Assessing the impacts of drought on UK wheat production

Project descripton

Using a biophysical crop simulation model to assess the impacts of drought on UK wheat yields and evaluating the performance of drought severity indicators (DSI) in quantifying future drought risk

Amount of wheat planted for each person in the world annually

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Research conducted between 2016-17

c.v Claire untreated trial at Cereals 2016, Cambridgeshire, UK

Motivation

- On average, 10 to 20% of total UK wheat production is lost due to drought (Foulkes et al., 2007)
- With the frequency and intensity of droughts expected to increase in future, an improved understanding of the impacts of drought and better systems for agricultural drought monitoring are required (Ilbery et al.,2013)
- Previous studies using national yield records have derived no significant relationship between wheat yields and commonly employed drought severity indices (DSI)

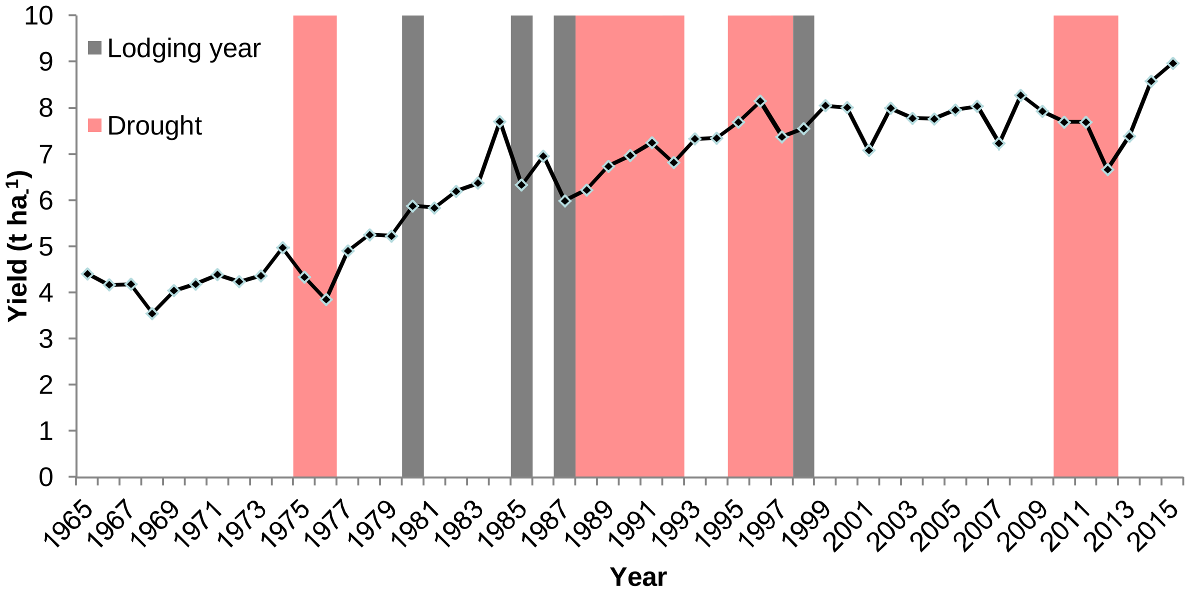

Figure 1 UK wheat yields (t ha^{-1}) with reported drought and lodging years highlighted 1965-2015

National yield records are useful for assessing trends but too coarse for understanding regional climate impacts (Figure 1)

- Droughts often display a regional focus (Marsh et al., 2007)
- Losses occur through other pressures (e.g. disease, lodging, pests and waterlogging)m, and;
- Rapid increase in yields (1.2% yr^{-1}) (Mackay et al., 2011) over the 20th Century may mask drought impacts

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Objectives

Using daily weather data for Cambridge (1911-2015) (Figure 2)

1. Parameterise and validate Sirius wheat crop simulation model (Jamieson et al., 1998);
2. Simulate impacts of historic climate variability on UK wheat yield, and;
3. Assess performance of selected drought indices for drought management by the UK wheat and agricultural sector

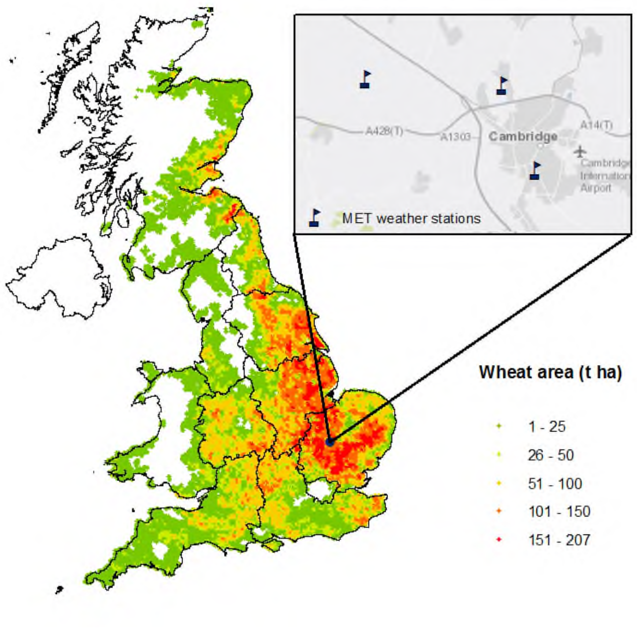

Figure 2 Met station featured in climate record and 2 km gridded UK wheat crop area in 2010 (Source: EDINA, 2016)

Cambridge (52.20° N, 0.12° E)

- Situated in the heart of the UK's largest wheat producing region (East Anglia)
- Sufficient yield records (9) from the AHDB recommended list trials for validation(Figure 3)
- Driest region in the UK, making it appropriate for a drought study

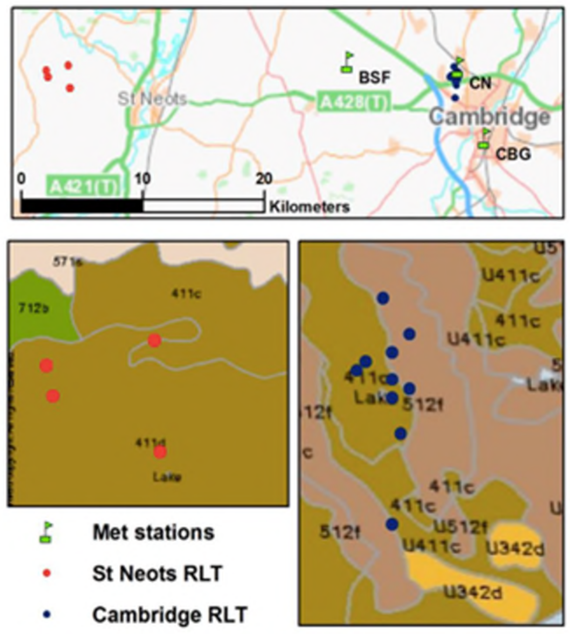

Figure 3 Met weather station and 9 yield records used in validation (AHDB, 2016)

Main findings – Drought severity indicators (DSI)

Harvest Year	SPEI 9	SPI 9	PDSI (9)	SPEI 6	SPI 6	SPEI 3	SPI 3	PSMDmax	Literature
1913	-0.6	-0.7	-1.0	-0.5	-0.9	-0.6	-1.2	244	(Cole and Marsh, 2006a)
1914	-1.1	-0.8	-2.2	-0.7	-0.2	-0.4	-0.3	297	(Cole and Marsh, 2006a)
1921	-2.2	-2.9	-6.2	-2.2	-2.9	-2.0	-2.4	458	(Cole and Marsh, 2006a)
1929	-1.5	-1.6	-2.4	-1.4	-1.2	-1.1	-1.2	324	(Cole and Marsh, 2006a)
1933	-1.7	-1.6	-2.5	-1.4	-0.7	-1.6	-1.0	339	(Cole and Marsh, 2006a)
1934	-2.0	-2.7	-6.3	-1.4	-1.3	-1.3	-0.9	361	(Cole and Marsh, 2006a)
1935	-0.7	-0.1	-3.0	-1.2	-1.0	-1.4	-0.8	321	
1938	-1.3	-1.6	-2.6	-1.4	-2.0	-0.7	-1.1	331	(Cole and Marsh, 2006a)
1940	-1.0	-0.6	-2.0	-1.0	-0.6	-1.3	-1.4	325	
1942	-1.0	-1.0	-2.1	-1.0	-0.8	-0.6	-0.5	289	
1943	-1.3	-1.1	-3.4	-1.6	-1.8	-0.9	-1.1	372	(Cole and Marsh, 2006a)
1944	-1.5	-2.0	-6.0	-1.1	-1.3	-0.2	-0.5	330	(Cole and Marsh, 2006a)
1945	-1.3	-1.4	-3.0	-1.1	-1.0	-0.4	-0.5	301	
1947	-0.5	-0.1	-1.6	-0.6	0.1	-1.0	-0.6	328	(Cole and Marsh, 2006a)
1949	-1.4	-0.9	-0.7	-1.0	-0.4	-1.0	-0.3	288	(Cole and Marsh, 2006a)
1952	-1.0	-0.5	-1.5	-0.7	0.0	-0.6	-0.4	291	
1955	-0.8	-0.6	-1.4	-1.0	-0.8	-1.1	-0.8	287	(Cole and Marsh, 2006a)
1957	-0.9	-0.6	-2.3	-1.0	-1.0	-0.2	0.0	282	
1961	-0.6	-0.5	-1.8	-1.1	-1.3	-0.6	-0.6	298	
1972	-0.8	-1.6	-2.0	-0.6	-1.3	-0.6	-1.4	252	(Cole and Marsh, 2006a)
1973	-1.1	-1.1	-4.5	-0.6	-0.4	-0.7	-0.4	244	(Cole and Marsh, 2006a)
1975	-0.5	0.1	-1.7	-0.1	0.4	-1.8	-1.7	326	(Cole and Marsh, 2006a)
1976	-2.2	-2.9	-6.6	-2.0	-2.2	-2.2	-1.5	450	(Cole and Marsh, 2006a)
1983	0.3	0.1	-0.8	0.3	0.3	-1.1	-1.4	233	(Wreford and Adger, 2011
1989	-1.4	-0.9	-2.6	-1.2	-0.5	-1.3	-0.7	339	(Cole and Marsh, 2006a)
1990	-1.1	-0.5	-3.6	-1.9	-2.8	-1.6	-2.0	405	(Cole and Marsh, 2006a)
1991	0.0	-0.4	-2.8	0.3	0.0	0.5	0.5	181	(Cole and Marsh, 2006a)
1994	-0.3	-0.1	-1.9	-0.8	-1.0	-1.6	-2.2	308	
1995	-1.4	-1.0	-3.5	-1.9	-2.4	-2.0	-2.5	417	(Cole and Marsh, 2006a)
1996	-1.0	-1.2	-3.5	-1.2	-1.8	-0.9	-0.5	336	(Cole and Marsh, 2006a)
1997	-0.7	-0.3	-2.3	-0.2	0.4	1.0	1.4	229	(Cole and Marsh, 2006a)
2000	0.3	0.2	0.6	0.4	0.2	-0.5	-1.0	179	
2003	-0.9	-0.6	-1.8	-1.4	-1.4	-0.9	-0.7	338	(Wreford and Adger, 2011
2005	-0.9	-1.1	-2.4	-0.5	-0.6	-0.2	-0.1	244	(Wreford and Adger, 2011
2006	-1.1	-1.1	0.5	-0.6	-0.3	-0.9	-0.3	263	(Wreford and Adger, 2011
2011	-1.5	-1.5	-3.2	-1.5	-1.6	0.0	0.1	353	(Kendon et al., 2013)
Classification	**%**	**%**	**%**	**%**	**%**	**%**	**%**		**(SPI,SPEI and PDSI)**
Extreme	2.9	3.8	4.8	1.9	4.8	2.9	3.8		Extreme drought
Severe	3.8	4.8	6.7	3.8	2.9	3.8	1.9		Severe drought
Moderate	13.5	7.7	12.5	15.4	9.6	8.7	8.7		Moderate drought

Figure 4 Analysis of DSI on agricultural relevant time steps (3, 6 and 9 months) from August (harvest)

Four commonly used DSI were calculated on various time-steps:

- **SPI** (Standardized Precipitation Index), 1-12 months
- **SPEI** (Standardized Precipitation and Evaporation index), 1-12 months
- **PDSI** (Palmer Drought Severity Indices) Monthly
- **PSMD** (Potential Soil Moisture Deficit), Maximum

- Despite the humid climate, one or more of the DSI, identified a ‘moderate’ drought in 30 of the 104 year weather record
- Droughts occur at varying magnitudes. The majority of the reported UK droughts (Cole and Marsh., 2006) were identified (i.e. 1921, 1934 and 1976)
- For some years, the DSI are in agreement (e.g. 1921, 1934, 1976 and 2011). However, years such as 1972 and 1990 show markedly different classifications between the DSI

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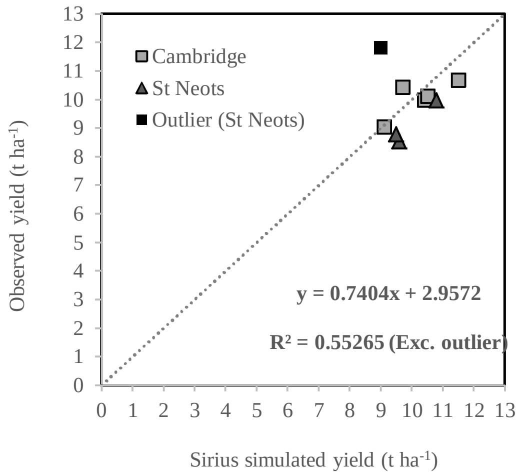
Main findings – biophysical crop modelling

1) Validation



$$RMSE = \left(\frac{1}{N} \sum_{i=1}^{N} d_i^2 \right)^{\frac{1}{2}}$$

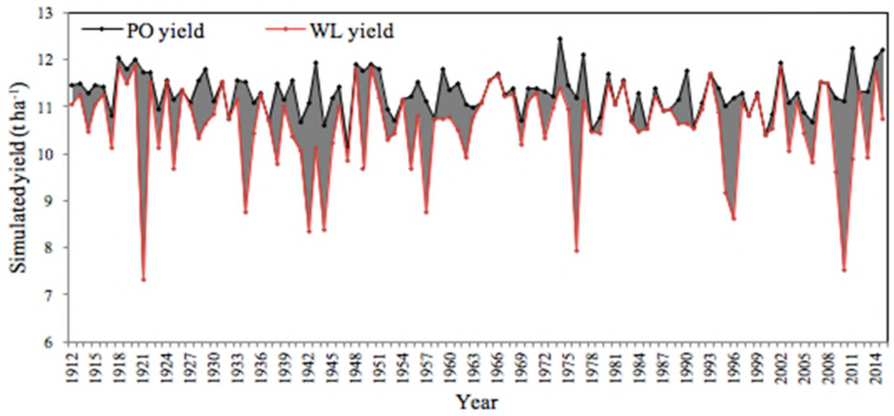
$$RRMSE = \frac{RMSE}{Y}$$

Statistic	RLT site Cambridge	RLT site St Neots	Combined
Number of samples (n)	5	4	9
Mean yield observed (t ha^{-1})	10.06	9.78	9.93
Mean yield simulated (t ha-1)	10.24	9.73	10.01
RMSE (t ha^{-1})	0.55	1.6	1.14
RRMSE (%)	5.48	16.34	11.49

Sirius (Jamieson et al., 1998) simulated yields to a 'good' level of accuracy (RRMSE=11.49%)

RRMSE: <10% = excellent, 10-20% = good, 20-30% = fair and >30% = Poor(Jamieson, 1991)

2) Yield simulation



- Water limited (WL) and Potential yield (PO) were simulated using the Cambridge weather data (1911-2015)

Yield loss = PO-WL

- Historic simulated yields showed the droughts of 1921, 1976 and 2010 as being the most detrimental to wheat yield

Year	Yield loss (%)
1921	37.7
1934	24.1
1942	24.7
1943	15.2
1944	21.2
1949	17.6
1957	21.3
1976	28.9
1995	17.0
1996	23.0
2010	32.4
2011	19.4

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Main findings – biophysical crop modelling and DSI

Non-parametric Spearman's Rho coefficient ($p<0.05$) applied to the simulated wheat yields and DSI on various time-steps (number of months lag)

SPI	No. months lag											
	1	2	3	4	5	6	7	8	9	10	11	12
SEP	0.00	-0.07	-0.08	-0.09	-0.07	-0.06	-0.05	-0.05	-0.07	-0.11	-0.08	-0.09
OCT (S)	0.06	0.01	-0.03	-0.03	-0.03	0.00	-0.01	-0.01	-0.03	-0.07	-0.04	-0.07
NOV	-0.03	0.04	0.00	-0.05	-0.05	-0.04	-0.02	-0.01	-0.03	-0.04	-0.08	-0.06
DEC	0.00	0.02	0.02	0.07	0.00	-0.04	-0.02	-0.03	0.00	0.00	0.00	-0.01
JAN	-0.12	-0.08	-0.07	-0.08	-0.03	0.01	0.02	0.01	0.00	-0.01	-0.02	-0.01
FEB	0.04	0.11	0.08	0.06	0.09	0.06	0.00	-0.01	-0.01	0.01	0.02	0.02
MAR	0.02	0.05	0.09	0.06	0.05	0.07	0.03	-0.01	-0.01	-0.02	0.00	0.01
APR	0.35	0.25	0.26	0.28	0.23	0.18	0.21	0.14	0.10	0.09	0.09	0.09
MAY	0.25	0.43	0.37	0.38	0.38	0.33	0.25	0.26	0.22	0.15	0.14	0.13
JUN	0.39	0.46	0.57	0.49	0.49	0.51	0.47	0.37	0.37	0.31	0.24	0.24
JUL	0.32	0.51	0.53	0.62	0.58	0.57	0.60	0.57	0.46	0.46	0.41	0.34
AUG (H)	0.19	0.36	0.49	0.53	0.65	0.62	0.60	0.62	0.58	0.51	0.50	0.45

SPEI	No. months lag											
	1	2	3	4	5	6	7	8	9	10	11	12
SEP	0.00	-0.09	-0.09	-0.10	-0.09	-0.08	-0.05	-0.04	-0.04	-0.06	-0.04	-0.05
OCT (S)	0.05	-0.02	-0.05	-0.04	-0.06	-0.03	-0.01	-0.01	-0.01	-0.02	-0.01	-0.04
NOV	-0.03	0.04	-0.02	-0.06	-0.07	-0.07	-0.04	-0.02	-0.01	-0.02	-0.03	-0.01
DEC	0.00	0.02	0.01	0.05	-0.04	-0.07	-0.06	-0.06	-0.03	-0.01	0.01	-0.01
JAN	-0.07	-0.06	-0.05	-0.05	0.01	0.05	0.04	0.05	0.03	0.00	-0.01	-0.01
FEB	0.00	0.06	0.03	0.03	0.05	-0.02	-0.04	-0.04	-0.05	-0.03	-0.01	0.00
MAR	-0.01	-0.02	0.04	0.00	0.01	0.03	-0.01	-0.05	-0.05	-0.06	-0.03	0.00
APR	0.36	0.24	0.23	0.25	0.21	0.16	0.17	0.11	0.07	0.04	0.04	0.04
MAY	0.21	0.39	0.32	0.31	0.33	0.30	0.22	0.23	0.16	0.12	0.10	0.08
JUN	0.41	0.44	0.53	0.46	0.45	0.46	0.42	0.35	0.33	0.27	0.22	0.20
JUL	0.41	0.58	0.58	0.65	0.60	0.58	0.59	0.56	0.48	0.48	0.40	0.34
AUG (H)	0.24	0.42	0.56	0.57	0.63	0.60	0.58	0.59	0.57	0.52	0.51	0.46

PDSI	
SEP	-0.02
OCT (S)	0.03
NOV	0.02
DEC	0.08
JAN	0.06
FEB	0.08
MAR	0.15
APR	0.33
MAY	0.37
JUN	0.46
JUL	0.53
AUG (H)	0.55

$PSMD_{Month}$	
SEP	-0.03
OCT (S)	-0.05
NOV	-0.13
DEC	0.16
JAN	0.13
FEB	0.01
MAR	-0.05
APR	0.18
MAY	0.32
JUN	0.51
JUL	0.66
AUG (H)	0.63

$PSMD_{Max}$
0.64

Key
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

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Results show DSI have a significant relationship to simulated wheat yields. However, variance in the strength and timing of the correlations between different DSI is apparent

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- On time steps before April, all DSI showed no significant correlation to simulated yields
- Although not significant (*p=0.13*) the PDSI showed a stronger correlation in March than the other DSI
- DSI correlations strengthen from April peaking in July or August. These time steps include early stem extension (April), flowering (June) and grain filling (June-July)- particularly drought sensitive stages
- PDSI showed the weakest correlation (0.55)
- SPI and SPEI do not differ considerably in their correlations with yield
- SPI requires fewer parameters making it potentially more suited for UK drought monitoring in wheat

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Perspective

- There is no nationwide agricultural drought monitoring and early warning system in the UK. This study shows that for certain times steps the DSI could be used by the wheat industry in monitoring potentially yield-limiting droughts

    - ‘Upstream’ input providers supplying seed, fertilisers and chemicals may be able to make estimates on product demand

    - ‘Intermediates’ such as grain merchants will be able to gauge supply scenarios, and output from contracts

    - “Downstream” stakeholders such as mills, retailers and consumers may also find a use in monitoring drought risk, as reductions in UK production may increase the need for imports, resulting in a price volatility for wheat based products

- The analysis presented demonstrates that the use of crop models to simulate impacts can be very useful particularly where there is limited long-term recorded data, e.g. national or regional crop yields

Next steps To produce a high impact scientific paper and disseminate research outputs to industry

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