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CONSTRUCTED WETLANDS FOR THE TREATMENT OF ORGANIC MICROPOLLUTANTS: LESSONS LEARNED ACROSS FIVE EXPERIMENTAL STUDIES

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› CWs removal efficiency

TABLE 3. Minimum, Maximum (in Parentheses), and Average Concentrations of PPCPs in the Wastewater Influent for All Loading Rates and the Removal Efficiencies (Percent) Observed in the Vertical Flow Constructed Wetland (VFCW) and the Sand Filter (SF) at a Hydraulic Loading Rate of 70 mm Day^{-1} and Working with either Unsaturated Water Flow or Saturated Flow[a]

		unsaturated flow		saturated flow			
	influent[b,c] (μg L^{-1})	VFCW (% rem)	SF (% rem)	VFCW (% rem)	SF (% rem)	HFCW (*9*) (% rem)	WWTP (% rem)
Pharmaceuticals							
salicylic acid	(45.7–72.3) 53.9	98 ± 1	98 ± 1	85 ± 7	77 ± 7	96	99 (*3*)
ibuprofen	(8.3–17.2) 11.7	99 ± 1	90 ± 3*[d]	55 ± 1	49 ± 1*	71	60–70 (*33*)/ 90 (*1*)
OH-ibuprofen	(12.4 – 16.9) 3.7	99 ± 1	86 ± 3*	51 ± 1	47 ± 2*	62	95 (*34*)
CA-ibuprofen	(8.7–12.4) 10.6	99 ± 1	95 ± 3*	71 ± 6	68 ± 8	87	95 (*34*)
naproxen	(0.96–2.15) 1.57	89 ± 5	80 ± 5	62 ± 3	66 ± 7	85	40–55 (*33*)/66 (*1*)
diclofenac	(0.48–1.28) 0.82	73 ± 3	76 ± 7	53 ± 2	39 ± 22	15	9–75 (*1*)/17 (*23*)
carbamazepine	(1.24–2.9) 2.06	26 ± 14	11 ± 7	20 ± 4	8 ± 15	16 (*35*)	8 (*23*)/7 (*1*)
caffeine	(35.2–64.0) 48.4	99 ± 1	98 ± 1	82 ± 1	75 ± 6*	97	99 (*23*)
Personal Care Products							
methyl-dihydrojasmonate	(18.8–31.8) 22.8	99 ± 1	98 ± 1*	78 ± 4	76 ± 8	99	98 (*21*)
hydrocinnamic acid	(11.2–17.6) 15.4	99 ± 1	99 ± 1	82 ± 3	69 ± 11	na[e]	na
oxybenzone	(8.58–22.1) 14.8	97 ± 1	95 ± 2	88 ± 3	64 ± 24	na	68–99 (*36*)
galaxolide	(3.05–12.4) 5.62	90 ± 1	92 ± 1	88 ± 2	88 ± 2	86	70–85 (*33*)/89 (*21*)
tonali							
HRT (							

[a] Re
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a signi

But:
what is the fate of the compounds?
what are the removal processes?

AIMS

- investigate removal (efficiencies and dynamics) in subsurface CWs both on the water and plant phases
- evaluate influencing factors on compound removal (initial concentration, CW configuration, plant type)
- compare removal mechanisms
- compare microbial metabolic functions

MODEL COMPOUNDS

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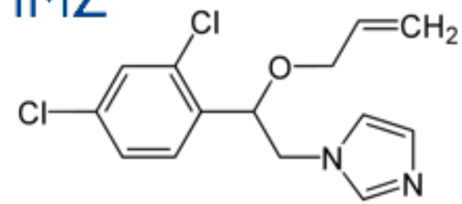
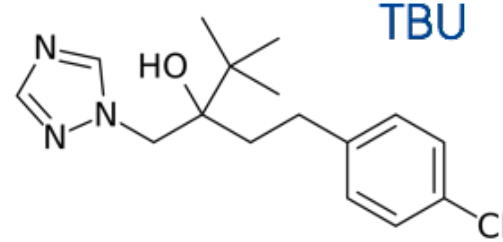
Compounds	MW (g/mol)	pK_a	Log K_{ow}
Pesticides			
Imazalil (IMZ)	297	6.77	4.10
Tebuconazole (TBU)	307	2.27	3.89
Pharmaceuticals			
Ibuprofen (IBP)	206	4.85	3.79
Iohexol (IHE)	821	11.73	-4.16

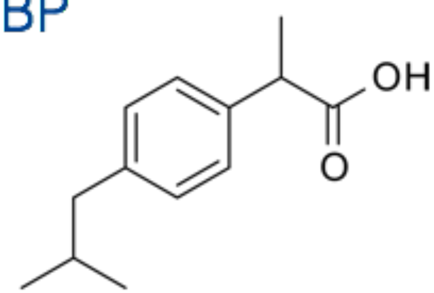
IMZ



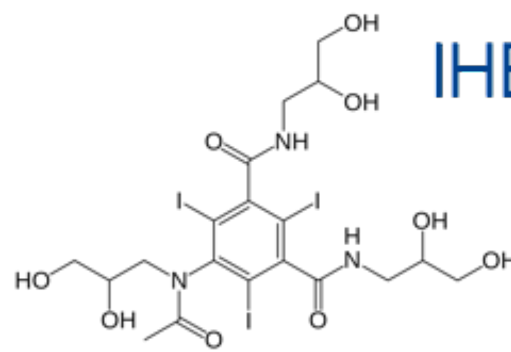
TBU



IBP



IHE



Typha latifolia

Phragmites australis

Iris pseudacorus

Berula erecta

Juncus effusus

2x Mesocosms

Seasonality

CW design

2x Hydroponics

Uptake

Plant metabolisation

Substrate sorption vs biofilm degradation

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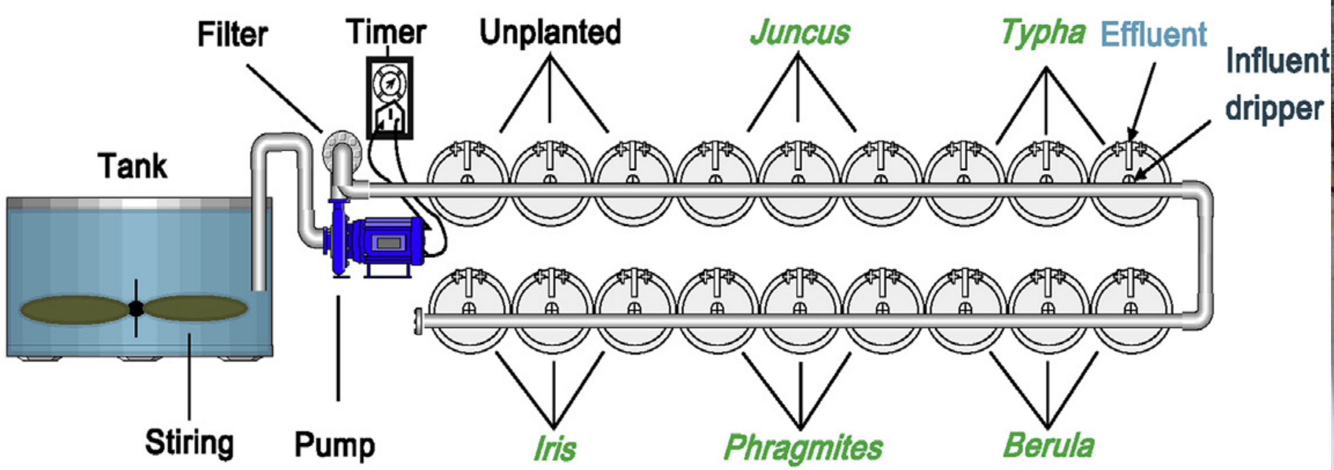
- Mesocosms reactors

- Artificial influent (nutrients + C)
- 5 HLR; 5 plant species; 2 initial concentrations; season
- 4 compounds



PHARMACEUTICALS

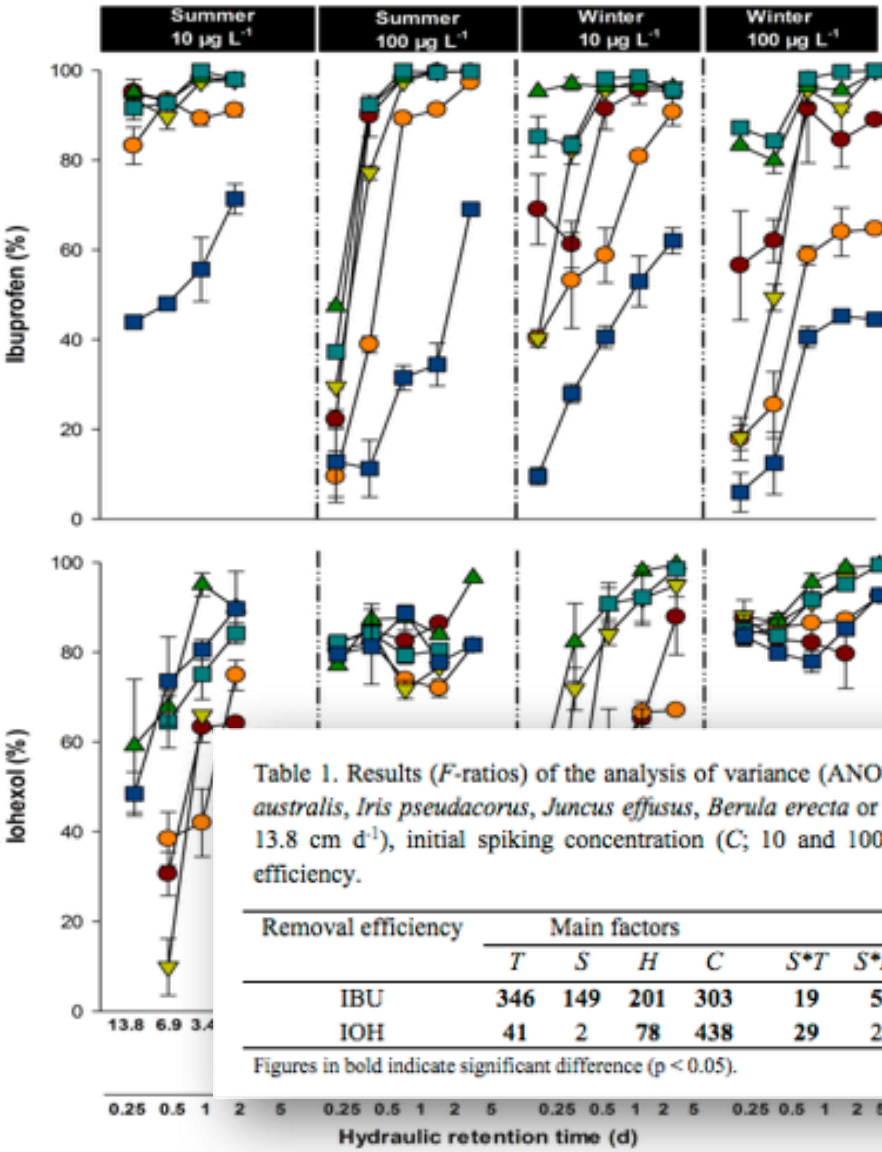
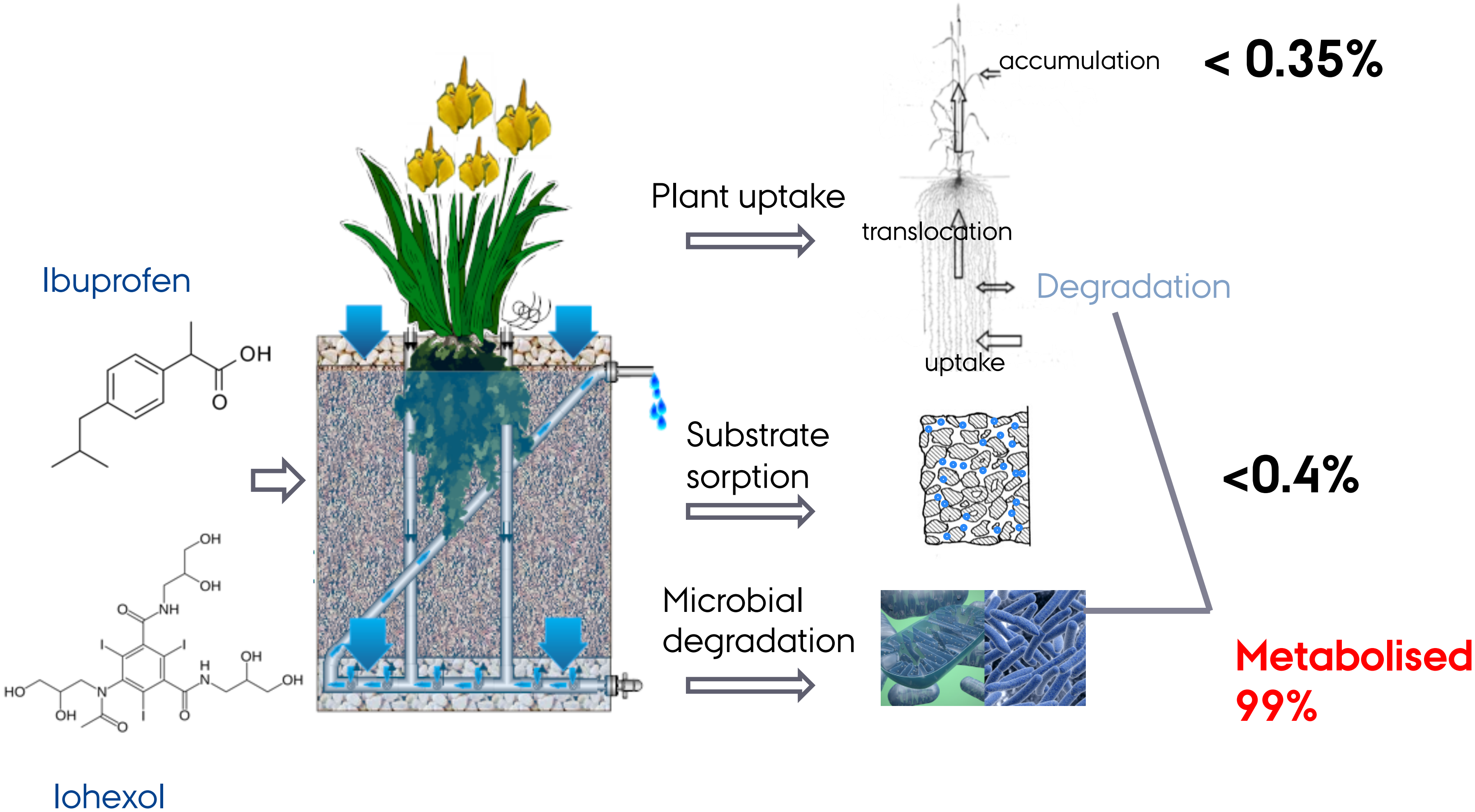


Table 1. Results (*F*-ratios) of the analysis of variance (ANOVA) on the effects of mesocosm type (*T*; planted with *Typha latifolia*, *Phragmites australis*, *Iris pseudacorus*, *Juncus effusus*, *Berula erecta* or unplanted control), season (*S*; summer and winter), HLR (*H*; 0.7, 1.7, 3.4, 6.9 and 13.8 cm d^{-1}), initial spiking concentration (*C*; 10 and 100 µg L^{-1}) and their interactions on ibuprofen (IBU) and iohexol (IOH) removal efficiency.

Removal efficiency	Main factors				Interactions										
	T	*S*	*H*	*C*	*S*T*	*S*H*	*S*C*	*T*H*	*T*C*	*H*C*	*S*T*H*	*S*T*C*	*S*H*C*	*T*H*C*	*S*T*H*C*
IBU	**346**	**149**	**201**	**303**	**19**	**5**	**21**	**11**	**20**	**30**	**5**	**5**	**22**	**3**	**2**
IOH	**41**	2	**78**	**438**	**29**	2	**14**	**3**	**21**	**48**	**2**	**16**	0.5	**3**	**3**

Figures in bold indicate significant difference (p < 0.05).

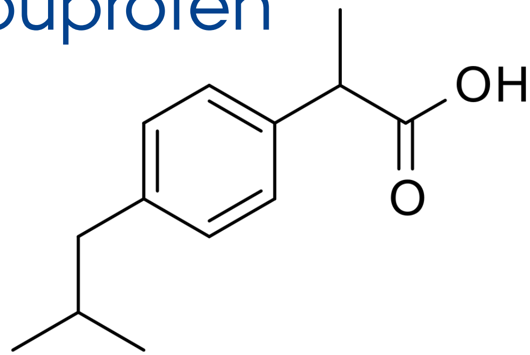
Zhang et al. Ecol. Eng. 2017, 98:394



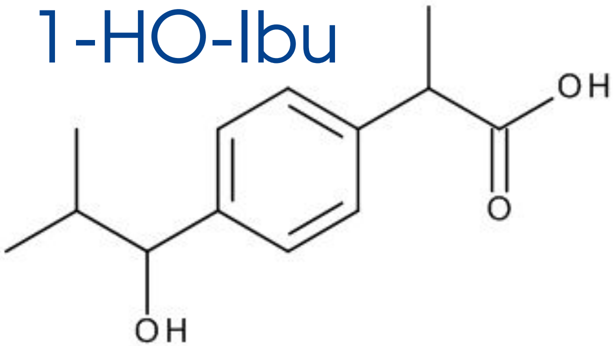
Zhang et al. Ecol. Eng. 2017, 98:394

Ibuprofen metabolites

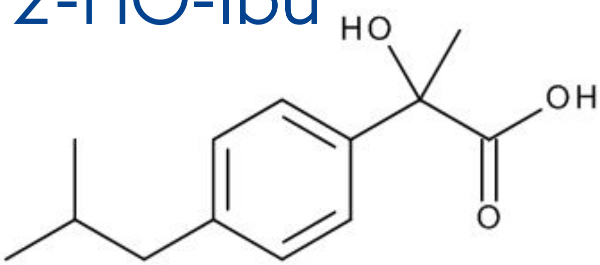
Ibuprofen



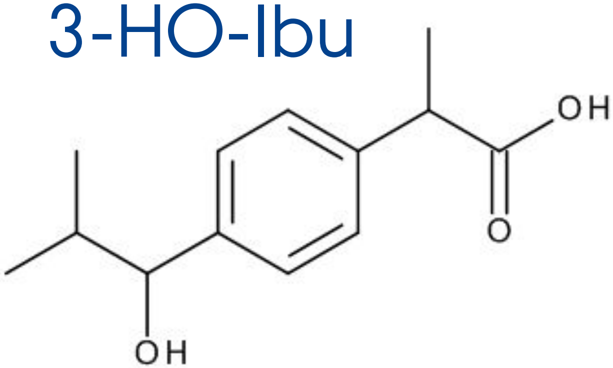
1-HO-Ibu



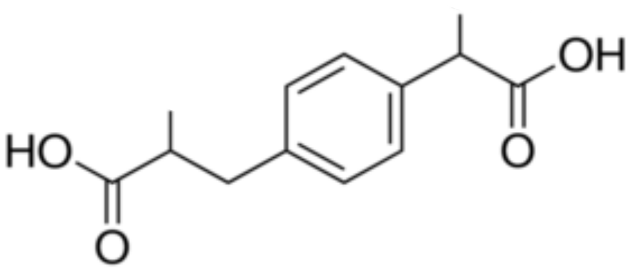
2-HO-Ibu



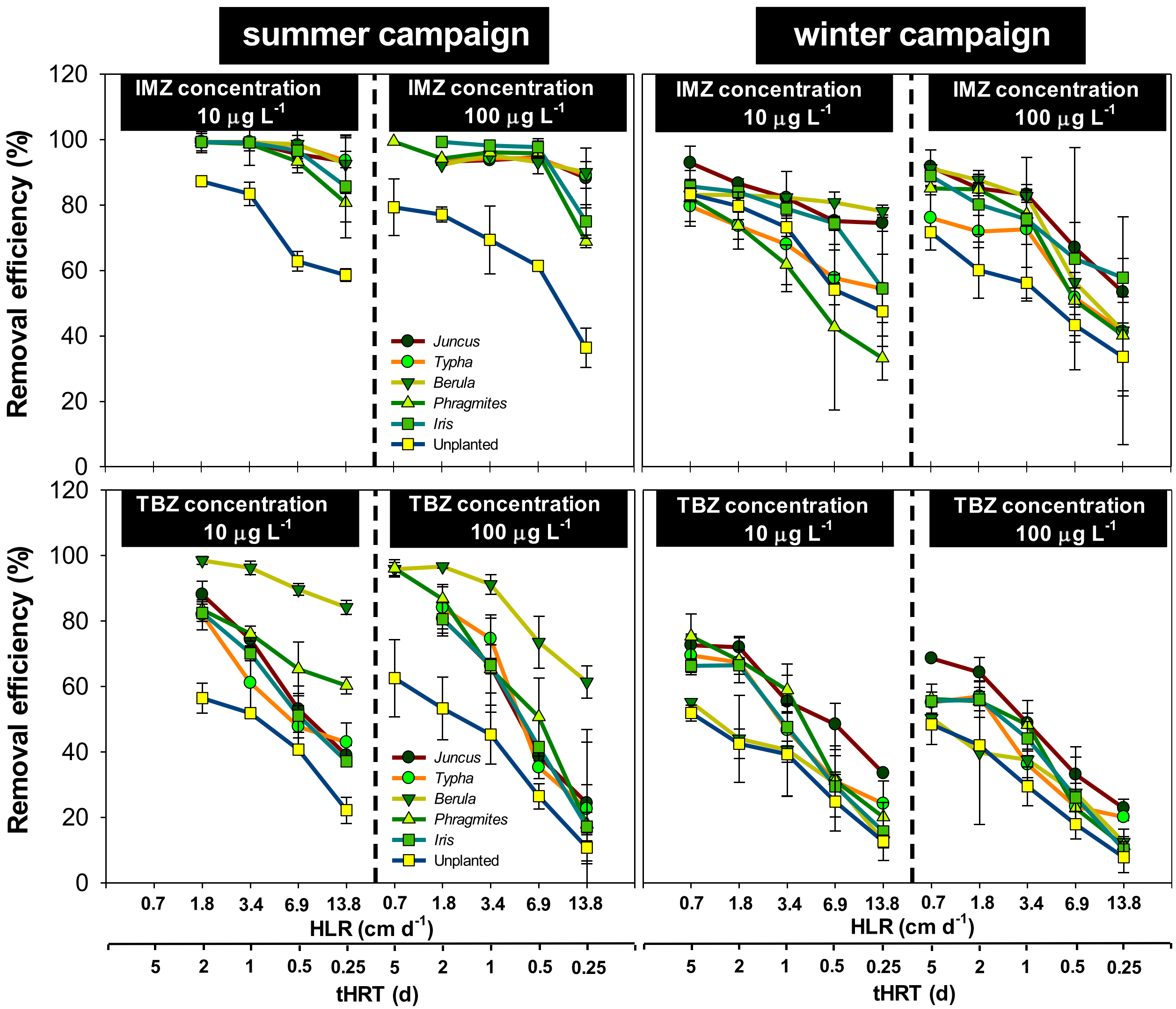
3-HO-Ibu



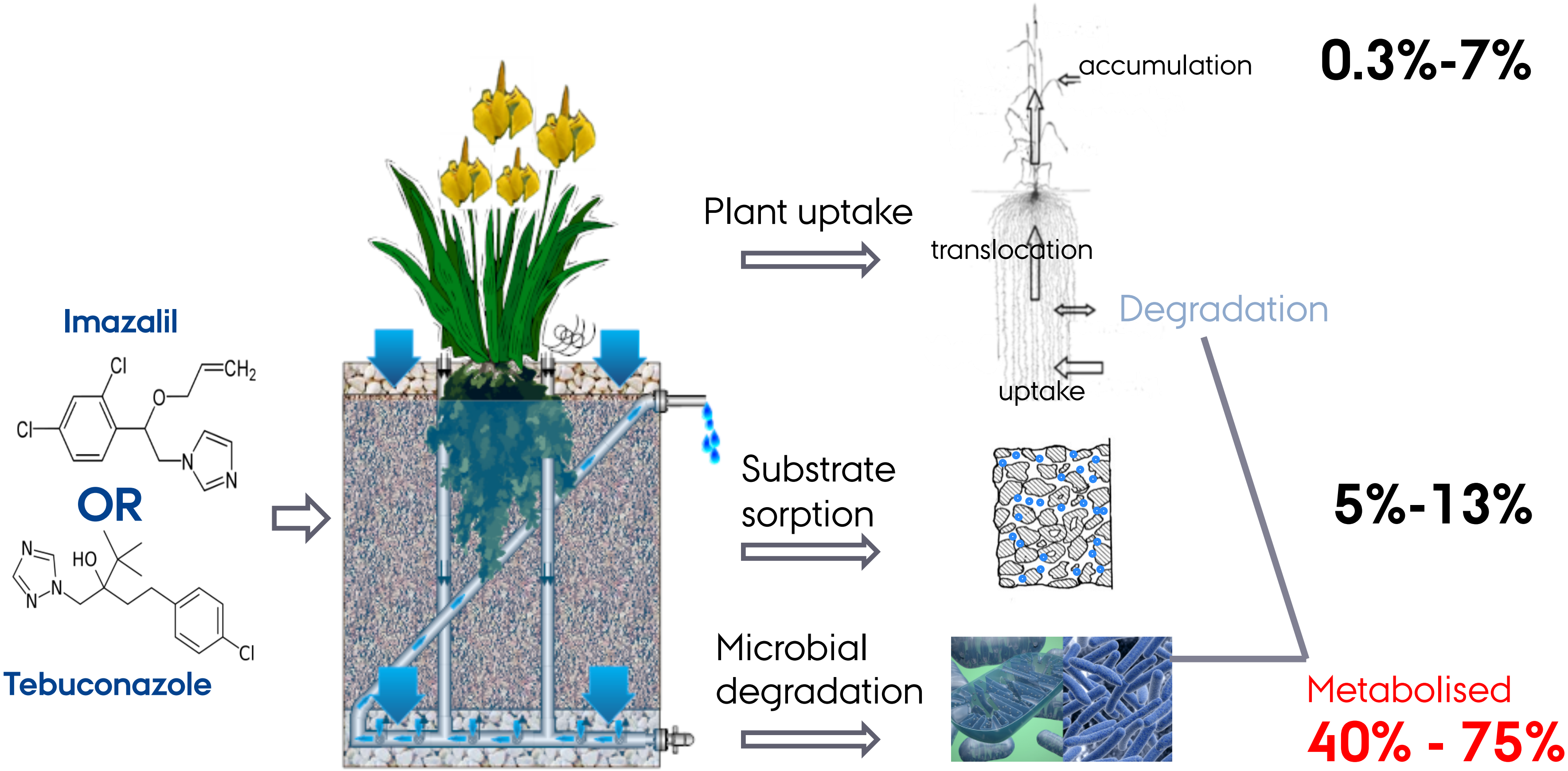
CA-Ibu



PESTICIDES



Lv et al. Water Res., 2016, 91:126



Lv et al. Water Res., 2016, 91:126

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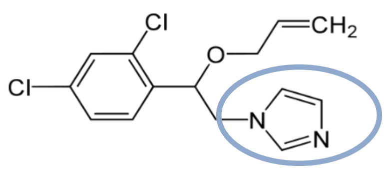
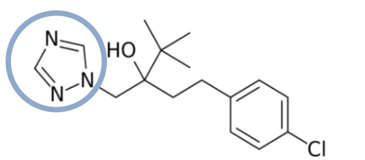
Pesticides removal

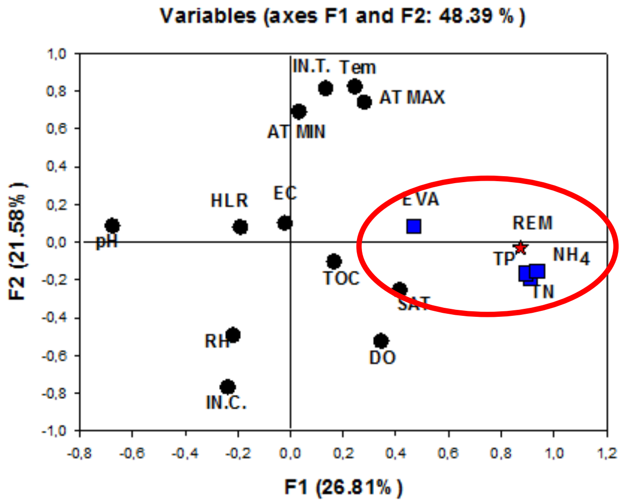
shows positive correlation with

Evapotranspiration,
TP removal
TN, NH_4^+-N removal,
DO, oxygen SAT

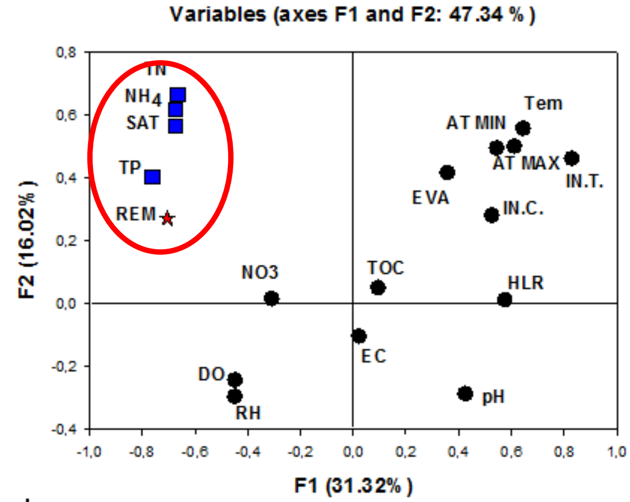
- Plant effect
- Nitrifying bacteria





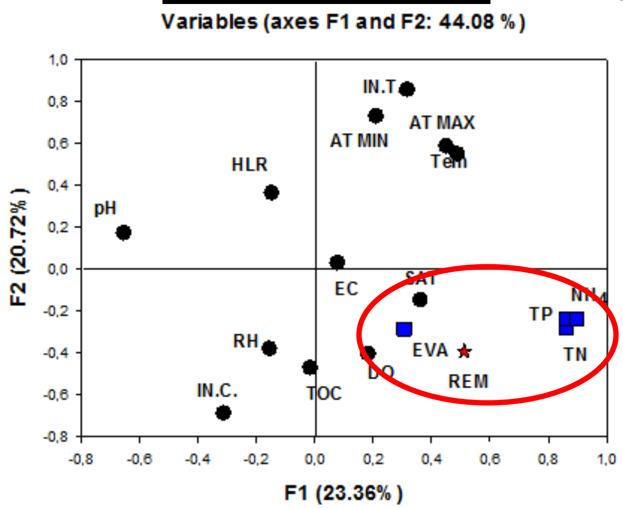


IMZ in summer

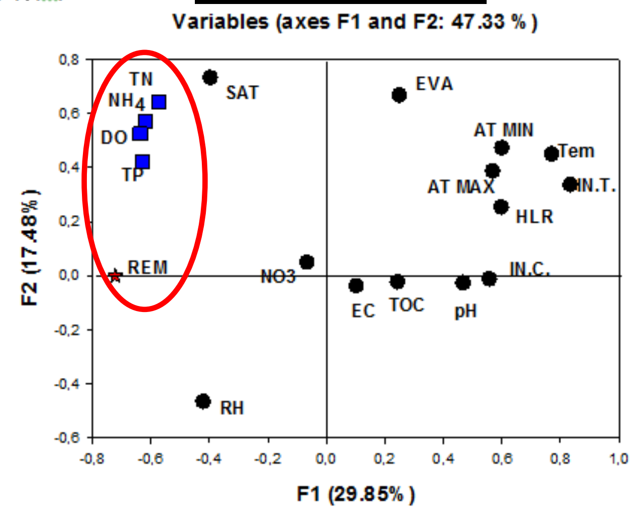


IMZ in winter

(a)|(b)
(c)|(d)



TBZ in summer



TBZ in winter

Lv et al. Water Res., 2016, 91:126

Microbial community analysis by
Community-level physiological profiling – Biolog EcoPlates

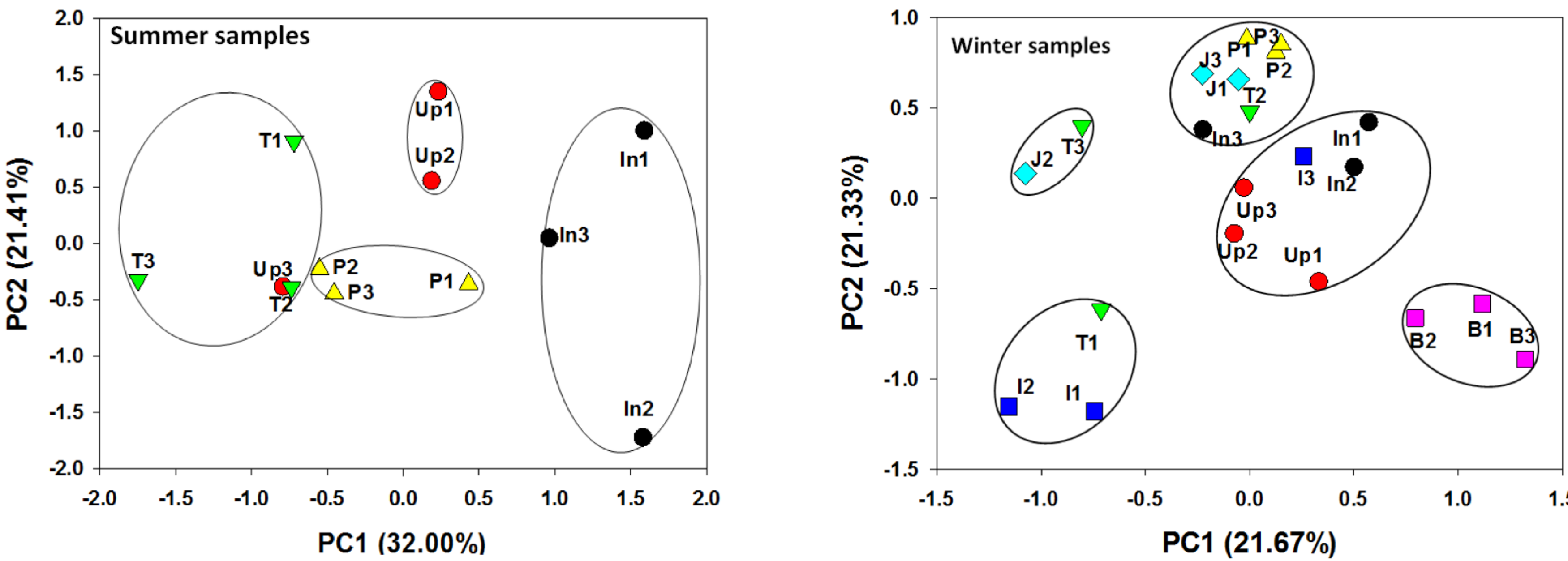
BIOLOG Microbial Community Analysis

EcoPlate™

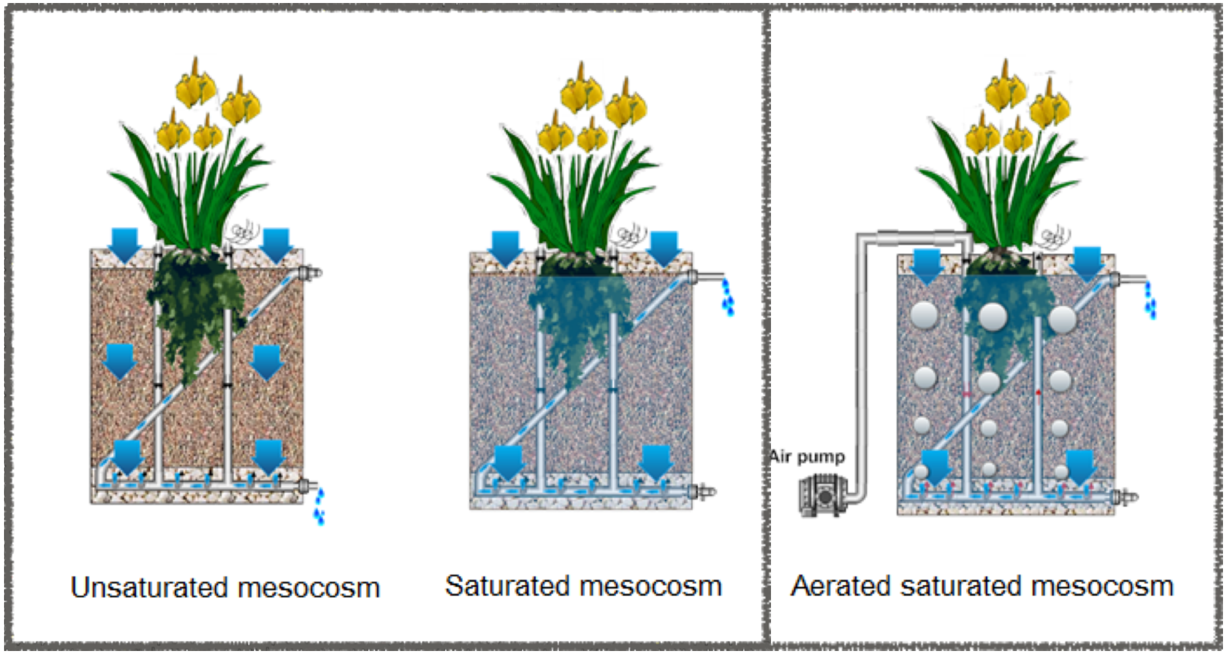
A1 Water	A2 β-Methyl-D-Glucoside	A3 D-Galactonic Acid γ-Lactone	A4 L-Arginine	A1 Water	A2 β-Methyl-D-Glucoside	A3 D-Galactonic Acid γ-Lactone	A4 L-Arginine	A1 Water	A2 β-Methyl-D-Glucoside	A3 D-Galactonic Acid γ-Lactone	A4 L-Arginine
B1 Pyruvic Acid Methyl Ester	B2 D-Xylose	B3 D-Galacturonic Acid	B4 L-Asparagine	B1 Pyruvic Acid Methyl Ester	B2 D-Xylose	B3 D-Galacturonic Acid	B4 L-Asparagine	B1 Pyruvic Acid Methyl Ester	B2 D-Xylose	B3 D-Galacturonic Acid	B4 L-Asparagine
C1 Tween 40	C2 i-Erythritol	C3 2-Hydroxy Benzoic Acid	C4 L-Phenylalanine	C1 Tween 40	C2 i-Erythritol	C3 2-Hydroxy Benzoic Acid	C4 L-Phenylalanine	C1 Tween 40	C2 i-Erythritol	C3 2-Hydroxy Benzoic Acid	C4 L-Phenylalanine
D1 Tween 80	D2 D-Mannitol	D3 4-Hydroxy Benzoic Acid	D4 L-Serine	D1 Tween 80	D2 D-Mannitol	D3 4-Hydroxy Benzoic Acid	D4 L-Serine	D1 Tween 80	D2 D-Mannitol	D3 4-Hydroxy Benzoic Acid	D4 L-Serine
E1 α-Cyclodextrin	E2 N-Acetyl-D-Glucosamine	E3 γ-Hydroxybutyric Acid	E4 L-Threonine	E1 α-Cyclodextrin	E2 N-Acetyl-D-Glucosamine	E3 γ-Hydroxybutyric Acid	E4 L-Threonine	E1 α-Cyclodextrin	E2 N-Acetyl-D-Glucosamine	E3 γ-Hydroxybutyric Acid	E4 L-Threonine
F1 Glycogen	F2 D-Glucosaminic Acid	F3 Itaconic Acid	F4 Glycyl-L-Glutamic Acid	F1 Glycogen	F2 D-Glucosaminic Acid	F3 Itaconic Acid	F4 Glycyl-L-Glutamic Acid	F1 Glycogen	F2 D-Glucosaminic Acid	F3 Itaconic Acid	F4 Glycyl-L-Glutamic Acid
G1 D-Cellobiose	G2 Glucose-1-Phosphate	G3 α-Ketobutyric Acid	G4 Phenylethyl-amine	G1 D-Cellobiose	G2 Glucose-1-Phosphate	G3 α-Ketobutyric Acid	G4 Phenylethyl-amine	G1 D-Cellobiose	G2 Glucose-1-Phosphate	G3 α-Ketobutyric Acid	G4 Phenylethyl-amine
H1 α-D-Lactose	H2 D,L-α-Glycerol Phosphate	H3 D-Malic Acid	H4 Putrescine	H1 α-D-Lactose	H2 D,L-α-Glycerol Phosphate	H3 D-Malic Acid	H4 Putrescine	H1 α-D-Lactose	H2 D,L-α-Glycerol Phosphate	H3 D-Malic Acid	H4 Putrescine

FIGURE 1. Carbon Sources in EcoPlate

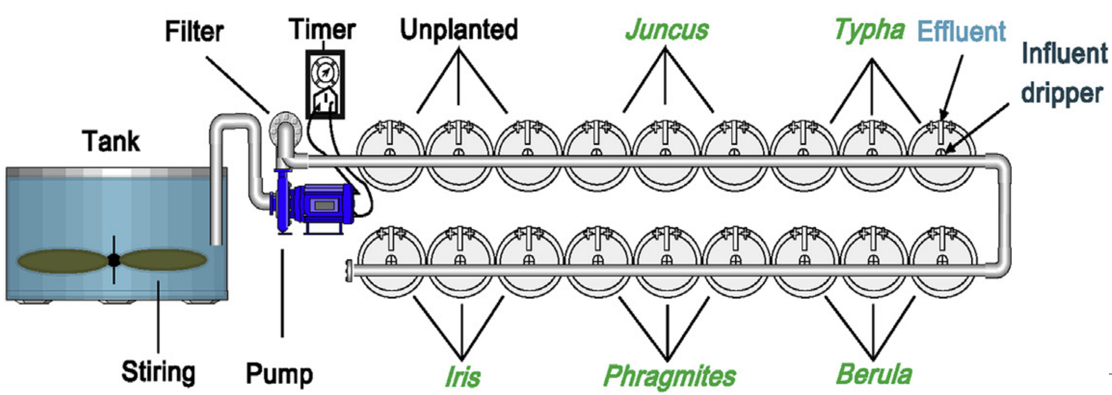
Weber & Legge Methods Mol Biol., 2010, 599:263

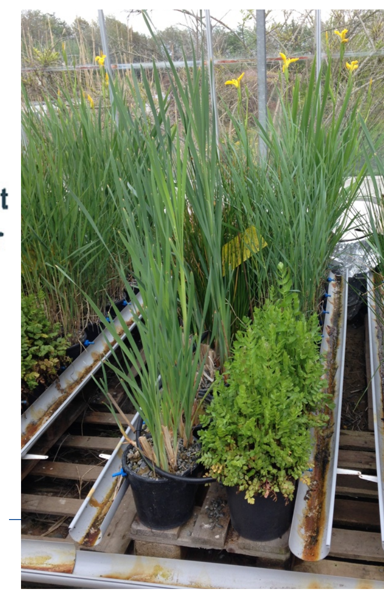


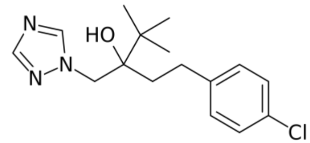
Lv et al. Ecol. Eng. 2017, 98:378



Tebuconazole
Ibuprofen







TEBUCONAZOLE

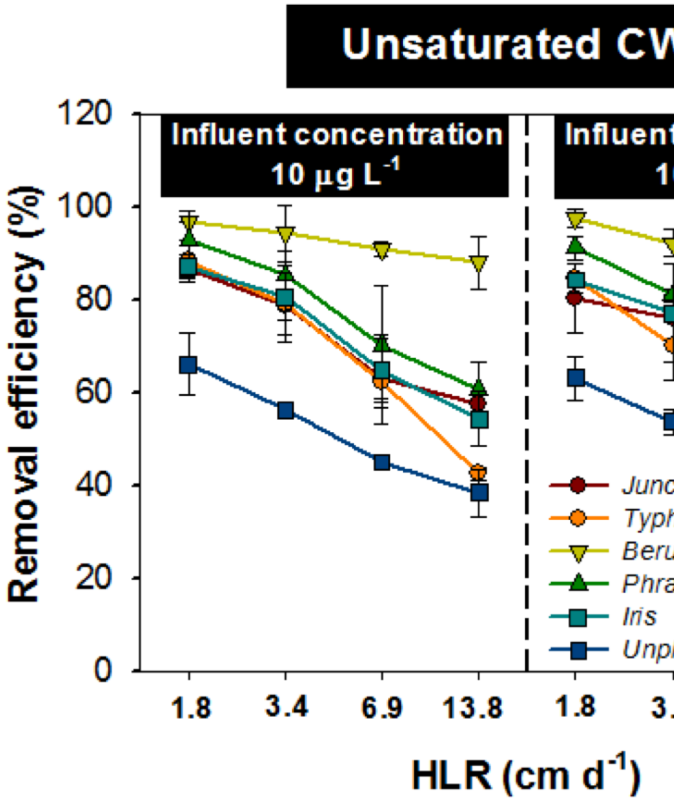


Table 2

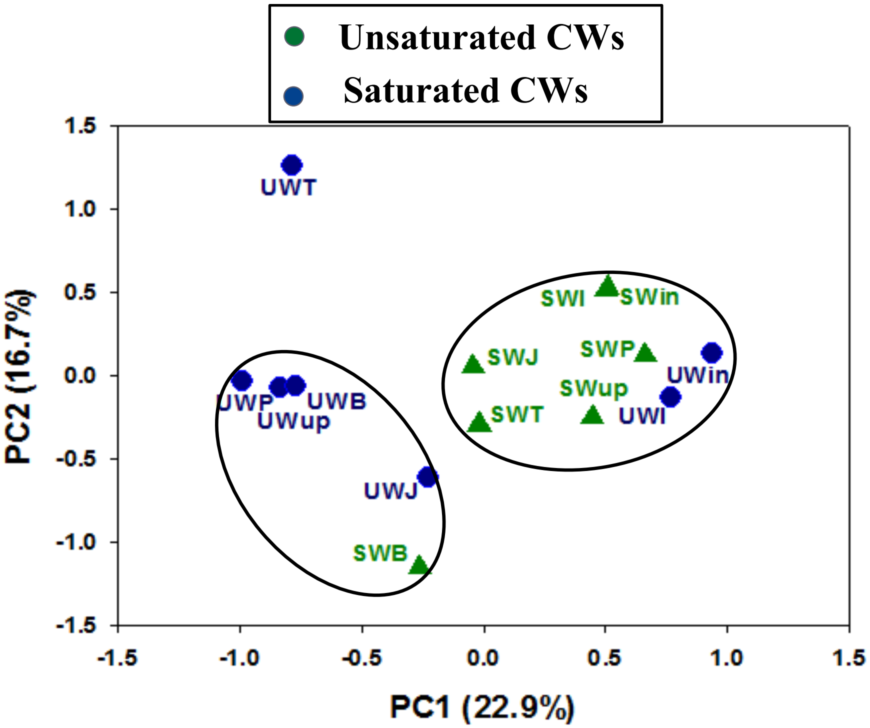
Observed first-order (aera-based and volume-based) removal rate constants (k and k_v), R^2 and half-lives of tebuconazole in all constructed wetland mesocosms. k values are presented as the means (standard deviation).

System design	Plants	Area-based k (cm d^{-1})	Area-based R^2	Volume-based k_v (d^{-1})	Volume-based R^2	Half-life (d)
Unsaturated CWs	Unplanted control	2.6^{c*} (0.8)	0.8	-	-	-
	Juncus	5.3^{b*} (2.0)	0.9	-	-	-
	Typha	4.7^{b} (1.5)	0.9	-	-	-
	Berula	10.9^{a*} (2.6)	0.7	-	-	-
	Phragmites	5.9^{b} (2.1)	0.9	-	-	-
	Iris	5.5^{b*} (2.2)	0.8	-	-	-
Saturated CWs	Unplanted control	1.7^{d} (0.5)	0.8	0.8^{b} (0.3)	0.8	0.9
	Juncus	3.8^{c} (1.1)	0.9	1.4^{b} (0.7)	0.8	0.5
	Typha	4.1^{bc} (1.1)	0.8	1.3^{b} (0.5)	0.8	0.5
	Berula	7.9^{a} (1.2)	0.8	3.3^{a} (0.8)	0.9	0.2
	Phragmites	5.2^{b} (1.2)	0.9	1.6^{b} (0.6)	0.9	0.4
	Iris	3.1^{c} (1.0)	0.7	1.5^{b} (0.7)	0.9	0.5

Manuscript submitted

Community-level physiological profiling – Biolog EcoPlates

Interstitial water

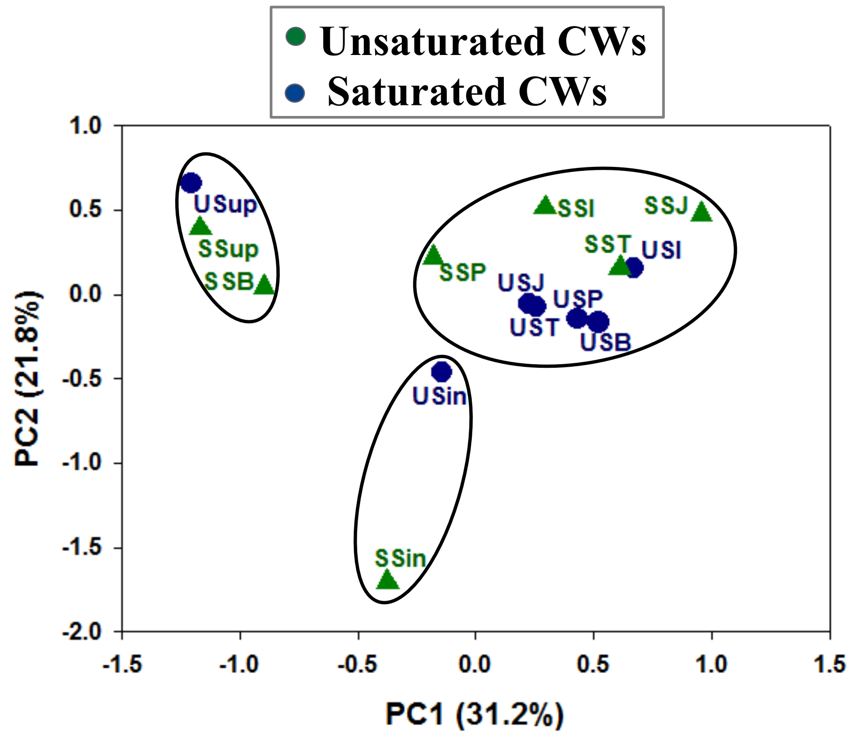


Carbon source utilization patterns

CW design effect

Plant types

Biofilm



Carbon source utilization patterns

CW design effect

Plant presence

Plant types

Lv et al. Water Res., 2017, 110:241

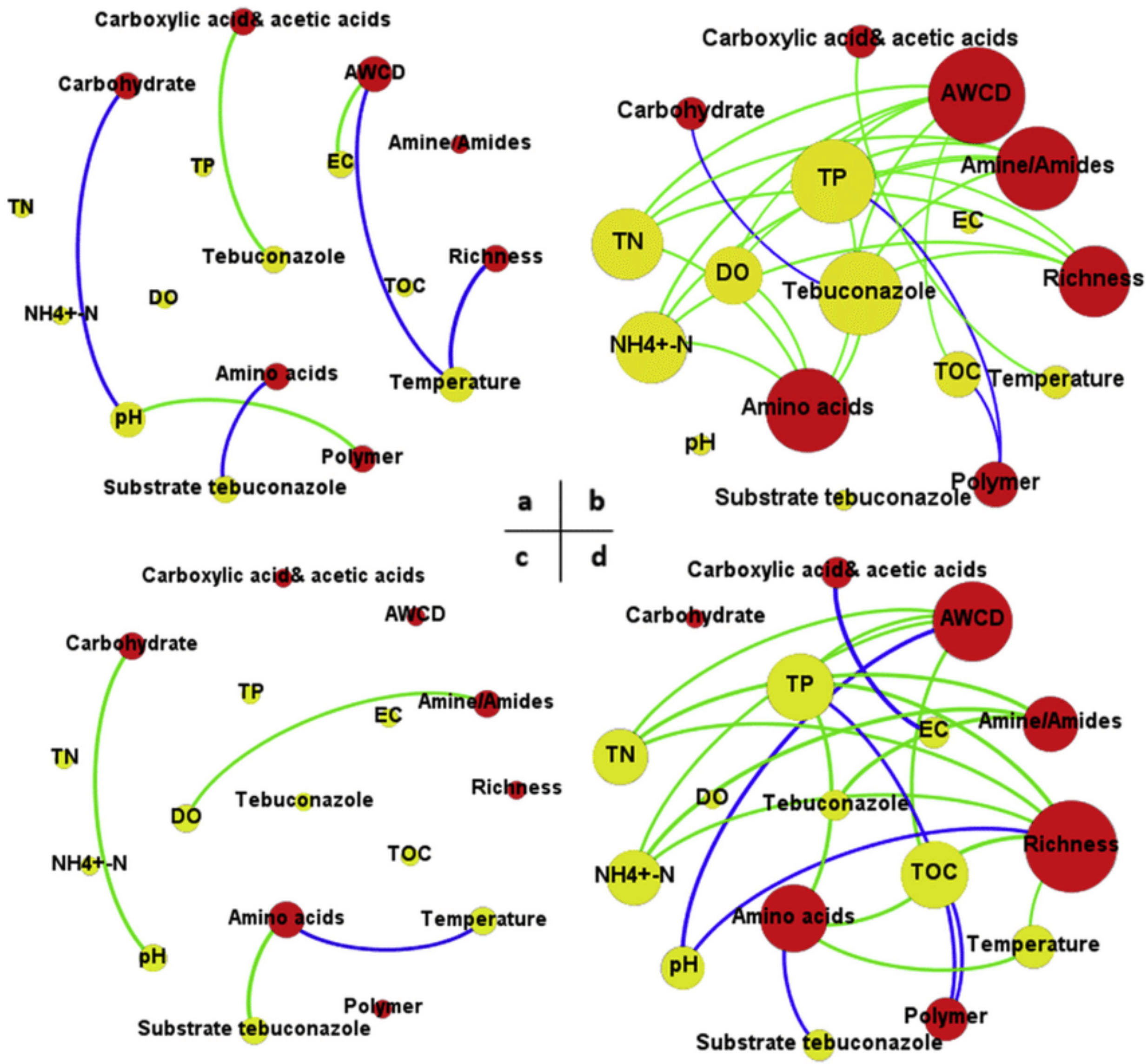
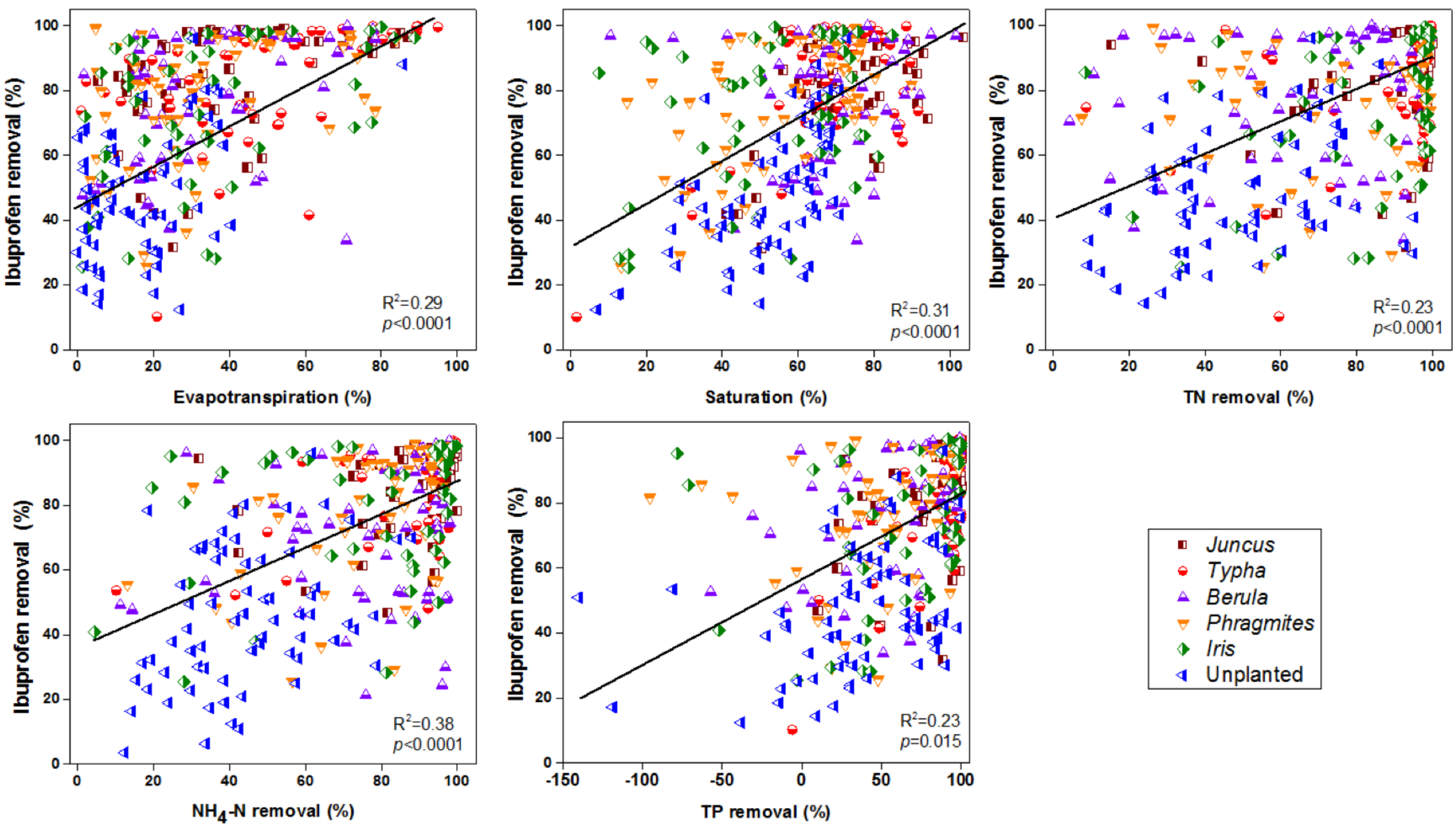


Fig. 8. Network analysis showing the correlation of water quality and substrate parameters and microbial community metrics for unsaturated ((a) interstitial water and (b) biofilm samples) and saturated ((c) interstitial water and (d) biofilm samples) constructed wetland mesocosms.

Lv et al. Water Res., 2017, 110:241



Zhang et al. Sci Total Environ, 2017, 609:38

SUBSTRATE SORPTION TESTS

- Zeolite
- Polonite
- Petcoke
- Sand
- crushed autoclaved aerated concrete (CAAC)
- Iron slags

Manuscript under revision

Plant uptake?

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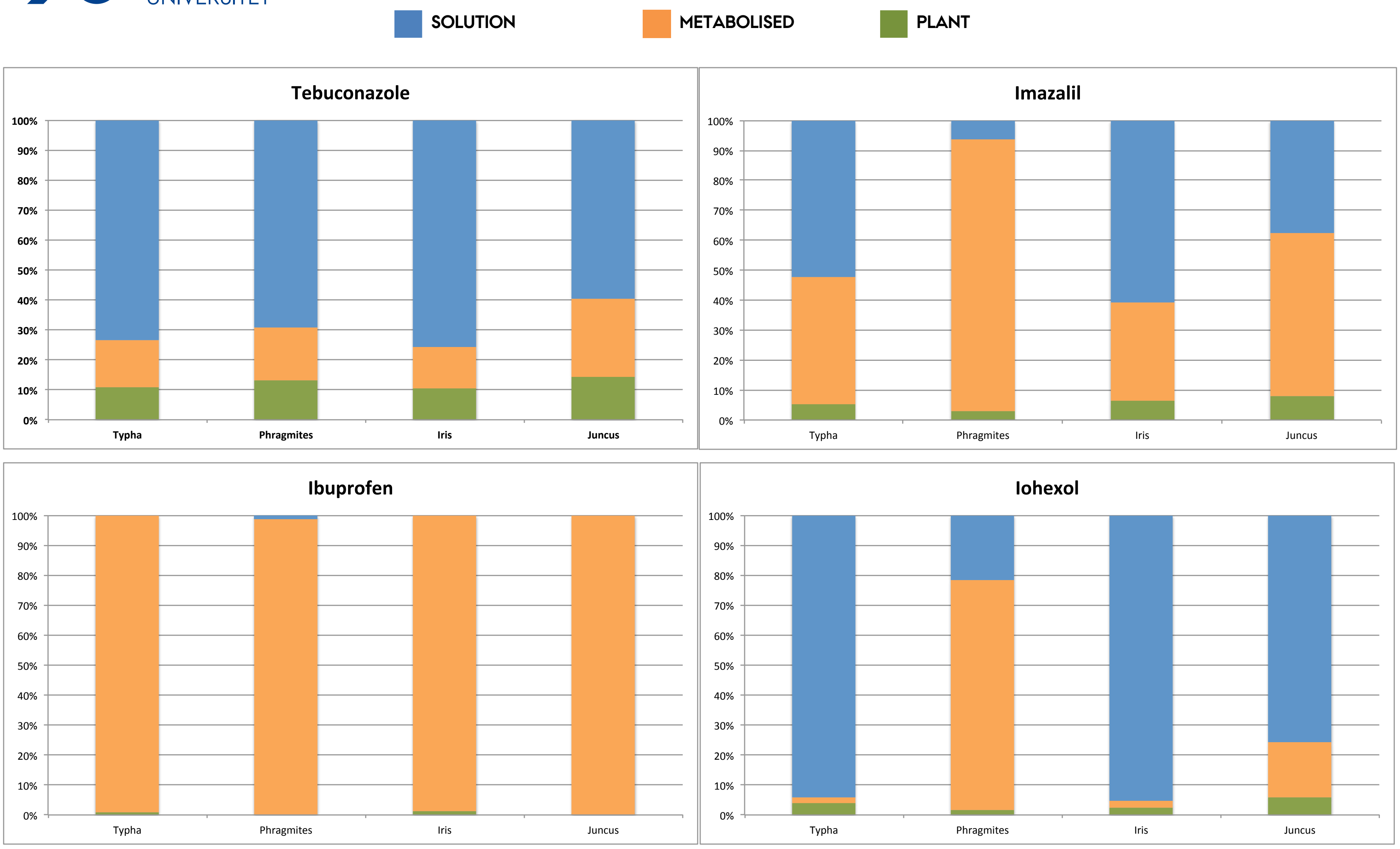
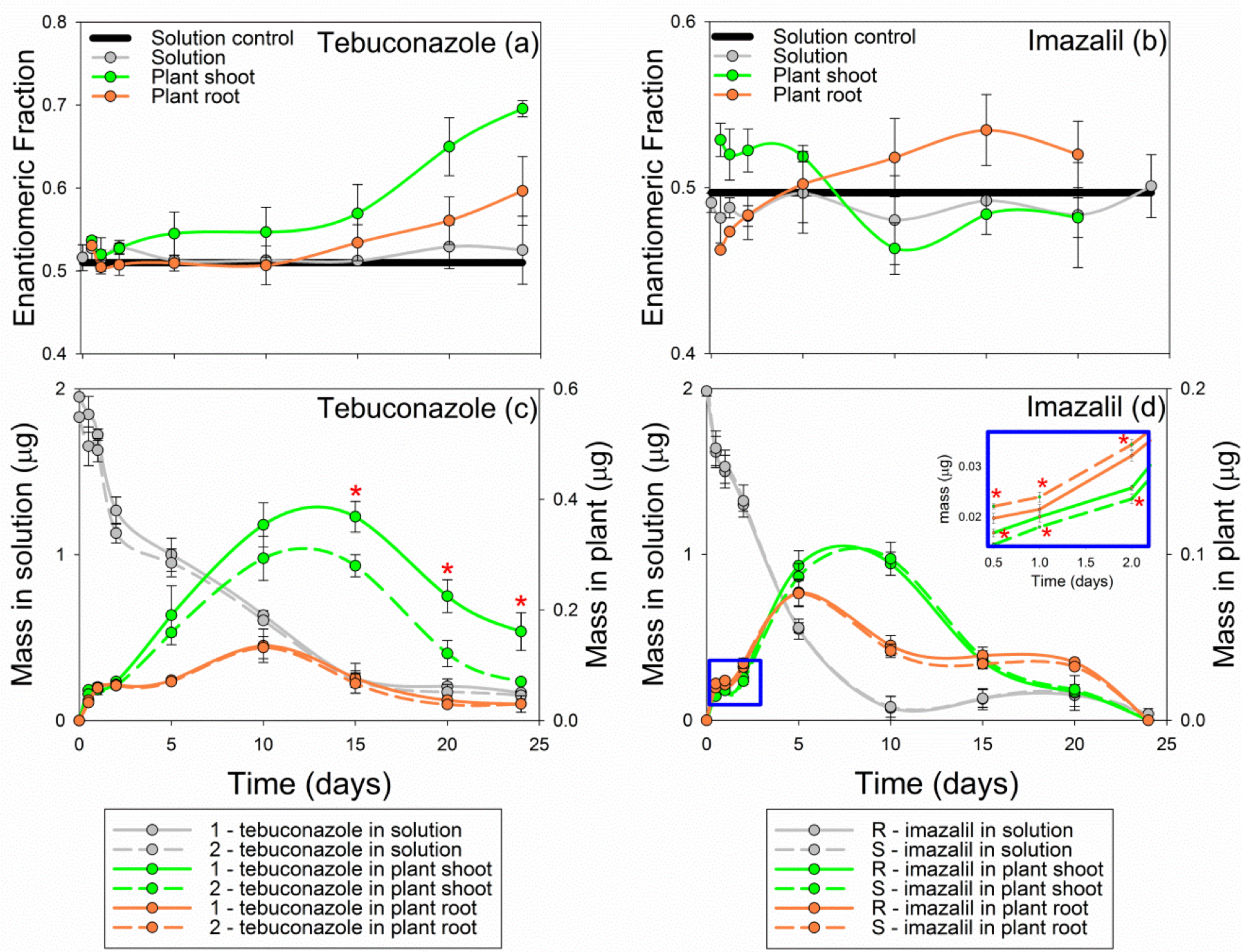
Mass balance (24 d)



Zhang et al. Environ. Sci. Pollut. Res. 2016, 23:2890
Lv et al. Chemosphere. 2016, 148:459



Lv et al. Environ. Pollut. 2017, 229:362

CONCLUSIONS – SUBSURFACE FLOW SYSTEMS

› Eco-technologies are also an effective solution to remove organic micropollutants from water

› Sorption to substrate is a less relevant mechanism

› Wetland plants can uptake and metabolise organic micropollutants

› Removal is due to biodegradation: unclear yet the extent of plant and microbial degradation

› Which microbial degradation pathways are more relevant? Can we enhance CECs removal by co-metabolisation?

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Monica Escola
Ulla Bollmann

Royal Military College of Canada
Kela Weber
Mark Button

THANK YOU!

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