



*Supplement of*

## **Warmer growing seasons improve cereal yields in Northern Europe only with increasing precipitation**

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## Supplementary information

### Equations showing both fixed and random effects

The MatLab code corresponds to the three models examining yield dependence on both fixed and random effects, facilitating reproducibility. The first model used the composite precipitation-temperature indicator, the dryness index, as the explanatory variable (Eq. S1). The second model quantified the effects of interacting conditions, either averaged over the entire period or extending over substantial intervals, such as dry spells (Eq. S2). The third model focused on short-term non-interacting damaging conditions (Eq. S3).

$$y \sim t + DI + DI^2 + (1|Year) + (1|ID) \quad \text{eq. S1}$$

$$y \sim t + X_P + X_T + X_P^2 + X_T^2 + X_P * X_T + X_P^2 * X_T + X_P * X_T^2 + X_P^2 * X_T^2 + (1|Year) + (1|ID) \quad \text{eq. S2}$$

$$y \sim t + NDP1 + NDP20 + NDT25 + Frost + NDP1^2 + NDP20^2 + NDT25^2 + Frost^2 + (1|Year) + (1|ID) \quad \text{eq. S3}$$

### Tables

Table S1 Model coefficient estimates, standard errors (SE) and p values for the winter wheat indicators according to eqs. 1-3 for interacting, short term and composite indicators over separate periods. Significant effects at  $p \leq 0.05$  are highlighted in bold. The  $r2marg$  and  $r2cond$  represent the fraction of explained variance when considering only marginal effects and when also considering the random effects, respectively. Over the post-flowering period there was no incident of Frost.

Period	Pre-growing (3 months prior to the main growing season)			Entire growing season			Pre-flowering			Post-flowering		
<i>Used indicators</i>	(1) DI			(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$			$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{P2} x_P^2 + \beta_{PT} x_P x_T$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
$\beta_0$ [ton·ha <sup>-1</sup> ]	3.147	0.285	<b>2.73E-13</b>	10.432	1.253	<b>4.78E-14</b>	4.294	0.584	<b>3.97E-09</b>	7.333	1.101	<b>3.61E-09</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.050	0.005	<b>2.46E-22</b>	0.054	0.004	<b>3.93E-31</b>	0.052	0.005	<b>8.21E-26</b>	0.051	0.005	<b>1.70E-25</b>
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	0.884	0.298	<b>3.09E-03</b>									
$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	-0.351	0.109	<b>1.29E-03</b>									
<i>AIC</i>	1450											
<i>r2marg</i>	0.44											
<i>r2cond</i>	0.85											

$\beta_P$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ]	-0.330	0.074	<b>1.04E-05</b>	0.01	0.115	9.33E-01	-0.273	0.087	<b>1.75E-03</b>
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.568	0.088	<b>1.67E-10</b>	-0.099	0.047	<b>3.45E-02</b>	-0.271	0.067	<b>6.33E-05</b>
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ·°C <sup>-1</sup> ]	0.032	0.005	<b>1.39E-10</b>	0.012	0.009	1.60E-01	0.024	0.005	<b>4.51E-06</b>
$\beta_{P2}$ [ton·ha <sup>-1</sup> ·cm <sup>-2</sup> ]	-0.003	0.001	<b>4.97E-09</b>	-0.010	0.004	<b>9.81E-03</b>	-0.004	0.001	<b>6.52E-06</b>
<i>AIC</i>	1394			1458			1428		
<i>r2marg</i>	0.50			0.45			0.46		
<i>r2cond</i>	0.87			0.85			0.86		
<i>Used indicators</i>	(3) Pvar (denoted as x_P) and Tvar (denoted as x_T)								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	3.457	0.269	<b>5.58E-17</b>	3.495	0.234	<b>2.26E-21</b>	3.701	0.245	<b>1.36E-22</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.051	0.005	<b>5.65E-23</b>	0.05	0.005	<b>1.88E-23</b>	0.051	0.005	<b>6.10E-23</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·mm <sup>-2</sup> ·day <sup>-2</sup> ]	-0.001	0.003	6.86E-01	0.011	0.004	<b>3.88E-03</b>	-0.002	0.002	<b>2.98E-01</b>
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ·day <sup>-2</sup> ]	0.011	0.01	2.63E-01	0.003	0.007	6.45E-01	-0.01	0.012	4.30E-01
<i>AIC</i>	1471			1464			1470		
<i>r2marg</i>	0.44			0.44			0.44		
<i>r2cond</i>	0.85			0.85			0.85		
<i>Used indicators</i>	(4) CDD (denoted as x_P) and Tmean (denoted as x_T)								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	5.585	0.735	<b>8.98E-11</b>	4.613	0.415	<b>2.12E-19</b>	3.927	0.717	<b>1.07E-05</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.050	0.005	<b>1.07E-25</b>	0.052	0.005	<b>1.11E-25</b>	0.048	0.005	<b>1.78E-21</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.032	0.004	<b>2.84E-12</b>	-0.018	0.007	<b>5.67E-03</b>	-0.037	0.005	<b>2.36E-11</b>
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.114	0.054	<b>3.58E-02</b>	-0.078	0.033	<b>1.96E-02</b>	0.007	0.047	8.78E-01
<i>AIC</i>	1409			1452			1420		
<i>r2marg</i>	0.47			0.45			0.46		
<i>r2cond</i>	0.86			0.85			0.86		
<i>Used indicators</i>	(5) DI								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	3.432	0.279	<b>5.72E-32</b>	2.911	0.266	<b>5.09E-26</b>	3.188	0.286	<b>7.80E-27</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.049	0.005	<b>9.71E-26</b>	0.051	0.005	<b>1.28E-25</b>	0.049	0.005	<b>1.05E-22</b>
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	-0.189	0.033	<b>1.45E-08</b>	-0.018	0.004	<b>3.95E-05</b>	-0.085	0.029	<b>3.66E-03</b>

$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	0.004	0.001	<b>3.81E-03</b>	0.001	0	<b>4.57E-04</b>	0.001	0.001	4.87E-01
<i>AIC</i>	1430			1468			1442		
<i>r2marg</i>	0.47			0.44			0.45		
<i>r2cond</i>	0.86			0.85			0.86		
<b>Used indicators</b>	(6) Short-term indicators								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{NDP1}(NDP1) + \beta_{NDT25}(NDT25) + \beta_{NDP20}(NDP20) + \beta_{Frost}(Frost) + \beta_{NDP1\_2}(NDP1)^2 + \beta_{NDT25\_2}(NDT25)^2 + \beta_{NDP20\_2}(NDP20)^2 + \beta_{Frost\_2}(Frost)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	1.156	0.411	<b>5.08E-03</b>	2.342	0.297	<b>1.12E-14</b>	1.88	0.352	<b>1.25E-07</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.051	0.005	<b>5.94E-27</b>	0.051	0.005	<b>2.75E-25</b>	0.049	0.005	<b>5.10E-24</b>
$\beta_{NDP20}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.013	0.046	7.86E-01	0.168	0.236	4.76E-01	-0.024	0.051	6.42E-01
$\beta_{NDP1}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.120	0.021	<b>1.56E-08</b>	0.081	0.025	<b>1.28E-03</b>	0.123	0.022	<b>4.73E-08</b>
$\beta_{NDT25}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.009	0.015	5.45E-01	0.016	0.032	6.19E-01	-0.01	0.018	5.92E-01
$\beta_{Frost}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.036	0.03	2.27E-01	0.042	0.03	1.58E-01	-	-	-
$\beta_{NDP20\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.008	0.013	5.52E-01	-0.052	0.176	7.68E-01	-0.006	0.015	6.84E-01
$\beta_{NDP1\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.002	0	<b>6.10E-08</b>	-0.003	0.001	<b>9.99E-03</b>	-0.003	0.001	<b>1.41E-08</b>
$\beta_{NDT25\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	0	0.001	9.36E-01	-0.003	0.004	3.73E-01	0	0.001	9.11E-01
$\beta_{Frost\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.002	0.004	5.40E-01	-0.002	0.004	5.30E-01	-	-	-
<i>AIC</i>	1499			1504			1478		
<i>r2marg</i>	0.46			0.44			0.45		
<i>r2cond</i>	0.85			0.85			0.85		

20 Table S2 Same as above but for spring barley.

Period	Pre-growing (3 months prior to the main growing season)		
<b>Used indicators</b>	(1) DI		
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$		
Name	Estimate	SE	p
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.149	0.214	<b>7.67E-23</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.025	0.003	<b>1.26E-17</b>
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	0.195	0.055	<b>4.68E-04</b>
$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	-0.014	0.004	<b>2.69E-03</b>
<i>AIC</i>	1756		
<i>r2marg</i>	0.18		
<i>r2cond</i>	0.80		
Period	Entire growing season		Post-flowering
<b>Used indicators</b>	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)		

<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T + \beta_{P^2} x_P^2$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
$\beta_0$ [ton·ha <sup>-1</sup> ]	9.138	0.765	<b>4.3E-31</b>	3.601	0.681	<b>1.45E-07</b>	3.807	0.425	<b>1.39E-18</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.028	0.002	<b>1.3E-28</b>	0.026	0.003	<b>6.47E-20</b>	0.027	0.003	<b>1.62E-20</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ]	-0.259	0.034	<b>3.03E-14</b>	-0.042	0.050	4.03E-01	-0.044	0.035	2.07E-01
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.530	0.050	<b>1.46E-25</b>	-0.147	0.048	<b>2.30E-03</b>	-0.103	0.022	<b>2.62E-06</b>
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ·°C <sup>-1</sup> ]	0.022	0.002	<b>2.58E-27</b>	0.012	0.003	<b>4.65E-04</b>	0.004	0.002	<b>3.01E-02</b>
$\beta_{P^2}$ [ton·ha <sup>-1</sup> ·cm <sup>-2</sup> ]	-0.001	0.000	<b>1.32E-05</b>	-0.004	0.000	<b>1.29E-15</b>	-0.001	0.001	2.38E-01
AIC	1598			1671			1766		
r2marg	0.24			0.20			0.20		
r2cond	0.82			0.81			0.80		
<b>Used indicators</b>	(3) Pvar (denoted as x_P) and Tvar (denoted as x_T)								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.617	0.225	<b>1.30E-29</b>	2.600	0.217	<b>3.27E-31</b>	2.280	0.213	<b>1.62E-25</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.025	0.003	<b>3.97E-17</b>	0.025	0.003	<b>5.33E-16</b>	0.025	0.003	<b>1.26E-16</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·mm <sup>-2</sup> ·day <sup>2</sup> ]	-0.005	0.002	<b>1.12E-02</b>	-0.005	0.002	<b>2.15E-02</b>	-0.001	0.001	3.71E-01
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ·day <sup>2</sup> ]	-0.015	0.006	<b>5.96E-03</b>	-0.015	0.004	<b>2.29E-04</b>	0.010	0.006	1.01E-01
AIC	1760			1755			1770		
r2marg	0.18			0.18			0.18		
r2cond	0.80			0.80			0.80		
<b>Used indicators</b>	(4) CDD (denoted as P) and Tmean (denoted as T)								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T + \beta_{T^2} x_T^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	-8.056	1.632	<b>9.16E-07</b>	-1.106	1.815	5.43E-01	1.512	0.733	<b>3.92E-02</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.027	0.002	<b>8.81E-28</b>	0.024	0.003	<b>1.65E-19</b>	0.028	0.003	<b>5.26E-22</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.226	0.031	<b>3.72E-13</b>	0.165	0.032	<b>3.30E-07</b>	0.094	0.025	<b>1.35E-04</b>
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	1.317	0.238	<b>3.85E-08</b>	0.373	0.279	1.82E-01	0.119	0.089	1.82E-01
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.017	0.002	<b>2.12E-15</b>	-0.014	0.002	<b>3.34E-09</b>	-0.006	0.001	<b>1.55E-04</b>
$\beta_{T^2}$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ]	-0.040	0.009	<b>8.41E-06</b>	-0.006	0.011	5.67E-01	-0.005	0.003	1.05E-01
AIC	1603			1696			1750		
r2marg	0.24			0.21			0.21		
r2cond	0.82			0.81			0.80		
<b>Used indicators</b>	(5) DI								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI^2}(DI)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.123	0.228	<b>6.70E-20</b>	2.468	0.208	<b>7.90E-31</b>	2.328	0.206	<b>3.83E-28</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.025	0.003	<b>2.06E-20</b>	0.025	0.003	<b>1.13E-18</b>	0.025	0.003	<b>1.32E-16</b>
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	0.171	0.056	<b>2.18E-03</b>	-0.028	0.020	1.65E-01	-0.001	0.001	5.14E-02
$\beta_{DI^2}$ [ton·ha <sup>-1</sup> ]	-0.031	0.006	<b>4.91E-07</b>	-0.001	0.001	1.56E-01	0.000	0.000	<b>1.94E-02</b>
AIC	1720			1740			1790		
r2marg	0.19			0.18			0.18		
r2cond	0.80			0.80			0.80		
<b>Used indicators</b>	(6) Short-term indicators								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{NDP1}(NDP1) + \beta_{NDT25}(NDT25) + \beta_{NDP20}(NDP20) + \beta_{Frost}(Frost) + \beta_{NDP1\_2}(NDP1)^2 + \beta_{NDT25\_2}(NDT25)^2 + \beta_{NDP20\_2}(NDP20)^2 + \beta_{Frost\_2}(Frost)^2$								

$\beta_0$ [ton·ha <sup>-1</sup> ]	0.820	0.308	<b>7.99E-03</b>	1.120	0.246	<b>6.00E-06</b>	2.166	0.237	<b>2.49E-19</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.028	0.002	<b>7.05E-31</b>	0.026	0.003	<b>1.30E-23</b>	0.027	0.003	<b>7.43E-22</b>
$\beta_{NDP20}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.033	0.029	2.51E-01	0.044	0.043	2.98E-01	-0.050	0.051	3.22E-01
$\beta_{NDP1}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.083	0.011	<b>5.74E-13</b>	0.112	0.012	<b>3.20E-19</b>	0.030	0.014	<b>3.24E-02</b>
$\beta_{NDT25}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.005	0.006	4.21E-01	-0.013	0.010	1.94E-01	-0.007	0.009	4.14E-01
$\beta_{Frost}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.007	0.015	6.34E-01	0.012	0.015	4.43E-01	-	-	-
$\beta_{NDP20\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.003	0.008	7.28E-01	-0.035	0.015	<b>2.47E-02</b>	0.014	0.024	5.46E-01
$\beta_{NDP1\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.001	0.000	<b>3.77E-14</b>	-0.002	0.000	<b>2.78E-21</b>	-0.001	0.000	<b>1.98E-02</b>
$\beta_{NDT25\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	0.000	0.000	<b>3.94E-03</b>	0.000	0.001	8.18E-01	-0.001	0.000	<b>3.25E-02</b>
$\beta_{Frost\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	0.000	0.002	8.76E-01	0.000	0.002	8.49E-01			
<i>AIC</i>	1719			1728			1770		
<i>r2marg</i>	0.23			0.21			0.20		
<i>r2cond</i>	0.81			0.81			0.80		

Table S3 Same as above but for spring wheat

Period	Pre-growing (2 months prior to the main growing season)								
<i>Used indicators</i>	(1) DI								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
Name	Estimate	SE	p						
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.747	0.228	<b>9.28E-18</b>						
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.028	0.004	<b>9.24E-11</b>						
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	0.414	0.145	<b>4.49E-03</b>						
$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	-0.075	0.032	<b>1.91E-02</b>						
<i>AIC</i>	1030								
<i>r2marg</i>	0.32								
<i>r2cond</i>	0.80								
Period	Entire growing season			Pre-flowering			Post-flowering		
<b>Used indicators</b>	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
<b>Model Structure [unit]</b>	$\beta_0 + \beta_t t + \beta_{Px\_P} + \beta_{Tx\_T} + \beta_{PTx\_Px\_T}$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
$\beta_0$ [ton·ha <sup>-1</sup> ]	9.868	1.320	<b>4.385E-12</b>	5.329	0.82	<b>5.202E-09</b>	7.252	1.027	<b>8.782E-11</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.040	0.004	<b>4.178E-17</b>	0.031	0.00	<b>3.079E-12</b>	0.033	0.004	<b>3.737E-15</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ]	-0.253	0.060	<b>5.876E-06</b>	-0.251	0.08	<b>1.128E-03</b>	-0.211	0.065	<b>1.300E-03</b>
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.471	0.092	<b>4.420E-07</b>	-0.182	0.07	<b>5.992E-03</b>	-0.252	0.061	<b>4.516E-05</b>
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ·°C <sup>-1</sup> ]	0.020	0.003	<b>9.612E-06</b>	0.020	0.01	<b>1.476E-03</b>	0.012	0.004	<b>1.985E-03</b>
<i>AIC</i>	1031			1042			1039		
<i>r2marg</i>	0.34			0.32			0.35		
<i>r2cond</i>	0.80			0.81			0.81		

<b>Used indicators</b>	(3) Pvar (denoted as x_P) and Tvar (denoted as x_T)								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	3.515	0.247	<b>7.014E-25</b>	3.333	0.218	<b>6.456E-26</b>	2.585	0.257	<b>3.176E-22</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.030	0.004	<b>1.915E-11</b>	0.030	0.004	<b>5.921E-11</b>	0.030	0.004	<b>2.341E-11</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·mm <sup>-2</sup> ·day <sup>2</sup> ]	-0.005	0.003	9.491E-02	-0.005	0.004	1.700E-01	-0.001	0.002	4.099E-01
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ·day <sup>2</sup> ]	-0.023	0.009	<b>1.006E-02</b>	-0.012	0.006	<b>4.098E-02</b>	0.015	0.015	3.122E-01
AIC	1040			1042			1046		
r2marg	0.32			0.31			0.31		
r2cond	0.81			0.81			0.80		
<b>Used indicators</b>	(4) CDD (denoted as x_P) and Tmean (denoted as x_T)								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{T2} x_T^2 + \beta_{PT} x_P x_T$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	-12.394	4.354	<b>3.186E-03</b>	-6.36	2.73	<b>1.228E-02</b>	-4.60	3.71	2.153E-01
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.033	0.003	<b>9.375E-17</b>	0.032	0.00	<b>8.009E-15</b>	0.03	0.00	<b>5.826E-15</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.130	0.054	<b>1.847E-02</b>	0.145	0.04	<b>7.625E-04</b>	0.14	0.08	8.009E-02
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	2.116	0.612	<b>5.808E-04</b>	1.415	0.44	<b>1.387E-03</b>	0.87	0.46	6.086E-02
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.009	0.003	<b>1.012E-02</b>	-0.012	0.00	<b>3.256E-04</b>	-0.01	0.00	7.022E-02
$\beta_{T2}$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ]	-0.071	0.021	<b>1.014E-03</b>	-0.051	0.02	<b>4.222E-03</b>	-0.03	0.01	7.021E-02
AIC	1029			1038			1045		
r2marg	<b>0.38</b>			<b>0.36</b>			<b>0.35</b>		
r2cond	<b>0.81</b>			<b>0.81</b>			<b>0.81</b>		
<b>Used indicators</b>	(5) DI								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{DI} (DI) + \beta_{DI2} (DI)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.64	0.28	<b>2.59E-19</b>	2.71	0.26	<b>3.94E-24</b>	2.70	0.25	<b>3.39E-25</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.03	0.00	<b>3.14E-13</b>	0.03	0.00	<b>7.28E-12</b>	0.03	0.00	<b>3.96E-12</b>
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	0.04	0.07	5.84E-01	-0.01	0.03	6.70E-01	-0.01	0.03	8.68E-01
$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	-0.01	0.01	8.39E-02	0.00	0.00	7.64E-01	0.00	0.00	2.92E-01
AIC	1034			1047			1042		
r2marg	0.32			0.31			0.31		
r2cond	0.80			0.80			0.80		
<b>Used indicators</b>	(6) Short-term indicators								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{NDP1} (NDP1) + \beta_{NDT25} (NDT25) + \beta_{NDP20} (NDP20) + \beta_{Frost} (Frost) + \beta_{NDP1\_2} (NDP1)^2 + \beta_{NDT25\_2} (NDT25)^2 + \beta_{NDP20\_2} (NDP20)^2 + \beta_{Frost\_2} (Frost)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	1.995	0.466	<b>2.18E-05</b>	2.547	0.307	<b>6.91E-16</b>	2.189	0.339	<b>2.14E-10</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.033	0.004	<b>1.10E-16</b>	0.031	0.004	<b>2.73E-13</b>	0.031	0.004	<b>3.83E-14</b>
$\beta_{NDP20}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.065	0.042	1.22E-01	-0.023	0.094	8.06E-01	-0.083	0.046	<b>7.30E-02</b>
$\beta_{NDP1}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.052	0.021	<b>1.29E-02</b>	0.033	0.022	1.44E-01	0.053	0.022	<b>1.78E-02</b>
$\beta_{NDT25}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.013	0.010	1.97E-01	-0.012	0.020	5.48E-01	-0.004	0.013	7.51E-01
$\beta_{Frost}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	-0.020	0.024	3.95E-01	-0.016	0.024	5.00E-01	-	-	-
$\beta_{NDP20\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	0.009	0.011	4.13E-01	-0.016	0.050	7.50E-01	0.018	0.013	1.80E-01
$\beta_{NDP1\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.001	0.000	<b>5.09E-03</b>	-0.001	0.001	5.84E-02	-0.001	0.001	<b>1.52E-02</b>
$\beta_{NDT25\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	0.000	0.000	3.50E-01	-0.001	0.001	3.09E-01	0.000	0.000	3.17E-01

$\beta_{Frost\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	0.001	0.003	8.18E-01	0.001	0.003	7.44E-01	-	-	-
<i>AIC</i>	1091			1093			1076		
<i>r2marg</i>	0.35			0.30			0.34		
<i>r2cond</i>	0.80			0.80			0.80		

Table S4 Same as above but for oats

Period	Pre-growing (3 months prior to the main growing season)								
<i>Used indicators</i>	(1) DI								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
Name	Estimate	SE	p						
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.764	0.184	<b>1.36E-26</b>						
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.021	0.004	<b>2.55E-07</b>						
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	-0.053	0.065	4.11E-01						
$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	0.001	0.005	7.72E-01						
<i>AIC</i>	<b>1580</b>								
<i>r2marg</i>	<b>0.15</b>								
<i>r2cond</i>	<b>0.75</b>								
Period	Entire growing season			Pre-flowering			Post-flowering		
<i>Used indicators</i>	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T + \beta_{T2} x_T^2$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
$\beta_0$ [ton·ha <sup>-1</sup> ]	-3.551	3.585	2.75E-01	7.926	2.014	<b>1.68E-04</b>	-3.657	2.185	<b>6.49E-02</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.024	0.003	<b>1.59E-13</b>	0.020	0.004	<b>1.86E-06</b>	0.025	0.003	<b>3.88E-16</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ]	-0.183	0.042	<b>1.62E-05</b>	-0.130	0.054	<b>1.78E-02</b>	-0.149	0.048	<b>1.13E-03</b>
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	1.246	0.490	<b>1.12E-02</b>	-0.796	0.314	<b>1.08E-02</b>	1.034	0.258	<b>6.46E-05</b>
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·cm <sup>-1</sup> ·°C <sup>-1</sup> ]	0.013	0.003	<b>1.37E-05</b>	0.010	0.004	<b>2.25E-02</b>	0.009	0.003	<b>1.26E-03</b>
$\beta_{T2}$	-0.057	0.016	<b>6.77E-04</b>	0.030	0.012	<b>1.32E-02</b>	-0.039	0.007	<b>2.56E-07</b>
<i>AIC</i>	1546			1591			1516		
<i>r2marg</i>	0.22			0.15			0.26		
<i>r2cond</i>	0.76			0.76			0.76		
<i>Used indicators</i>	(3) Pvar (denoted as P) and Tvar (denoted as T)								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_P P + \beta_T T$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	3.194	0.205	<b>9.19E-32</b>	2.804	0.187	<b>5.39E-27</b>	2.718	0.182	<b>2.08E-26</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.0198	0.003	<b>1.91E-07</b>	0.020	0.004	<b>3.47E-07</b>	0.020	0.004	<b>1.70E-07</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·mm <sup>-2</sup> ·day <sup>2</sup> ]	0.00	0.002	6.94E-01	0.00	0.003	9.77E-01	0.00	0.001	5.62E-01
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ·day <sup>2</sup> ]	-0.030	0.006	<b>5.94E-07</b>	-0.01	0.004	1.24E-01	-0.003	0.009	6.83E-01
<i>AIC</i>	1562			1585			1586		
<i>r2marg</i>	0.17			0.15			0.15		
<i>r2cond</i>	0.76			0.75			0.75		
<i>Used indicators</i>	(4) CDD (denoted as P) and Tmean (denoted as T)								
<i>Model Structure</i>	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{T2} x_T^2 + \beta_{PT} x_P x_T$								

$\beta_0$ [ton·ha <sup>-1</sup> ]	-9.544	2.905	<b>6.90E-04</b>	4.170	1.75	<b>2.81E-02</b>	-5.991	2.003	<b>1.50E-03</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.023	0.002	<b>1.63E-15</b>	0.019	0.00	<b>2.70E-07</b>	0.026	0.003	<b>1.07E-16</b>
$\beta_P$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.134	0.036	<b>2.41E-04</b>	0.095	0.03	<b>2.34E-03</b>	0.066	0.041	1.15E-01
$\beta_T$ [ton·ha <sup>-1</sup> ·°C <sup>-1</sup> ]	1.741	0.419	<b>3.56E-05</b>	-0.367	0.28	1.93E-01	1.194	0.250	<b>2.17E-06</b>
$\beta_{PT}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ·°C <sup>-1</sup> ]	-0.011	0.002	<b>1.67E-05</b>	-0.008	0.00	<b>4.69E-04</b>	-0.004	0.002	7.86E-02
$\beta_{T2}$ [ton·ha <sup>-1</sup> ·°C <sup>-2</sup> ]	-0.060	0.015	<b>8.25E-05</b>	0.021	0.01	6.22E-02	-0.040	0.007	<b>3.22E-07</b>
AIC	1501			1576			1521		
<i>r2marg</i>	0.26			0.16			0.26		
<i>r2cond</i>	0.77			0.76			0.77		
<b>Used indicators</b>	(5) DI								
<b>Model Structure</b>	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	2.75	0.23	<b>7.47E-31</b>	2.43	0.22	<b>1.46E-26</b>	2.40	0.21	<b>1.79E-27</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.02	0.00	<b>1.93E-08</b>	0.02	0.00	<b>1.07E-07</b>	0.02	0.00	<b>1.62E-07</b>
$\beta_{DI}$ [ton·ha <sup>-1</sup> ]	-0.13	0.05	<b>1.19E-02</b>	0.00	0.02	9.98E-01	0.00	0.01	8.85E-01
$\beta_{DI2}$ [ton·ha <sup>-1</sup> ]	0.01	0.00	2.19E-01	0.00	0.00	2.25E-01	0.00	0.00	9.31E-01
AIC	1570			1580			1602		
<i>r2marg</i>	0.16			0.15			0.15		
<i>r2cond</i>	0.76			0.75			0.75		
<b>Used indicators</b>	(6) Short-term indicators								
<b>Model Structure</b>	$\beta_0 + \beta_{tt} t + \beta_{NDP1}(NDP1) + \beta_{NDT25}(NDT25) + \beta_{NDP20}(NDP20) + \beta_{Frost}(Frost) + \beta_{NDP1\_2}(NDP1)^2 + \beta_{NDT25\_2}(NDT25)^2 + \beta_{NDP20\_2}(NDP20)^2 + \beta_{Frost\_2}(Frost)^2$								
$\beta_0$ [ton·ha <sup>-1</sup> ]	1.881	0.263	<b>1.65E-12</b>	1.781	0.321	<b>3.59E-08</b>	2.141	0.235	<b>4.62E-19</b>
$\beta_t$ [ton·ha <sup>-1</sup> ·yr <sup>-1</sup> ]	0.021	0.004	<b>2.90E-08</b>	0.023	0.003	<b>8.65E-15</b>	0.023	0.003	<b>6.13E-13</b>
$\beta_{NDP20}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.097	0.055	7.72E-02	0.011	0.033	7.45E-01	-0.009	0.037	8.17E-01
$\beta_{NDP1}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.053	0.016	<b>8.65E-04</b>	0.040	0.014	<b>3.03E-03</b>	0.041	0.014	<b>3.25E-03</b>
$\beta_{NDT25}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.014	0.015	3.60E-01	-0.022	0.008	<b>3.76E-03</b>	-0.030	0.010	<b>1.94E-03</b>
$\beta_{Frost}$ [ton·ha <sup>-1</sup> ·day <sup>-1</sup> ]	0.024	0.016	1.38E-01	0.023	0.016	1.46E-01	-	-	-
$\beta_{NDP20\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.032	0.024	1.73E-01	-0.002	0.009	7.86E-01	-0.002	0.012	8.80E-01
$\beta_{NDP1\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.001	0.000	<b>1.49E-04</b>	-0.001	0.000	<b>3.82E-03</b>	-0.001	0.000	<b>6.96E-03</b>
$\beta_{NDT25\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.001	0.001	2.41E-01	0.000	0.000	4.50E-01	0.000	0.000	6.98E-01
$\beta_{Frost\_2}$ [ton·ha <sup>-1</sup> ·day <sup>-2</sup> ]	-0.001	0.001	3.83E-01	-0.002	0.001	2.56E-01	-	-	-
AIC	1630			1606			1569		
<i>r2marg</i>	0.16			0.23			0.23		
<i>r2cond</i>	0.75			0.75			0.76		

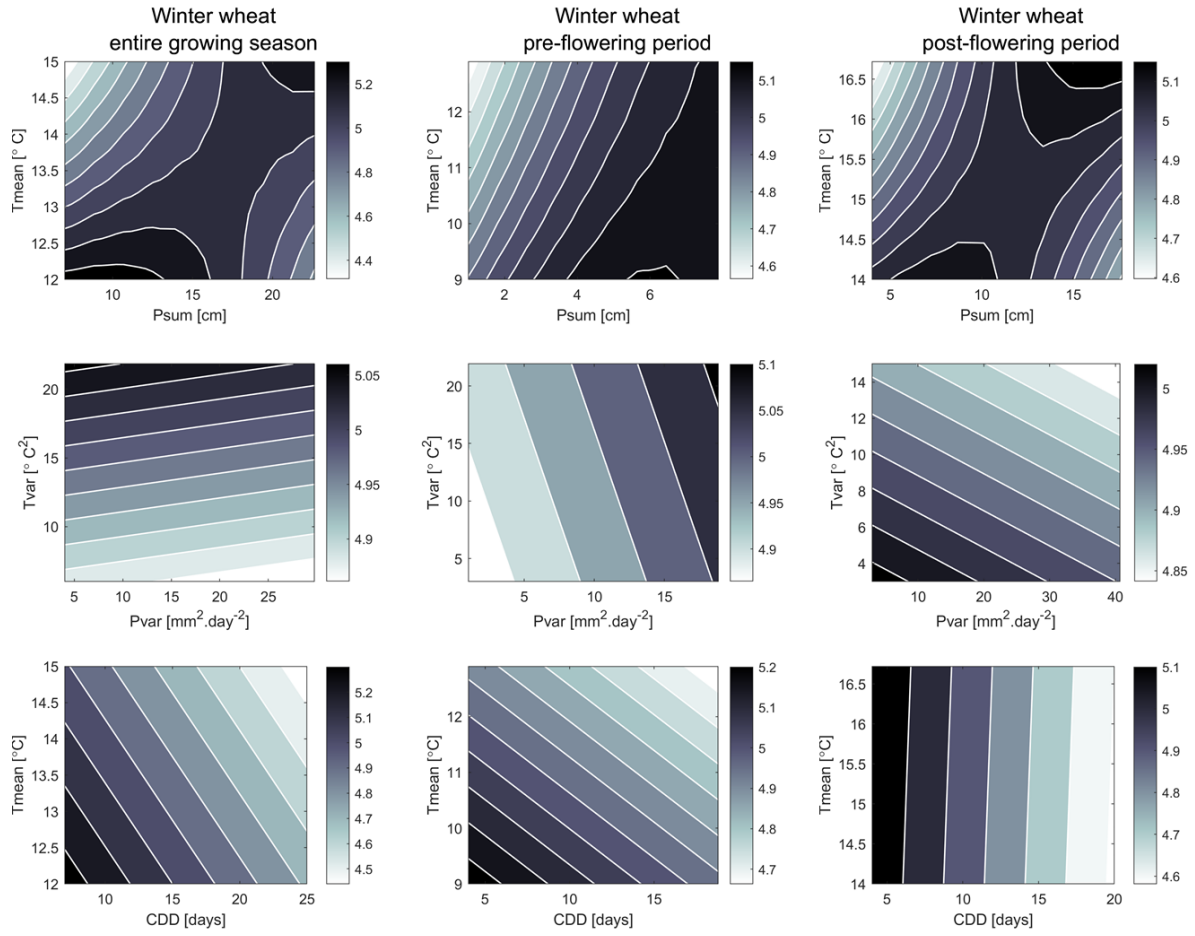


Figure S1 The model representing interacting indicators for winter wheat

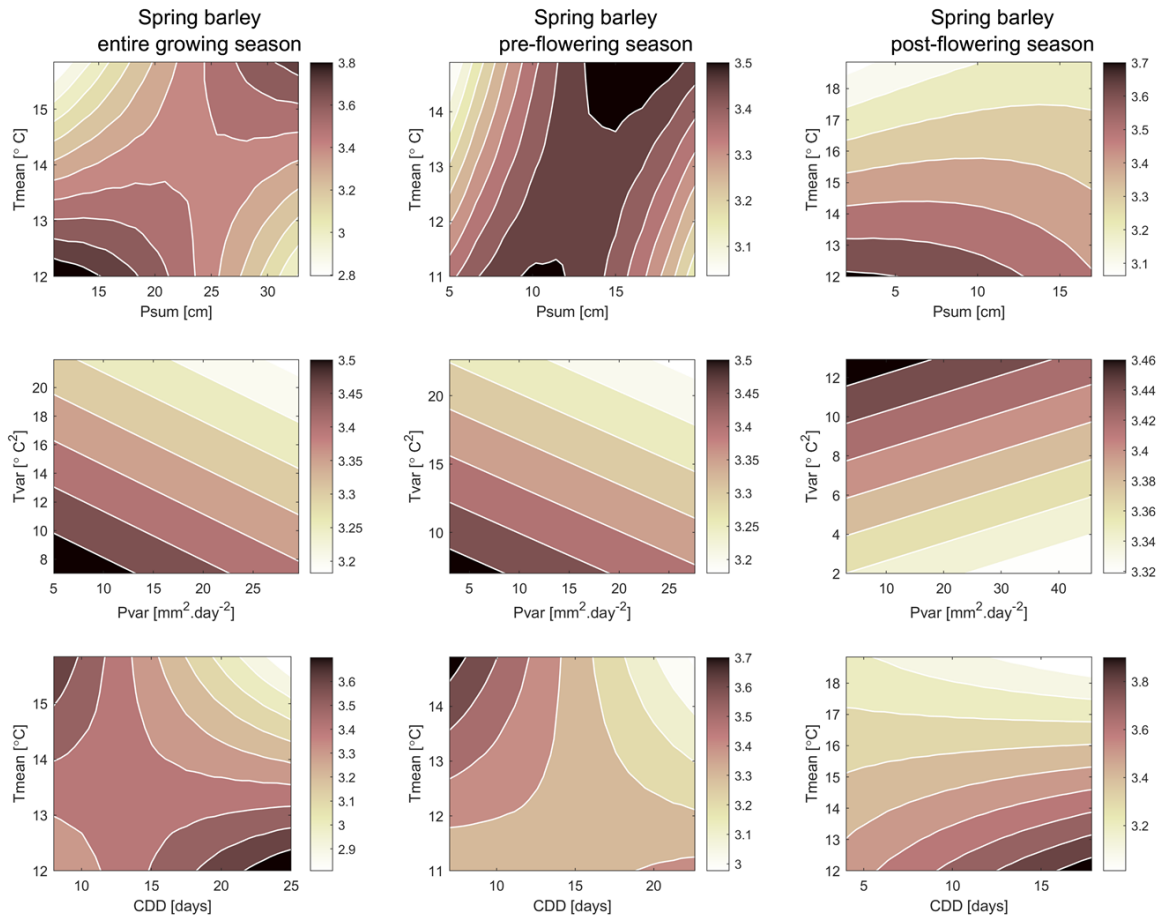


Figure. S2 Same as above but for spring barley

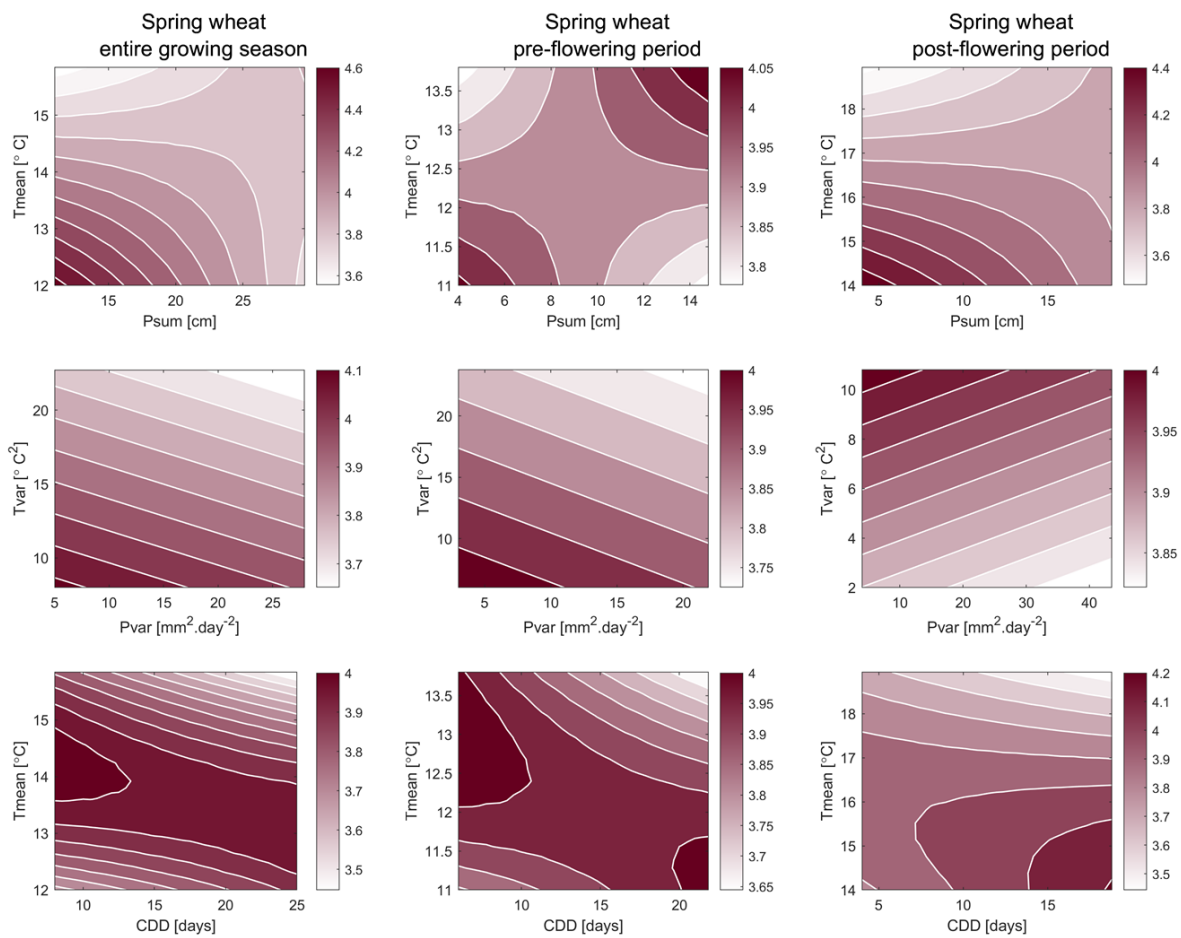


Figure. S3 Same as above but for spring wheat

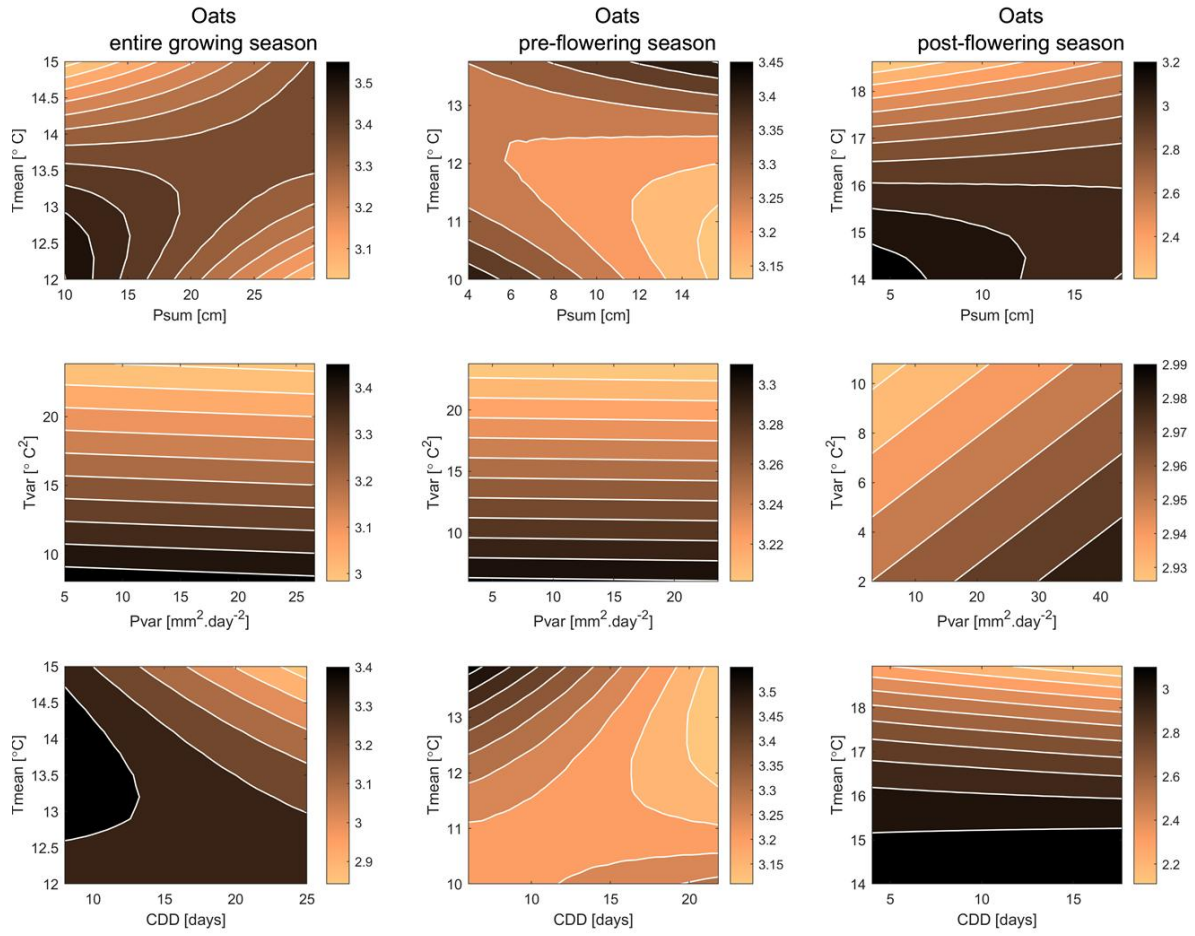


Figure S4 Same as above but for oats