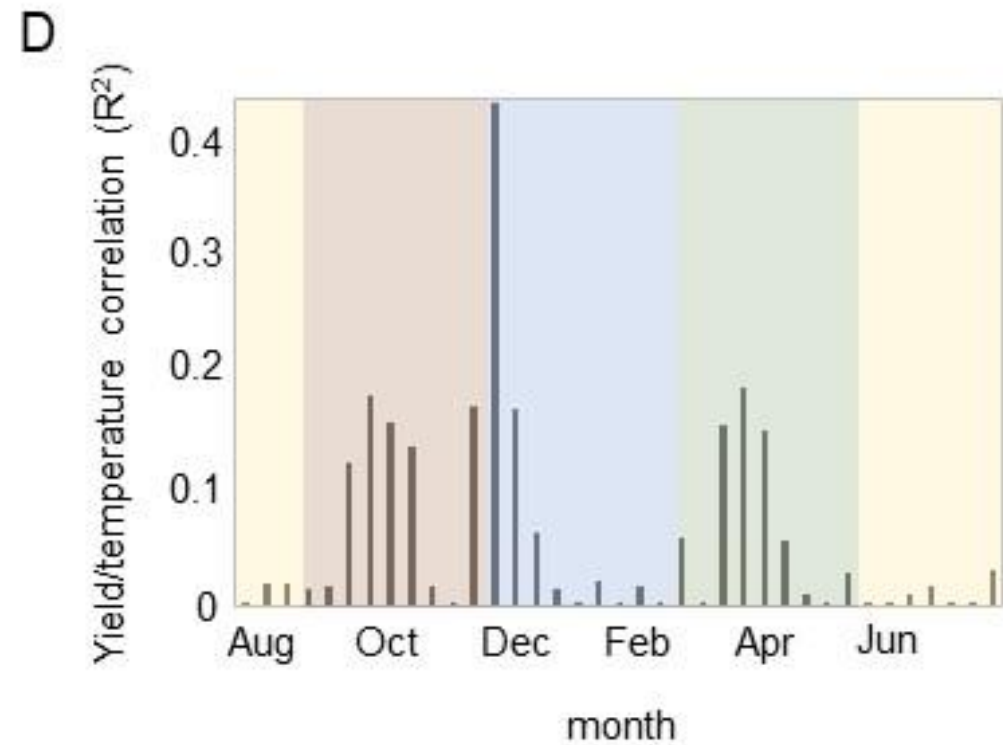
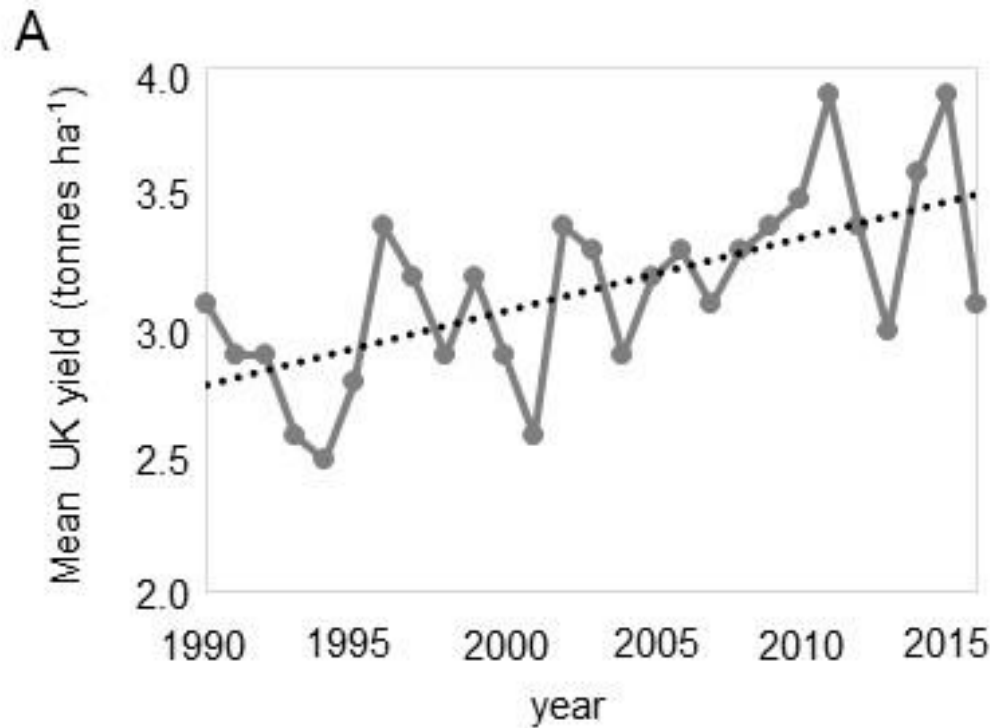


Causes of yield stability in the UK WOSR harvest

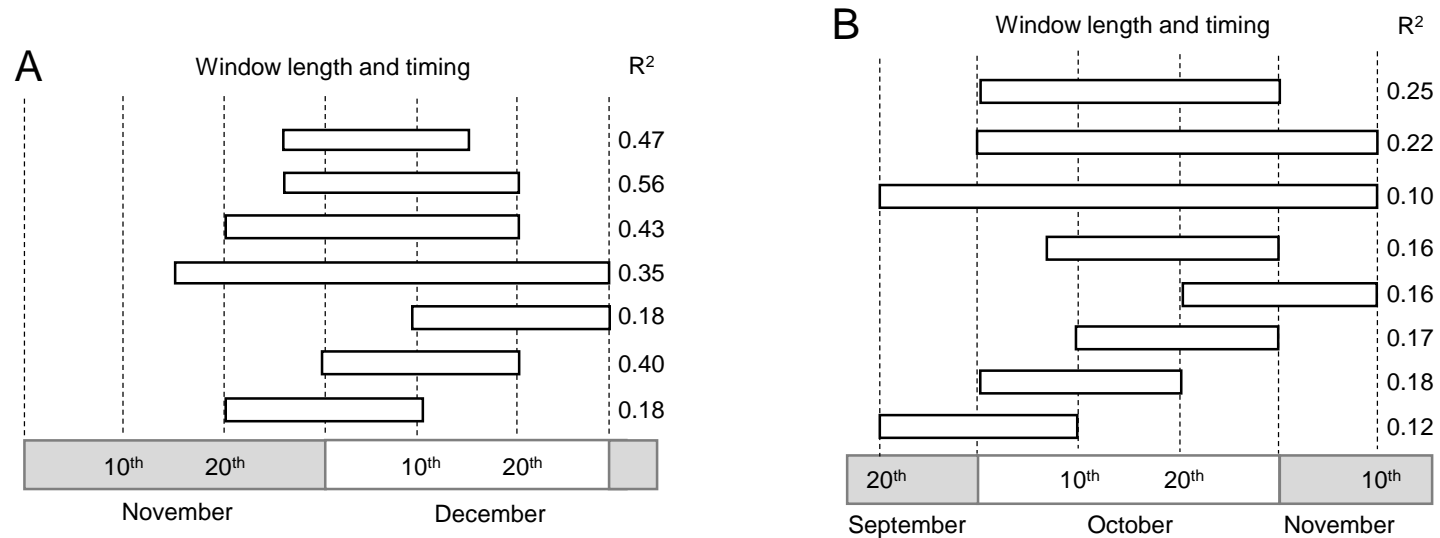
James Brown, Steven Penfield, JIC

Unreliable yields is the major barrier to growing more WOSR in the UK



Yield vs HadCET2 temperature 1990-2014

Optimised temperature windows affecting UK crop yields



Linear model analysis of UK WOSR yields

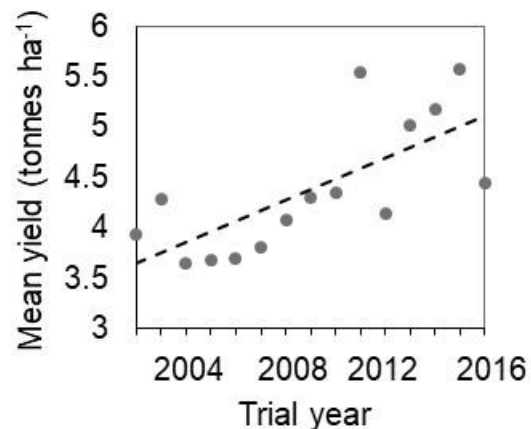
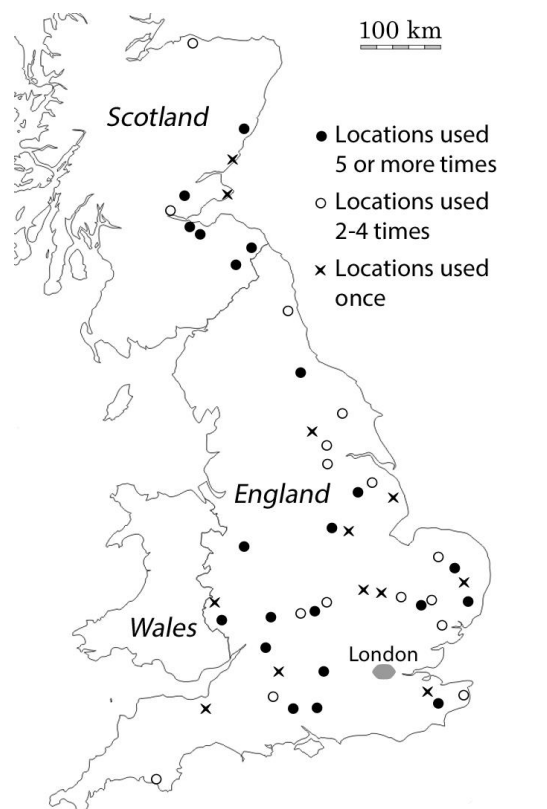
Linear model: $Yield = Year + octT + decT + aprT$

VARIABLE	DF	F STATISTIC	VARIANCE EXPLAINED	YIELD GAIN/LOSS PER 1°C TEMPERATURE RISE (KG HA ⁻¹), OR PER YEAR +/- SE	SIGNIFICANCE
Year	1	55.14	25.3	21 +/- 3	P < 0.001
Dec(1-20)T _m	1	43.14	19.5	107 +/- 18	P < 0.001
Oct(1-20)T _m	1	11.17	11.1	77 +/- 22	P = 0.004
Apr(1-20)T _m	1	0.56	3.7	25 +/- 33	P = 0.5

Added value of breeders
0.2 tonnes ha⁻¹ decade⁻¹

A 10°C change in temperature
in December costs 1.1 tonnes ha⁻¹

WOSR RL trials database at JIC



Location	Site names	County/Area	Country	Harvest years	Trials
Aby	Aby	Lincolnshire	England	2012	1
Alkerton	Alkerton	Oxfordshire	England	2012, 2014, 2015	3
Anstruther	Anstruther	Fife	Scotland	2012	1
Arbroath	Arbroath	Angus	Scotland	2009	1
Ashford	Ashford, Wye	Kent	England	2002, 2004, 2005, 2009, 2012	5
Berwickshire	Coldstream, Duns, Whitsome	Scottish Borders	Scotland	2002-2008	7
Bingham	Bingham, Cropwell Butler	Nottinghamshire	England	2002-2014	13
Broughton	Broughton	Hampshire	England	2007, 2009, 2010, 2013, 2015, 2016	6
Callow	Callow	Herefordshire	England	2004-2006, 2008-2016	12
Cirencester	Cirencester	Gloucestershire	England	2002-2006	5
Cliffe	Cliffe	North Yorkshire	England	2010, 2011	2
Colchester	Horkesley, Wormingford	Essex	England	2012, 2014	2
Cowlinge	Cowlinge	Suffolk	England	2008-2011, 2013, 2014	6
Croft-on-Tees	Croft-on-Tees	North Yorkshire	England	2009-2012, 2015, 2016	6
Deal	Betteshanger, Tilmanstone	Kent	England	2014, 2016	2
E.Dereham	East Dereham, Swaffham	Norfolk	England	2002, 2003	2
E.Howgate	Easter Howgate	Midlothian	Scotland	2009-2011, 2012, 2014-2016	7
Elgin	Elgin	Moray	Scotland	2004, 2006	2
Framlingham	Framlingham, Tannington, Wilby	Suffolk	England	2002- 2011, 2013, 2014, 2016	13
Goring	Goring, Ipsden, South Stoke	Oxfordshire	England	2003, 2005-2008, 2010, 2011	7
Harlaxton	Harlaxton	Lincolnshire	England	2015	1
King'sPyon	King's Pyon	Herefordshire	England	2002	1
Kingston	Kingston	Devon	England	2002, 2003, 2005	3
Knapwell	Knapwell	Cambridgeshire	England	2002	1
L.Staughton	Little Staughton	Bedfordshire	England	2003	1
Laurencekirk	Fordoun, Laurencekirk, Luthermuir	Aberdeenshire	Scotland	2003-2006, 2008, 2010, 2011, 2013-2016	11
Lenham	Lenham	Kent	England	2011	1
LongMarston	Long Marston	North Yorkshire	England	2002	1
Malton	Duggleby, Malton	North Yorkshire	England	2003-2005, 2007	4
Milnathort	Kinross, Milnathort, Perth	Kinrossshire	Scotland	2002-2008, 2010, 2011	9
Morley	Attleborough, Morley, Wymondham	Norfolk	England	2005, 2007, 2008, 2011, 2013, 2015, 2016	7
Morpeth	Morpeth	Northumberland	England	2002- 2005	4
N.Glos	Blockley, Chipping Campden	Gloucestershire	England	2008-2011, 2015	5
Northants	Daventry, Harlestone, Northampton	Northamptonshire	England	2002, 2003, 2005, 2007	4
Owmbly	Owmbly-by-Spital	Lincolnshire	England	2005-2008, 2010-2014	9
PulhamMkt	Pulham Market	Norfolk	England	2004	1
Rothwell	Caistor, Market Rasen, Rothwell	Lincolnshire	England	2002, 2003, 2012, 2016	4
Roxburghshire	Kelso, St Boswells	Scottish Borders	Scotland	2010-2012, 2014-2016	6
S.Yorks	Moorends, Sykehouse, Thorne	South Yorkshire	England	2013, 2015, 2016	3
Stonehenge	Shrewton, Wylde	Wiltshire	England	2004, 2005	2
Swindon	Swindon	Wiltshire	England	2003	1
Telford	Edgmond, Harper Adams, Newport, Telford	Shropshire	England	2002-2004, 2006-2009, 2012, 2013, 2015	10
Teversham	Teversham	Cambridgeshire	England	2005, 2006, 2007	3
Thurloxton	Thurloxton	Somerset	England	2002	1
W.Fife	Culross, Kincardine	Fife	Scotland	2013-2016	4
W.Loathian	Edinburgh, Kirkliston, Newbridge, Ratho, Wilkieston	Edinburgh & West Lothian	Scotland	2002-2008	7
Wardington	Wardington	Oxfordshire	England	2009-2016	8
Wickhambrook	Wickhambrook	Suffolk	England	2013, 2014	2

AHDB linear mixed model analysis

Fixed Model: $Yield = Trialsite + YearL + DecT + OctT$

Random Model: $Yield = Variety + Variety.DecT + Trialsite.Year$

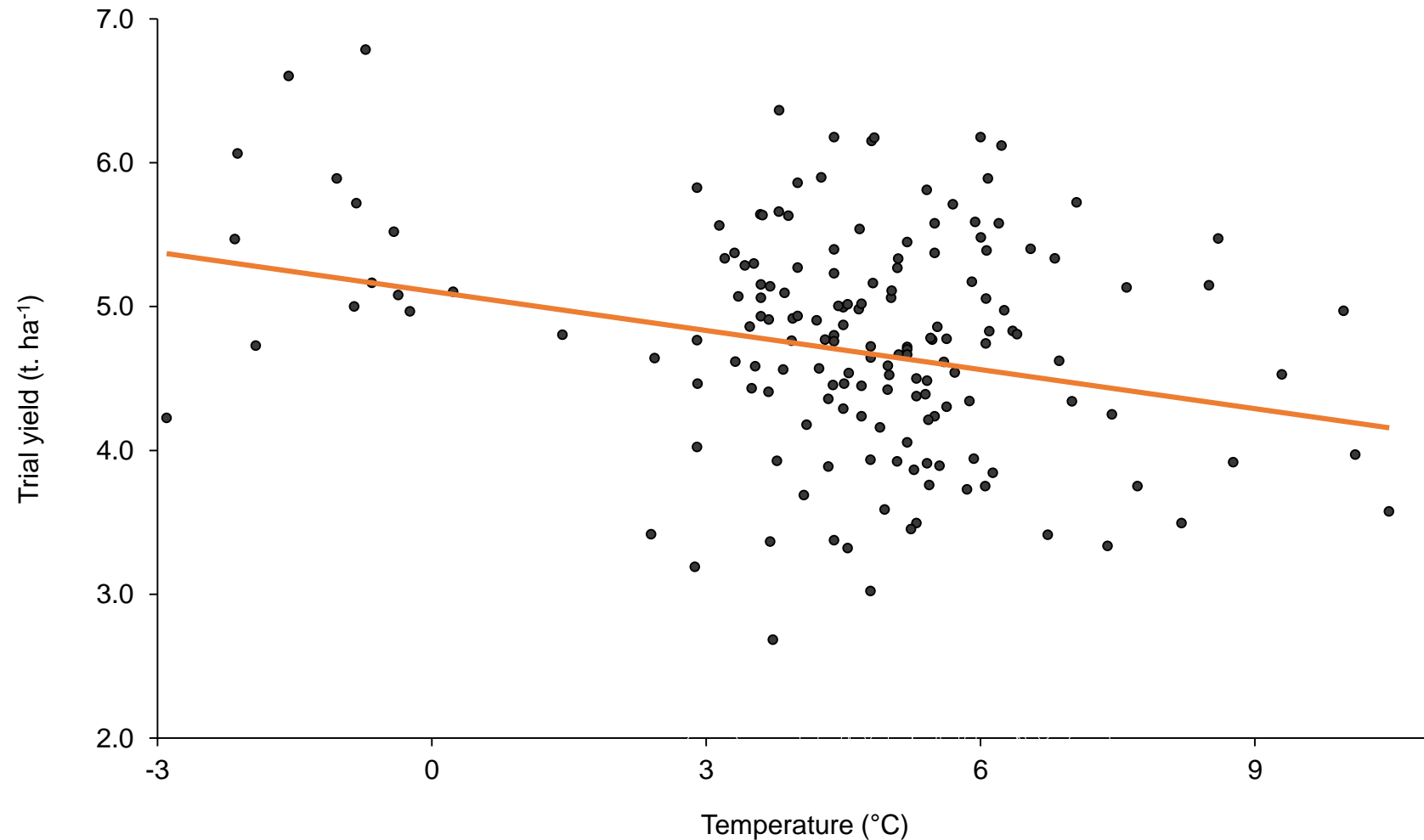
AHDB linear mixed model analysis

No effect of year

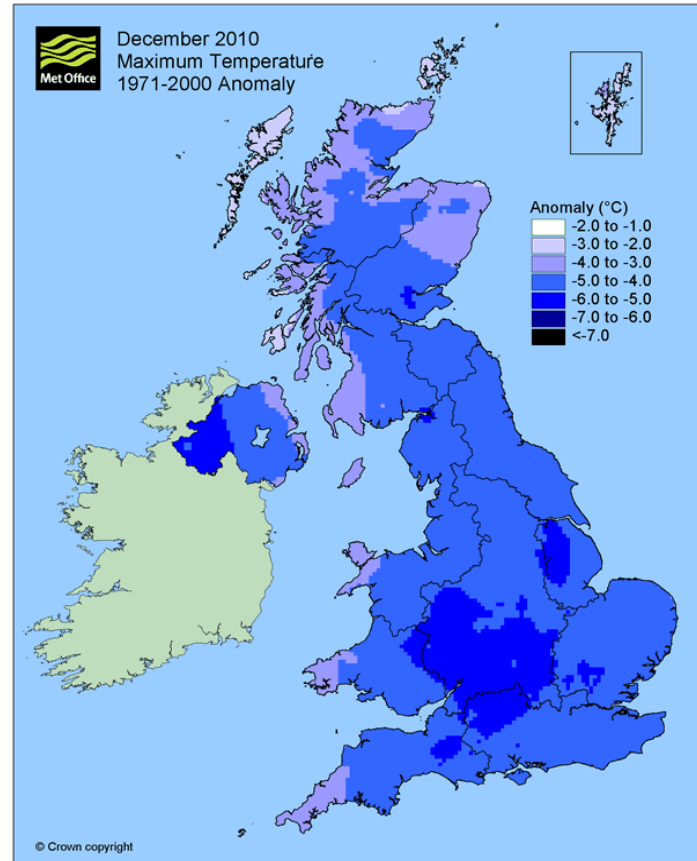


Predictor variable	d.f.	F statistic	Estimate (kg ha ⁻¹ °C ⁻¹) ± SE	Significance
Locations & varieties used in at least 5 years (1685 yield data)				
Location	20, 140	5.09		P < 0.001
YearL	1, 153	0.72	-13 ± 15	P = 0.4
OctTm	1, 141	2.55	57 ± 36	P = 0.1
DecTm	1, 156	26.46	-127 ± 25	P < 0.001
YearL and OctTm removed from model				
Location	20, 142	5.04		P < 0.001
DecTm	1, 158	24.12	-116 ± 24	P < 0.001
Locations used in at least 2 years (6378 yield data)				
Location	36, 170	4.40		P < 0.001
YearL	1, 177	0.00	1 ± 14	P = 1.0
OctTm	1, 171	1.48	39 ± 32	P = 0.2
DecTm	1, 179	28.78	-122 ± 23	P < 0.001
YearL and OctTm removed from model				
Location	36, 172	4.41		P < 0.001
DecTm	1, 182	27.80	-113 ± 21	P < 0.001

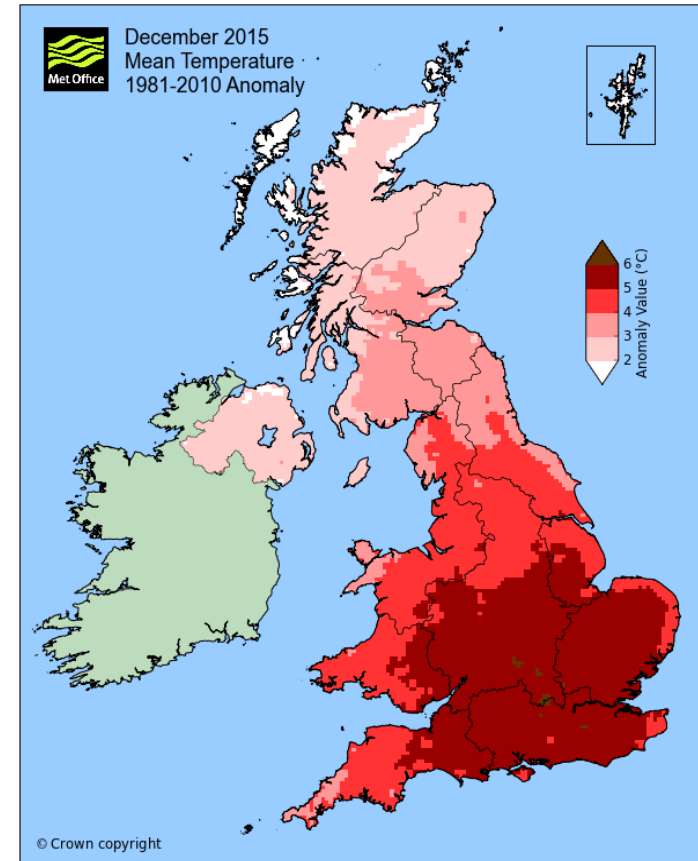
Correlation between December temperature and RL trial yield 2002-2016.



Difference between 2011 and 2016 yields is almost entirely attributable to December chilling



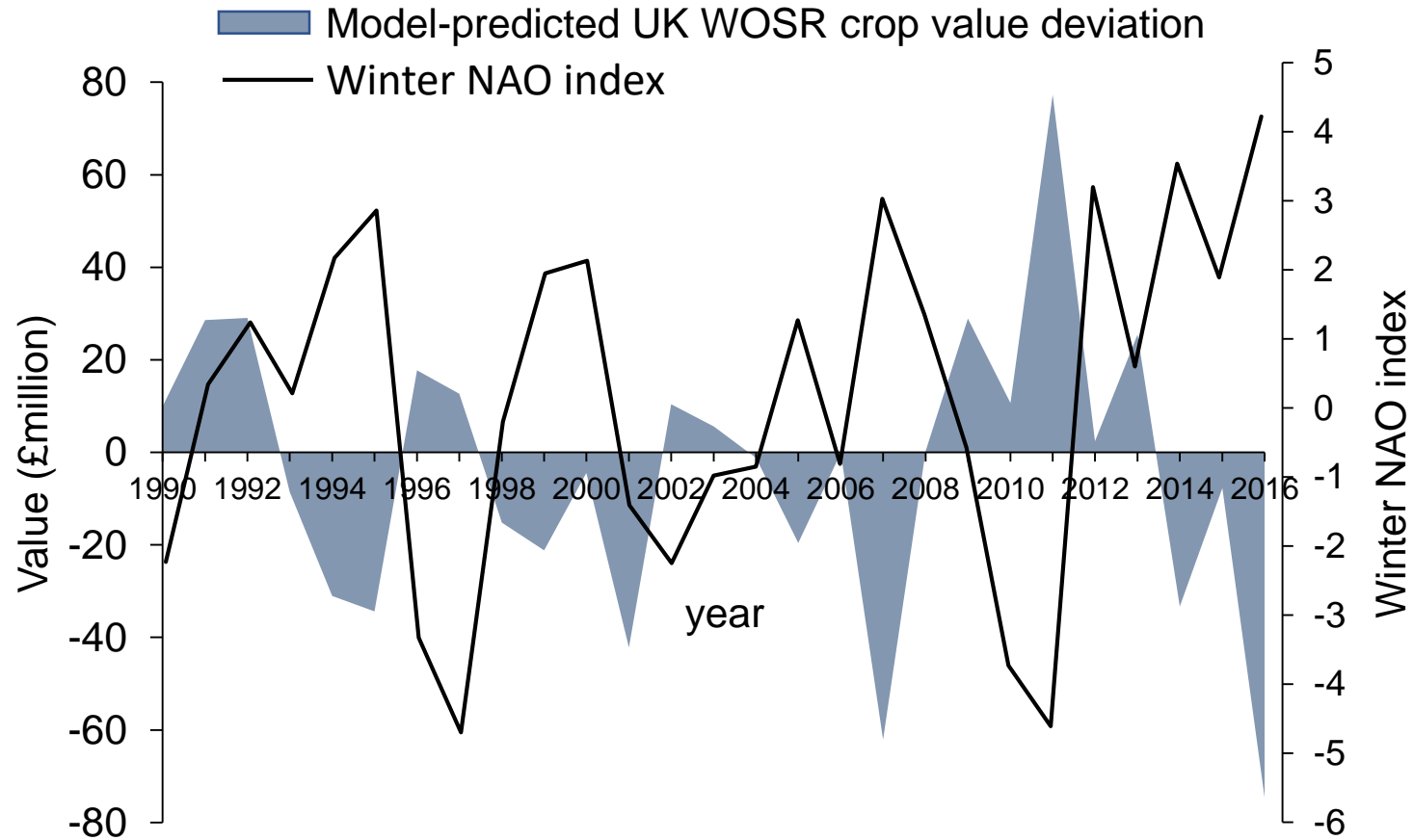
Temperature 4-5°C below mean.
Mean 2011 UK WOSR yield: 4 t ha⁻¹



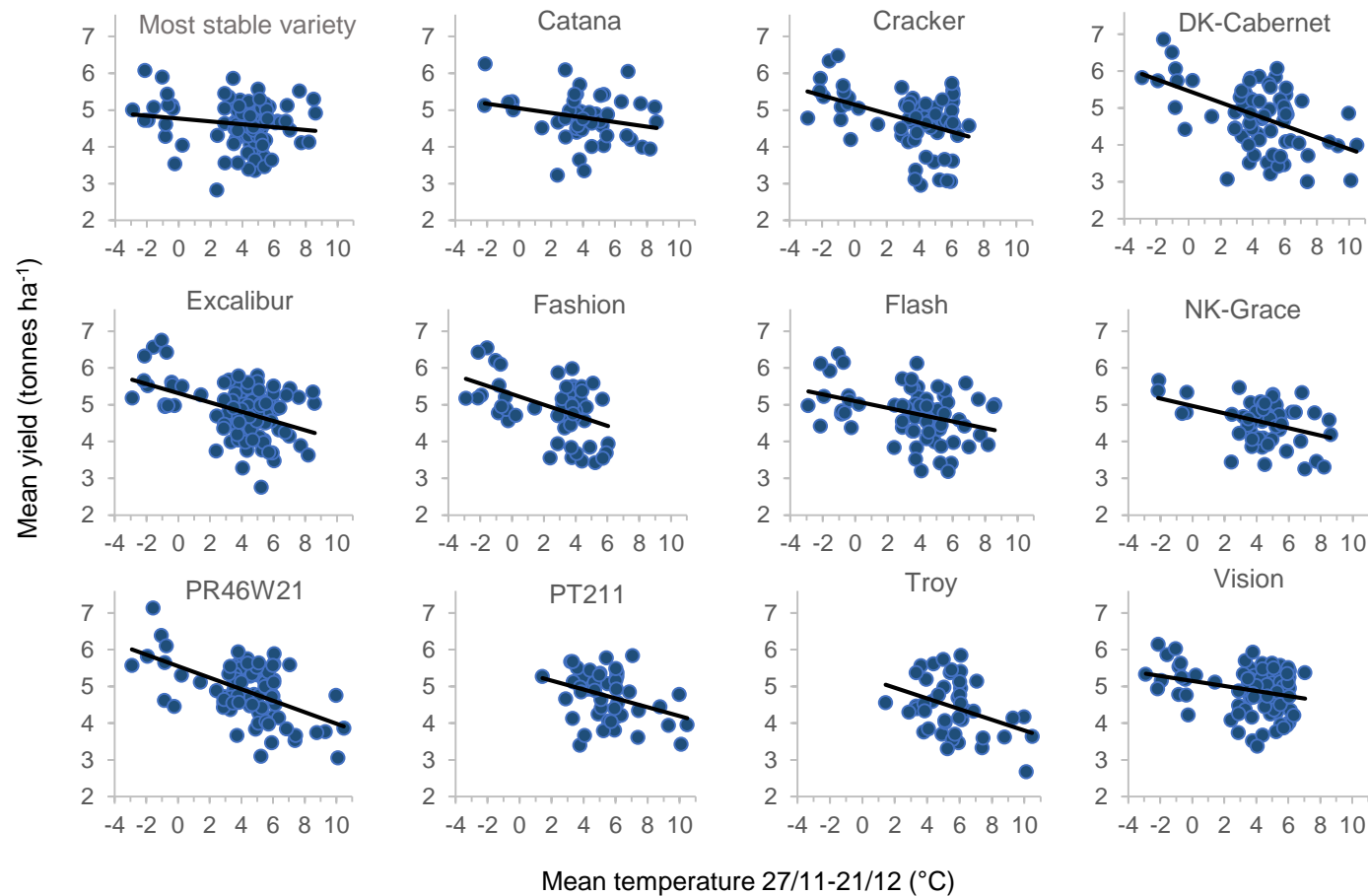
Temperature 4-6°C above mean.
Mean 2016 UK WOSR yield: 3 t ha⁻¹

Model predicted yield difference based on December temperature difference alone: 1.07 tonnes ha⁻¹.

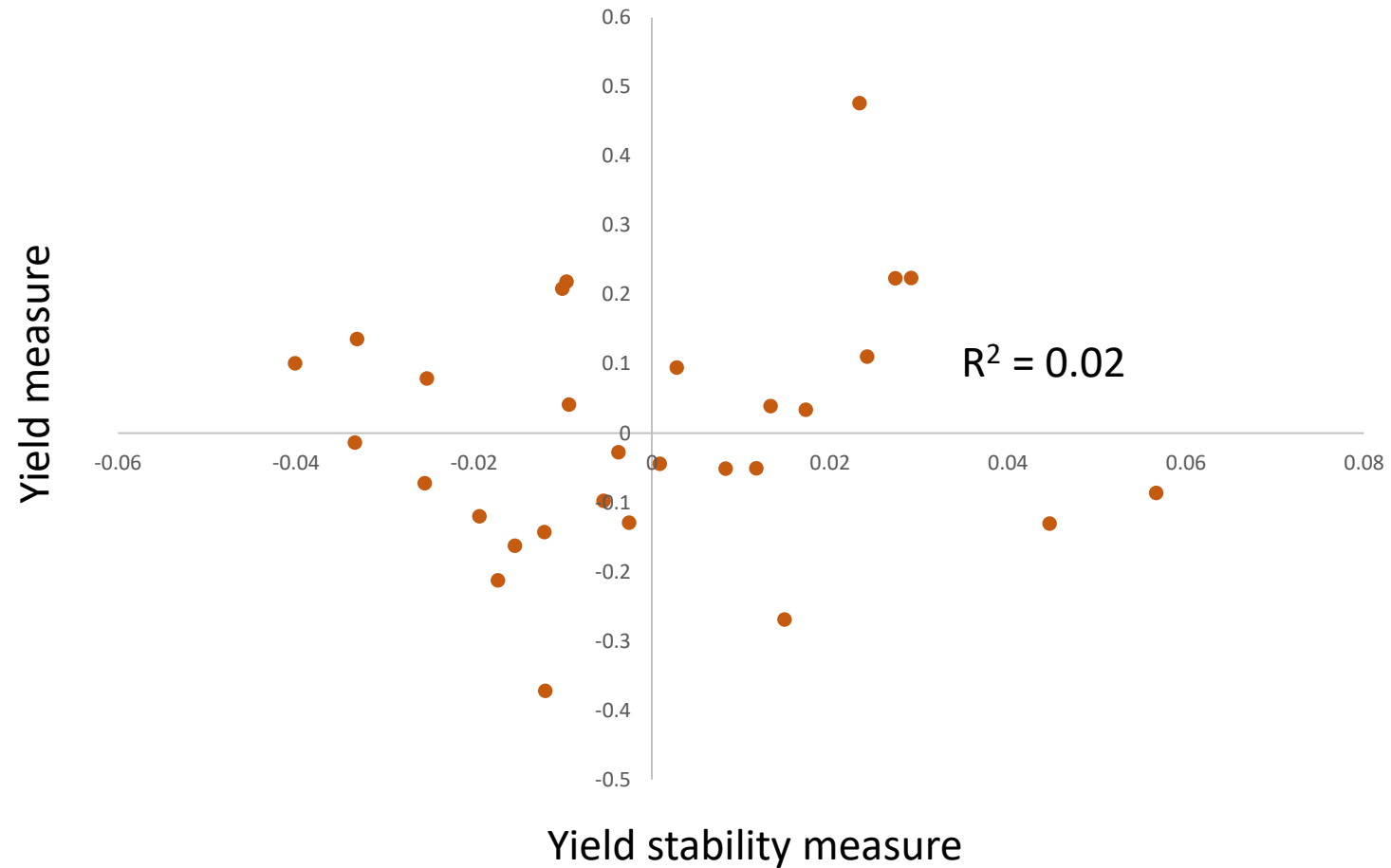
Annual variation in the UK WOSR harvest value attributable to December temperature and correlation with NAO



For varieties with lots of datapoints we can very accurately measure yield stability



Independence of yield and yield stability traits in WOSR varieties bred for the UK market



conclusions

- Yield stability in WOSR is equivalent to 50 years of gains from breeding
- December chilling is critical for high yields, accounting for up to 1 tonnes ha⁻¹ between the best and worst years.
- significant interaction between variety and temperature indicates variation in yield stability between varieties.
- yield and yield stability are inherited separately, thus it is theoretically possible to breed for both.

acknowledgments

BBSRC for funding

- JIC:
- James Brown
- Rebecca Beeby
- Steven Penfield

AHDB: Jenna Watts