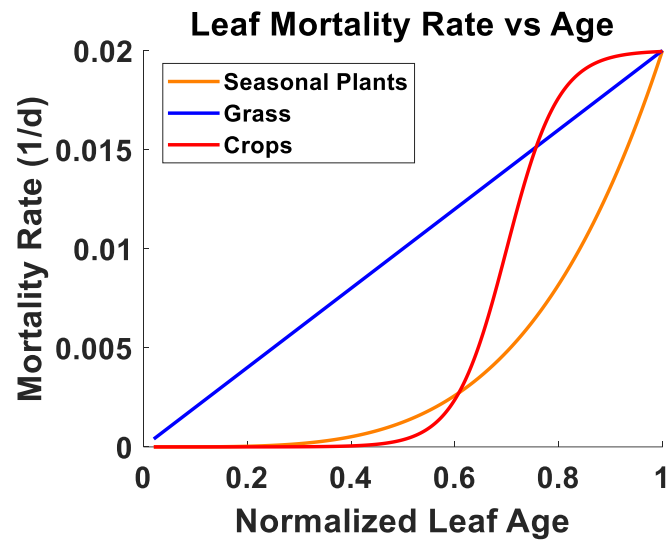


## Section S1: Leaf Turnover Modification



**Figure S1** Our modification, in the form of a sigmoidal function, ensures that the majority of leaf turnover occurs as leaf age approaches the critical age, rather than in the early phases, which is more realistic for crops.

## **Section S2: Crop Parameters**

This is attached as Supplementary 2 which is an Excel Spreadsheet.

## Section S3: Crop Planting and Harvest Dates

<b>BE-LON</b>	Sugar Beet	30/03/2004	29/09/2004	<b>CH-OE2</b>	Winter Barley	29/09/2004	14/07/2005
	Winter Wheat	14/10/2004	03/08/2005		Cover crop	09/08/2005	
	Potatoes	01/05/2006	19/09/2006		Potato	05/05/2006	
	Winter Wheat	13/10/2006	05/08/2007		Winter Wheat	19/10/2006	15/07/2007
	Sugar Beet	22/04/2008	04/11/2008		Winter Rapeseed	28/08/2007	16/07/2008
	Winter Wheat	13/11/2008	07/08/2009		Winter Wheat	07/10/2008	21/07/2009
	Mustard	01/09/2009	01/12/2009		Cover crop	12/08/2009	
	Potatoes	24/04/2010	03/09/2010		Peas	09/05/2010	19/07/2010
	Winter Wheat	13/10/2010	16/08/2011		Winter Wheat	15/10/2010	02/08/2011
	Maize	14/05/2012	13/10/2012		Winter Barley	24/09/2011	09/07/2012
	Winter Wheat	25/10/2012	12/08/2013		Winter Rapeseed	04/09/2012	28/07/2013
	Mustard	05/09/2013	15/11/2013		Winter Wheat	19/10/2013	24/07/2014
	Potatoes	05/04/2014	21/08/2014		Winter Barley	29/09/2014	04/07/2015
	Winter Wheat	14/10/2014	02/08/2015		Cover crop	03/08/2015	
	Mustard	21/08/2015	07/12/2015		Peas	09/05/2016	25/07/2016
	Sugar Beet	12/04/2016	27/10/2016		Winter Wheat	12/10/2016	19/07/2017
	Winter Wheat	29/10/2016	29/07/2017		Winter Rapeseed	30/08/2017	12/07/2018
	Mustard	06/09/2017	06/12/2017		Winter Wheat	11/10/2018	19/07/2019
	Potatoes	22/04/2018	11/09/2018		Winter Barley	04/10/2019	01/07/2020
	Winter Wheat	10/10/2018	01/08/2019		Grass	03/04/2020	19/10/2020
<b>US-NE1</b>	Oat/Faba Bean	09/08/2019	04/12/2019	<b>US-NE1</b>	Maize	01/04/2020	09/11/2009
	Sugar Beet	01/04/2020	12/11/2020		Maize	01/04/2019	21/09/2010
	Spinach	01/04/2021	09/06/2021		Maize	01/05/2018	26/10/2011
	Green Dwarf Bean	22/07/2021	24/10/2021		Maize	01/04/2024	10/10/2012
	Maize	01/05/2010	18/10/2001		Maize	01/04/2029	22/10/2013
	Maize	01/05/2009	04/11/2002		Maize	01/04/2021	28/10/2014
	Maize	01/05/2015	27/10/2003		Maize	01/04/1930	26/10/2015
	Maize	01/05/2003	15/10/2004		Maize	01/05/2019	22/09/2016
	Maize	01/05/2004	15/10/2005		Maize	01/04/2027	25/10/2017
	Maize	01/05/2005	05/10/2006		Maize	01/05/2008	31/10/2018
<b>US-NE1</b>	Maize	01/05/2001	05/11/2007	<b>US-NE1</b>	Maize	01/04/2019	04/11/2019
	Maize	01/04/2029	18/11/2008		Maize	01/04/2020	17/09/2020

**Table S1** Illustrating planting and harvest dates for the different crops.

## Section S4: Fertilizer Applications CHOE2

CHOE2 Recorded Fertilizer Applications							
Date	N (g m <sup>-2</sup> )	P(g m <sup>-2</sup> )	K(g m <sup>-2</sup> )	Date	N (g m <sup>-2</sup> )	P(g m <sup>-2</sup> )	K(g m <sup>-2</sup> )
15.04.2004	4	0.00	0.00	01.04.2011	5	0.00	0.00
03.05.2004	4	0.70	1.33	02.04.2011	4	0.70	1.33
07.06.2004	2.5	0.00	0.00	02.08.2011	3.75	0.00	0.00
04.08.2004	2.2	0.00	0.00	03.04.2012	4	0.00	0.00
14.04.2005	4	0.00	0.00	28.04.2012	2	0.35	0.67
13.05.2005	2	0.35	0.67	04.09.2012	0	2.27	8.33
14.07.2005	4.05	0.00	0.00	05.04.2013	8.1	0.00	0.00
01.05.2006	7.69	2.52	8.03	18.04.2013	6.3	0.22	0.00
05.05.2006	4.2	2.10	12.00	30.03.2014	5	0.00	0.00
05.05.2006	0	0.00	16.67	17.05.2014	4	0.70	1.33
01.06.2006	8.4	0.00	0.00	24.07.2014	4.4	0.00	0.00
18.10.2006	3.15	0.00	0.00	12.09.2014	0	2.01	8.33
15.03.2007	5	0.00	0.00	10.04.2015	5	0.00	0.00
27.05.2007	4	0.70	1.33	23.04.2015	4	0.70	1.33
15.07.2007	5	0.00	0.00	04.07.2015	2.5	0.00	0.00
28.08.2007	0	0.00	0.00	18.03.2016	11.93	3.91	12.45
28.08.2007	0	0.00	0.00	27.03.2017	5.5	0.00	0.00
02.09.2007	0.5	0.57	2.08	02.04.2017	4.7109	0.54	5.62
17.04.2008	2.7	0.00	0.00	27.05.2017	2.5	0.00	0.00
18.03.2009	0	0.96	5.50	19.07.2017	2.7	0.00	0.00
02.04.2009	3.75	0.00	0.00	29.08.2017	1	0.87	4.17
20.05.2009	4	0.70	1.33	28.02.2018	2.7	2.01	5.00
21.07.2009	3.85	0.00	0.00	09.04.2018	8.1	0.00	0.00
12.08.2009	3.43	3.65	6.88	09.04.2018	6.3	0.22	0.00
27.03.2010	4	4.00	4.00	09.10.2018	0.5	0.44	2.08
06.05.2010	0	0.00	0.00	11.10.2018	0	1.75	5.00
09.05.2010	5.96	1.96	6.23	01.04.2019	5	0.00	0.00
04.06.2010	0	3.01	7.50	24.05.2019	4	0.00	0.00
15.03.2011	3	0.00	0.00	19.07.2019	4.6	0.00	0.00

**Table S2** Illustrating fertilizer dates and quantities at site CHOE2.

## Section S5: Site Statistics

USNE1 – MAIZE CONTINUOUS ROTATION		
<b>Yields (Annual)</b> R-squared: 0.01 RMSE: 2.98 [gC / m2] IOA: 0.14	<b>LAI DAILY</b> R-squared: 0.77 RMSE: 1.11 IOA: 0.93	<b>GPP Daily</b> R-squared: 0.81 RMSE: 4.16 IOA: 0.94
<b>Rn Monthly</b> R-squared: 0.98 RMSE: 12.95 [W/m2 ] IOA: 0.99	<b>H Monthly</b> R-squared: 0.70 RMSE: 9.73 [W/m2 ] IOA: 0.90	<b>QE Monthly</b> R-squared: 0.98 RMSE: 10.5 [W/m2 ] IOA: 0.99
<b>Rn HOURLY</b> R-squared: 0.99 RMSE: 13.51 [W/m2 ] IOA: 0.99	<b>H HOURLY</b> R-squared: 0.93 RMSE: 20.60 [W/m2 ] IOA: 0.92	<b>QE HOURLY</b> R-squared: 0.99 RMSE: 4.98 [W/m2 ] IOA: 0.99
CHCHA – GRASS		
<b>Yields (Annual)</b> R-squared: 0.89 RMSE: 0.56 IOA: 0.97	<b>LAI DAILY</b> R-squared: 0.3666 RMSE: 1.3896 IOA: 0.7598	<b>GPP Daily</b> R-squared: 0.4672 RMSE: 4.6963 IOA: 0.8097
<b>Rn Monthly</b> R-squared: 0.9989 RMSE: 10.8123 IOA: 0.9899	<b>H Monthly</b> R-squared: 0.9576 RMSE: 12.4517 IOA: 0.7558	<b>QE Monthly</b> R-squared: 0.9851 RMSE: 9.8401 IOA: 0.9832
<b>Rn HOURLY</b> R-squared: 0.9857 RMSE: 16.8752 IOA: 0.9951	<b>H HOURLY</b> R-squared: 0.8241 RMSE: 14.4625 IOA: 0.9022	<b>QE HOURLY</b> R-squared: 0.9654 RMSE: 13.6610 IOA: 0.9862
BELON – CROP ROTATION		
<b>Yields (Annual)</b> R-squared: 0.52 RMSE: 1.98 IOA: 0.66	<b>LAI DAILY</b> R-squared: 0.3267 RMSE: 1.4596 IOA: 0.7345	<b>GPP Daily</b> R-squared: 0.59 RMSE: 5.1289 IOA: 0.7713
<b>Rn Monthly</b> R-squared: 0.9668 RMSE: 10.6468 IOA: 0.9882	<b>H Monthly</b> R-squared: 0.6534 RMSE: 15.8937 IOA: 0.7371	<b>QE Monthly</b> R-squared: 0.9505 RMSE: 21.3993 IOA: 0.8779
<b>Rn HOURLY</b> R-squared: 0.9988 RMSE: 8.5020 IOA: 0.9984	<b>H HOURLY</b> R-squared: 0.9748 RMSE: 14.4316 IOA: 0.9371	<b>QE HOURLY</b> R-squared: 0.9949 RMSE: 11.6733 IOA: 0.9729
CHOE2 – CROP ROTATION		
<b>Yields (Annual)</b> R-squared: 0.89 RMSE: 0.56 IOA: 0.97	<b>LAI DAILY</b> R-squared: 0.2604 RMSE: 1.0635 IOA: 0.7040	<b>GPP Daily</b> R-squared: 0.5153 RMSE: 3.9298 IOA: 0.8375
<b>Rn Monthly</b> NA site data	<b>H Monthly</b> R-squared: 0.6862 RMSE: 19.6352 IOA: 0.7063	<b>QE Monthly</b> R-squared: 0.9455 RMSE: 19.0611 IOA: 0.9176
<b>Rn HOURLY</b> NA site data	<b>H HOURLY</b> R-squared: 0.9026 RMSE: 18.1636 IOA: 0.9124	<b>QE HOURLY</b> R-squared: 0.9967 RMSE: 23.2496 IOA: 0.9162

**Table S3** Illustrating model validation statistics across sites.

## Section S6: Site Statistics

Yields: USNE1			
Year	MODGRAIN	OBSGRAIN	$\Delta$ (%)
2002	4.2	5.6	24.6
2003	4.5	5.2	13.8
2004	4.6	5.3	14.1
2005	4.7	5.2	10.5
2006	4.4	4.5	2.8
2007	4.2	5.5	23.6
2008	4.2	5.2	18.7
2009	4.6	5.8	20.4
2010	-	-	-
2011	4.2	5.2	18.1
2012	5.6	5.6	0.2
<b>AVG</b>	<b>4.5</b>	<b>5.3</b>	<b>14.7</b>

**Table S4** Modelled Grain and Observed Grain yields at USNE1 site, the delta  $\Delta$  (%) refers to percentage difference.

Yields: CHOE2									
CROP	OBS AGB	MOD AGB	$\Delta$ (%)	OBS STRAW	MOD STRAW	$\Delta$ (%)	OBS GRAIN	MOD GRAIN	$\Delta$ (%)
Wheat (2004)	4.5	3.7	<b>17.1</b>	1.6	1.3	<b>17.8</b>	2.9	2.4	<b>15.7</b>
Barley (2005)	4.0	3.5	<b>13.4</b>	0.7	1.2	- <b>79.9</b>	3.3	2.2	<b>32.5</b>
Wheat (2007)	4.0	2.4	<b>39.0</b>	1.7	0.9	<b>47.5</b>	2.3	1.6	<b>30.0</b>
Rape Seed (2008)	NaN	3.7		NaN	NaN		1.8	2.1	- <b>16.6</b>
Wheat (2009)	4.1	3.4	<b>17.1</b>	1.4	1.2	<b>14.2</b>	2.6	2.2	<b>18.1</b>
Peas (2010)	0.4	NaN		NaN	NaN		<b>0.4</b>	<b>0.7</b>	
Wheat (2011)	4.2	4.3	<b>-0.2</b>	1.5	1.6	<b>-2.4</b>	2.7	2.7	<b>-0.6</b>
Bareley (2012)	4.0	4.3	<b>-7.2</b>	0.8	1.4	- <b>79.6</b>	3.2	2.9	<b>10.1</b>
Rape Seed (2013)	NaN	4.1		NaN	NaN		2.0	2.0	<b>0.1</b>
Wheat (2014)	4.5	3.2	<b>28.5</b>	1.8	1.1	<b>40.1</b>	2.8	2.2	<b>18.9</b>
Barley (2015)	3.8	3.9	<b>-3.7</b>	0.6	1.1	- <b>71.4</b>	3.1	2.9	<b>8.4</b>
Wheat (2017)	4.1	4.4	<b>-7.2</b>	1.6	1.8	- <b>10.9</b>	2.5	2.6	<b>-5.1</b>
Rape Seed (2018)	NaN	3.3		NaN	NaN		2.3	2.4	<b>-5.2</b>
Wheat (2019)	4.6	4.3	<b>5.1</b>	2.1	1.6	<b>26.1</b>	2.5	2.8	- <b>14.0</b>

**Table S5** Modelled vs Observed yields across different crops at the CHOE2 site, the delta  $\Delta$  (%) refers to percentage difference.

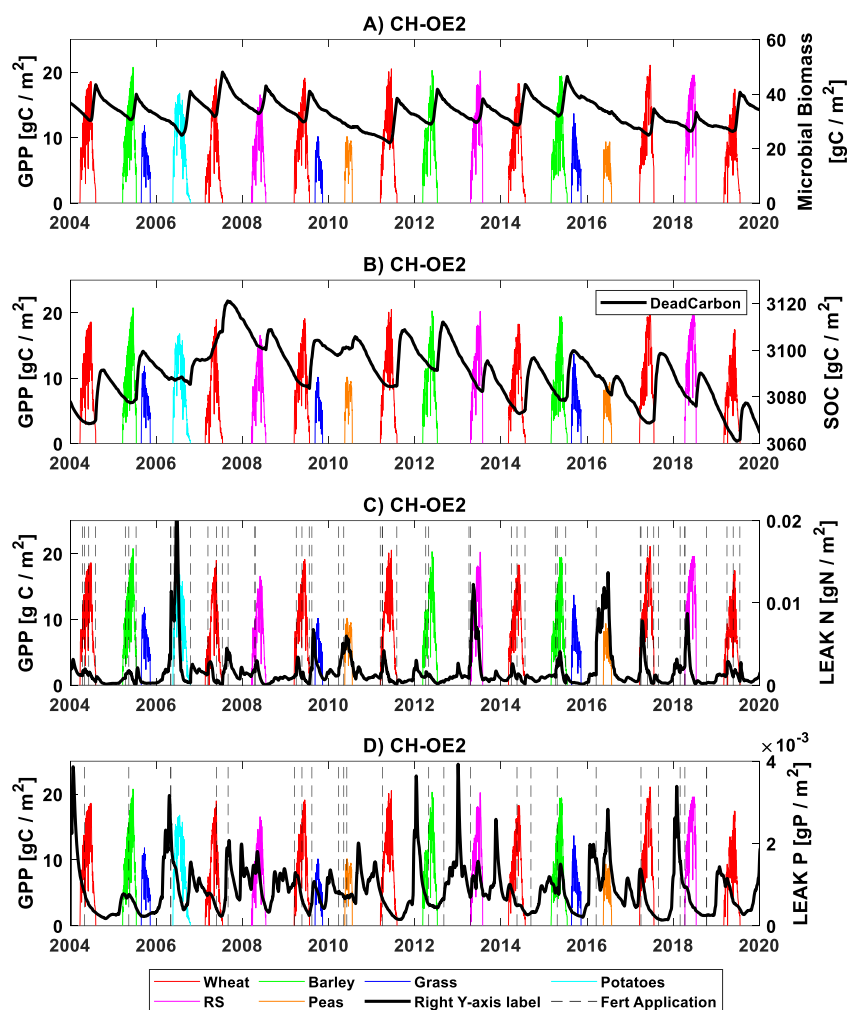
Yields: BELON										
CROP	YEA R	OBS AGB	MOD AGB	$\Delta$ (%)	OBS Grain	MOD Grain	$\Delta$ (%)	OBS Straw	MOD straw	$\Delta$ (%)
Sugar Beet	2004	7.82	6.75	15	NaN	3.89		NaN	2.85	
'Winter wheat (cv. Dekan)'	2005	5.68	5.97	-5	3.97	3.62	9	1.71	2.37	-28
'Potato (cv. Spunta)'	2006	2.93	2.24	30	NaN	0.37	NaN	NaN	1.87	NaN
'Winter wheat (cv. Rosario)'	2007	4.56	5.98	-23	3.16	3.42	-7	1.39	2.62	-46
'Sugar beet (cv. Calgahri)'	2008	9.89	7.42	33	NaN	4.49	NaN	NaN	2.98	NaN
'Winter wheat (cv. Ararat)'	2009	5.37	6.28	-14	3.84	3.79	1	1.52	2.55	-40
'Potato (cv. Draga)'	2010	3.05	2.42	26	NaN	0.429	NaN	NaN	1.99	NaN
'Winter wheat (cv. Sahara)'	2011	5.49	5.68	-3	3.69	3.11	18	1.79	2.63	-32
'Maize'	2012	7.76	7.24	7	4.15	4.15	0	3.59	4.15	-13
'Winter wheat (cv. Matrix)'	2013	5.98	5.33	12	3.86	3.20	20	2.11	2.18	-3
'Potato (cv. Draga)'	2014	3.2	1.86	71	NaN	0.24	NaN	NaN	1.61	NaN
'Winter wheat (cv. Sahara)'	2015	5.36	6.18	-13	3.55	3.68	-3	1.80	2.53	-28
'Sugar beet (cv. Lisanna KWS)'	2016	9.04	6.67	35	NaN	4.06	NaN	NaN	2.61	NaN
'Winter wheat (cv. Tobak)'	2017	4.99	5.82	-14	3.64	3.29	10	1.34	2.55	-47
'Potato (cv. Agria)'	2018	4.11	2.19	87	NaN	0.37	NaN	NaN	1.81	NaN
'Winter wheat (cv. Smart)'	2019	6.78	5.95	13	4.09	3.56	14	2.67	2.42	10

**Table S6** Modelled vs Observed yields across different crops at the BELON site, the delta  $\Delta$  (%) refers to percentage difference.

CHCHA				
Cut Date	CkgPerHa	OBS TC ha	MOD TC ha	$\Delta$ (%)
'29/06/2010'	728.68	1.03	1.02	-0.01
'22/08/2010'	1026.80	0.73	0.86	0.15
'12/10/2010'	728.33	1.03	1.19	0.13
'19/04/2011'	1030.76	0.82	1.25	0.34
'15/06/2011'	824.19	0.79	1.08	0.27
'12/07/2011'	789.69	0.95	1.19	0.20
'24/08/2011'	945.38	0.76	0.53	-0.42
'28/09/2011'	759.57	0.85	0.99	0.14

**Table S7** Modelled vs Observed yields across different crops at the CHCHA site, the delta  $\Delta$  (%) refers to percentage difference.

## Section S7: Soil Biogeochemistry



**Figure S2** Illustrating simulated soil biogeochemistry.