

Supplementary information

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 $r2_{\text{marg}}$ and $r2_{\text{cond}}$ 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)								
Used indicators	(1) DI								
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
Name	Estimate	SE	p						
β_0 [ton·ha ⁻¹]	3.147	0.285	2.73E-13						
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.050	0.005	2.46E-22						
β_{DI} [ton·ha ⁻¹]	0.884	0.298	3.09E-03						
β_{DI2} [ton·ha ⁻¹]	-0.351	0.109	1.29E-03						
AIC	1450								
r2marg	0.44								
r2cond	0.85								
Period	Entire growing season			Pre-flowering			Post-flowering		
Used indicators	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{P2} x_P^2 + \beta_{PT} x_P x_T$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
β_0 [ton·ha ⁻¹]	10.432	1.253	4.78E-14	4.294	0.584	3.97E-09	7.333	1.101	3.61E-09
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.054	0.004	3.93E-31	0.052	0.005	8.21E-26	0.051	0.005	1.70E-25
β_P [ton·ha ⁻¹ ·cm ⁻¹]	-0.330	0.074	1.04E-05	0.01	0.115	9.33E-01	-0.273	0.087	1.75E-03
β_T [ton·ha ⁻¹ ·°C ⁻¹]	-0.568	0.088	1.67E-10	-0.099	0.047	3.45E-02	-0.271	0.067	6.33E-05
β_{PT} [ton·ha ⁻¹ ·cm ⁻¹ ·°C ⁻¹]	0.032	0.005	1.39E-10	0.012	0.009	1.60E-01	0.024	0.005	4.51E-06
β_{P2} [ton·ha ⁻¹ ·cm ⁻²]	-0.003	0.001	4.97E-09	-0.010	0.004	9.81E-03	-0.004	0.001	6.52E-06
AIC	1394			1458			1428		
r2marg	0.50			0.45			0.46		
r2cond	0.87			0.85			0.86		
Used indicators	(3) Pvar (denoted as x_P) and Tvar (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
β_0 [ton·ha ⁻¹]	3.457	0.269	5.58E-17	3.495	0.234	2.26E-21	3.701	0.245	1.36E-22

β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.051	0.005	5.65E-23	0.05	0.005	1.88E-23	0.051	0.005	6.10E-23
β_P [ton·ha ⁻¹ ·mm ⁻² ·day ²]	-0.001	0.003	6.86E-01	0.011	0.004	3.88E-03	-0.002	0.002	2.98E-01
β_T [ton·ha ⁻¹ ·°C ⁻² ·day ²]	0.011	0.01	2.63E-01	0.003	0.007	6.45E-01	-0.01	0.012	4.30E-01
AIC	1471			1464			1470		
r2marg	0.44			0.44			0.44		
r2cond	0.85			0.85			0.85		
Used indicators	(4) CDD (denoted as x_P) and Tmean (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
β_0 [ton·ha ⁻¹]	5.585	0.735	8.98E-11	4.613	0.415	2.12E-19	3.927	0.717	1.07E-05
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.050	0.005	1.07E-25	0.052	0.005	1.11E-25	0.048	0.005	1.78E-21
β_P [ton·ha ⁻¹ ·day ⁻¹]	-0.032	0.004	2.84E-12	-0.018	0.007	5.67E-03	-0.037	0.005	2.36E-11
β_T [ton·ha ⁻¹ ·°C ⁻¹]	-0.114	0.054	3.58E-02	-0.078	0.033	1.96E-02	0.007	0.047	8.78E-01
AIC	1409			1452			1420		
r2marg	0.47			0.45			0.46		
r2cond	0.86			0.85			0.86		
Used indicators	(5) DI								
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
β_0 [ton·ha ⁻¹]	3.432	0.279	5.72E-32	2.911	0.266	5.09E-26	3.188	0.286	7.80E-27
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.049	0.005	9.71E-26	0.051	0.005	1.28E-25	0.049	0.005	1.05E-22
β_{DI} [ton·ha ⁻¹]	-0.189	0.033	1.45E-08	-0.018	0.004	3.95E-05	-0.085	0.029	3.66E-03
β_{DI2} [ton·ha ⁻¹]	0.004	0.001	3.81E-03	0.001	0	4.57E-04	0.001	0.001	4.87E-01
AIC	1430			1468			1442		
r2marg	0.47			0.44			0.45		
r2cond	0.86			0.85			0.86		
Used indicators	(6) Short-term indicators								
Model Structure	$\beta_0 + \beta_t t + \beta_{NDP1}(NDP1) + \beta_{NDT25}(NDT25) + \beta_{NDP20}(NDP20) + \beta_{Frost}(Frost) + \beta_{NDP1_2}(NDP1)^2 + \beta_{NDT25_2}(NDT25)^2 + \beta_{NDP20_2}(NDP20)^2 + \beta_{Frost_2}(Frost)^2$								
β_0 [ton·ha ⁻¹]	1.156	0.411	5.08E-03	2.342	0.297	1.12E-14	1.88	0.352	1.25E-07
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.051	0.005	5.94E-27	0.051	0.005	2.75E-25	0.049	0.005	5.10E-24
β_{NDP20} [ton·ha ⁻¹ ·day ⁻¹]	0.013	0.046	7.86E-01	0.168	0.236	4.76E-01	-0.024	0.051	6.42E-01
β_{NDP1} [ton·ha ⁻¹ ·day ⁻¹]	0.120	0.021	1.56E-08	0.081	0.025	1.28E-03	0.123	0.022	4.73E-08

β_{NDT25} [ton·ha ⁻¹ ·day ⁻¹]	-0.009	0.015	5.45E-01	0.016	0.032	6.19E-01	-0.01	0.018	5.92E-01
β_{Frost} [ton·ha ⁻¹ ·day ⁻¹]	0.036	0.03	2.27E-01	0.042	0.03	1.58E-01	-	-	-
β_{NDP20_2} [ton·ha ⁻¹ ·day ⁻²]	-0.008	0.013	5.52E-01	-0.052	0.176	7.68E-01	-0.006	0.015	6.84E-01
β_{NDP1_2} [ton·ha ⁻¹ ·day ⁻²]	-0.002	0	6.10E-08	-0.003	0.001	9.99E-03	-0.003	0.001	1.41E-08
β_{NDT25_2} [ton·ha ⁻¹ ·day ⁻²]	0	0.001	9.36E-01	-0.003	0.004	3.73E-01	0	0.001	9.11E-01
β_{Frost_2} [ton·ha ⁻¹ ·day ⁻²]	-0.002	0.004	5.40E-01	-0.002	0.004	5.30E-01	-	-	-
AIC	1499			1504			1478		
r2marg	0.46			0.44			0.45		
r2cond	0.85			0.85			0.85		

Table S2 Same as above but for spring barley.

Period	Pre-growing (3 months prior to the main growing season)								
Used indicators	(1) DI								
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
Name	Estimate	SE	p						
β_0 [ton·ha ⁻¹]	2.149	0.214	7.67E-23						
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.025	0.003	1.26E-17						
β_{DI} [ton·ha ⁻¹]	0.195	0.055	4.68E-04						
β_{DI2} [ton·ha ⁻¹]	-0.014	0.004	2.69E-03						
AIC	1756								
r2marg	0.18								
r2cond	0.80								
Period	Entire growing season			Pre-flowering			Post-flowering		
Used indicators	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T + \beta_{P2} x_P^2$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
β_0 [ton·ha ⁻¹]	9.138	0.765	4.3E-31	3.601	0.681	1.45E-07	3.807	0.425	1.39E-18
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.028	0.002	1.3E-28	0.026	0.003	6.47E-20	0.027	0.003	1.62E-20
β_P [ton·ha ⁻¹ ·cm ⁻¹]	-0.259	0.034	3.03E-14	-0.042	0.050	4.03E-01	-0.044	0.035	2.07E-01
β_T [ton·ha ⁻¹ ·°C ⁻¹]	-0.530	0.050	1.46E-25	-0.147	0.048	2.30E-03	-0.103	0.022	2.62E-06
β_{PT} [ton·ha ⁻¹ ·cm ⁻¹ ·°C ⁻¹]	0.022	0.002	2.58E-27	0.012	0.003	4.65E-04	0.004	0.002	3.01E-02
β_{P2} [ton·ha ⁻¹ ·cm ⁻²]	-0.001	0.000	1.32E-05	-0.004	0.000	1.29E-15	-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		
Used indicators	(3) Pvar (denoted as x_P) and Tvar (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
β_0 [ton·ha ⁻¹]	2.617	0.225	1.30E-29	2.600	0.217	3.27E-31	2.280	0.213	1.62E-25

β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.025	0.003	3.97E-17	0.025	0.003	5.33E-16	0.025	0.003	1.26E-16
β_p [ton·ha ⁻¹ ·mm ⁻² ·day ²]	-0.005	0.002	1.12E-02	-0.005	0.002	2.15E-02	-0.001	0.001	3.71E-01
β_T [ton·ha ⁻¹ ·°C ⁻² ·day ²]	-0.015	0.006	5.96E-03	-0.015	0.004	2.29E-04	0.010	0.006	1.01E-01
AIC	1760			1755			1770		
<i>r2marg</i>	0.18			0.18			0.18		
<i>r2cond</i>	0.80			0.80			0.80		
Used indicators	(4) CDD (denoted as P) and Tmean (denoted as T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T + \beta_{T^2} x_T^2$								
β_0 [ton·ha ⁻¹]	-8.056	1.632	9.16E-07	-1.106	1.815	5.43E-01	1.512	0.733	3.92E-02
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.027	0.002	8.81E-28	0.024	0.003	1.65E-19	0.028	0.003	5.26E-22
β_P [ton·ha ⁻¹ ·day ⁻¹]	0.226	0.031	3.72E-13	0.165	0.032	3.30E-07	0.094	0.025	1.35E-04
β_T [ton·ha ⁻¹ ·°C ⁻¹]	1.317	0.238	3.85E-08	0.373	0.279	1.82E-01	0.119	0.089	1.82E-01
β_{PT} [ton·ha ⁻¹ ·day ⁻¹ ·°C ⁻¹]	-0.017	0.002	2.12E-15	-0.014	0.002	3.34E-09	-0.006	0.001	1.55E-04
β_{T^2} [ton·ha ⁻¹ ·°C ⁻²]	-0.040	0.009	8.41E-06	-0.006	0.011	5.67E-01	-0.005	0.003	1.05E-01
AIC	1603			1696			1750		
<i>r2marg</i>	0.24			0.21			0.21		
<i>r2cond</i>	0.82			0.81			0.80		
Used indicators	(5) DI								
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI^2}(DI)^2$								
β_0 [ton·ha ⁻¹]	2.123	0.228	6.70E-20	2.468	0.208	7.90E-31	2.328	0.206	3.83E-28
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.025	0.003	2.06E-20	0.025	0.003	1.13E-18	0.025	0.003	1.32E-16
β_{DI} [ton·ha ⁻¹]	0.171	0.056	2.18E-03	-0.028	0.020	1.65E-01	-0.001	0.001	5.14E-02
β_{DI^2} [ton·ha ⁻¹]	-0.031	0.006	4.91E-07	-0.001	0.001	1.56E-01	0.000	0.000	1.94E-02
AIC	1720			1740			1790		
<i>r2marg</i>	0.19			0.18			0.18		
<i>r2cond</i>	0.80			0.80			0.80		
Used indicators	(6) Short-term indicators								

Table S3 Same as above but for spring wheat

Period	Pre-growing (2 months prior to the main growing season)		
Used indicators	(1) DI		
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI^2}(DI)^2$		
Name	Estimate	SE	p
β_0 [ton·ha ⁻¹]	2.747	0.228	9.28E-18
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.028	0.004	9.24E-11
β_{DI} [ton·ha ⁻¹]	0.414	0.145	4.49E-03
β_{DI^2} [ton·ha ⁻¹]	-0.075	0.032	1.91E-02
AIC	1030		
<i>r2marg</i>	0.32		
<i>r2cond</i>	0.80		

Period	Entire growing season			Pre-flowering			Post-flowering		
Used indicators	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
Model Structure [unit]	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
β_0 [ton·ha ⁻¹]	9.868	1.320	4.385E-12	5.329	0.82	5.202E-09	7.252	1.027	8.782E-11
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.040	0.004	4.178E-17	0.031	0.00	3.079E-12	0.033	0.004	3.737E-15
β_P [ton·ha ⁻¹ ·cm ⁻¹]	-0.253	0.060	5.876E-06	-0.251	0.08	1.128E-03	-0.211	0.065	1.300E-03
β_T [ton·ha ⁻¹ ·°C ⁻¹]	-0.471	0.092	4.420E-07	-0.182	0.07	5.992E-03	-0.252	0.061	4.516E-05
β_{PT} [ton·ha ⁻¹ ·cm ⁻¹ ·°C ⁻¹]	0.020	0.003	9.612E-06	0.020	0.01	1.476E-03	0.012	0.004	1.985E-03
AIC	1031			1042			1039		
r2marg	0.34			0.32			0.35		
r2cond	0.80			0.81			0.81		
Used indicators	(3) Pvar (denoted as x_P) and Tvar (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T$								
β_0 [ton·ha ⁻¹]	3.515	0.247	7.014E-25	3.333	0.218	6.456E-26	2.585	0.257	3.176E-22
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.030	0.004	1.915E-11	0.030	0.004	5.921E-11	0.030	0.004	2.341E-11
β_P [ton·ha ⁻¹ ·mm ⁻² ·day ²]	-0.005	0.003	9.491E-02	-0.005	0.004	1.700E-01	-0.001	0.002	4.099E-01
β_T [ton·ha ⁻¹ ·°C ⁻² ·day ²]	-0.023	0.009	1.006E-02	-0.012	0.006	4.098E-02	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		
Used indicators	(4) CDD (denoted as x_P) and Tmean (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{T2} x_T^2 + \beta_{PT} x_P x_T$								
β_0 [ton·ha ⁻¹]	-12.394	4.354	3.186E-03	-6.36	2.73	1.228E-02	-4.60	3.71	2.153E-01
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.033	0.003	9.375E-17	0.032	0.00	8.009E-15	0.03	0.00	5.826E-15
β_P [ton·ha ⁻¹ ·day ⁻¹]	0.130	0.054	1.847E-02	0.145	0.04	7.625E-04	0.14	0.08	8.009E-02
β_T [ton·ha ⁻¹ ·°C ⁻¹]	2.116	0.612	5.808E-04	1.415	0.44	1.387E-03	0.87	0.46	6.086E-02
β_{PT} [ton·ha ⁻¹ ·day ⁻¹ ·°C ⁻¹]	-0.009	0.003	1.012E-02	-0.012	0.00	3.256E-04	-0.01	0.00	7.022E-02
β_{T2} [ton·ha ⁻¹ ·°C ⁻²]	-0.071	0.021	1.014E-03	-0.051	0.02	4.222E-03	-0.03	0.01	7.021E-02
AIC	1029			1038			1045		
r2marg	0.38			0.36			0.35		
r2cond	0.81			0.81			0.81		
Used indicators	(5) DI								
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$								
β_0 [ton·ha ⁻¹]	2.64	0.28	2.59E-19	2.71	0.26	3.94E-24	2.70	0.25	3.39E-25
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.03	0.00	3.14E-13	0.03	0.00	7.28E-12	0.03	0.00	3.96E-12
β_{DI} [ton·ha ⁻¹]	0.04	0.07	5.84E-01	-0.01	0.03	6.70E-01	-0.01	0.03	8.68E-01
β_{DI2} [ton·ha ⁻¹]	-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		

Used indicators	(6) Short-term indicators								
Model Structure	$\beta_0 + \beta_t t + \beta_{NDP1} (NDP1) + \beta_{NDT25} (NDT25) + \beta_{NDP20} (NDP20) + \beta_{Frost}(Frost)$ $+ \beta_{NDP1_2}(NDP1)^2 + \beta_{NDT25_2}(NDT25)^2 + \beta_{NDP20_2}(NDP20)^2$ $+ \beta_{Frost_2}(Frost)^2$								
β_0 [ton·ha ⁻¹]	1.995	0.466	2.18E-05	2.547	0.307	6.91E-16	2.189	0.339	2.14E-10
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.033	0.004	1.10E-16	0.031	0.004	2.73E-13	0.031	0.004	3.83E-14
β_{NDP20} [ton·ha ⁻¹ ·day ⁻¹]	-0.065	0.042	1.22E-01	-0.023	0.094	8.06E-01	-0.083	0.046	7.30E-02
β_{NDP1} [ton·ha ⁻¹ ·day ⁻¹]	0.052	0.021	1.29E-02	0.033	0.022	1.44E-01	0.053	0.022	1.78E-02
β_{NDT25} [ton·ha ⁻¹ ·day ⁻¹]	-0.013	0.010	1.97E-01	-0.012	0.020	5.48E-01	-0.004	0.013	7.51E-01
β_{Frost} [ton·ha ⁻¹ ·day ⁻¹]	-0.020	0.024	3.95E-01	-0.016	0.024	5.00E-01	-	-	-
β_{NDP20_2} [ton·ha ⁻¹ ·day ⁻²]	0.009	0.011	4.13E-01	-0.016	0.050	7.50E-01	0.018	0.013	1.80E-01
β_{NDP1_2} [ton·ha ⁻¹ ·day ⁻²]	-0.001	0.000	5.09E-03	-0.001	0.001	5.84E-02	-0.001	0.001	1.52E-02
β_{NDT25_2} [ton·ha ⁻¹ ·day ⁻²]	0.000	0.000	3.50E-01	-0.001	0.001	3.09E-01	0.000	0.000	3.17E-01
β_{Frost_2} [ton·ha ⁻¹ ·day ⁻²]	0.001	0.003	8.18E-01	0.001	0.003	7.44E-01	-	-	-
AIC	1091			1093			1076		
r2marg	0.35			0.30			0.34		
r2cond	0.80			0.80			0.80		

Table S4 Same as above but for oats

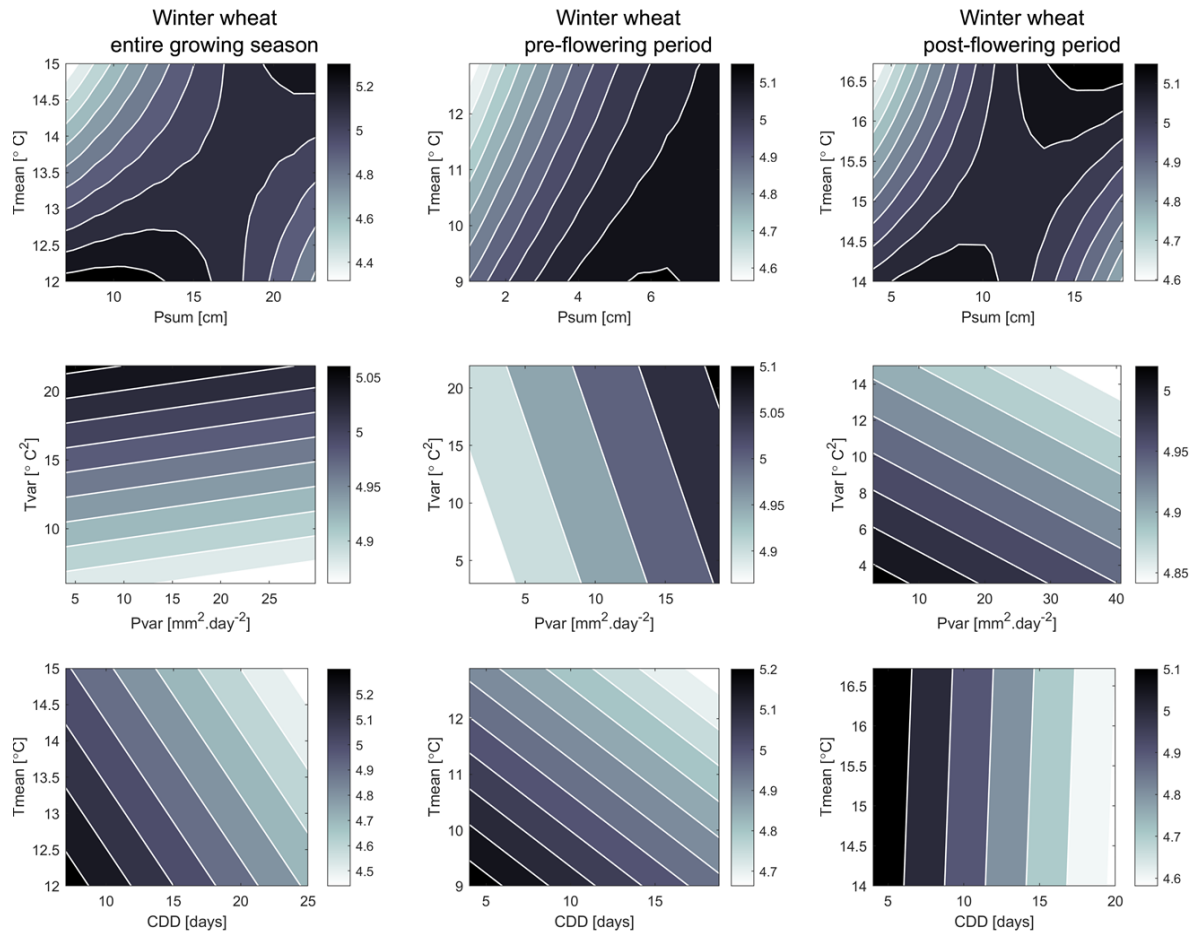
Period	Pre-growing (3 months prior to the main growing season)		
Used indicators	(1) DI		
Model Structure	$\beta_0 + \beta_t t + \beta_{DI}(DI) + \beta_{DI2}(DI)^2$		
Name	Estimate	SE	p
β_0 [ton·ha ⁻¹]	2.764	0.184	1.36E-26
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.021	0.004	2.55E-07
β_{DI} [ton·ha ⁻¹]	-0.053	0.065	4.11E-01
β_{DI2} [ton·ha ⁻¹]	0.001	0.005	7.72E-01
AIC	1580		
r2marg	0.15		
r2cond	0.75		

Period	Entire growing season			Pre-flowering			Post-flowering		
Used indicators	(2) Psum (denoted as x_P) and Tmean (denoted as x_T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{PT} x_P x_T + \beta_{T2} x_T^2$								
Name	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
β_0 [ton·ha ⁻¹]	-3.551	3.585	2.75E-01	7.926	2.014	1.68E-04	-3.657	2.185	6.49E-02
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.024	0.003	1.59E-13	0.020	0.004	1.86E-06	0.025	0.003	3.88E-16
β_P [ton·ha ⁻¹ ·cm ⁻¹]	-0.183	0.042	1.62E-05	-0.130	0.054	1.78E-02	-0.149	0.048	1.13E-03
β_T [ton·ha ⁻¹ ·°C ⁻¹]	1.246	0.490	1.12E-02	-0.796	0.314	1.08E-02	1.034	0.258	6.46E-05
β_{PT} [ton·ha ⁻¹ ·cm ⁻¹ ·°C ⁻¹]	0.013	0.003	1.37E-05	0.010	0.004	2.25E-02	0.009	0.003	1.26E-03
β_{T2}	-0.057	0.016	6.77E-04	0.030	0.012	1.32E-02	-0.039	0.007	2.56E-07
AIC	1546			1591			1516		

<i>r2marg</i>	0.22			0.15			0.26		
<i>r2cond</i>	0.76			0.76			0.76		
Used indicators	(3) Pvar (denoted as P) and Tvar (denoted as T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P P + \beta_T T$								
β_0 [ton·ha ⁻¹]	3.194	0.205	9.19E-32	2.804	0.187	5.39E-27	2.718	0.182	2.08E-26
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.0198	0.003	1.91E-07	0.020	0.004	3.47E-07	0.020	0.004	1.70E-07
β_P [ton·ha ⁻¹ ·mm ⁻² ·day ²]	0.00	0.002	6.94E-01	0.00	0.003	9.77E-01	0.00	0.001	5.62E-01
β_T [ton·ha ⁻¹ ·°C ⁻² ·day ²]	-0.030	0.006	5.94E-07	-0.01	0.004	1.24E-01	-0.003	0.009	6.83E-01
AIC	1562			1585			1586		
<i>r2marg</i>	0.17			0.15			0.15		
<i>r2cond</i>	0.76			0.75			0.75		
Used indicators	(4) CDD (denoted as P) and Tmean (denoted as T)								
Model Structure	$\beta_0 + \beta_t t + \beta_P x_P + \beta_T x_T + \beta_{T2} x_T^2 + \beta_{PT} x_P x_T$								
β_0 [ton·ha ⁻¹]	-9.544	2.905	6.90E-04	4.170	1.757	2.81E-02	-5.991	2.003	1.50E-03
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.023	0.002	1.63E-15	0.019	0.004	2.70E-07	0.026	0.003	1.07E-16
β_P [ton·ha ⁻¹ ·day ⁻¹]	0.134	0.036	2.41E-04	0.095	0.031	2.34E-03	0.066	0.041	1.15E-01
β_T [ton·ha ⁻¹ ·°C ⁻¹]	1.741	0.419	3.56E-05	-0.367	0.281	1.93E-01	1.194	0.250	2.17E-06
β_{PT} [ton·ha ⁻¹ ·day ⁻¹ ·°C ⁻¹]	-0.011	0.002	1.67E-05	-0.008	0.002	4.69E-04	-0.004	0.002	7.86E-02
β_{T2} [ton·ha ⁻¹ ·°C ⁻²]	-0.060	0.015	8.25E-05	0.021	0.011	6.22E-02	-0.040	0.007	3.22E-07
AIC	1501			1576			1521		
<i>r2marg</i>	0.26			0.16			0.26		
<i>r2cond</i>	0.77			0.76			0.77		
Used indicators	(5) DI								
Model Structure	$\beta_0 + \beta_t t + \beta_{DI} (DI) + \beta_{DI2} (DI)^2$								
β_0 [ton·ha ⁻¹]	2.75	0.23	7.47E-31	2.43	0.22	1.46E-26	2.40	0.21	1.79E-27
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.02	0.00	1.93E-08	0.02	0.00	1.07E-07	0.02	0.00	1.62E-07
β_{DI} [ton·ha ⁻¹]	-0.13	0.05	1.19E-02	0.00	0.02	9.98E-01	0.00	0.01	8.85E-01
β_{DI2} [ton·ha ⁻¹]	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		
Used indicators	(6) Short-term indicators								
Model Structure	$\beta_0 + \beta_t t + \beta_{NDP1} (NDP1) + \beta_{NDT25} (NDT25) + \beta_{NDP20} (NDP20) + \beta_{Frost} (Frost) + \beta_{NDP1_2} (NDP1)^2 + \beta_{NDT25_2} (NDT25)^2 + \beta_{NDP20_2} (NDP20)^2 + \beta_{Frost_2} (Frost)^2$								
β_0 [ton·ha ⁻¹]	1.881	0.263	1.65E-12	1.781	0.321	3.59E-08	2.141	0.235	4.62E-19
β_t [ton·ha ⁻¹ ·yr ⁻¹]	0.021	0.004	2.90E-08	0.023	0.003	8.65E-15	0.023	0.003	6.13E-13
β_{NDP20} [ton·ha ⁻¹ ·day ⁻¹]	0.097	0.055	7.72E-02	0.011	0.033	7.45E-01	-0.009	0.037	8.17E-01
β_{NDP1} [ton·ha ⁻¹ ·day ⁻¹]	0.053	0.016	8.65E-04	0.040	0.014	3.03E-03	0.041	0.014	3.25E-03
β_{NDT25} [ton·ha ⁻¹ ·day ⁻¹]	0.014	0.015	3.60E-01	-0.022	0.008	3.76E-03	-0.030	0.010	1.94E-03
β_{Frost} [ton·ha ⁻¹ ·day ⁻¹]	0.024	0.016	1.38E-01	0.023	0.016	1.46E-01	-	-	-
β_{NDP20_2} [ton·ha ⁻¹ ·day ⁻²]	-0.032	0.024	1.73E-01	-0.002	0.009	7.86E-01	-0.002	0.012	8.80E-01

$\beta_{NDP1_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	-0.001	0.000	1.49E-04	-0.001	0.000	3.82E-03	-0.001	0.000	6.96E-03
$\beta_{NDT25_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	-0.001	0.001	2.41E-01	0.000	0.000	4.50E-01	0.000	0.000	6.98E-01
$\beta_{Frost_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	-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		

Model Structure	$\beta_0 + \beta_t t + \beta_{NDP1}(NDP1) + \beta_{NDT25}(NDT25) + \beta_{NDP20}(NDP20) + \beta_{Frost}(Frost) + \beta_{NDP1_2}(NDP1)^2 + \beta_{NDT25_2}(NDT25)^2 + \beta_{NDP20_2}(NDP20)^2 + \beta_{Frost_2}(Frost)^2$								
$\beta_0 [\text{ton}\cdot\text{ha}^{-1}]$	0.820	0.308	7.99E-03	1.120	0.246	6.00E-06	2.166	0.237	2.49E-19
$\beta_t [\text{ton}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}]$	0.028	0.002	7.05E-31	0.026	0.003	1.30E-23	0.027	0.003	7.43E-22
$\beta_{NDP20}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-1}]$	-0.033	0.029	2.51E-01	0.044	0.043	2.98E-01	-0.050	0.051	3.22E-01
$\beta_{NDP1}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-1}]$	0.083	0.011	5.74E-13	0.112	0.012	3.20E-19	0.030	0.014	3.24E-02
$\beta_{NDT25} [\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-1}]$	-0.005	0.006	4.21E-01	-0.013	0.010	1.94E-01	-0.007	0.009	4.14E-01
$\beta_{Frost}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-1}]$	0.007	0.015	6.34E-01	0.012	0.015	4.43E-01	-	-	-
$\beta_{NDP20_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	-0.003	0.008	7.28E-01	-0.035	0.015	2.47E-02	0.014	0.024	5.46E-01
$\beta_{NDP1_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	-0.001	0.000	3.77E-14	-0.002	0.000	2.78E-21	-0.001	0.000	1.98E-02
$\beta_{NDT25_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	0.000	0.000	3.94E-03	0.000	0.001	8.18E-01	-0.001	0.000	3.25E-02
$\beta_{Frost_2}[\text{ton}\cdot\text{ha}^{-1}\cdot\text{day}^{-2}]$	0.000	0.002	8.76E-01	0.000	0.002	8.49E-01			
AIC	1719			1728			1770		
<i>r2marg</i>	0.23			0.21			0.20		
<i>r2cond</i>	0.81			0.81			0.80		



15

Figure S1 The model representing interacting indicators for winter wheat

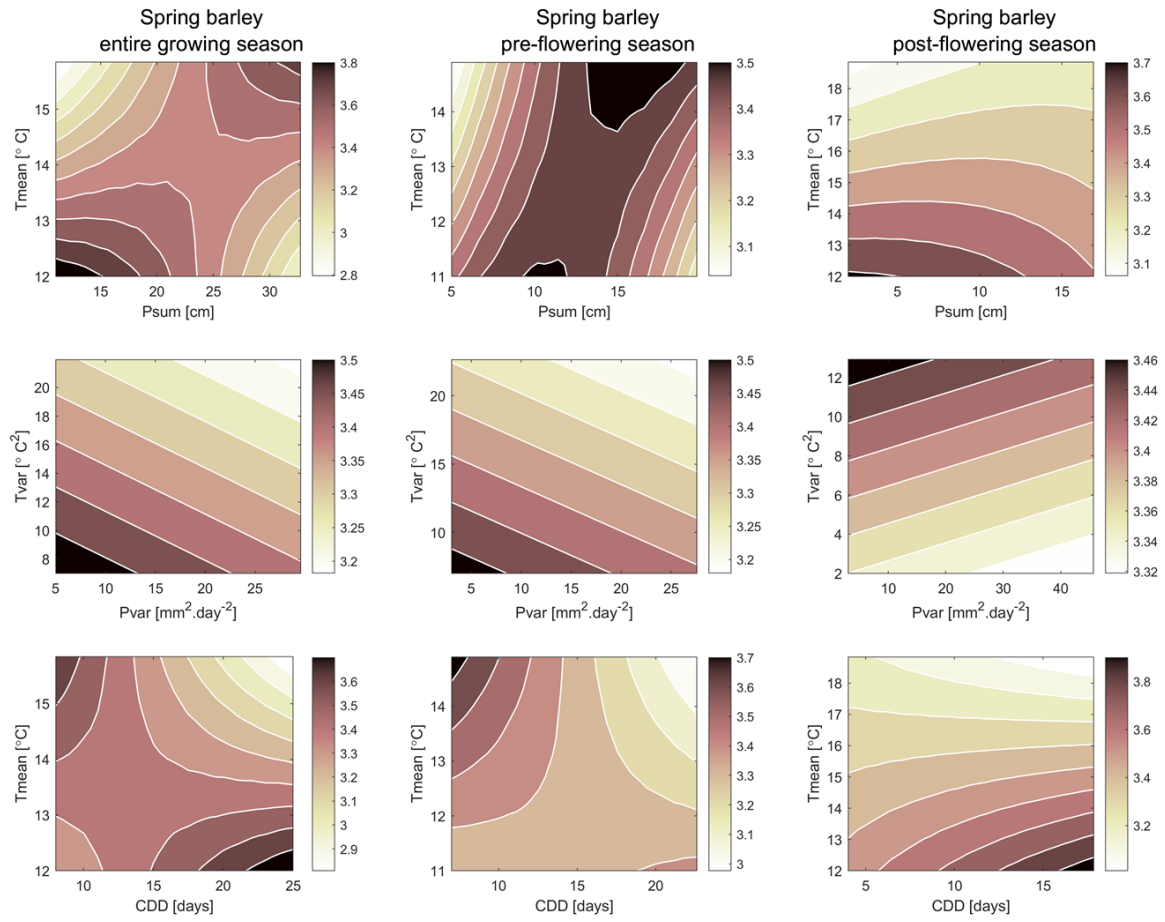


Figure. S2 Same as above but for spring barley

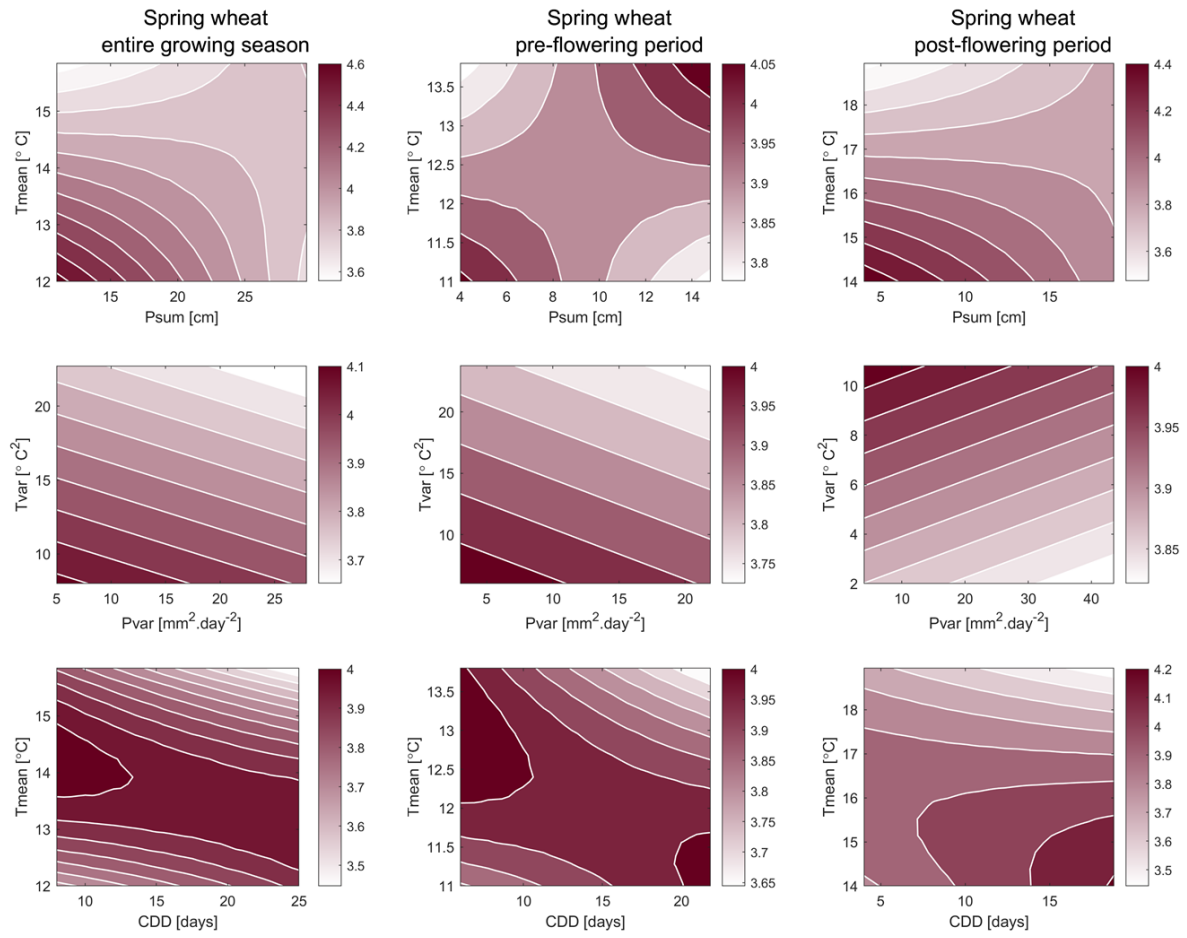


Figure. S3 Same as above but for spring wheat

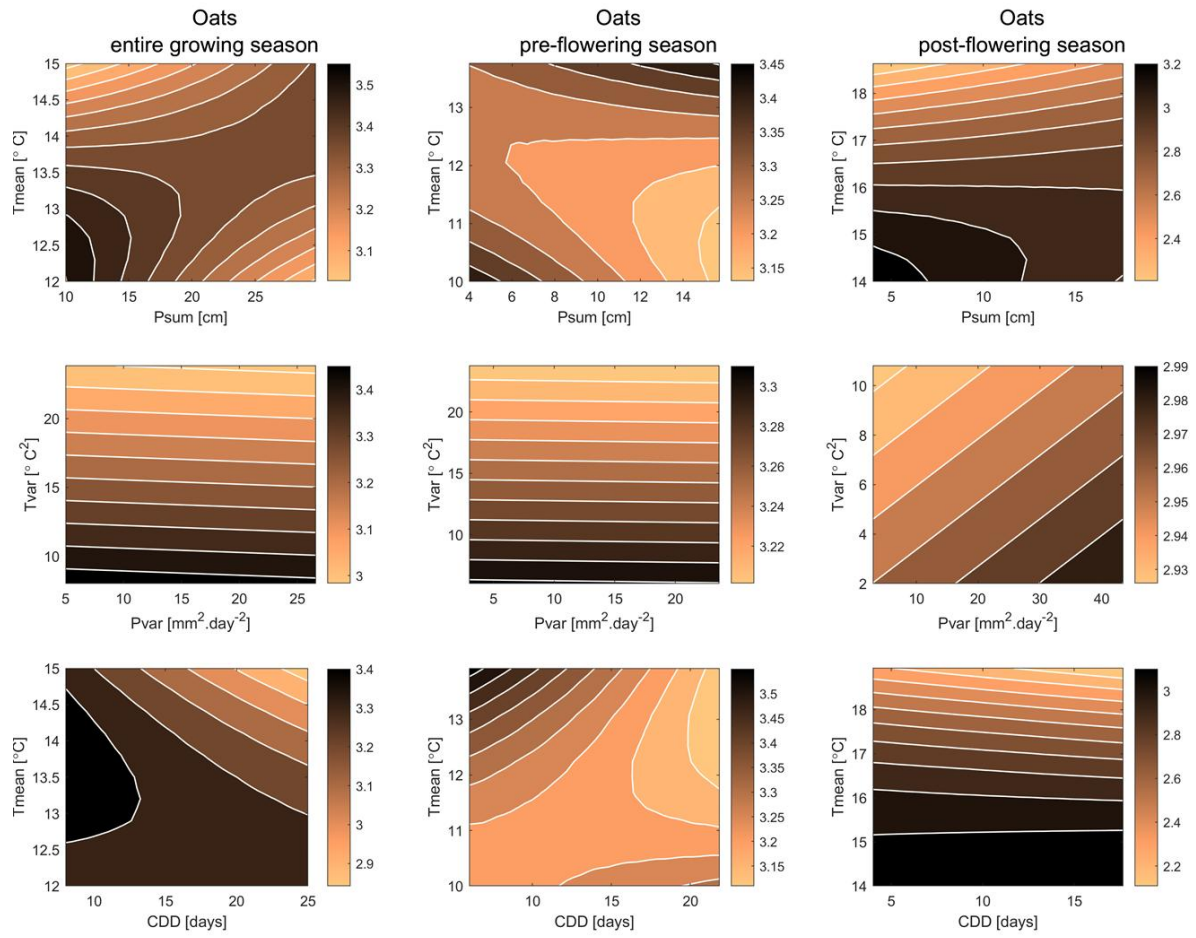


Figure S4 Same as above but for oats