MICROBIAL PRODUCTIVITY IN VARIABLE RESOURCE ENVIRONMENTS

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Online appendices

Appendix A. Summary of measurements taken from the mesocosms in the field experiment for each treatment. Dissolved organic carbon (DOC), bacterial productivity (BP), bacterial growth efficiency (BGE), and dissolved oxygen (O_2) were measured daily and are expressed as averages across time and replicates within a treatment. Temperature (Temp) and pH were measured on three occasions and are expressed as averages across time and replicates within a treatment. Measurements of chlorophyll a (Chl *a*), total nitrogen (TN), and total phosphorus (TP), and crustacean zooplankton abundance (Zoop) were obtained on the last day of the experiment. All data represent the mean ± SEM.

Response variable	Control	Low Quality DOC		High Quality DOC	
		Press	Pulse	Press	Pulse
DOC (mg/L)	2.4 ± 0.02	3.9 ± 0.32	5.2 ± 0.379	4.1 ± 0.33	5.3 ± 0.39
BP ($\mu g\ L^{-1}\ d^{-1}$)	0.77 ± 0.184	1.44 ± 0.282	4.02 ± 2.135	1.70 ± 0.438	2.59 ±1.127
BR ($\mu g\ L^{-1}\ d^{-1}$)	2.15 ± 0.831	4.43 ± 0.704	5.49 ± 0.734	3.69 ± 0.601	4.43 ± 0.510
BGE	0.30 ± 0.055	0.26 ± 0.040	0.29 ± 0.053	0.30 ± 0.055	0.28 ± 0.048
O_2 (mg/L)	6.98 ± 0.031	7.12 ± 0.058	6.88 ± 0.076	6.75 ± 0.094	6.83 ± 0.039

Response variable	Control	Low Quality DOC		High Quality DOC	
		Press	Pulse	Press	Pulse
Chl *a* (μg/L)	7.69 ± 0.078	19.5 ± 1.68	18.9 ± 2.36	33.7 ± 1.57	28.7 ± 2.86
TN (μg/L)	746 ± 73.7	827 ± 39.2	968 ± 82.8	782 ± 35.1	793 ± 53.9
TP (μg/L)	6.3 ± 1.32	28.1 ±1.29	32.4 ± 3.09	38.0 ± 2.45	39.5 ± 3.59
Zoop (#/L)	23.1 ± 3.04	20.6 ± 2.54	29.4 ± 4.27	21.2 ± 3.87	32.6 ± 4.28
Temp (°C)	20.7 ± 0.35	20.7 ± 0.32	20.7 ± 0.32	20.7 ± 0.32	20.7 ± 0.32
pH	7.2 ± 0.07	7.0 ± 0.08	7.0 ± 0.04	6.9 ± 0.08	7.2 ± 0.11

Appendix A continued: Summary tables for the repeated measures analysis of variance (RM-ANOVA) for each response variable in the field experiment.

Response: DOC **covariance structure: compound symmetry**

Effect	Num DF	Den DF	F value	*P*
time	11	131	1919.17	<0.0001
quality	1	13	6.27	0.0263
schedule	1	13	666.23	<0.0001
time * quality	11	131	1.95	0.0386
time * schedule	11	131	595.9	<0.0001
time * quality * schedule	12	131	2.06	0.0239

Response: BP **covariance structure: unstructured**

Effect	Num DF	Den DF	F value	*P*
time	11	13	2519.41	<0.0001
quality	1	13	2	0.1812
schedule	1	13	20.56	0.0006
time * quality	11	13	368.42	<0.0001
time * schedule	11	13	999.9	<0.0001
time * quality * schedule	12	13	6686.35	<0.0001

Response: BR	**covariance structure: compound symmetry**			
Effect	Num DF	Den DF	F value	*P*
time	11	131	5.57	<0.0001
quality	1	13	3.65	0.0782
schedule	1	13	1.99	0.182
quality * time	11	131	0.91	0.53
schedule * time	11	131	2.28	0.014
quality * schedule * time	12	131	1.55	0.1159

Response: BGE	**covariance structure: unstructured**			
Effect	Num DF	Den DF	F value	*P*
time	11	117	6.13	<0.0001
quality	1	13	0.04	0.8367
schedule	1	13	0.02	0.883
quality * time	11	117	0.49	0.9065
schedule * time	11	117	0.32	0.9803
quality * schedule * time	12	117	0.78	0.666

Appendix A (continued): Summary tables for the two-way analysis of variance (ANOVA) for cumulative bacterial productivity (BP) and cumulative bacterial respiration (BR) in the field experiment.

Cumulative BP, two-way ANOVA

Effect	Num DF	Den DF	SS	F value	*P*
Quality	1	1	178.6	2.93	0.1127
Schedule	1	1	1436.2	23.56	0.0004
Quality x Schedule	1	1	331.7	5.44	0.0379

Cumulative BR, two-way ANOVA

Effect	Num DF	Den DF	SS	F value	*P*
Quality	1	1	282.9	2.78	0.1212
Schedule	1	1	440.1	4.33	0.0596
Quality x Schedule	1	1	7.7	0.08	0.7882

Appendix B. Derivation of the bacterial growth efficiency (BGE) function and parameters.

Two comparative studies (del Giorgio and Cole 1998; Kritzberg et al 2005) have reported that BGE increases as a hyperbolic function of bacterial productivity (BP, µg L^{-1} h^{-1}):

$BGE = 0.015 + (0.037 * BP)/(BP + 1.8)$	del Giorgio and Cole (1998)
$BGE = 0.015 + (0.41 * BP)/(BP + 0.48)$	Kritzberg et al. (2005)

$BGE = BP/(BP+BR)$, where BR is bacterial respiration.

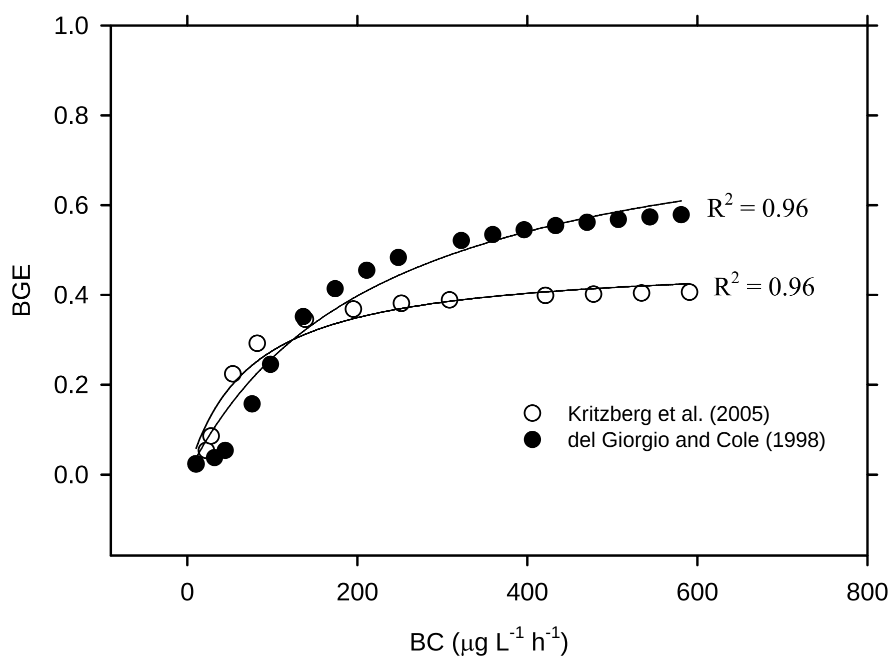
We rearranged this equation and used it to solve for BR:

$BR = (BP/BGE) - BP$

With this information, we calculated bacterial consumption (BC = BP + BR) for each of the two data sets. This method for estimating BC has been used to represent the rate of DOC uptake by heterotrophic bacteria (del Giorgio and Davis 2003).

Next, we multiplied the estimated BC by 24 to get daily estimates (µg L^{-1} d^{-1}). We then re-plotted the predicted BGE as a function of BC. Finally, we fit the BGE-BC data to a Michaelis-Menten model: $BGE = [BC*M_{BGE}]/[BC+K_{BGE}]$, where M_{BGE} is the maximum BGE and K_{BGE} is the BC that corresponds with ½ the M_{BGE}.

The figure below shows the relationships between BGE and BC derived from del Giorgio and Cole (1998) and Kritzberg et al (2005). The lines represent predicted values generated from the Michaelis-Menten curve fitting (Sigma Plot, version 8.0).

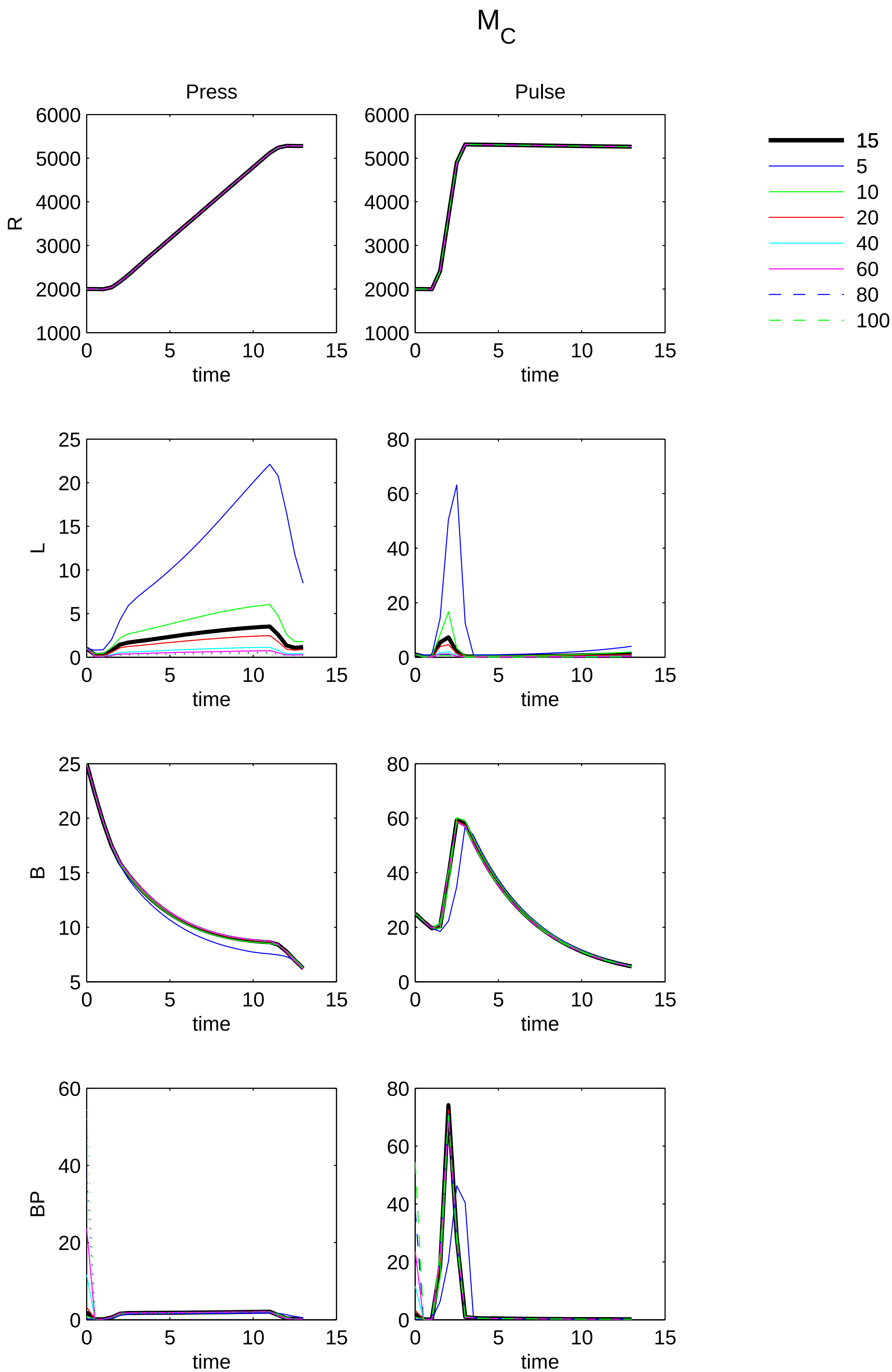


The table below represents the parameter values (mean ± SEM) and their associated *P*-values for the BGE and BC relationships derived from del Giorgio and Cole (1998) and Kritzberg et al (2005).

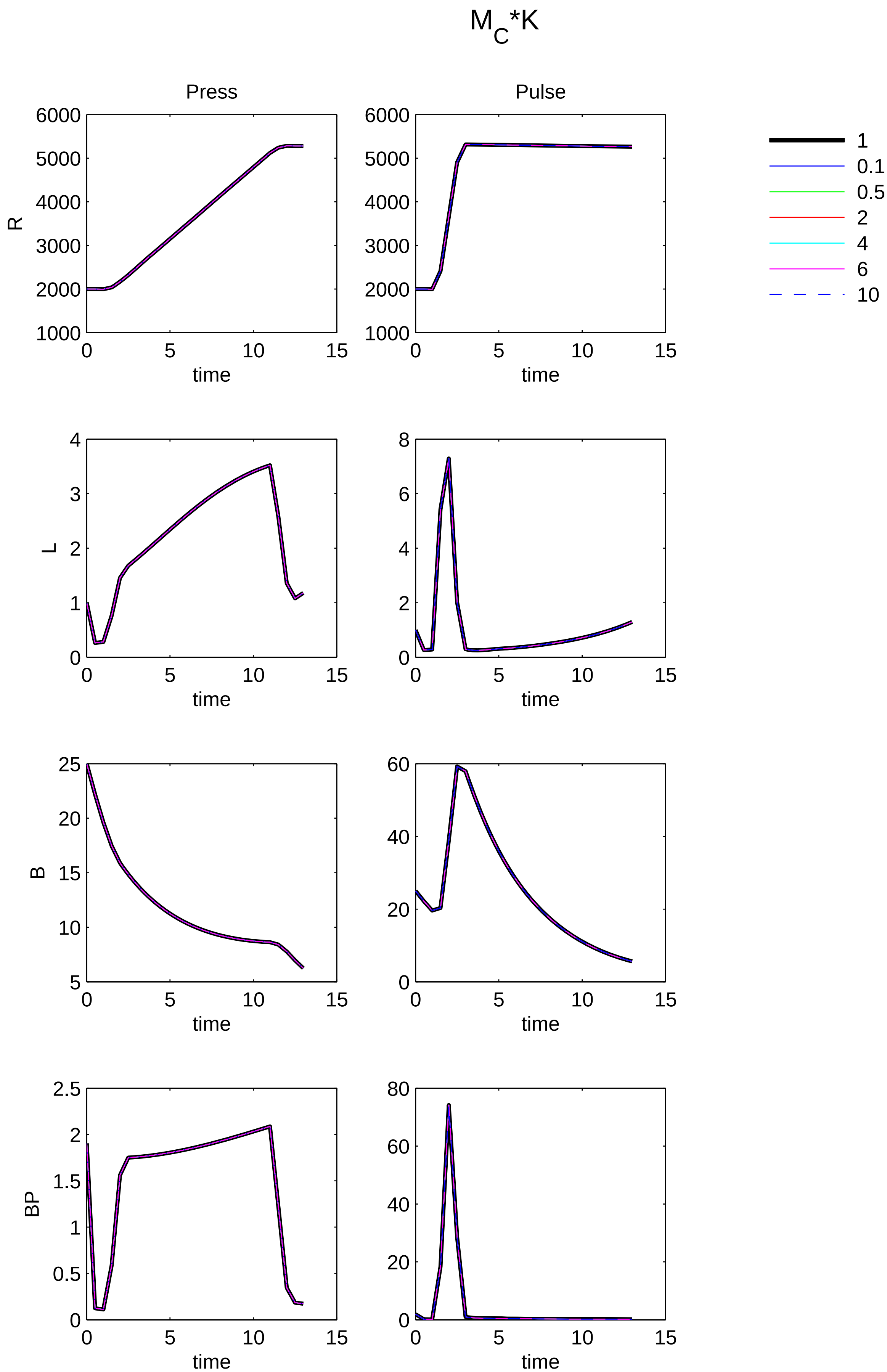
Parameter	del Giorgio and Cole (1998)	Kritzberg et al. (2005)
M_{BGE}	0.83 ± 0.058	0.46 ± 0.014
	P <0.0001	P <0.0001
K_{BGE}	216 ± 39.0	66.5 ± 10.09
	P <0.0001	P <0.0001

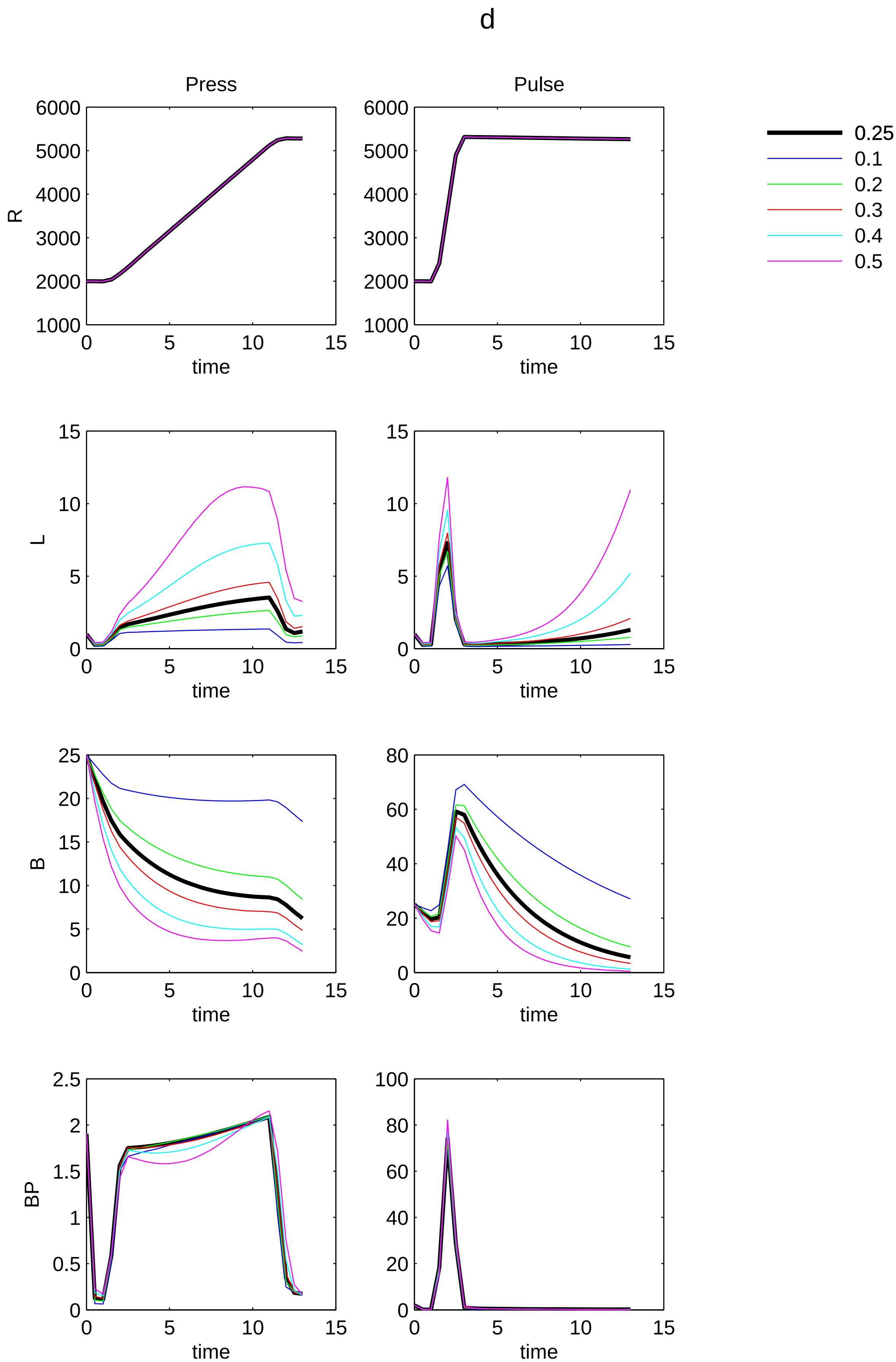
Appendix C. Detailed figures for single parameter sensitivity analysis.

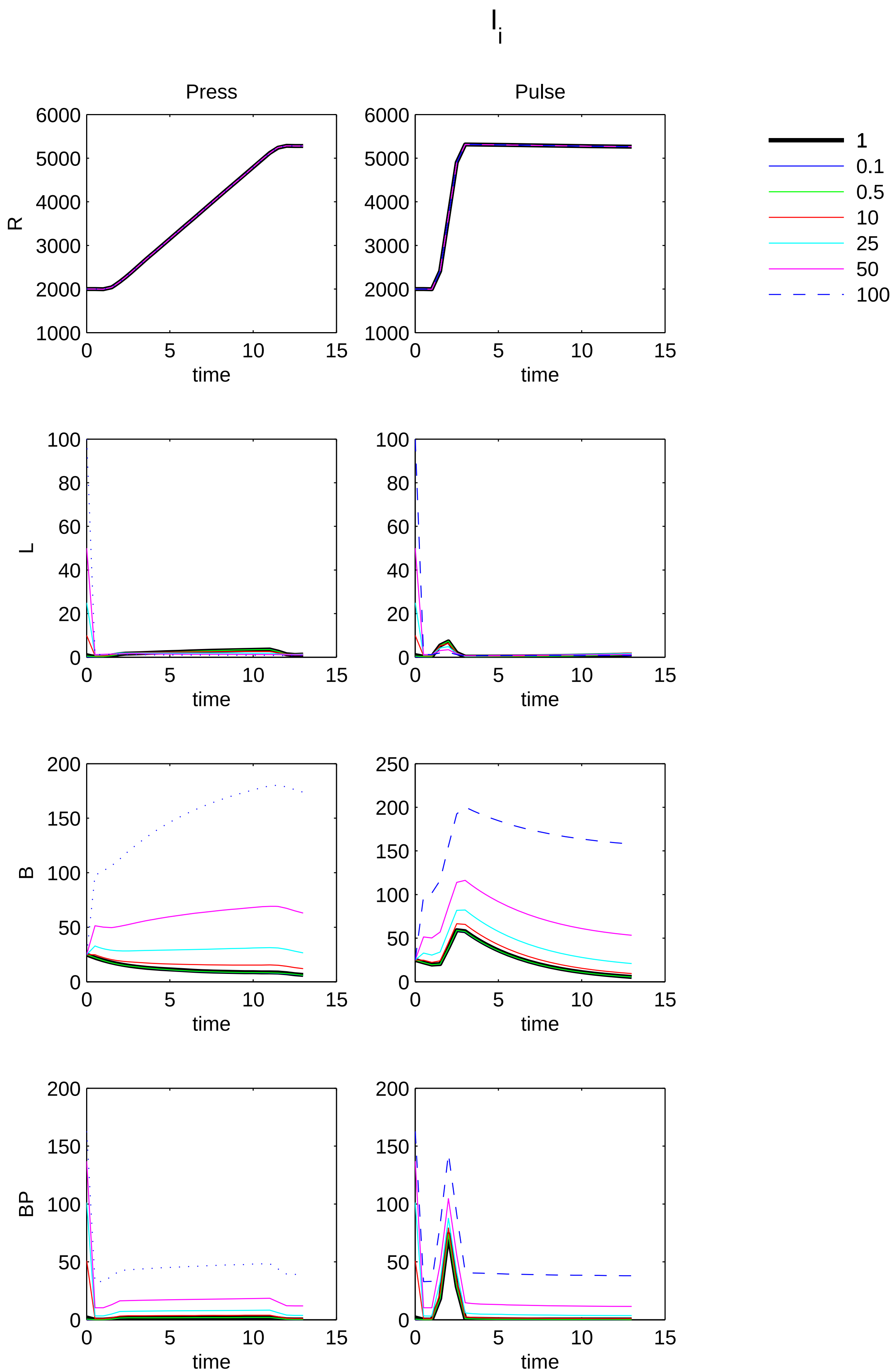
The following figures show the temporal dynamics of each model compartment (R = Refractory C ; L = Labile C; B = Bacteria, each as μg C L^{-1}), as well as bacterial productivity (BP, in μg C L^{-1} h^{-1}), as a function of different values of a particular model parameter. The nominal value for each parameter is indicated by the thick black line; different colors are used to indicate higher and lower values as summarized by the legend on each figure. Columns represent Pulse (left) and Press (right) inputs of carbon resources.



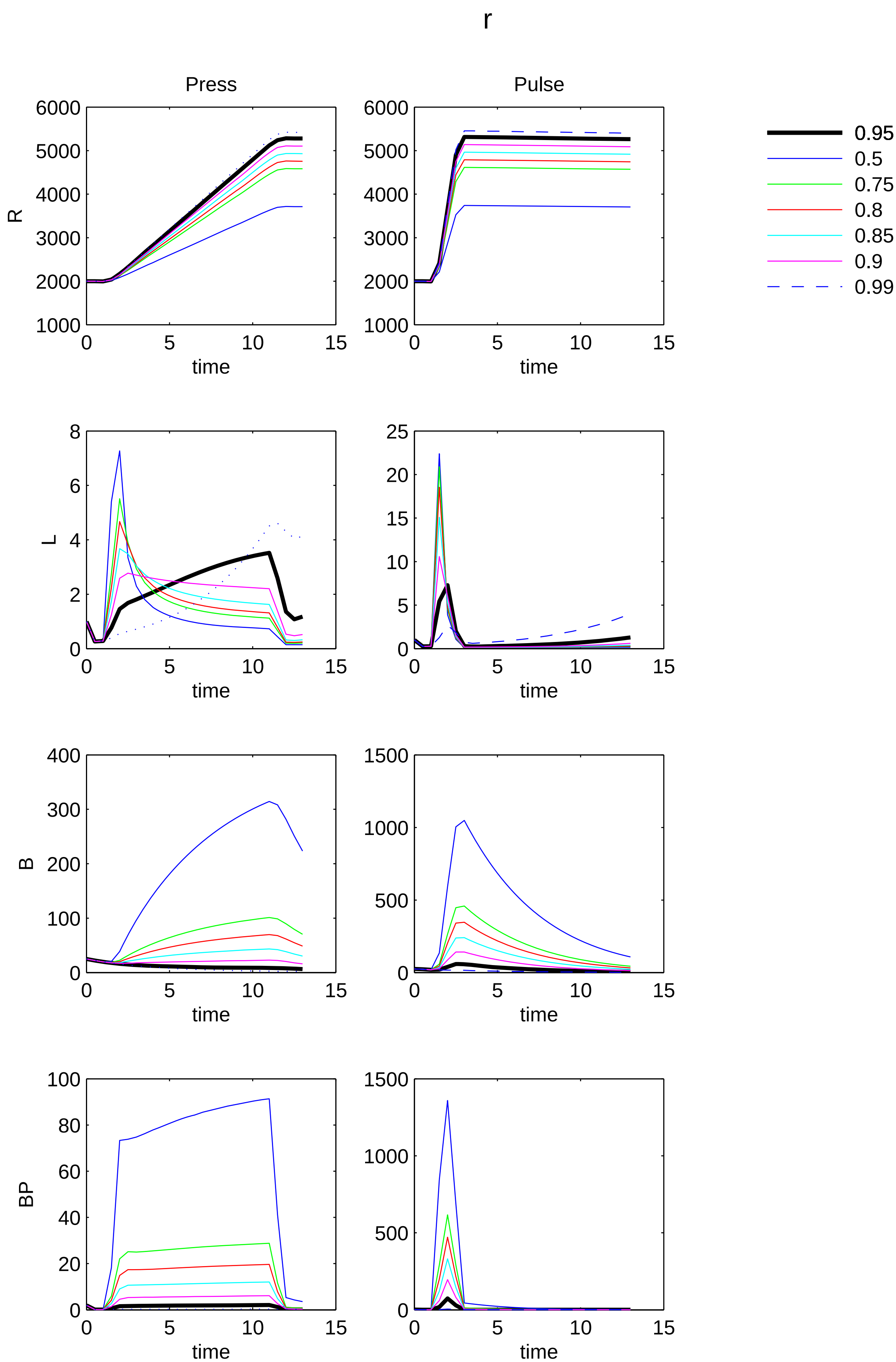
M_C
Press
Pulse
R
L
B
BP
time
15
5
10
20
40
60
80
100

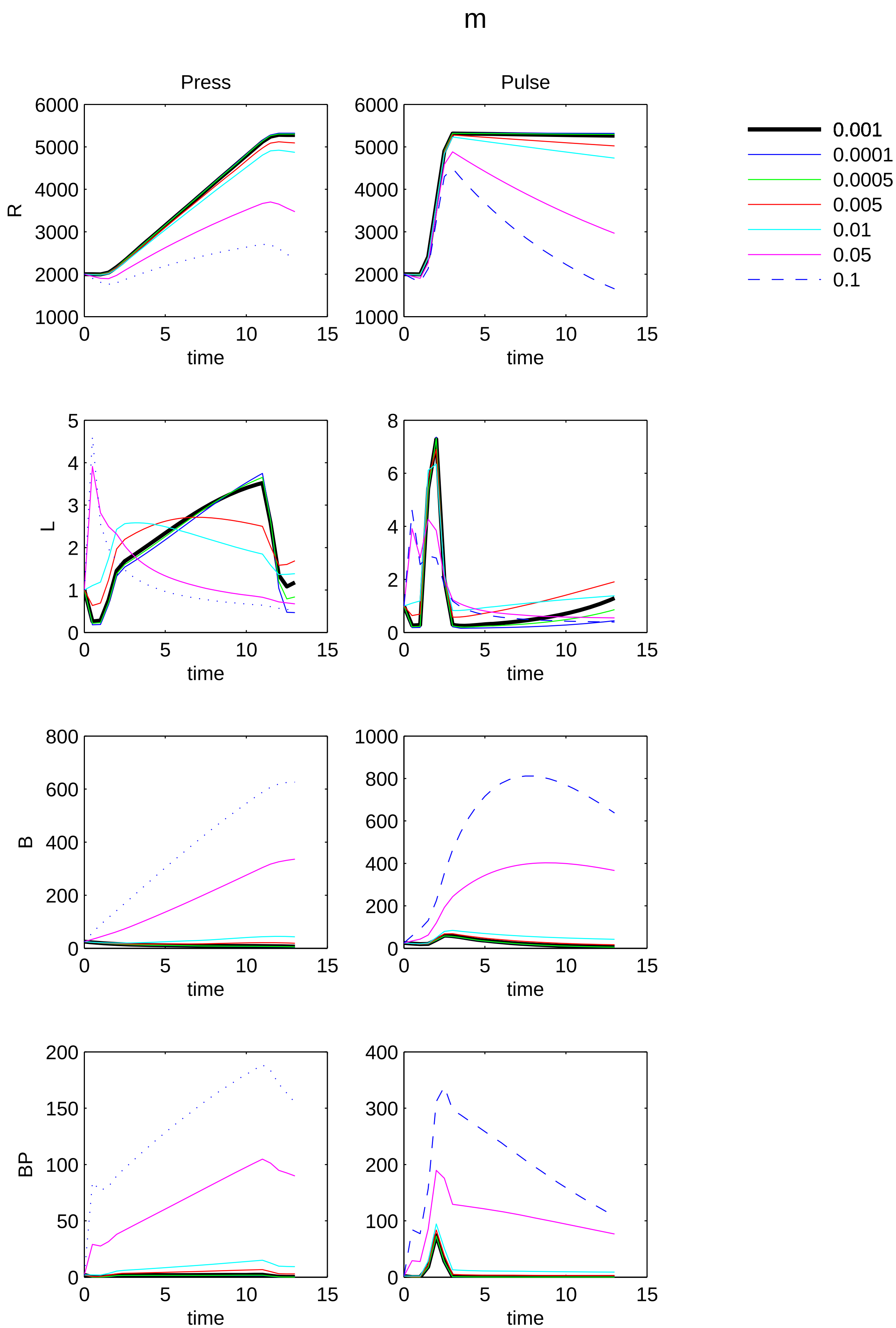

M_C*K
Press
Pulse
R
L
B
BP
time
1
0.1
0.5
2
4
6
10

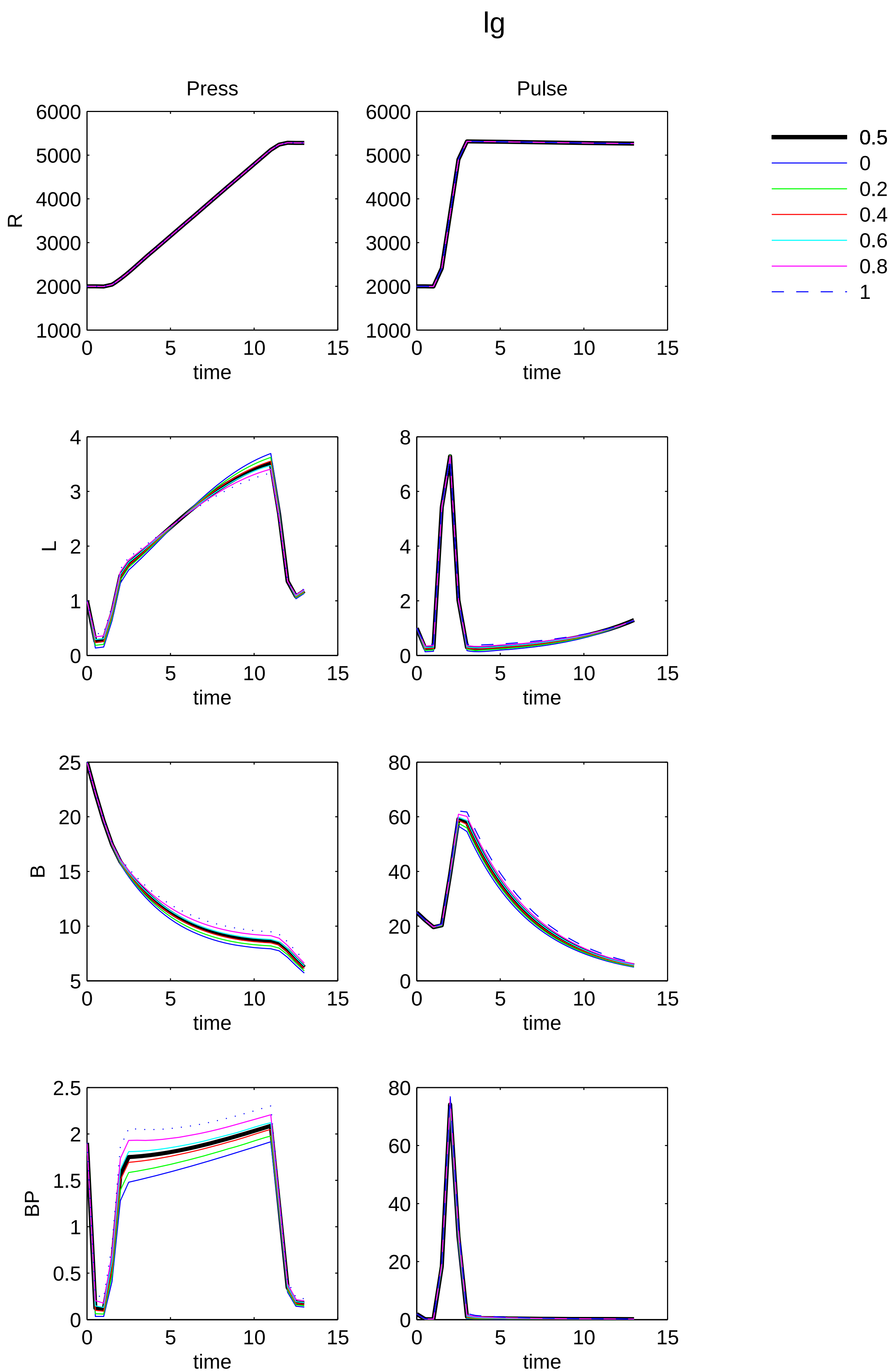

d
Press
Pulse
R
L
B
BP
time
0.25
0.1
0.2
0.3
0.4
0.5



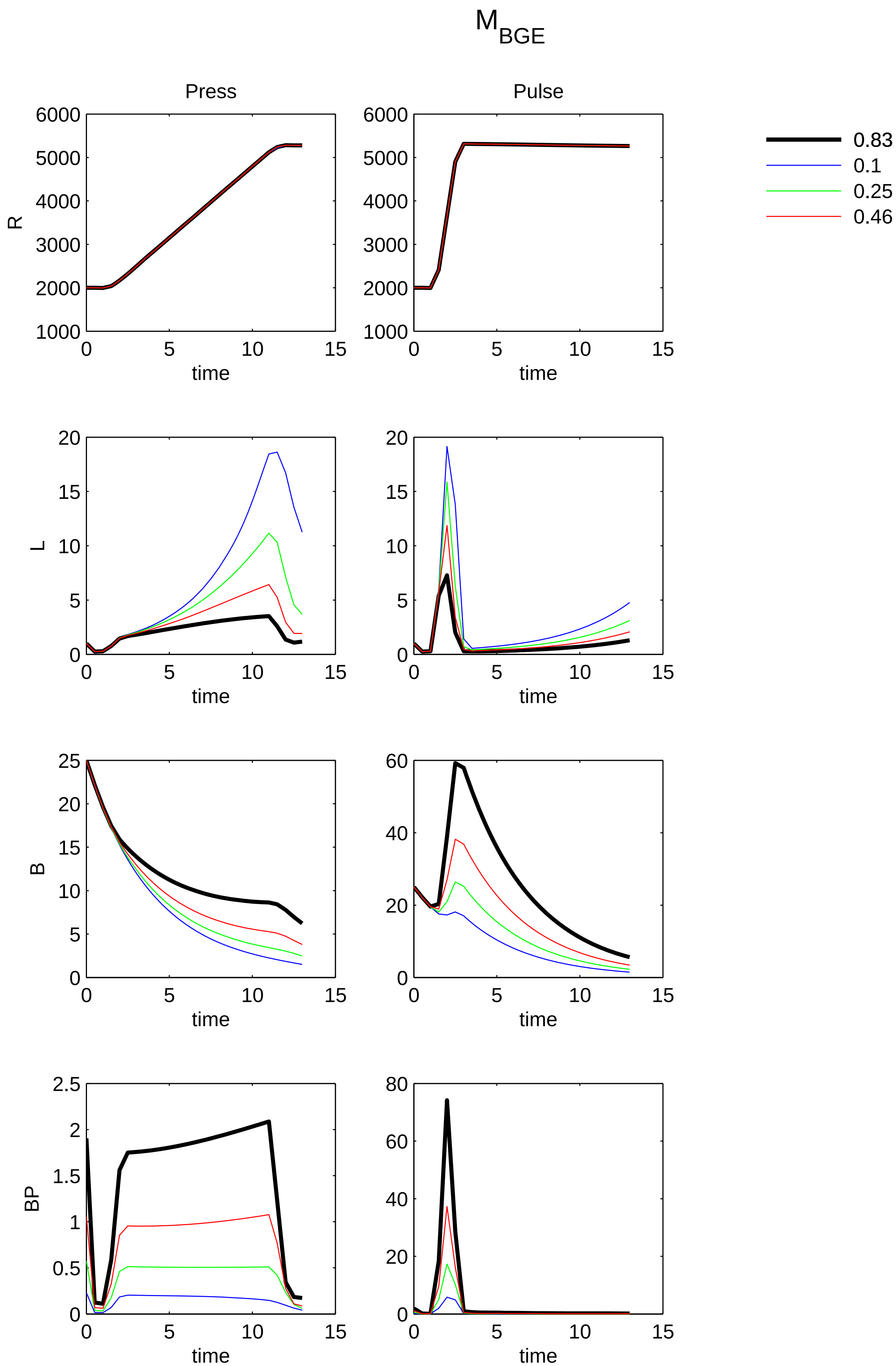
I_i
Press
Pulse
R
L
B
BP
time
1
0.1
0.5
10
25
50
100


r
Press
Pulse
R
L
B
BP
time
0.95
0.5
0.75
0.8
0.85
0.9
0.99

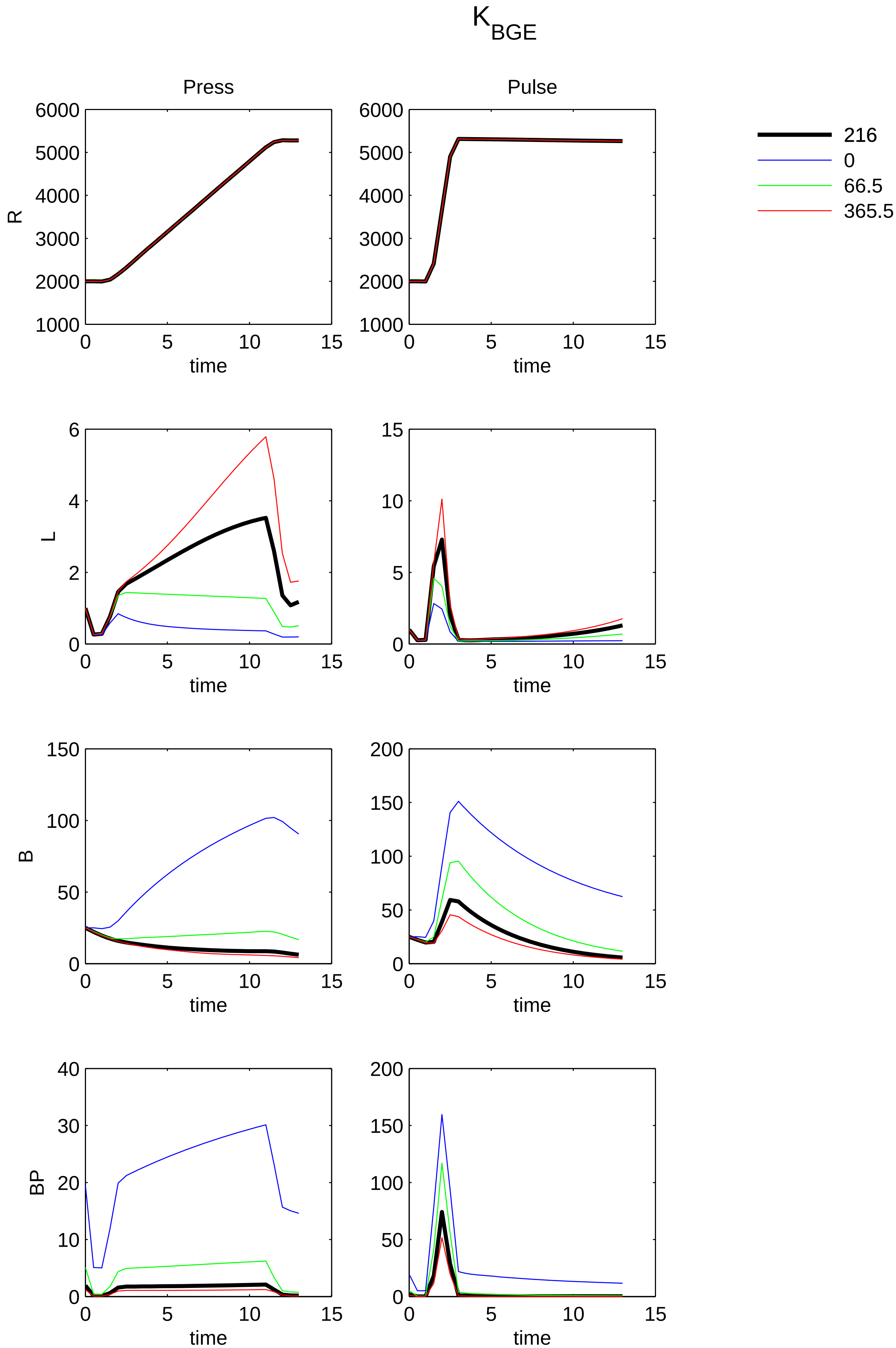

m
Press
Pulse
R
L
B
BP
time
0.001
0.0001
0.0005
0.005
0.01
0.05
0.1



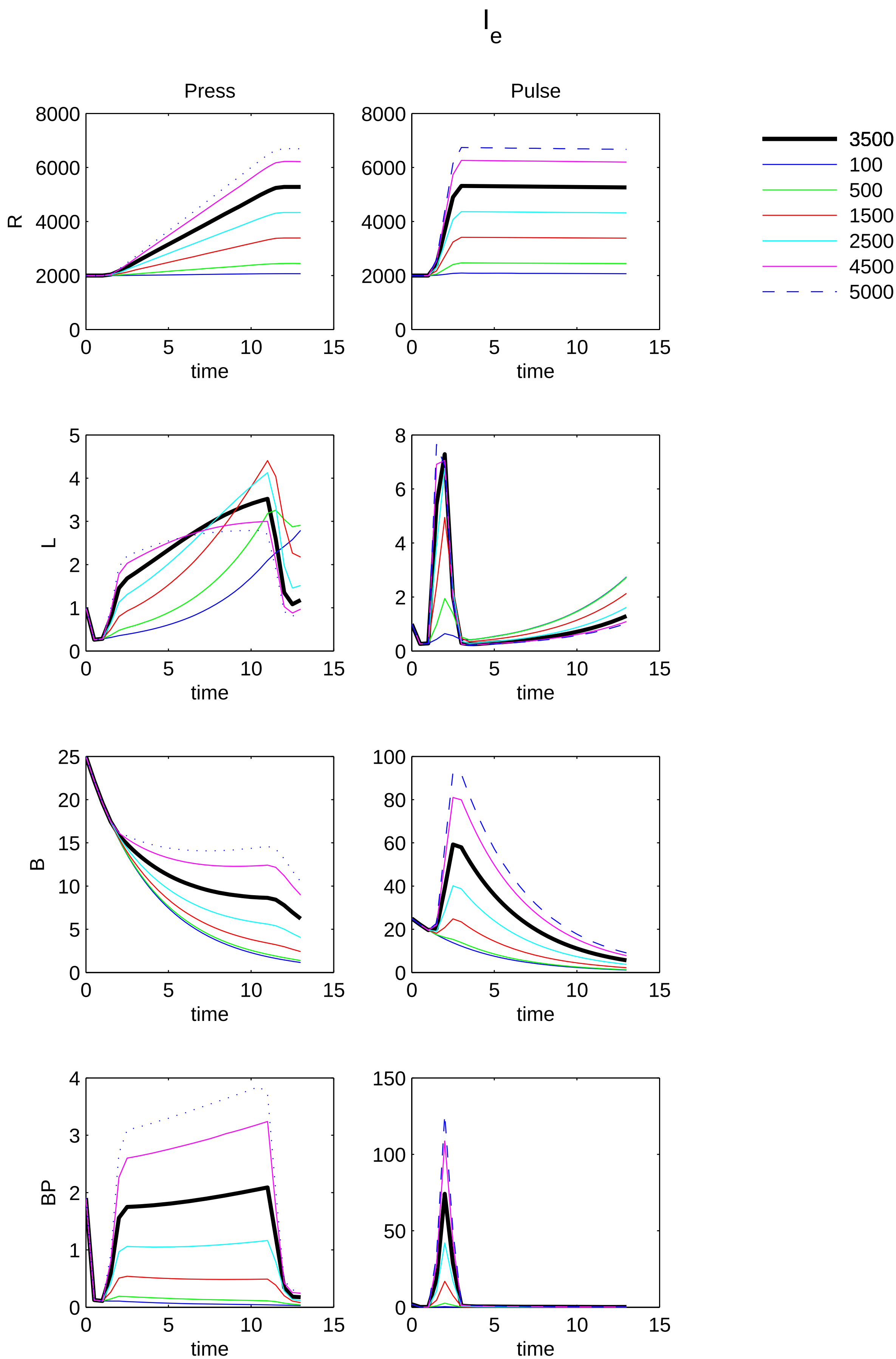
lg
Press
Pulse
R
L
B
BP
time
0.5
0
0.2
0.4
0.6
0.8
1



M_{BGE}
Press
Pulse
0.83
0.1
0.25
0.46
R
L
B
BP
time



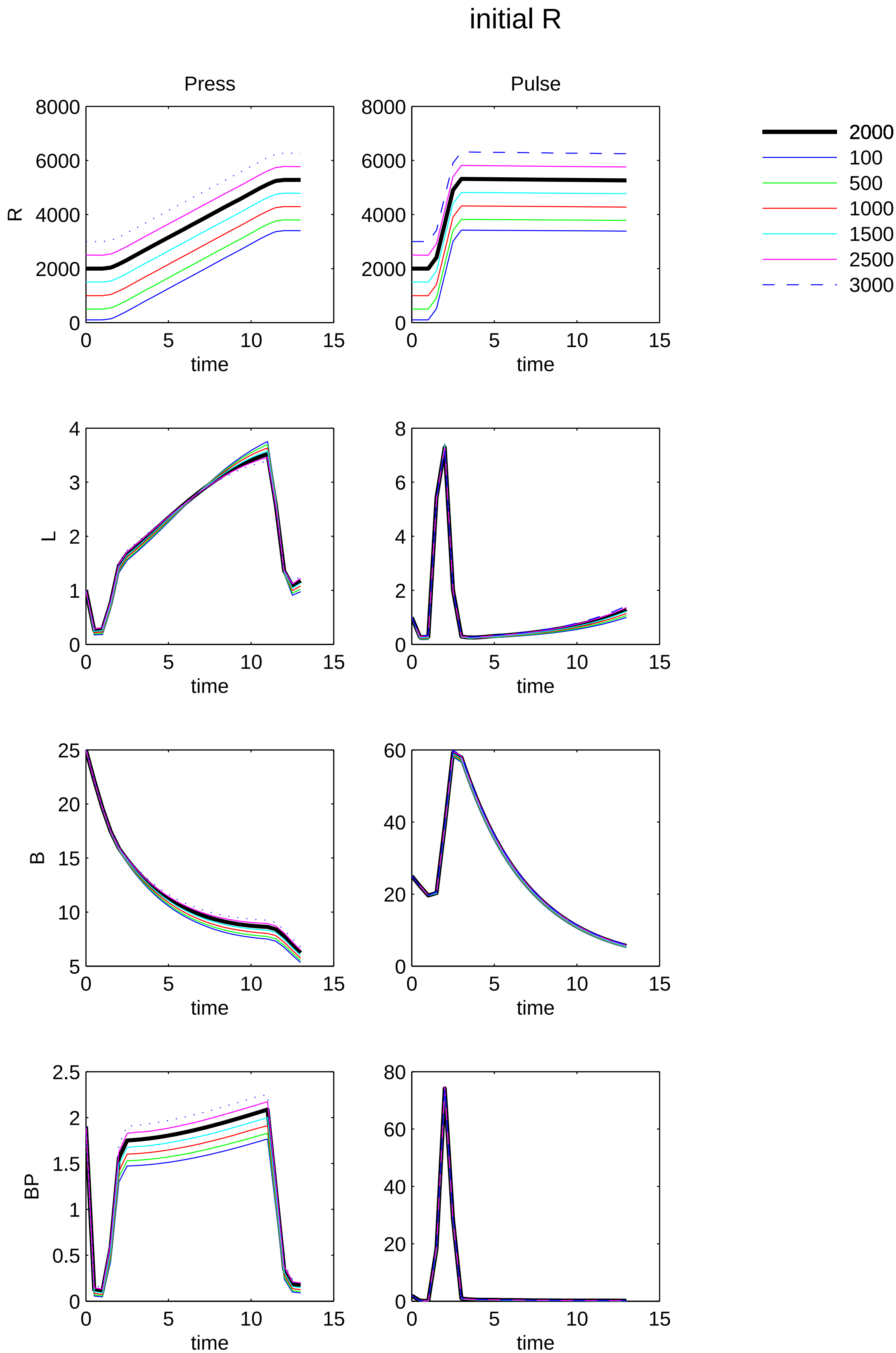
K_{BGE}
Press
Pulse
R
L
B
BP
time
216
0
66.5
365.5



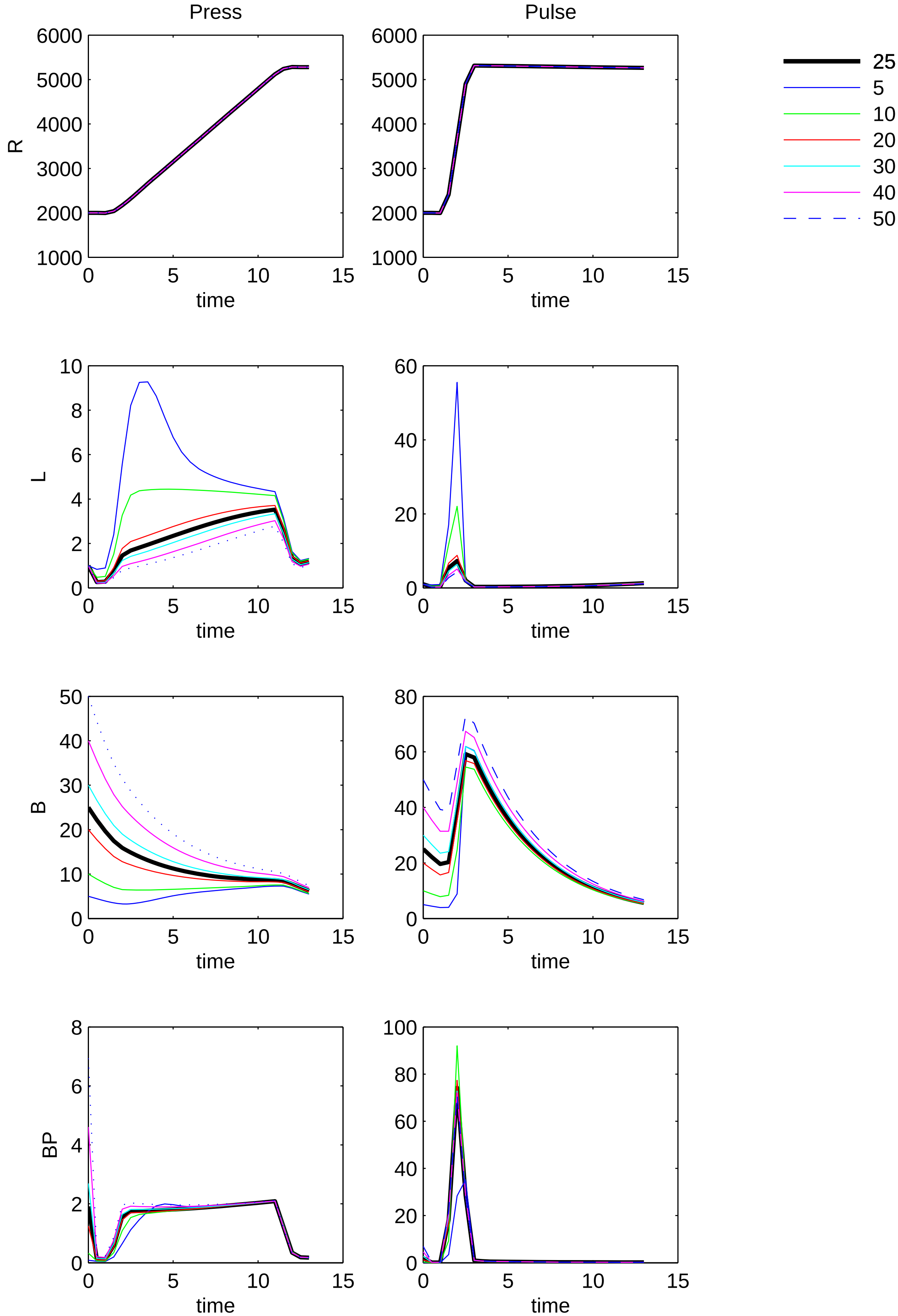
I_e
Press
Pulse
R
L
B
BP
time
3500
100
500
1500
2500
4500
5000

Appendix D. Effects of initial conditions.

As Appendix C, but for the initial conditions for the Refractory C (R) and Bacteria (B) compartments. The initial level for the labile carbon compartment was always set to $I_{i,}$ so that figure is identical to the one in Appendix B.


initial R
Press
Pulse
R
L
B
BP
time
2000
100
500
1000
1500
2500
3000

initial B



Appendix E. Output from PROC MIXED for the factorial manipulations of six parameters plus initial bacterial carbon concentrations.

Table E-1.

Factor	Variance Component	Factor	Variance Component
m	0.032050	drip*initB	0.000203
r	0.007718	S*initB	0.000201
Ad	0.004994	S*Ad	0.000150
S*m	0.004897	S*drip*Ad	0.000135
drip	0.004341	S*drip*An	0.000133
Residual	0.004015	S*r*Ad	0.000122
m*Ad	0.003344	r*drip	0.000115
r*m	0.002555	m*An*initB	0.000098
S*m*An	0.002351	r*An*Ad	0.000098
S	0.002073	m*drip*initB	0.000073
m*drip	0.001984	S*r*initB	0.000056
S*m*drip	0.001414	r*An	0.000043
An*Ad	0.001215	S*r*drip	0.000040
An*initB	0.001178	r*drip*initB	0.000038
S*r*m	0.001087	r*m*Ad	0.000020
m*drip*Ad	0.000954	r*drip*An	0.000017
drip*An*initB	0.000814	m*Ad*initB	0.000014
S*An*initB	0.000797	drip*Ad*initB	0.000013
An*Ad*initB	0.000577	r*Ad*initB	0.000009
initB	0.000541	r*m*initB	0.000005
S*drip	0.000513	S*r*An	0.000002
S*m*Ad	0.000460	r*m*An	0.000002
S*An*Ad	0.000433	r*initB	0.000000
drip*Ad	0.000411	drip*An	0.000000
An	0.000406	m*An	0.000000
m*An*Ad	0.000384	m*initB	0.000000
S*m*initB	0.000326	r*Ad	0.000000
drip*An*Ad	0.000319	r*An*initB	0.000000
S*drip*initB	0.000299	r*drip*Ad	0.000000
m*drip*An	0.000291	S*Ad*initB	0.000000
r*m*drip	0.000245	S*An	0.000000
Ad*initB	0.000241	S*r	0.000000

Appendix F. Labile carbon concentrations are the key to understanding the effects of variable BGE on Pulse/Press differences.

If we solve for bacterial growth efficiency BGE by substituting the equation for BC (text eqn. 4) into the equation for BGE (text eqn. 5), we can express BGE in terms of the labile carbon concentration L:

$$BGE = \frac{M_C * M_{BGE} * \mathrm{L}}{(K_C * K_{BGE}) + (K_{BGE} + M_C) * \mathrm{L}} \qquad \text{eq, F-1}$$

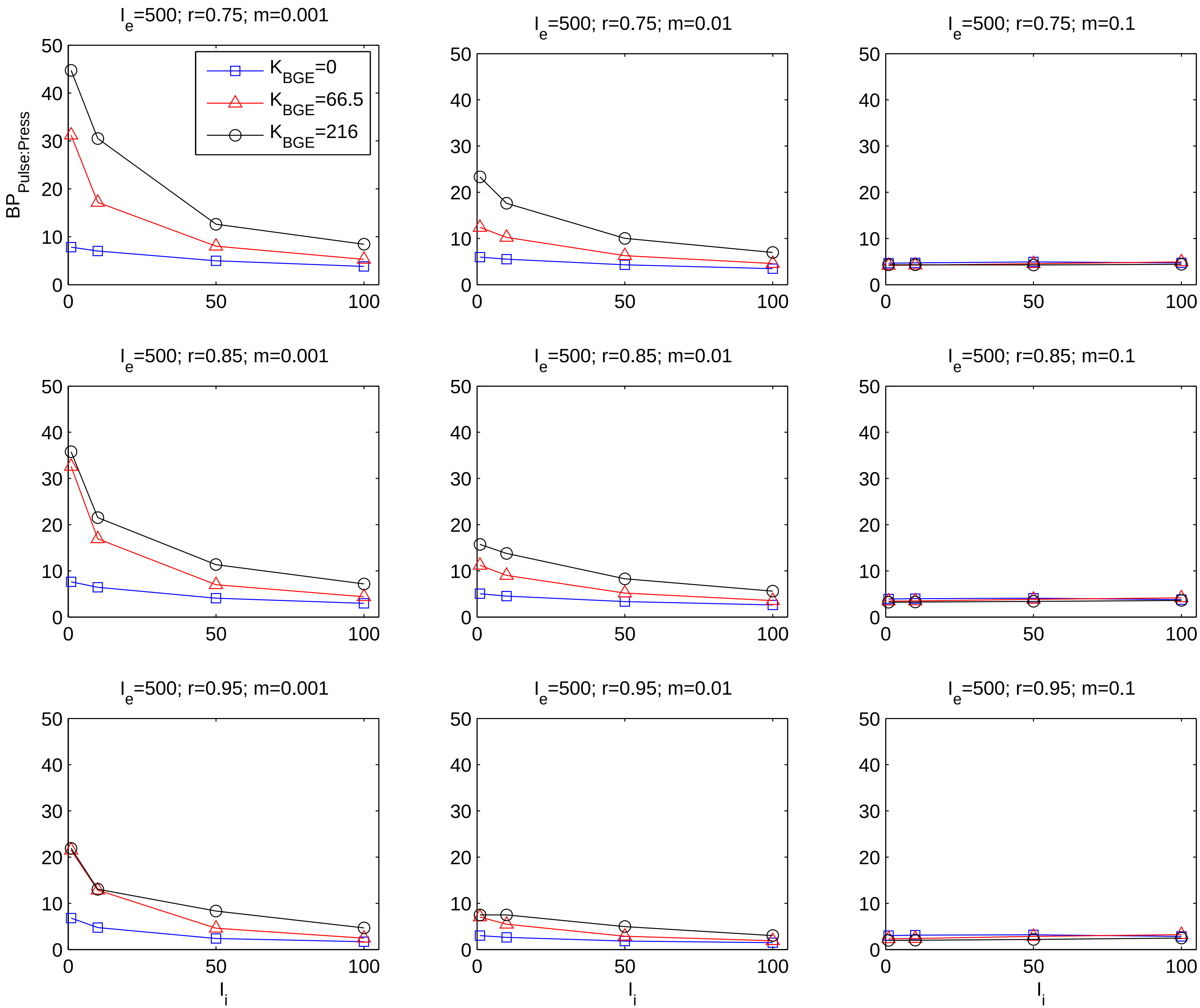
This indicates that BGE is a saturating function of L whose shape depends on the Michaelis-Menten parameters for both carbon uptake and BGE. If K_{BGE}=0, the labile carbon concentration does not affect BGE because BGE = M_{BGE}.

For non-zero K_{BGE}, we expect BGE to increase with increased M_{BGE} and decrease with increased K_{BGE} or K_C. As M_C increases, the maximum BGE increases (the function becomes "taller") but so does the rate of increase (the function becomes "steeper"), making it difficult to predict the effects of this parameter alone.

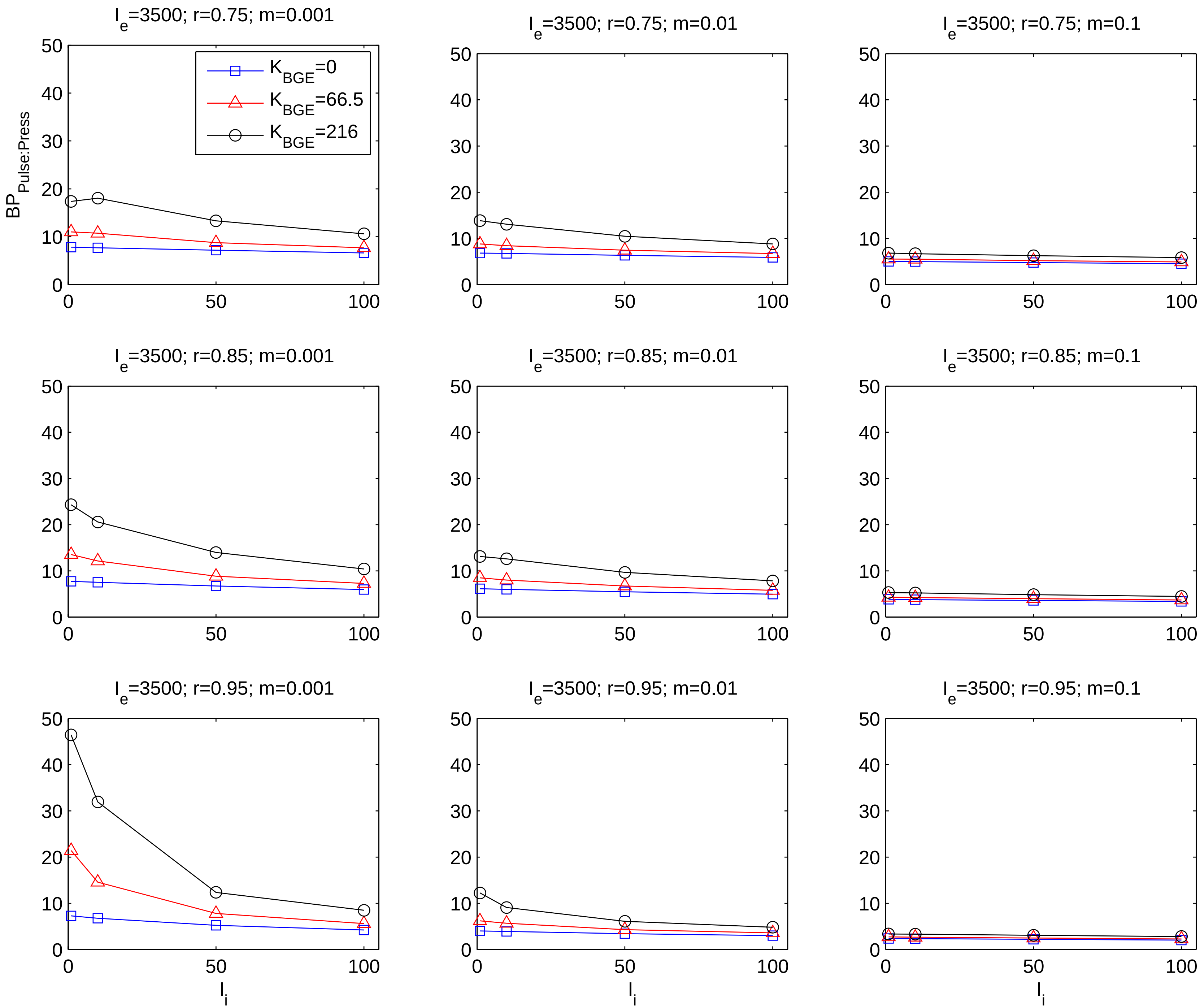
Based on the equation for dL/dt (text eqn. 2), we expect that Press-Pulse differences will be exacerabated by factors that create differences in the labile C concentration such that bacteria in the Pulse treatment are able to realize their maximum BGE, whereas bacteria in the Press treatment are not.

Specifically, we would expect that $BP_{Pulse:Press}$ will be larger when L is much larger in the Pulse treatment; this can happen with decreased *r* or increased I_e (L increases with $(1-r)*I_e$). However, as seen in Figure F-1, the exact relationship with *r* and I_e depends on the values of *r*, I_e, I_i, and K_{BGE}.

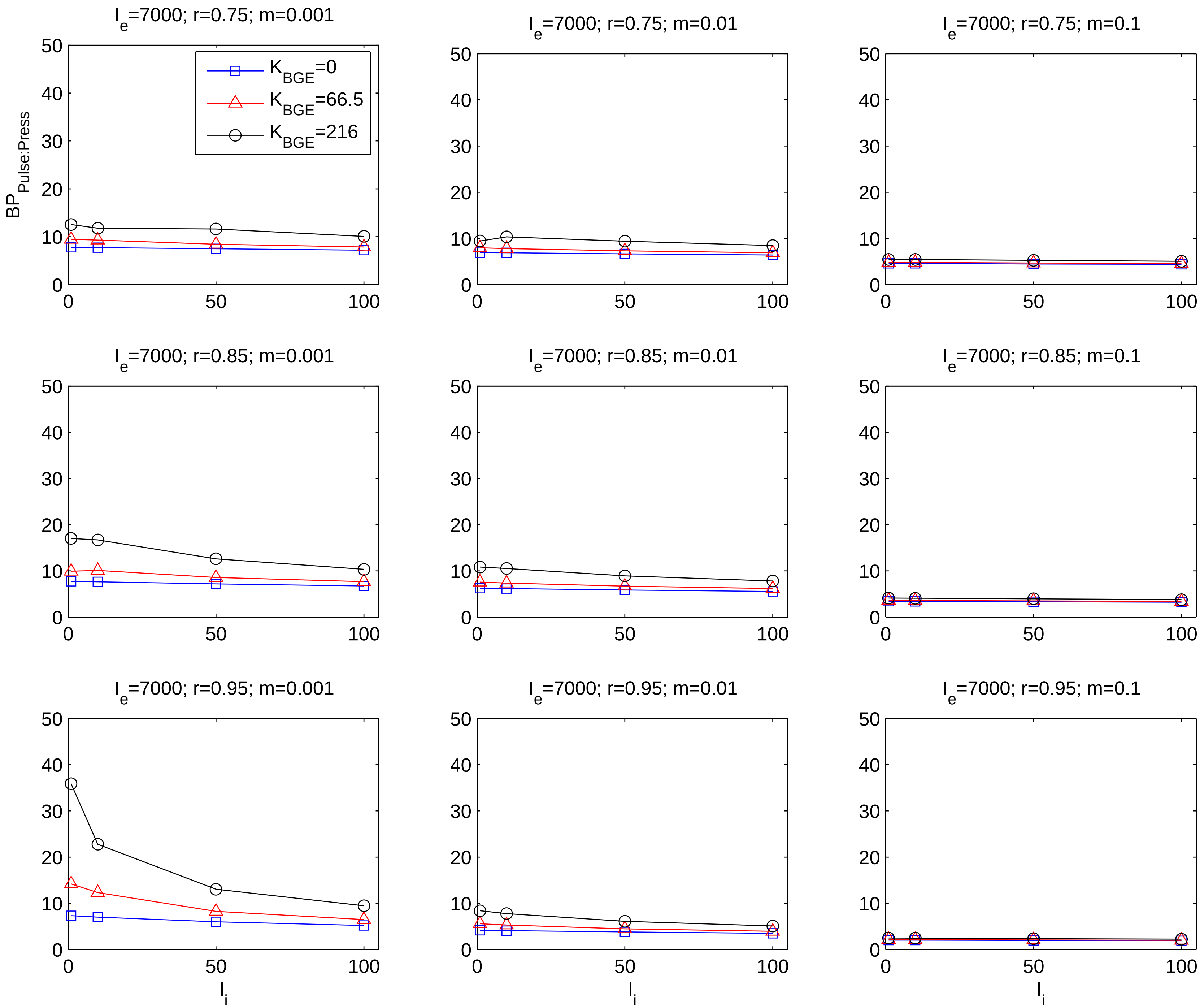
Moreover, we expect smaller $BP_{Pulse:Press}$ ratios when there is a larger background mineralization of refractory carbon ($_m$) or drip of labile C (I_i), since these would be identical in the two scenarios.



I_e=500; r=0.75; m=0.001
I_e=500; r=0.75; m=0.01
I_e=500; r=0.75; m=0.1
I_e=500; r=0.85; m=0.001
I_e=500; r=0.85; m=0.01
I_e=500; r=0.85; m=0.1
I_e=500; r=0.95; m=0.001
I_e=500; r=0.95; m=0.01
I_e=500; r=0.95; m=0.1
K_BGE=0
K_BGE=66.5
K_BGE=216
BP_Pulse:Press
I_i



I_e=3500; r=0.75; m=0.001
I_e=3500; r=0.75; m=0.01
I_e=3500; r=0.75; m=0.1
I_e=3500; r=0.85; m=0.001
I_e=3500; r=0.85; m=0.01
I_e=3500; r=0.85; m=0.1
I_e=3500; r=0.95; m=0.001
I_e=3500; r=0.95; m=0.01
I_e=3500; r=0.95; m=0.1
K_{BGE}=0
K_{BGE}=66.5
K_{BGE}=216
$BP_{Pulse:Press}$
I_i



I_e=7000; r=0.75; m=0.001
I_e=7000; r=0.75; m=0.01
I_e=7000; r=0.75; m=0.1
I_e=7000; r=0.85; m=0.001
I_e=7000; r=0.85; m=0.01
I_e=7000; r=0.85; m=0.1
I_e=7000; r=0.95; m=0.001
I_e=7000; r=0.95; m=0.01
I_e=7000; r=0.95; m=0.1
K_BGE=0
K_BGE=66.5
K_BGE=216
BP_Pulse:Press
I_i
0
10
20
30
40
50
100

Appendix G. The effect of simulation duration on cumulative BP (left) and $BP_{Pulse:Press}$ ratios (right) for nominal parameter values (see Table 1). These results demonstrate that the discrepancy between BP in Pulse versus Press treatments ($BP_{Pulse:Press} > 1$) is most likely not an artifact of the duration of our field experiment.