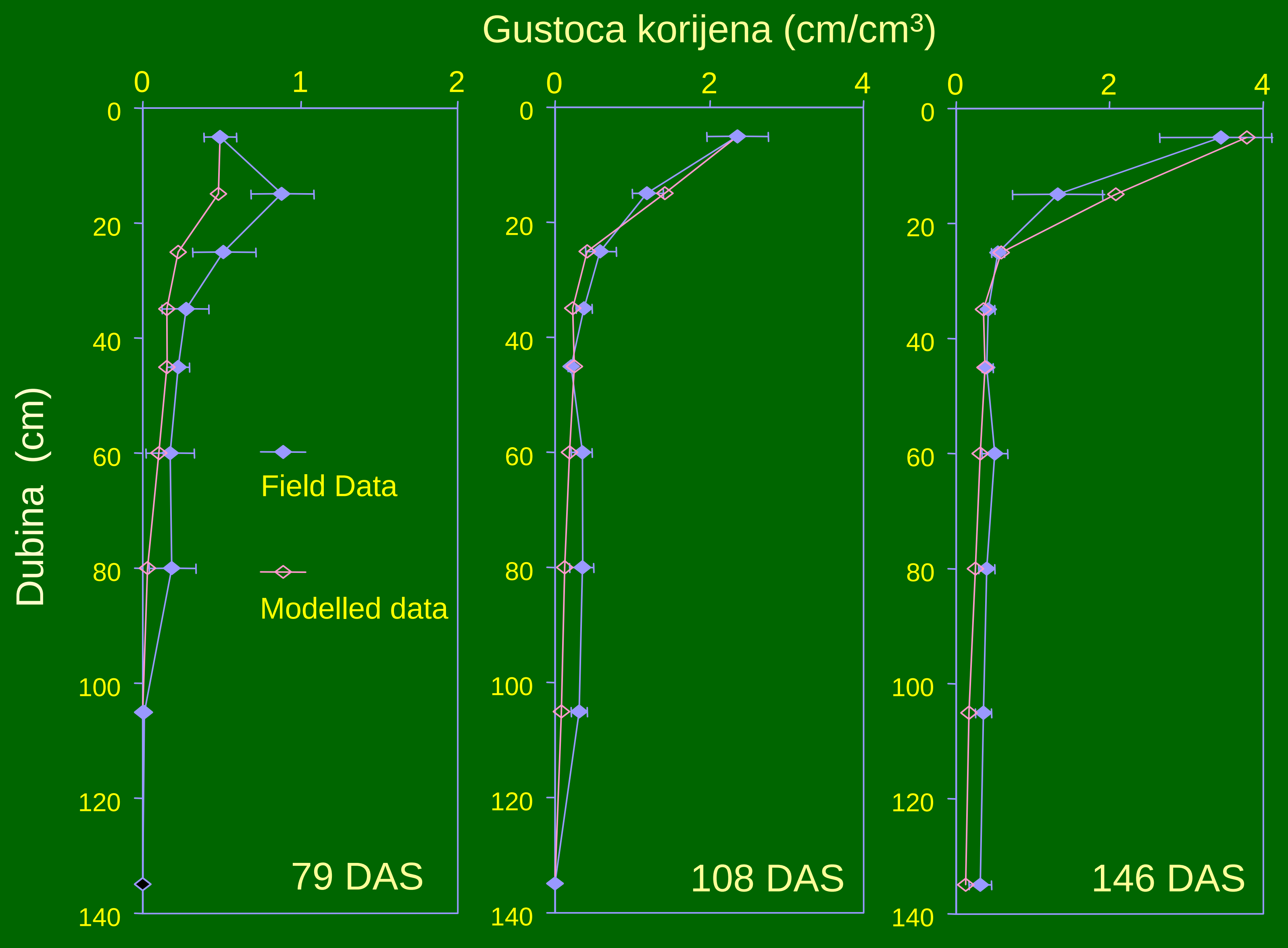




Dunbabin, Diggle & Rengel 2002. Plant Soil 239, 39-54.

Rast korijena simuliran modelom

- L. angustifolius (rasla na polju 1996) -

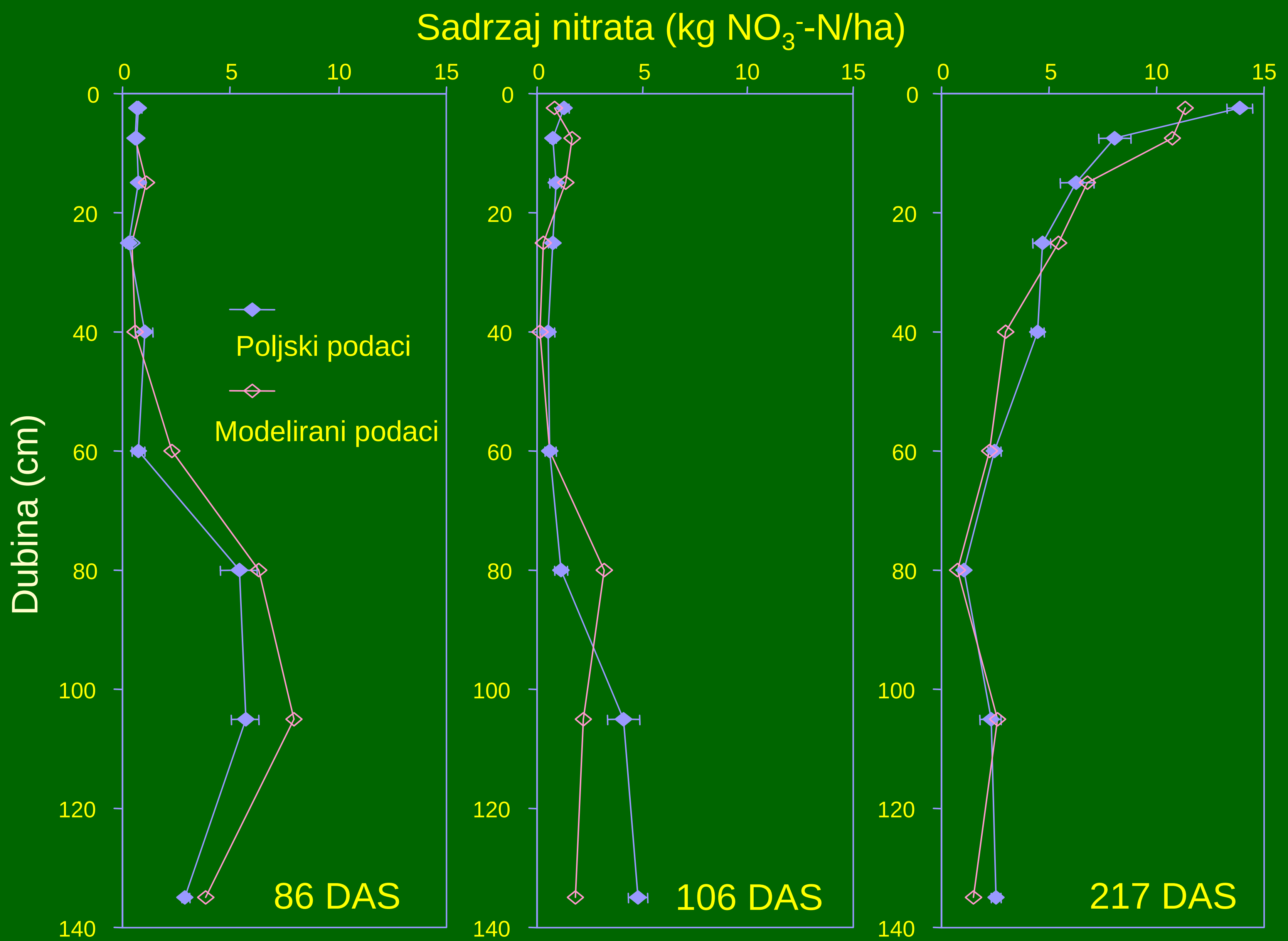


DAS=dana nakon sijanja

Dunbabin, Diggle & Rengel 2002. Plant Soil 239, 39-54.

Nitratni profili simulirani modelom

- L. angustifolius (rasla na polju) -

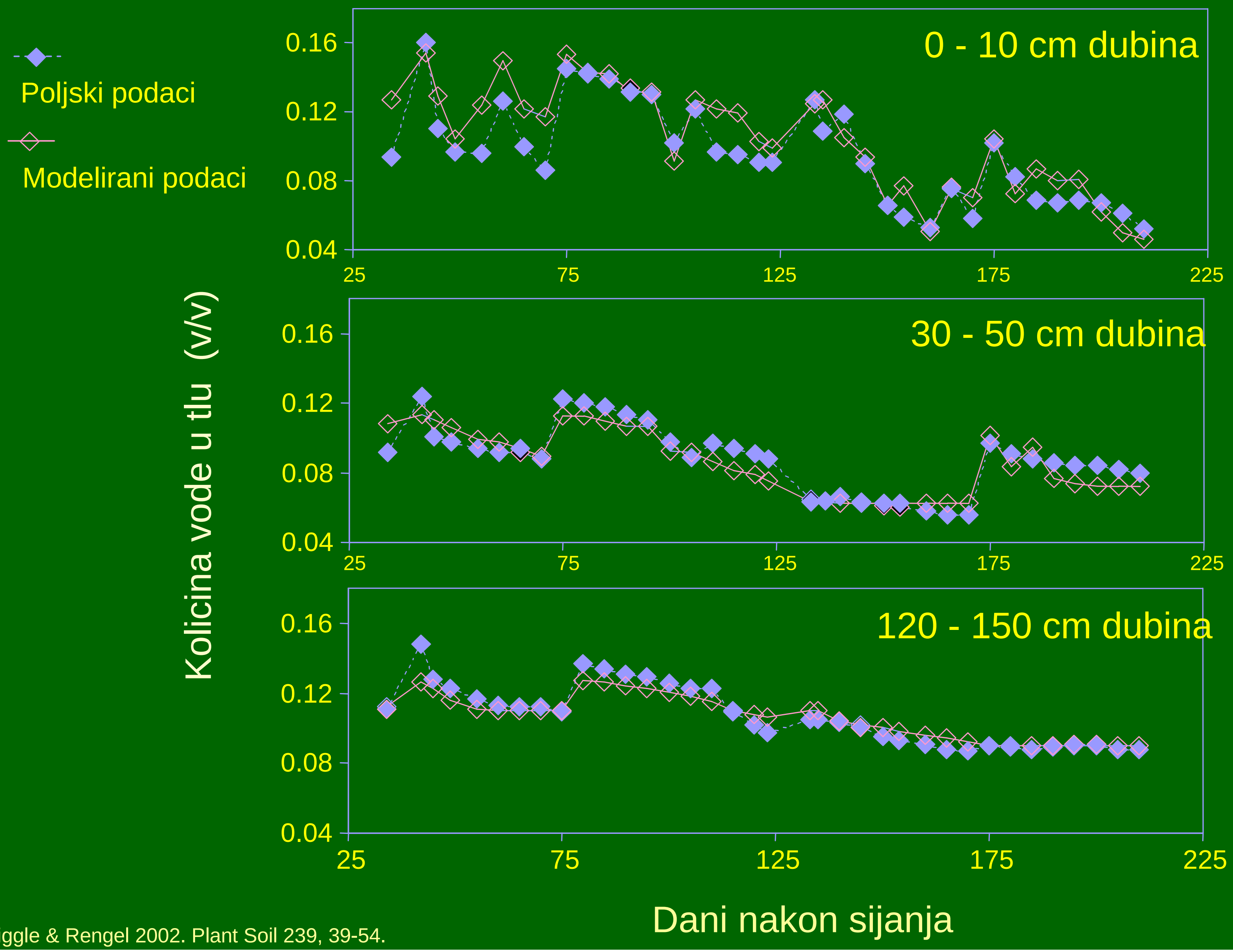


DAS=dani nakon sijanja

Dunbabin, Diggle & Rengel 2002. Plant Soil 239, 39-54.

Profil vode tla simularog modelom

- L. angustifolius (rasla na polju 1996) -



Dunbabin, Diggle & Rengel 2002. Plant Soil 239, 39-54.

Nitratni budget simuliran modelom

- u 1.5 m simuliranog profila -

	1995	1996
Izvor/sink za nitrate	------ kg nitrata / ha ------	
pocetni	32	57
Lupina: primanje	-21	-26
Capeweed: primanje	-0	-28
mineralizirano	60	69
ispiranje	-32 (-35)	-26 (-23)
zavrsno	39	46

Izmjereno i objavljeno: Anderson et al. 1988

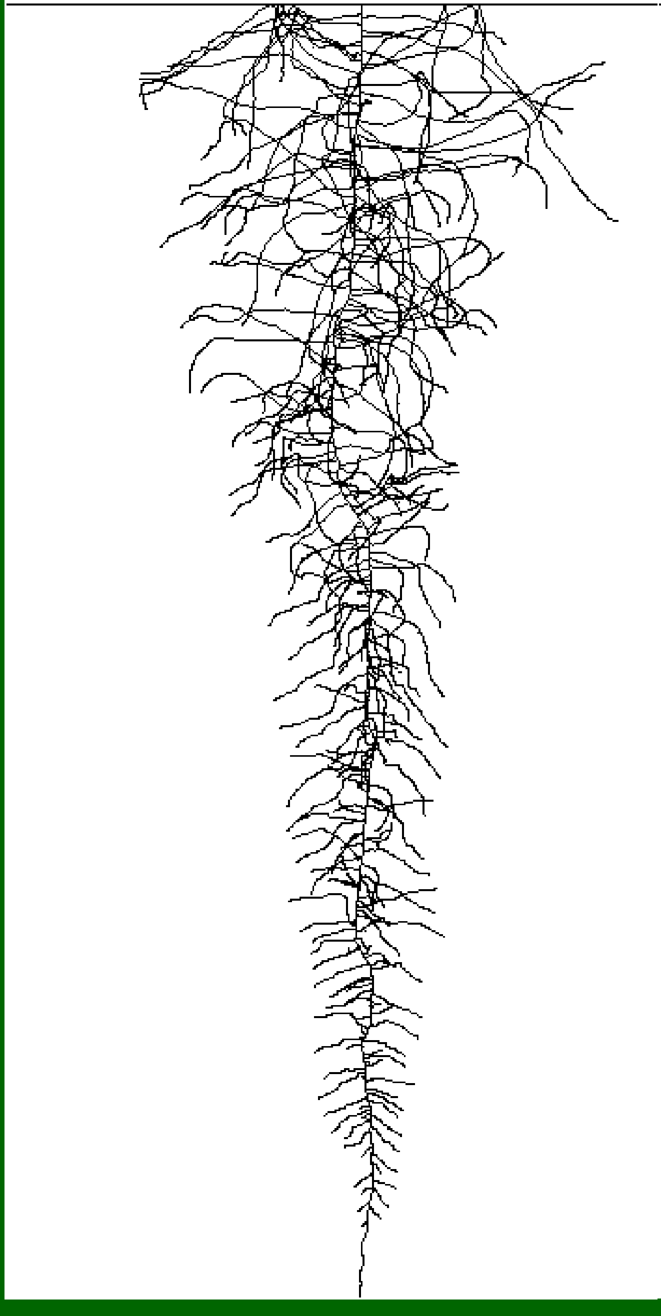
Dunbabin, Diggle & Rengel 2002. Plant Soil 239, 39-54.

Kratak opis modela

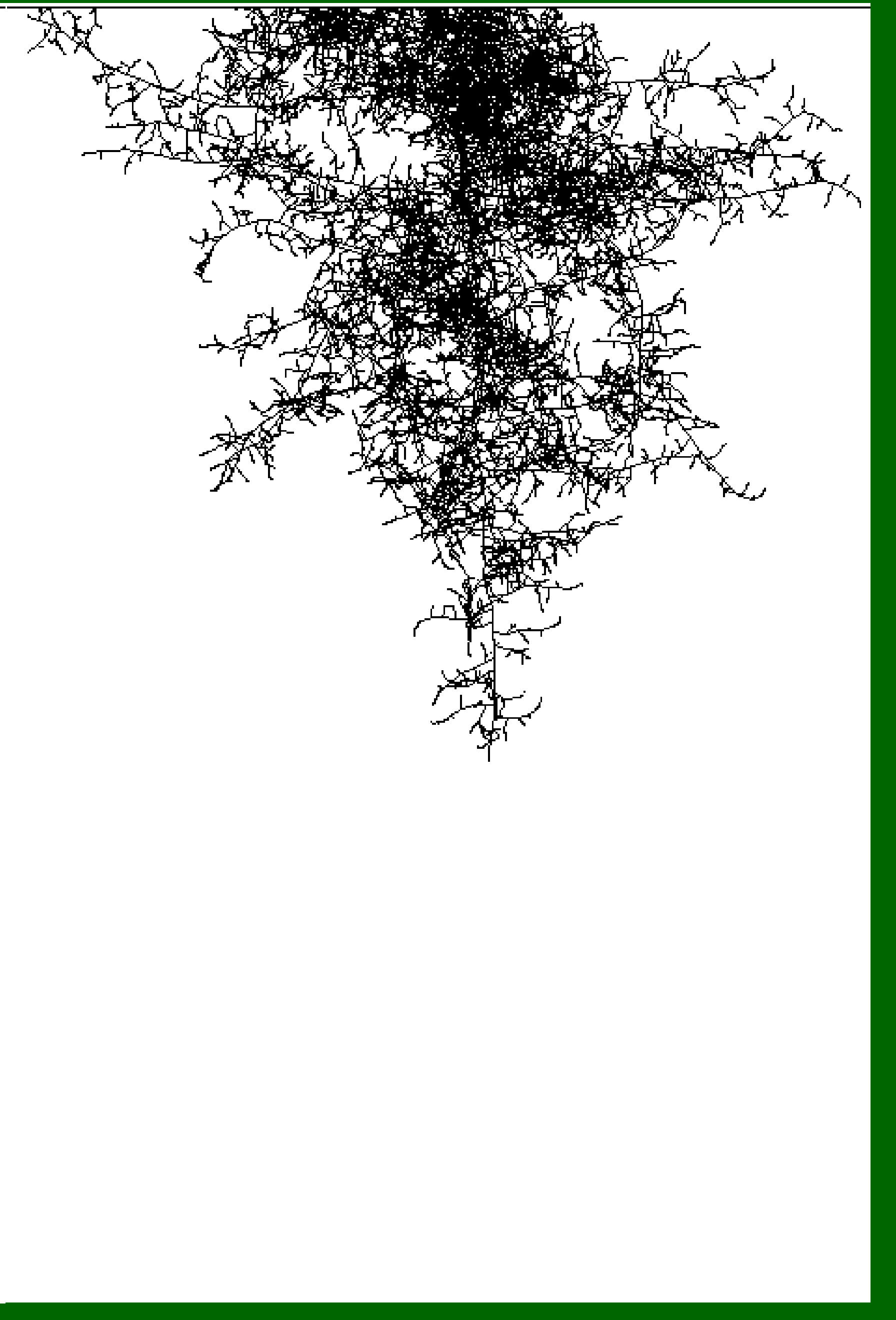
Komponenta modela za reakciju korijena

Koristenje modela u simulaciji poljskih pokusa

Koristenje modela za istrazivanje rasta korijena i primanja nitrata u heterogenom tlu



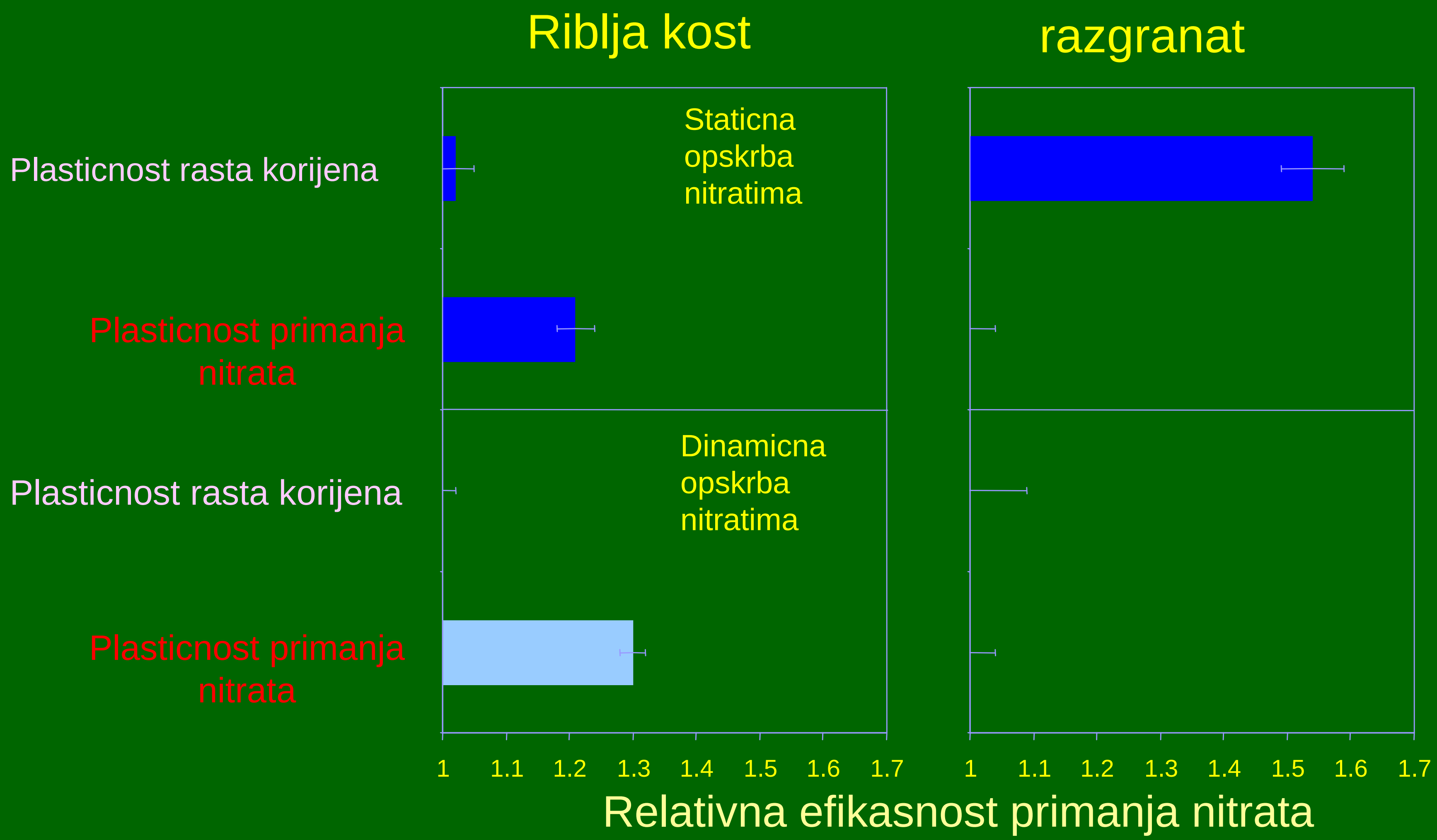
Riblja kost



razgranati

Simulirana efikasnost primanja nitrata za razne arhitekture korijena

- plasticitet primanje nitrata ili plasticitet rasta korijena je bio onemogucen -

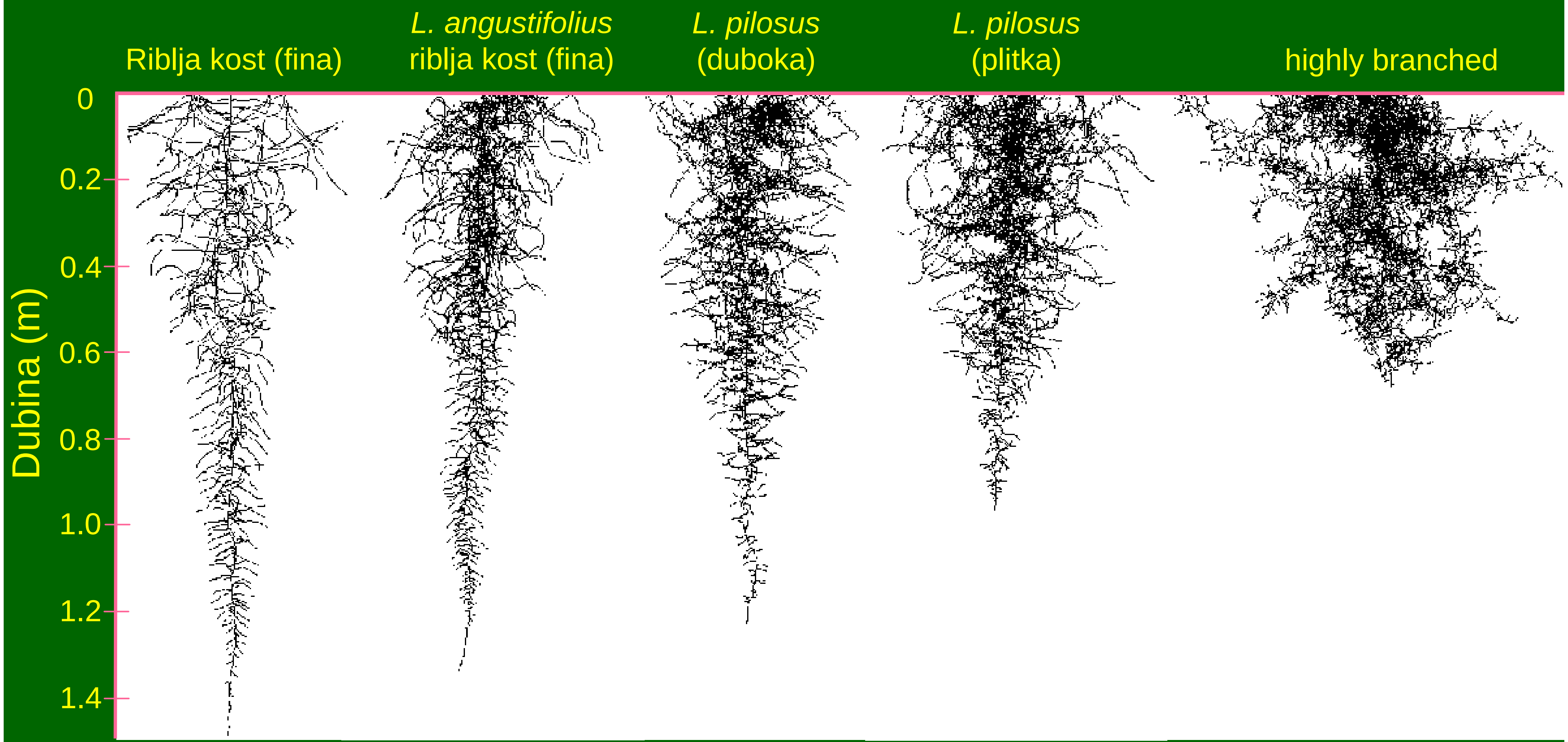


Dunbabin, Rengel & Diggle (2004). Func. Ecol. 18, 204-211

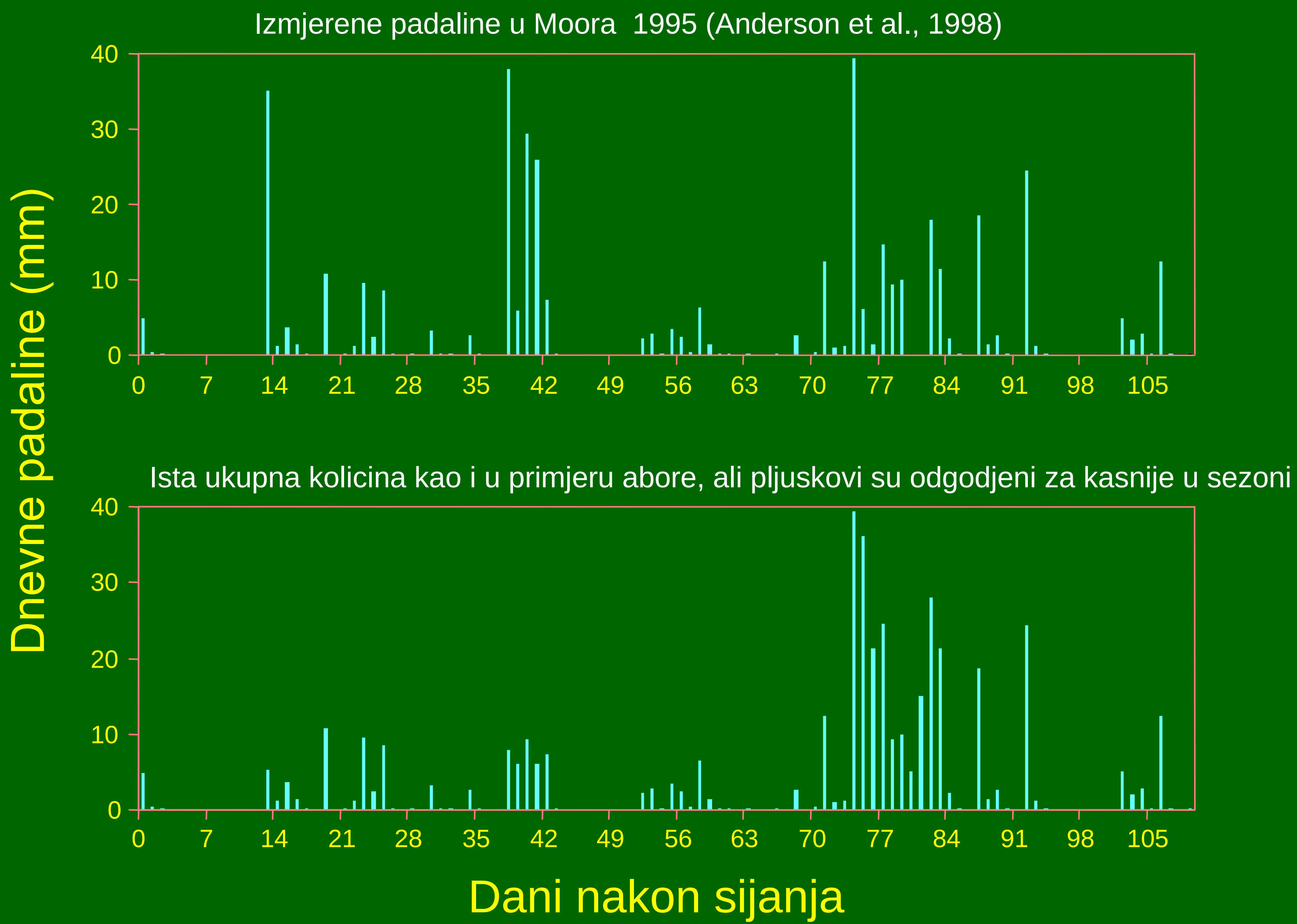
Modelirane arhitekture korijena

(s istim volumenom korijena)

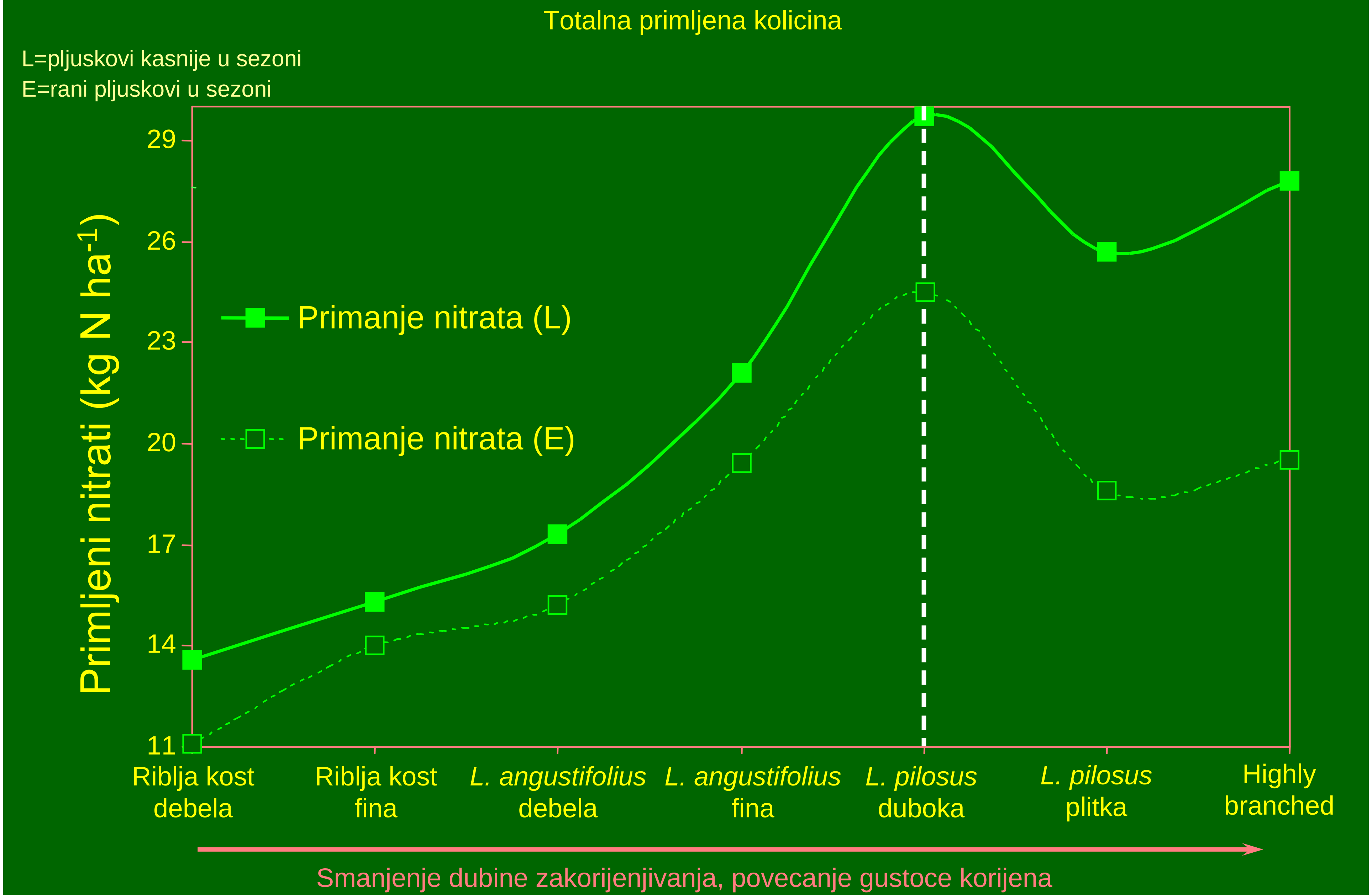
Razne arhitekture su identicne po ‘troskovima’ (tj. ista kolicina asimilata je koristena)



Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844


Izmjerene padaline u Moora 1995 (Anderson et al., 1998)
Ista ukupna kolicina kao i u primjeru abore, ali pljuskovi su odgodjeni za kasnije u sezoni
Dnevne padaline (mm)
0
10
20
30
40
0
7
14
21
28
35
42
49
56
63
70
77
84
91
98
105
Dani nakon sijanja

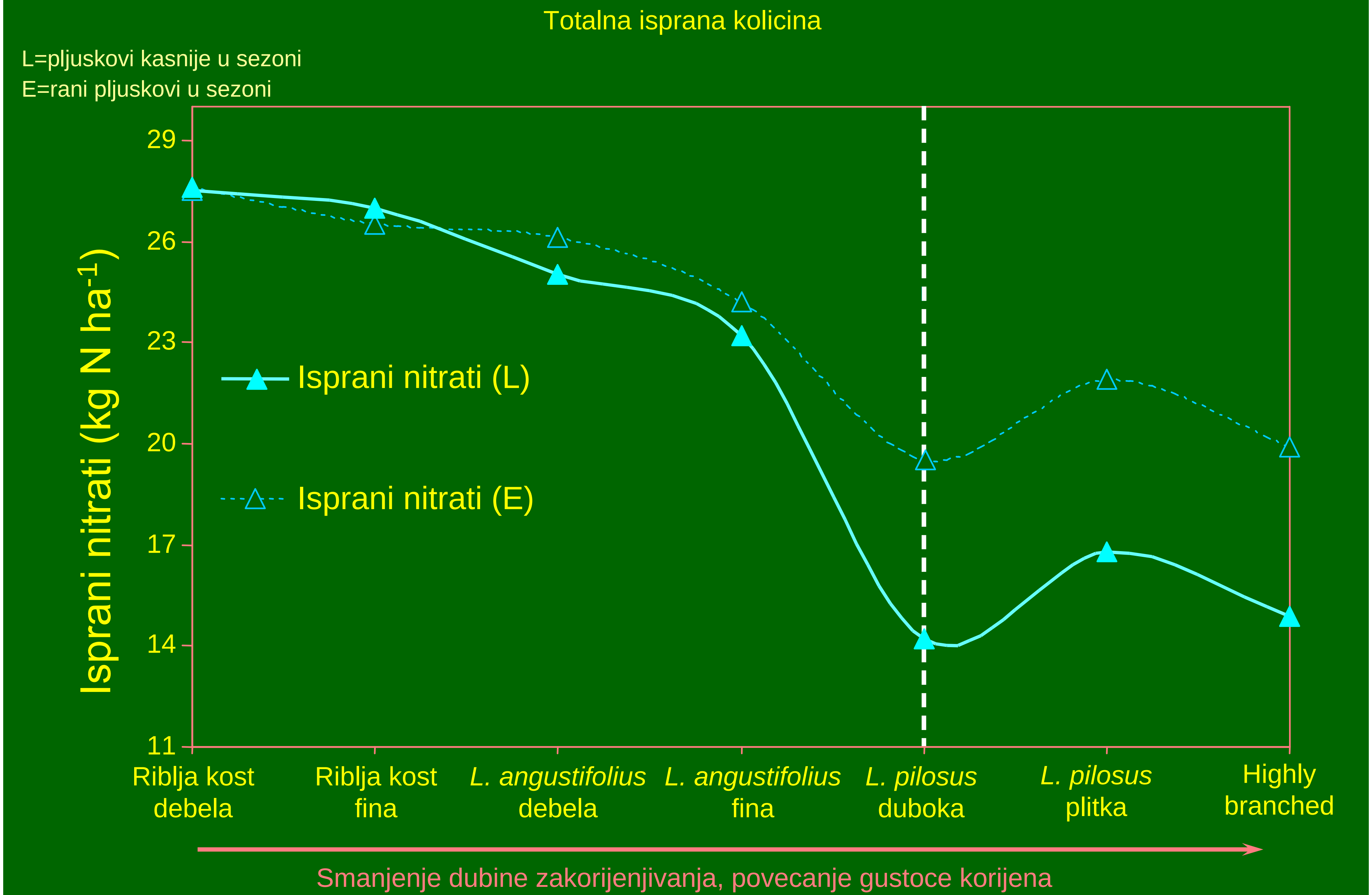
Primanje nitrata raznim arhitekturama korijena



108 dana nakon sijanja

Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844

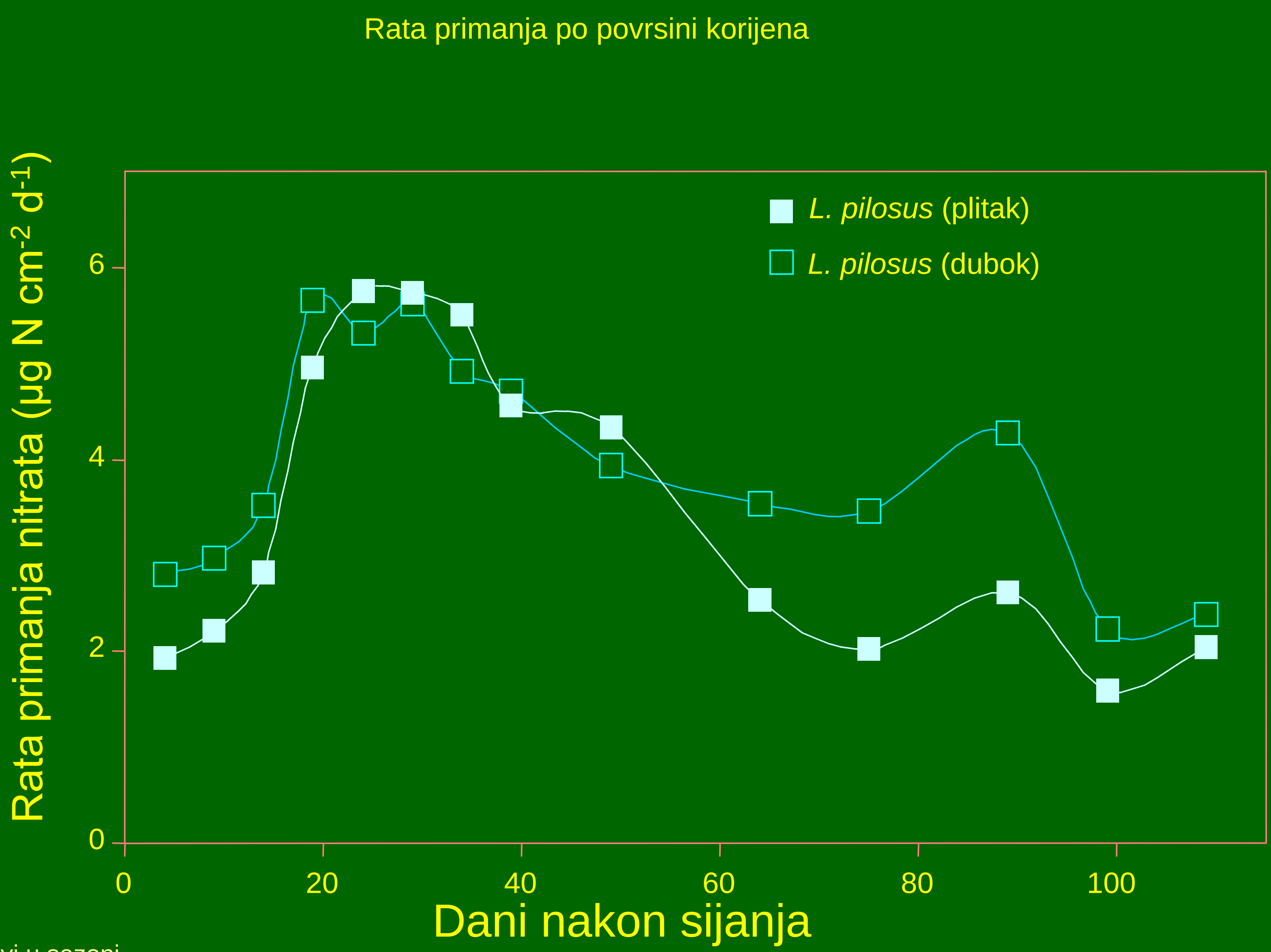
Ispiranje nitrata - razne arhitekture korijena -



108 dana nakon sijanja

Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844

Primanje nitrata raznim arhitekturama korijena

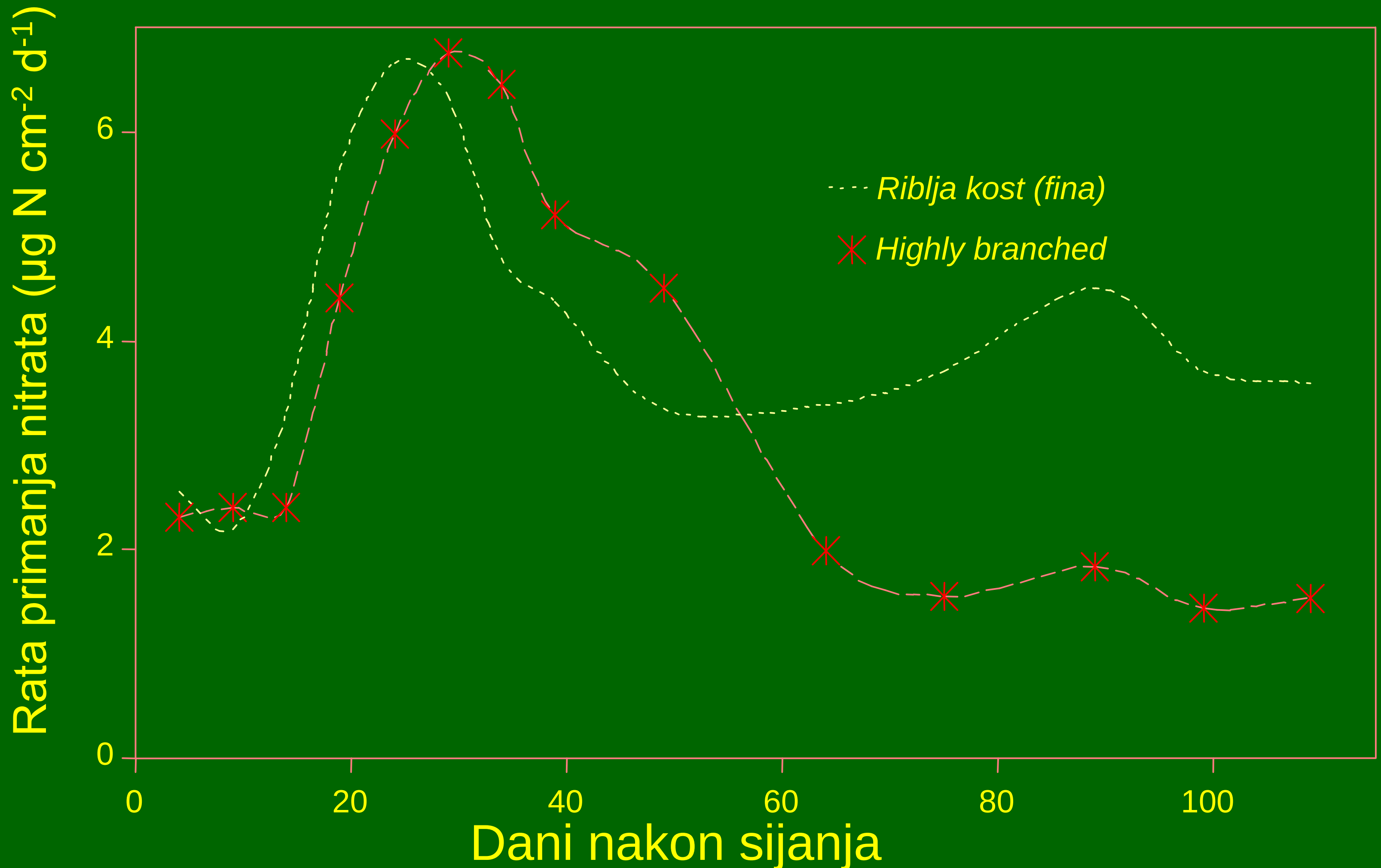


E=rani pljuskovi u sezoni
(izmjereno u Anderson et al 1988)

Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844

Primanje nitrata raznim arhitekturama korijena

Rata primanja po povrsini korijena



E=rani pljuskovi u sezoni
(izmjereno u Anderson et al 1988)

Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844

Zakljucci

Sistemi opskrbe/potreba (supply/demand) se mogu koristiti za simuliranje reakcija korijena na okolis

Rast korijena, primanje nitrata i sadrzaj vode su uspjesno modelirani u sistemu lupina-tlo

Kapacitet simuliranja reagirajuceg korijenovog sistema omogucava studiranje interakcija izmedju korijena i heterogenog okolisa

Uspjeh u primanju nitrata je balans izmedju brzine akvizicije i velicine ukupnog volumena eksploatiranog tla s jedne strane I brzine ispiranja nitrata s druge

Acknowledgements

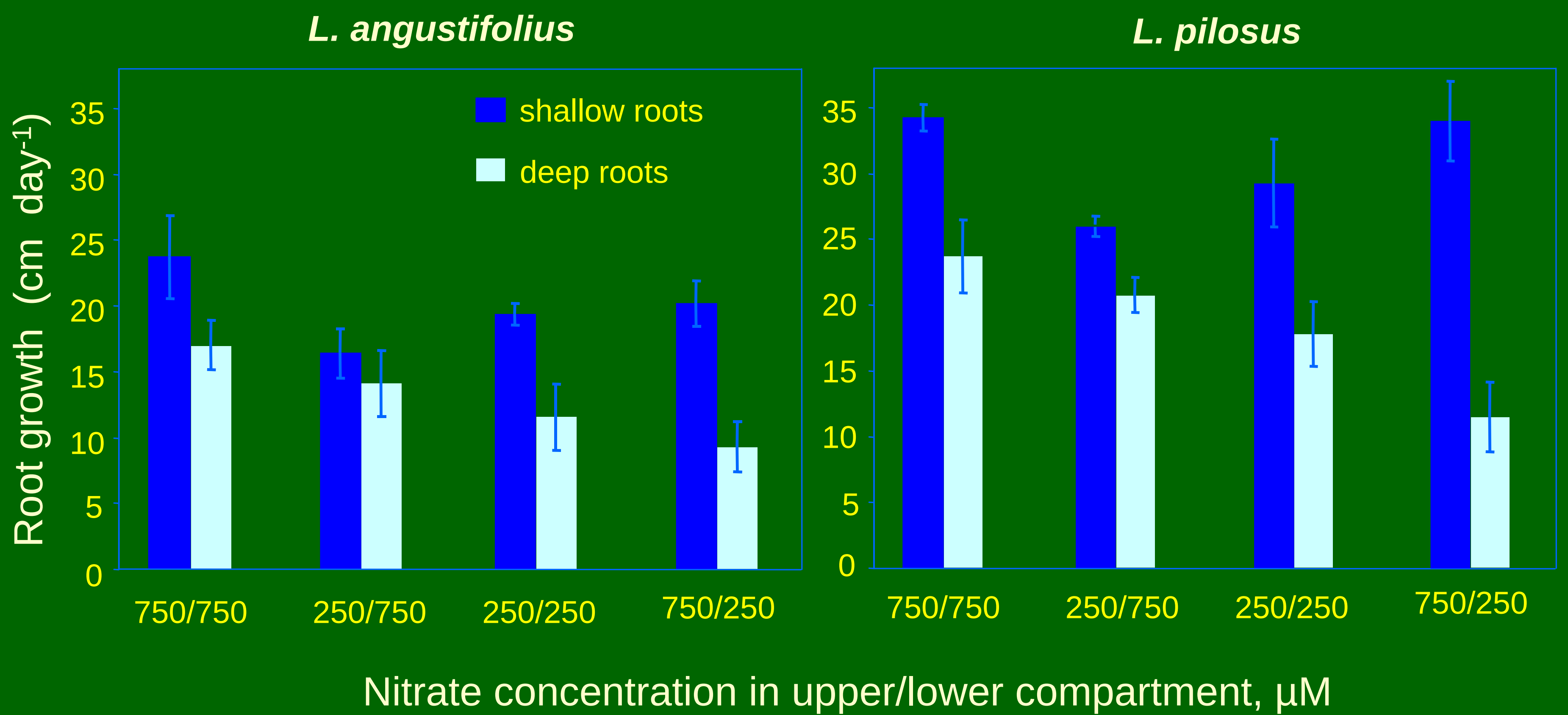
Dr Vanessa Dunbabin (UWA, now Univ Tasmania)
Dr Art Diggle (State Dept of Agric)

Root length density and cumulative nitrate leached after the main rainfall event

- four L. angustifolius plants grown in the field in 1996 -

Root growth as influenced by the nitrate supply

- first order laterals -

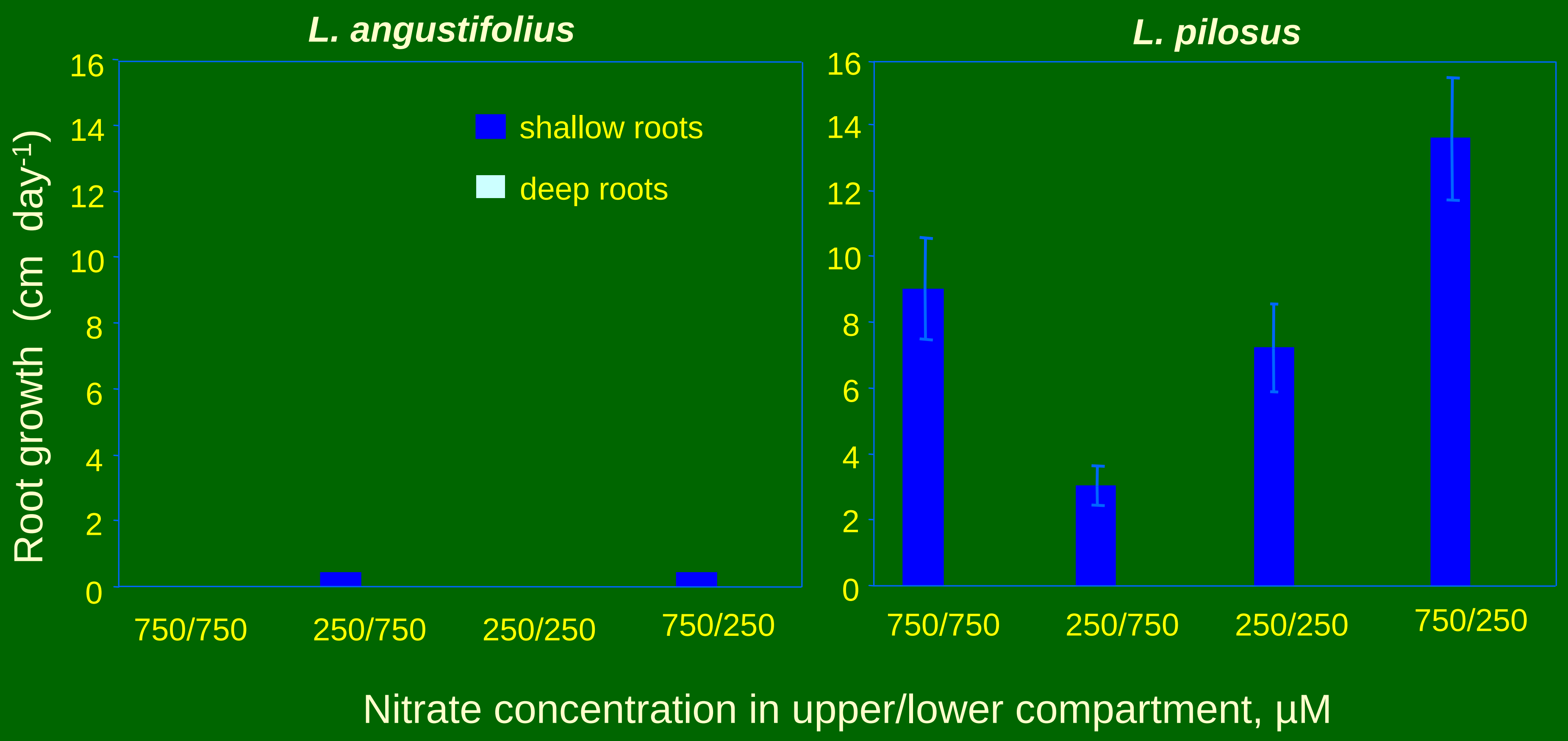


21-d-old plants at t=0,
growth after 9 days.

Dunbabin et al. 2001. Aust J Agric Res 52, 495.

Root growth as influenced by the nitrate supply

- second order laterals -

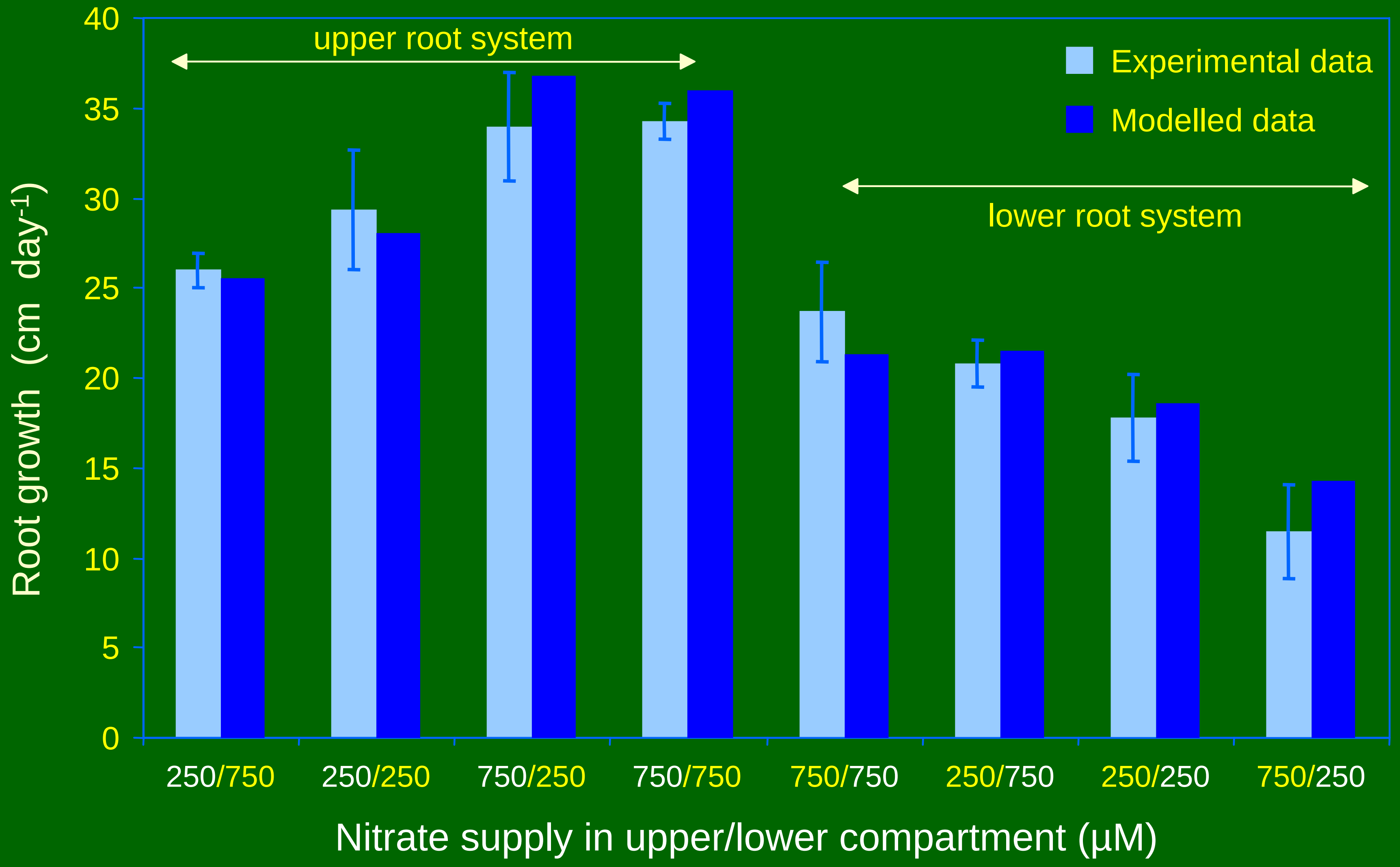


21-d-old plants at t=0,
growth after 9 days.

Dunbabin et al. 2001. Aust J Agric Res 52, 495.

Modelling root growth of *L. pilosus*

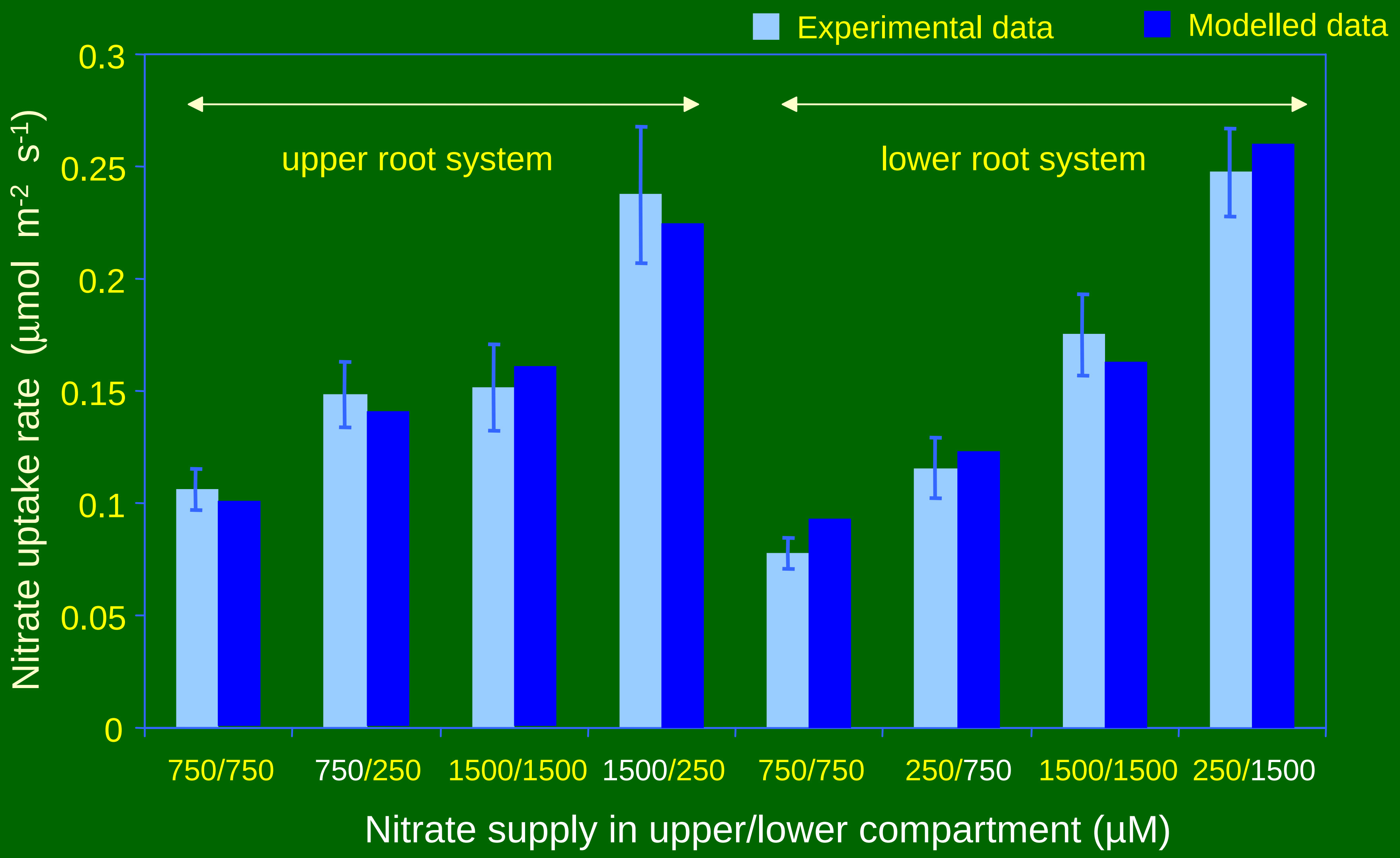
- first order laterals -



Dunbabin et al. 2002. Plant Soil 239, 19.

Modelling nitrate uptake by *L. angustifolius*

- in the high nitrate patch when split-nitrate supply -



Dunbabin et al. 2002. Plant Soil 239, 39.

Parameters used in the model for simulation of lupin root growth and nutrient uptake in nutrient solution (determined by parameter fitting and from experimental data) for three orders of branching: tap root (0), primary laterals (1), secondary laterals (2). The branch lag time = the time lag before a branch will grow (eg. a primary lateral) from a node on the previous branching order (eg. the tap root).

Parameter description	**Symbol**	***L. angustifolius***	***L. pilosus***	**Units**
root radius 0	a_0	1.0	0.8	mm
root radius 1	a_1	0.5	0.4	mm
root radius 2	a_2	0.3	0.2	mm
unit N growth rate 0*	μ_{gN0}	0.08	0.08	$\mu m\ mol^{-1}\ s^{-1}$
unit N growth rate 1*	μ_{gN1}	0.12	0.14	$\mu m\ mol^{-1}\ s^{-1}$
unit N growth rate 2*	μ_{gN2}	0.14	0.96	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 0*	μ_{gnN0}	3.5	4.2	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 1*	μ_{gnN1}	0.77	0.73	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 2*	μ_{gnN2}	0.54	0.73	$\mu m\ mol^{-1}\ s^{-1}$
unit N branch density 1*	μ_{bN1}	5.9	3.5	branches $m^{-1}\ mol^{-1}$
unit N branch density 2*	μ_{bN2}	2.1	3.5	branches $m^{-1}\ mol^{-1}$
unit nN branch density 1*	μ_{bnN1}	0.42	1.2	branches $m^{-1}\ mol^{-1}$
unit nN branch density 2*	μ_{bnN2}	0.42	0.42	branches $m^{-1}\ mol^{-1}$
branch lag time 0	T_{bl0}	192	216	h
branch lag time 1	T_{bl1}	528	291	h
initial branch angle	θ	90	90	deg
deflection index	D	0.25	0.25	unitless
unit N fix*	μ_{fix}	0.05	0.05	mol $nodule^{-1}\ s^{-1}$
unit nodule cost*	μ_{nodm}	0.075	0.075	mol $nodule^{-1}$
unit nodule growth rate*	μ_{nodg}	9	9	nodule mol^{-1}
total seed reserve	$(N+nN)_{seed}$	56	265	mol
N down regulation factor	ω	1.6	1.1	unitless
max. N net influx rate	F_{max}	5.3	2.6	nmol $m^{-2}\ s^{-1}$
kinetic constant	K_m	0.119	0.115	mol m^{-3}
poten. transpiration rate	T_{max}	$2.55*10^{-8}$	$1.89*10^{-8}$	$m^3\ m^{-2}\ s^{-1}$

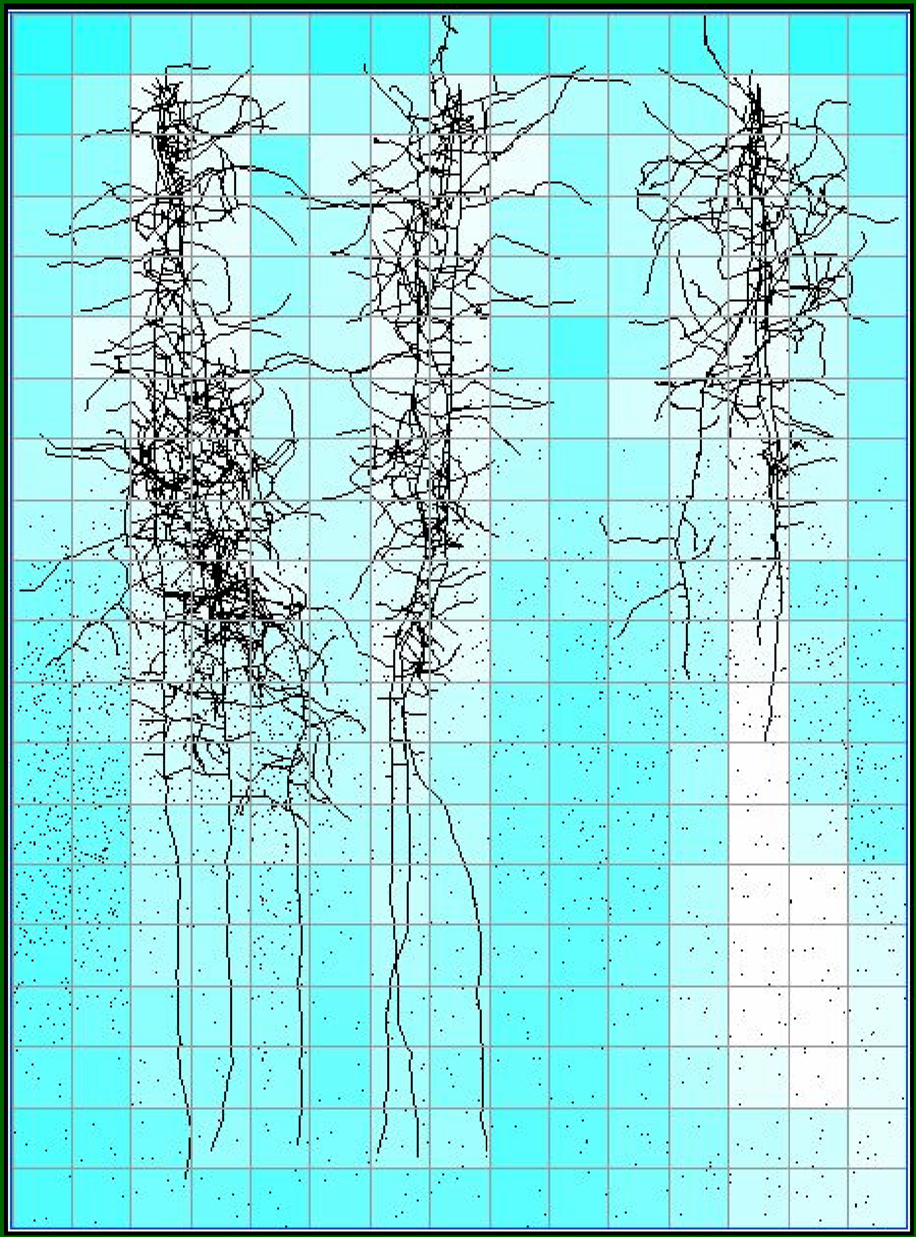
Parameters used in the model for simulation of lupin root growth and nutrient uptake in soil [4 orders of branching: tap root (0), primary laterals (1), secondary laterals (2) and tertiary laterals (3)]. The branch lag time represents the time lag before a branch will grow (eg. a primary lateral) from a node on the previous branching order (eg. the tap root).

* represents those parameters previously calibrated in the model through simulating nutrient solution experiments.

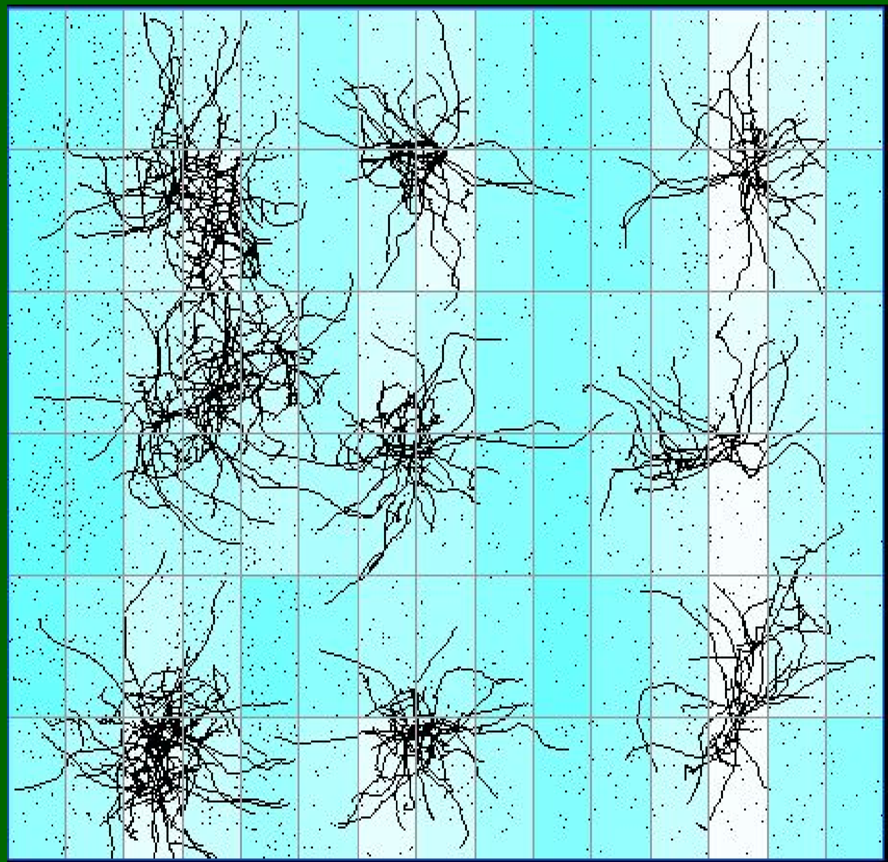
Field data were used only to initialise the environmental variables required by the model, eg. soil bulk density, initial soil water contents, drained upper limit and wilting point parameters and rainfall

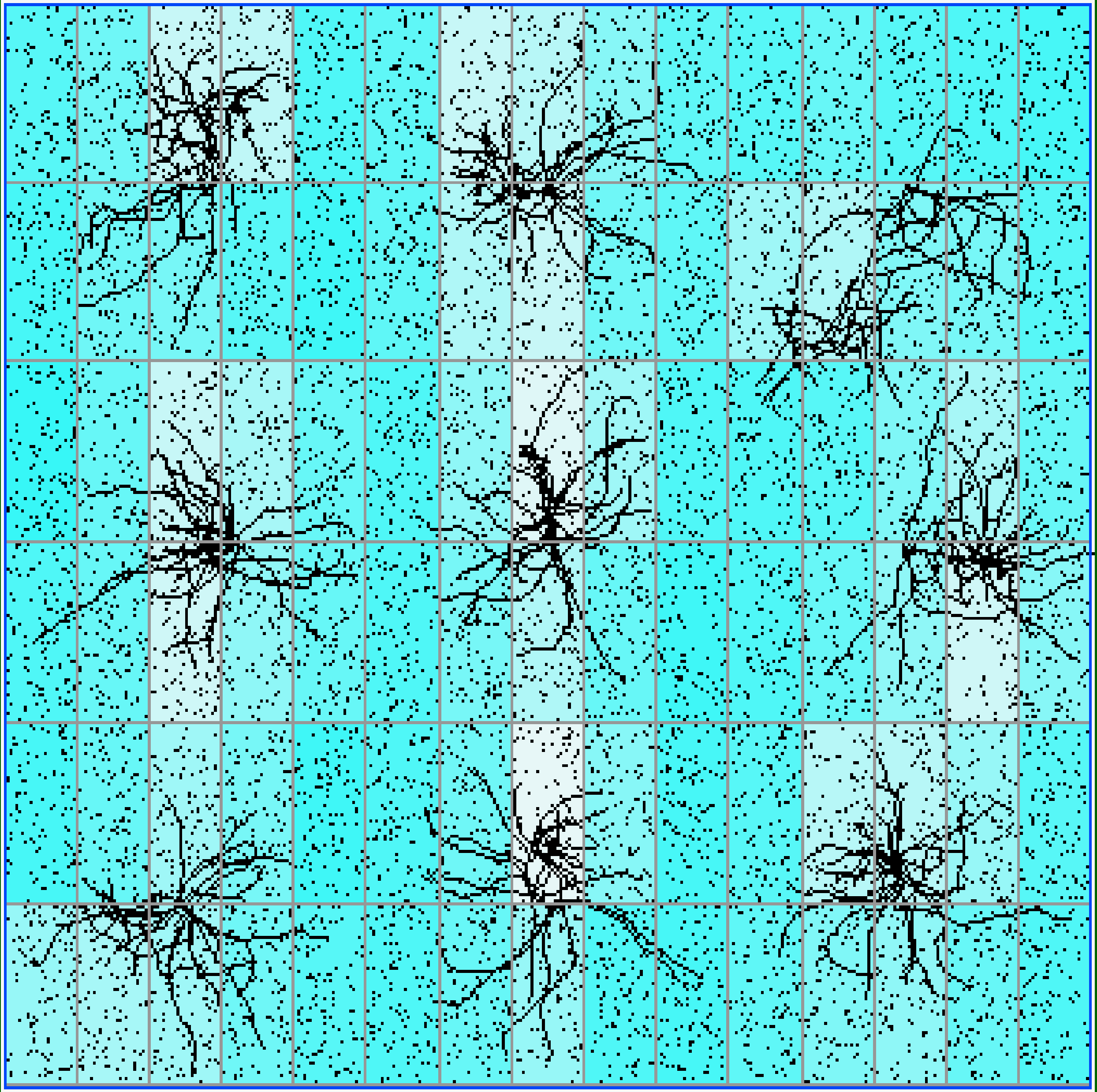
Parameter description	Symbol	*L. angustifolius*	Units
root radius 0	a_0	1.0	mm
root radius 1	a_1	0.5	mm
root radius 2	a_2	0.3	mm
root radius 3	a_3	0.2	mm
unit N growth rate 0*	μ_{gN0}	0.08	$\mu m\ mol^{-1}\ s^{-1}$
unit N growth rate 1*	μ_{gN1}	0.12	$\mu m\ mol^{-1}\ s^{-1}$
unit N growth rate 2*	μ_{gN2}	0.14	$\mu m\ mol^{-1}\ s^{-1}$
unit N growth rate 3*	μ_{gN3}	0.14	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 0*	μ_{gnN0}	3.5	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 1*	μ_{gnN1}	0.77	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 2*	μ_{gnN2}	0.54	$\mu m\ mol^{-1}\ s^{-1}$
unit nN growth rate 3*	μ_{gnN3}	0.54	$\mu m\ mol^{-1}\ s^{-1}$
branch spacing 0	μ_{bN0}	8	mm
branch spacing 1	μ_{bN1}	8	mm
branch spacing 2	μ_{bnN0}	5	mm
branch spacing 3	μ_{bnN1}	5	mm
branch lag time 0	T_{bl0}	192	h
branch lag time 1	T_{bl1}	528	h
branch lag time 2	T_{bl1}	528	h
initial branch angle	θ	90	deg
deflection index	D	0.25	unitless
unit N fix*	μ_{fix}	0.05	$mol\ nodule^{-1}\ s^{-1}$
unit nodule cost*	μ_{nodm}	0.075	$mol\ nodule^{-1}$
unit nodule growth rate*	μ_{nodg}	9	$nodule\ mol^{-1}$
total seed reserve	$(N+nN)_{seed}$	56	mol
maximum N net influx rate	F_{max}	5.3	$nmol\ m^{-2}\ s^{-1}$
kinetic constant	K_m	0.119	$mol\ m^{-3}$
potential transpiration rate	T_{max}	$2.55*10^{-8}$	$m^3\ m^{-2}\ s^{-1}$
displacement dependent dispersivity	ε	30	mm
nitrate diffusion coefficient	D	$1.9*10^{-9}$	$m^2\ s^{-1}$

Model Output



The intensity of the blue background shows the water content and the black dots represent the nitrate content in soil

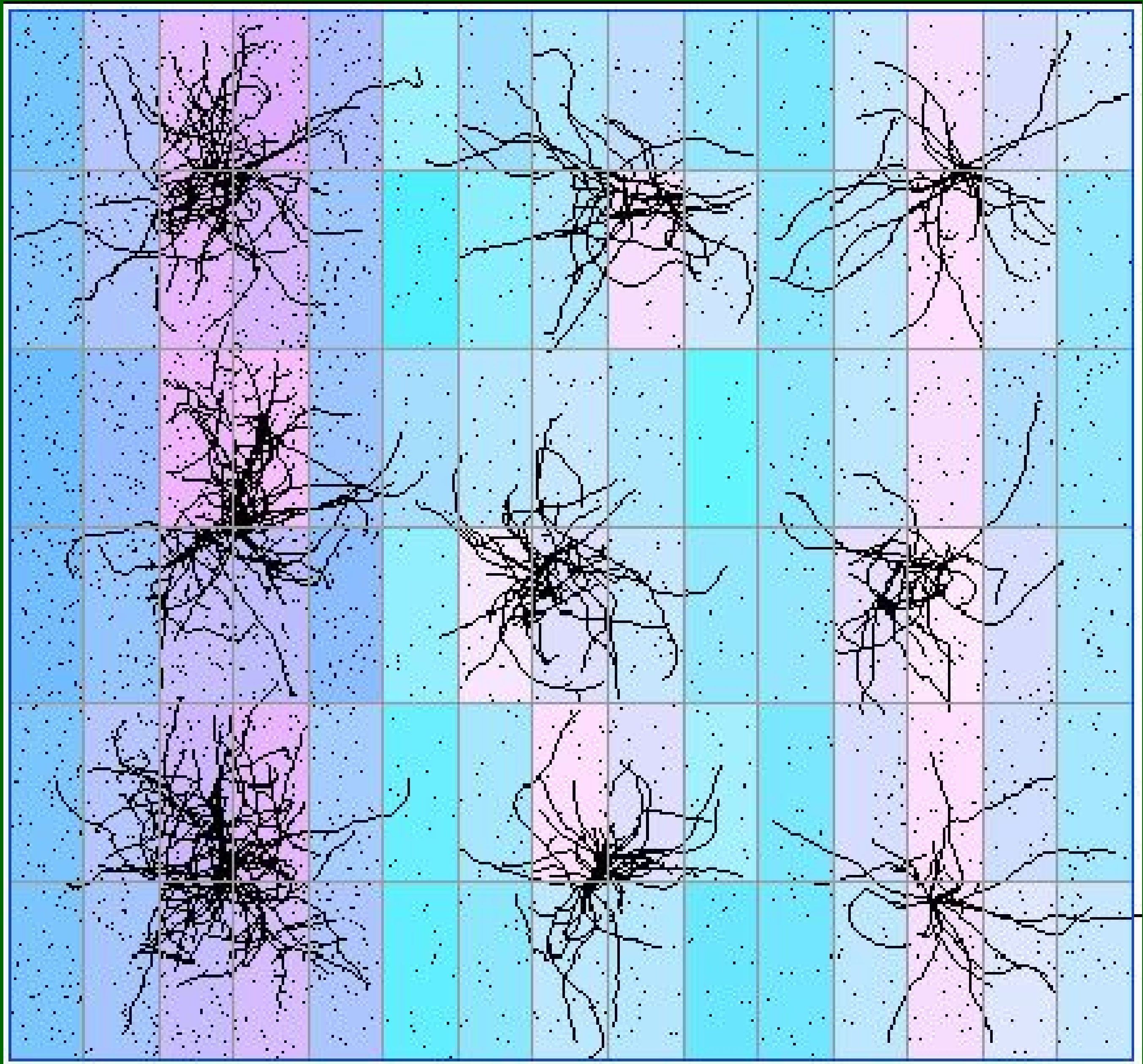




Model Output

***L. angustifolius* plants growing in sandy soil**

The intensity of the blue background shows the water content and the black dots represent the nitrate content in soil

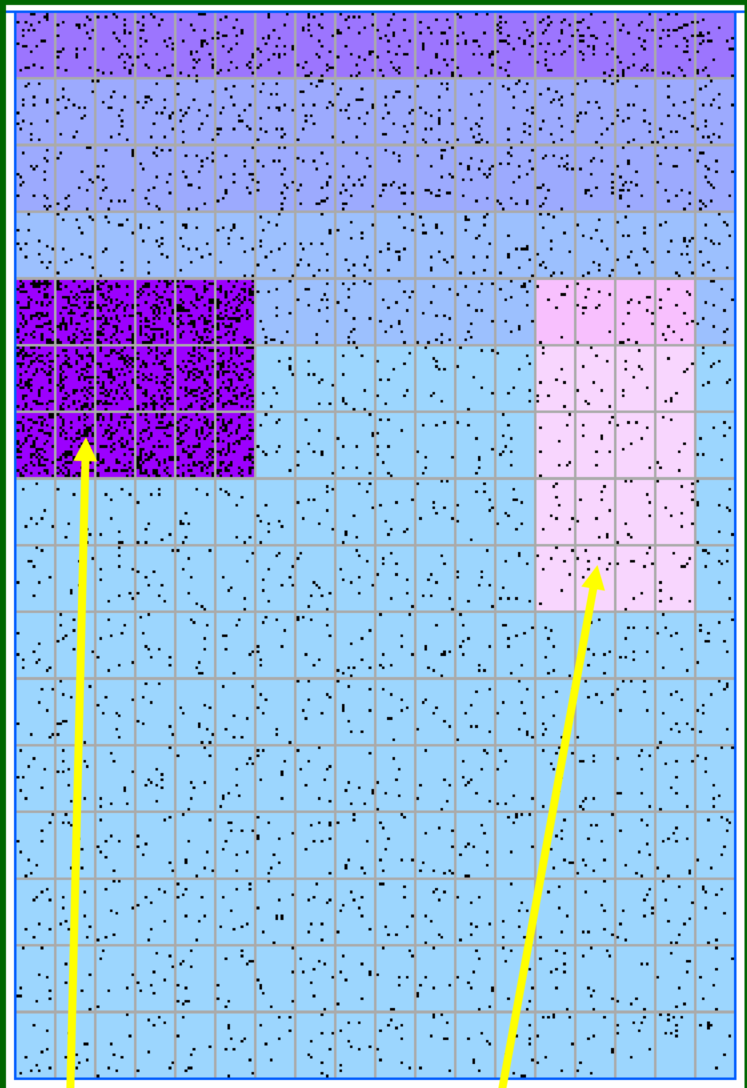


Model Output

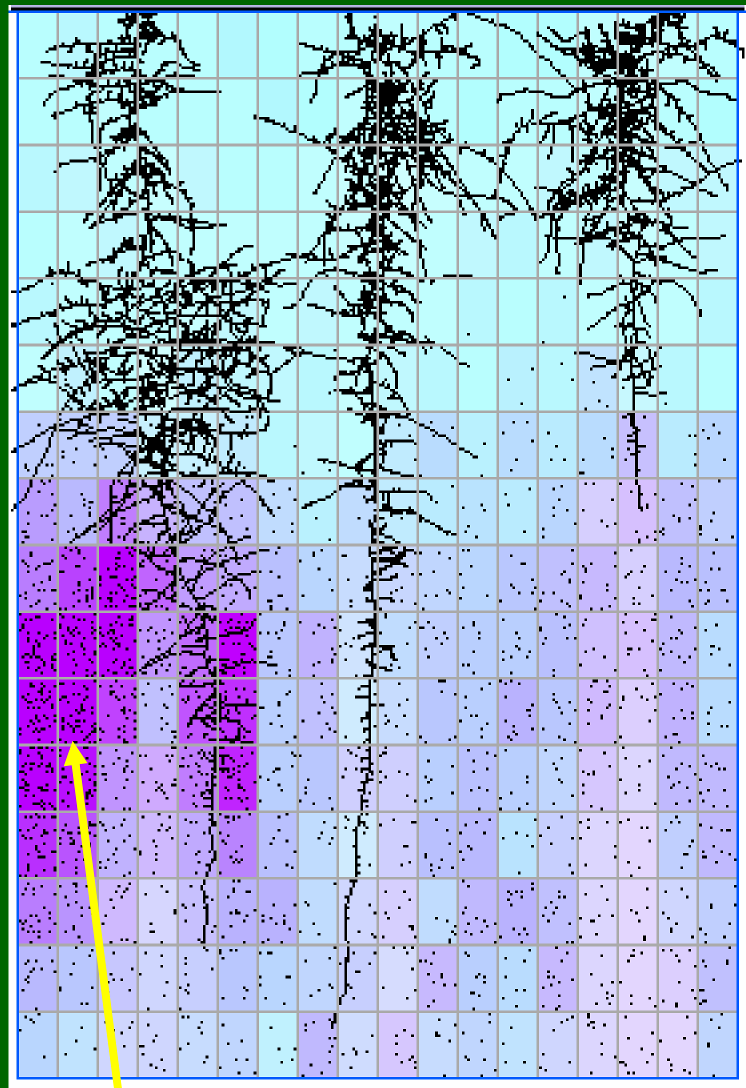
***L. angustifolius* plants growing in sandy soil**

The intensity of the blue background shows the water content and the intensity of pink colour (also black dots) represent the nitrate content in soil

initial soil profile



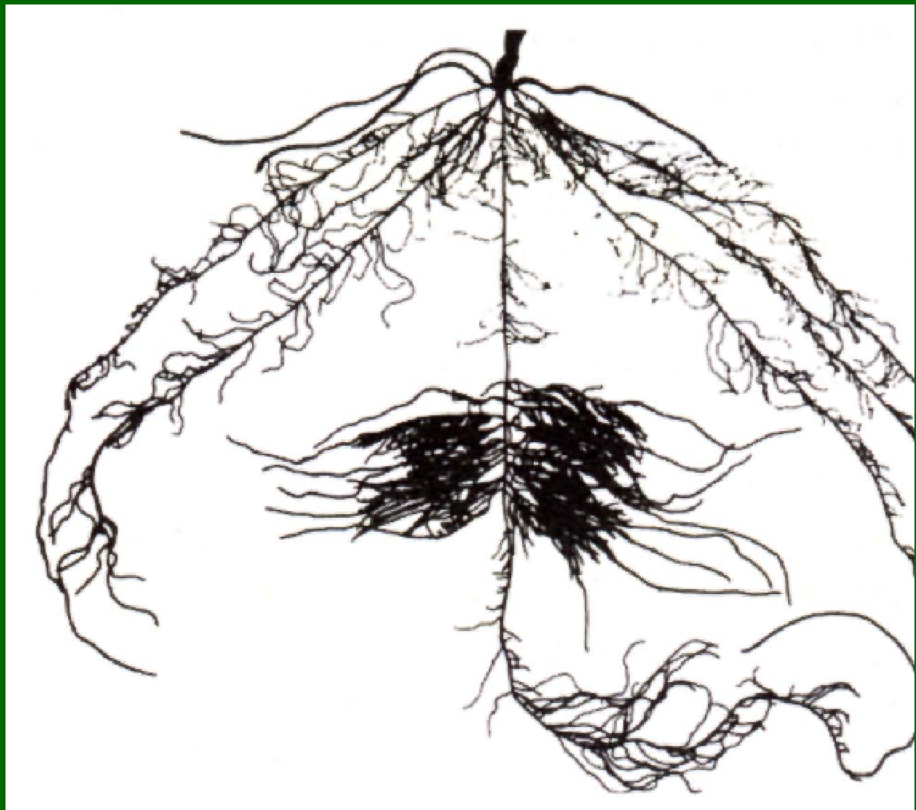
root systems responding to their local environment



local high nitrate patch

local dry patch

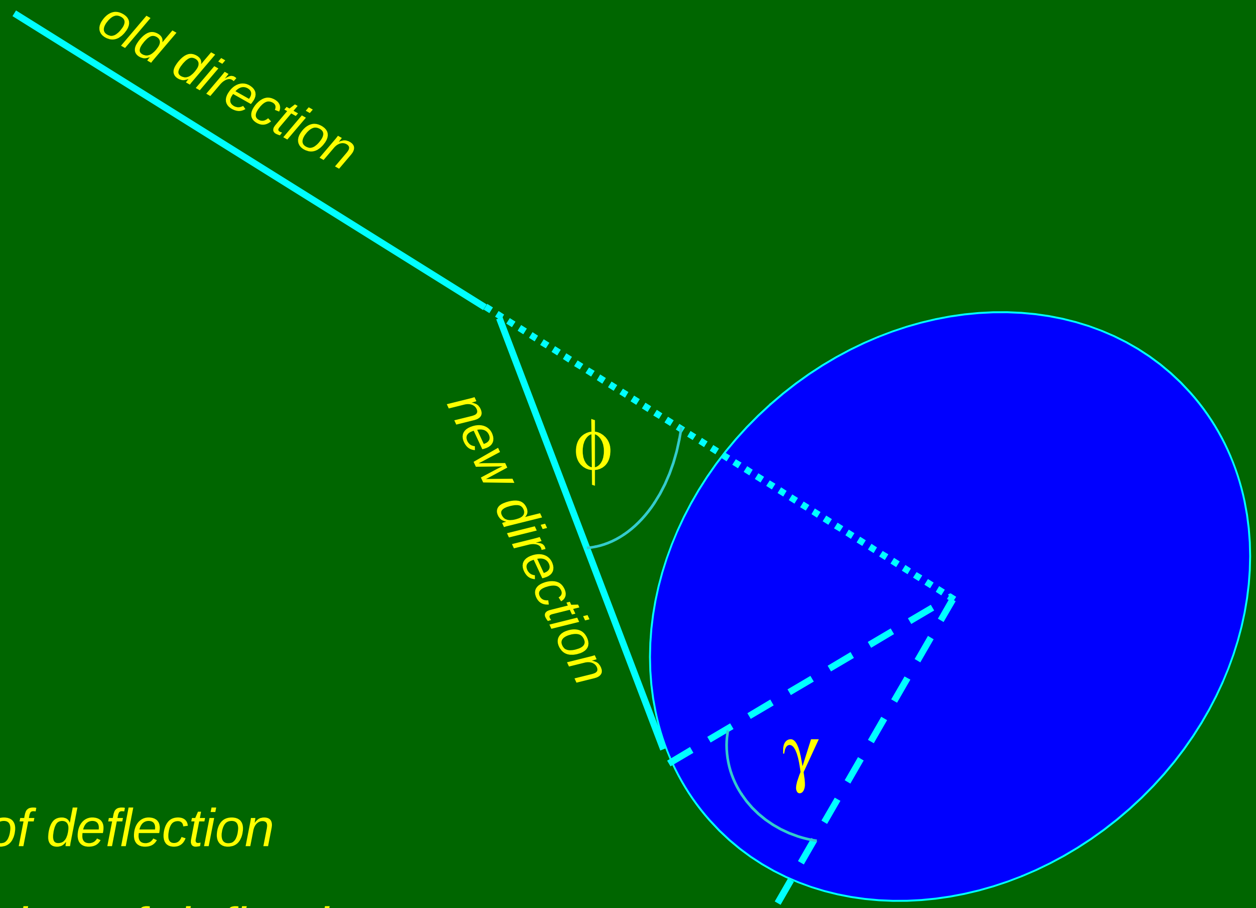
nitrate leaching through soil profile after successive rain events




- root elongation rate
- branching density
- duration of apical non-branching

- soil resistance
- time of appearance of each branching order
- axis initiation parameters
- direction of branching

Root branching

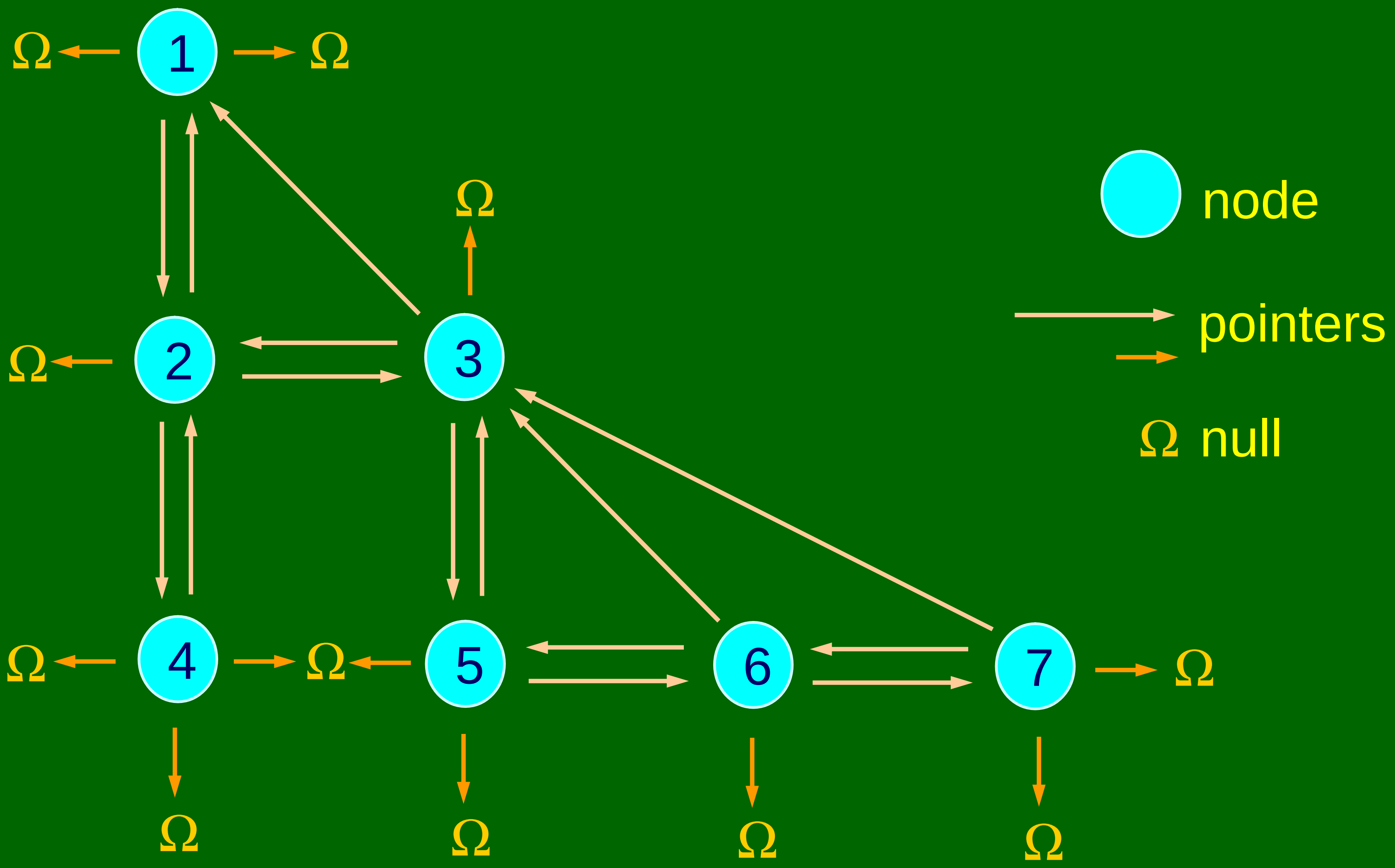


ϕ = *angle of deflection*

γ = *orientation of deflection*

Extensible tree:

data structure to store information on root architecture



If the influx, I_n, is known, the driving force for the diffusive flux can be calculated

$$\Delta C_L = \bar{C}_L - C_{L0} = -\frac{I_n}{4\pi D_L \Theta f}\left(1 - \frac{1}{1 - \pi r_0^2 RL_v} \ln \frac{1}{\pi r_0^2 RL_v}\right)$$

$\bar{C}_L$ = average soil solution concentration of the bulk soil

C_{L0} = solution concentration at the root surface

D_L = diffusion coefficient in water

θ = volumetric soil water content

f = tortuosity factor

r_0 = root radius

RL_v = root length density

Transport equation

incorporating diffusion and mass flow

$$b\frac{\partial C_L}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}\left(rD_e b\frac{\partial C_L}{\partial r} + v_0 r_0 C_L \right)$$

b = buffer power

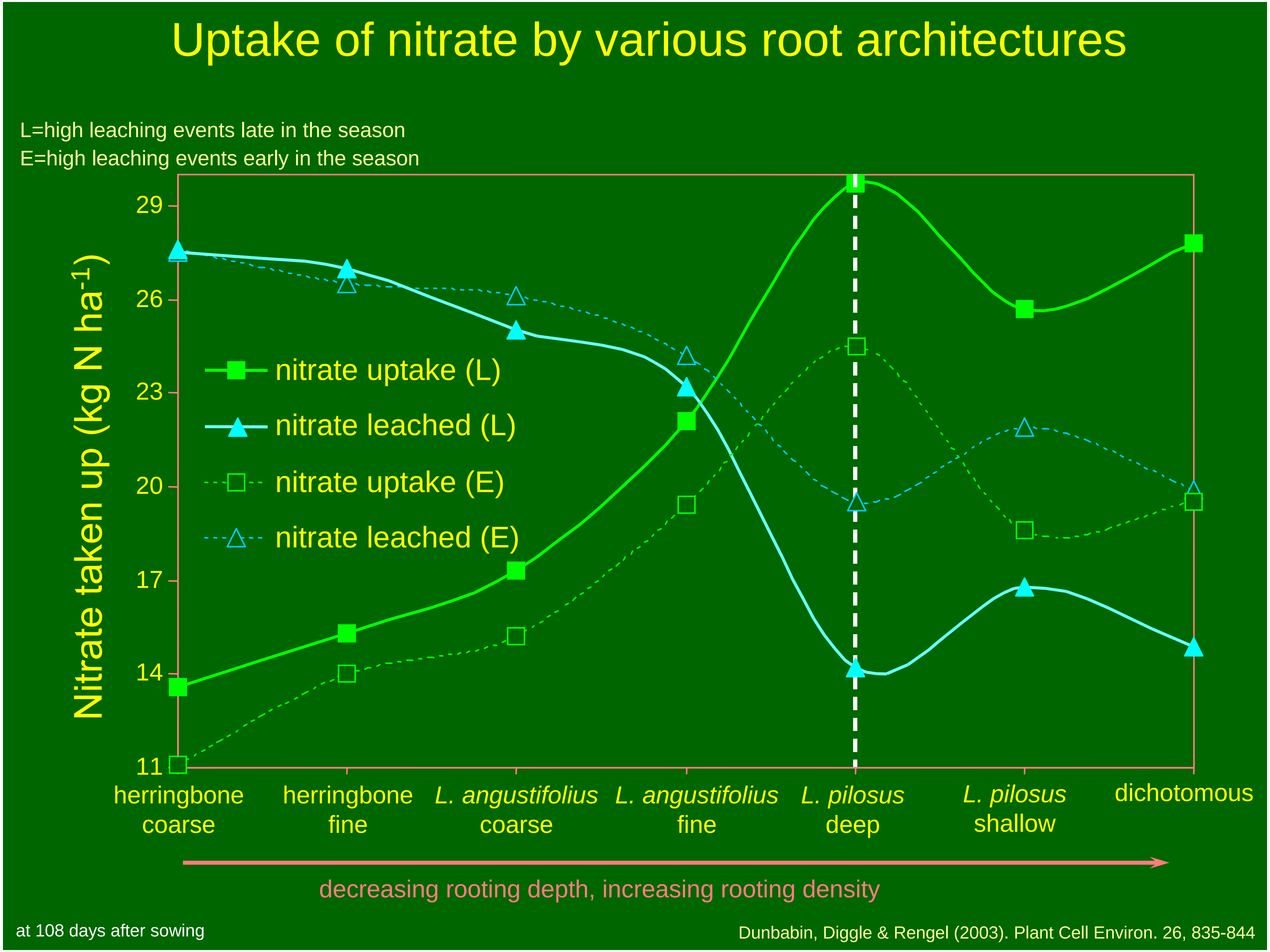
C_L = soil solution concentration in the bulk soil

r = radial distance from the root axis

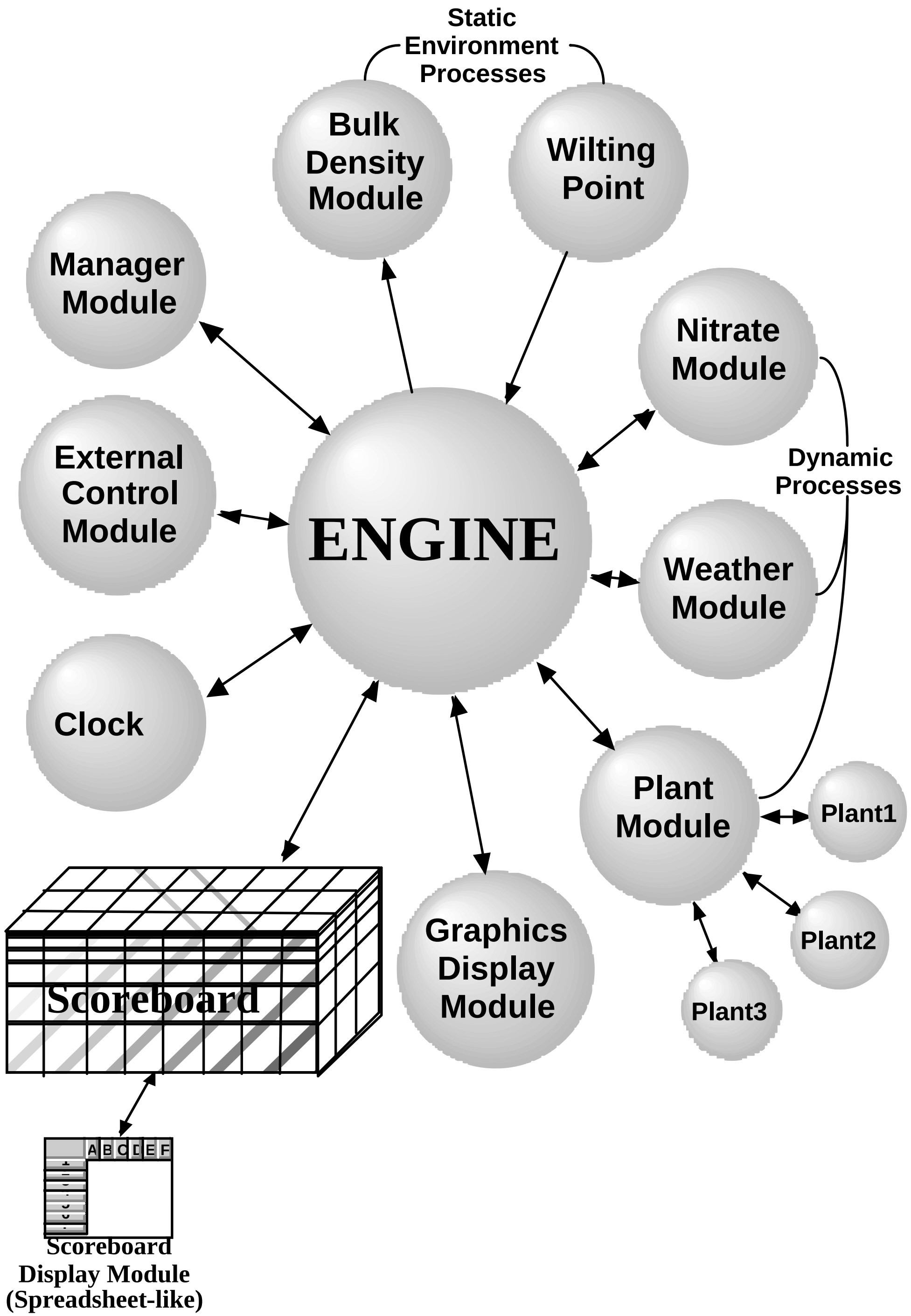
D_e = effective diffusion coefficient in soil

v_0 = water flux across the soil-root interface

r_0 = root radius



Uptake of nitrate by various root architectures
L=high leaching events late in the season
E=high leaching events early in the season
Nitrate taken up (kg N ha-1)
29
26
23
20
17
14
11
nitrate uptake (L)
nitrate leached (L)
nitrate uptake (E)
nitrate leached (E)
herringbone coarse
herringbone fine
L. angustifolius coarse
L. angustifolius fine
L. pilosus deep
L. pilosus shallow
dichotomous
decreasing rooting depth, increasing rooting density
at 108 days after sowing
Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844

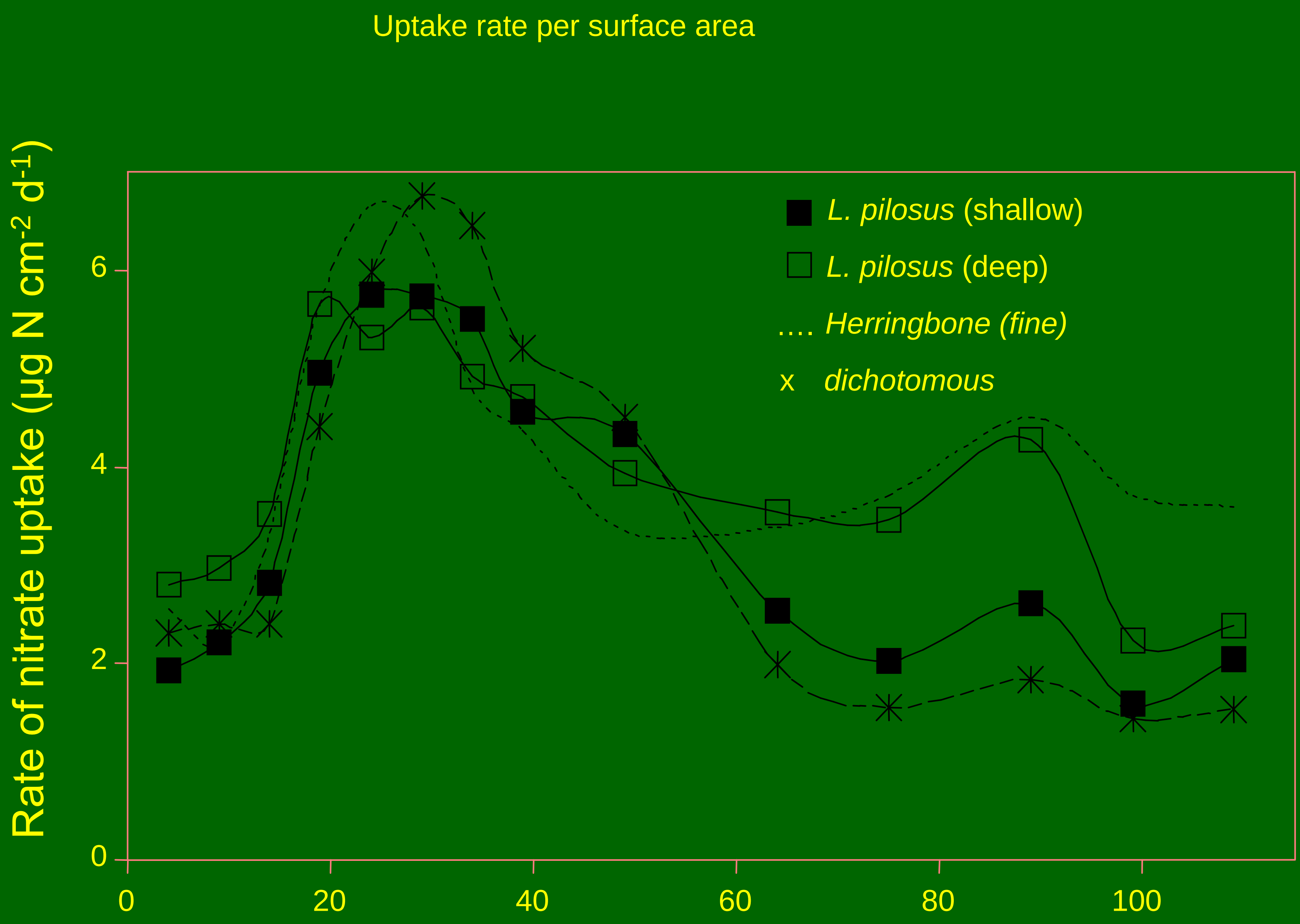


Model structure

Engine interacts with modules, with modelling activities synchronised by the clock.

The scoreboard represents the simulation volume, containing all 3-D parameter values.

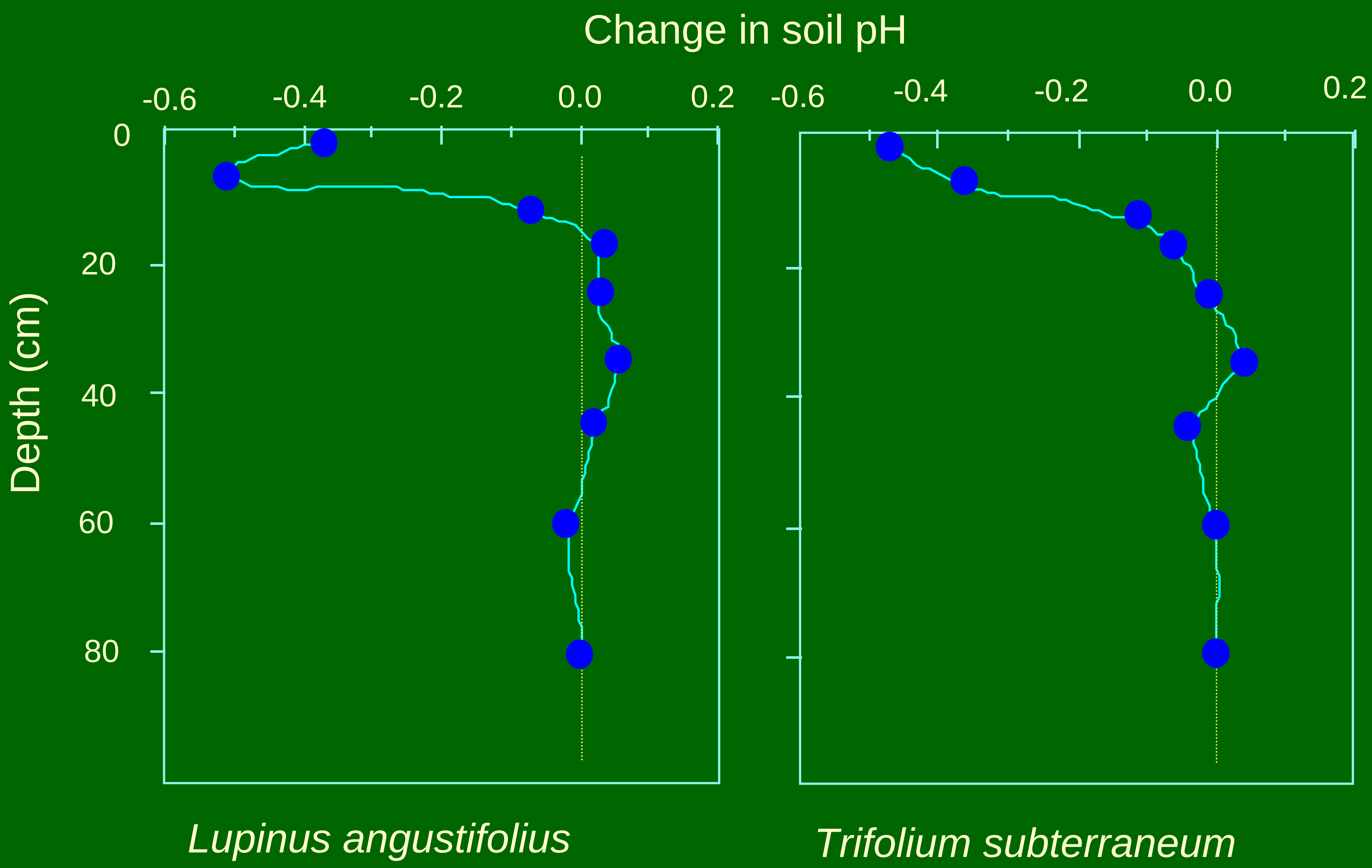
Uptake of nitrate by various root architectures



E=high leaching events early in the season
(as measured by Anderson et al 1988)

Dunbabin, Diggle & Rengel (2003). Plant Cell Environ. 26, 835-844

Nitrate leaching from topsoil causes topsoil acidification



Tang, Raphael, Rengel & Bowden 2001 Aust J Soil Res 38, 837-849.

Simulating nitrate uptake efficiency of root architectures

Relative nitrate uptake efficiency (dynamic/static nitrate supply)	
herringbone	highly branched
1.8 (±0.11)	0.78 (±0.21)

Averaged over 30 simulations and 5 replicates

Dunbabin, Rengel & Diggle (2003). In: *Innovative Soil-Plant Systems for Sustainable Agricultural Practices*, pp.2-16.

This document was created with Win2PDF available at http://www.daneprairie.com.
The unregistered version of Win2PDF is for evaluation or non-commercial use only.