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ABSTRACT

We aimed to characterise the coincidence of yield variations with weather variables for major field crops using long-term datasets and reveal whether there are commonalities across the European agricultural regions. Long-term national and/or regional yield datasets were used from 14 European countries (total of 25 regions). Crops studied were spring and winter barley and wheat, winter oilseed rape, potato and sugar beet. Relative yield deviations were determined for all crops. Meteorological data on monthly means for temperature variables, solar radiation, accumulated precipitation and evapotranspiration were provided for the relevant agricultural regions of each country for 1975–2008. Harmful effects of high precipitation during grain-filling in grain and seed crops and at flowering in oilseed rape were recorded. In potato reduced precipitation at tuber formation was associated with yield penalties. Elevated temperatures had harmful effects for cereals and rapeseed yields.

1. Introduction

Despite major developments in cropping systems and technologies, as well as advances in breeding for phenotypic stability, especially in industrialised countries, management of climate-induced fluctuations in yields is often inefficient. The results of such yield perturbations are reflected as marked changes in global market prices for crop products, as has been recorded worldwide over recent years. For example, despite the complexity of the global food supply, Lobell and Field (2007) showed that simple indicators of growing season temperatures and precipitation explained 30% or more of year-to-year variations in global average yields for the 6 most grown crops.

Farm characteristics, such as intensity of cropping, farm size and land use, contribute to the capacity to resist climate-induced yield variability (Reidsma et al., 2010). Despite local initiatives that

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A total of 25 regions and 7 field crops

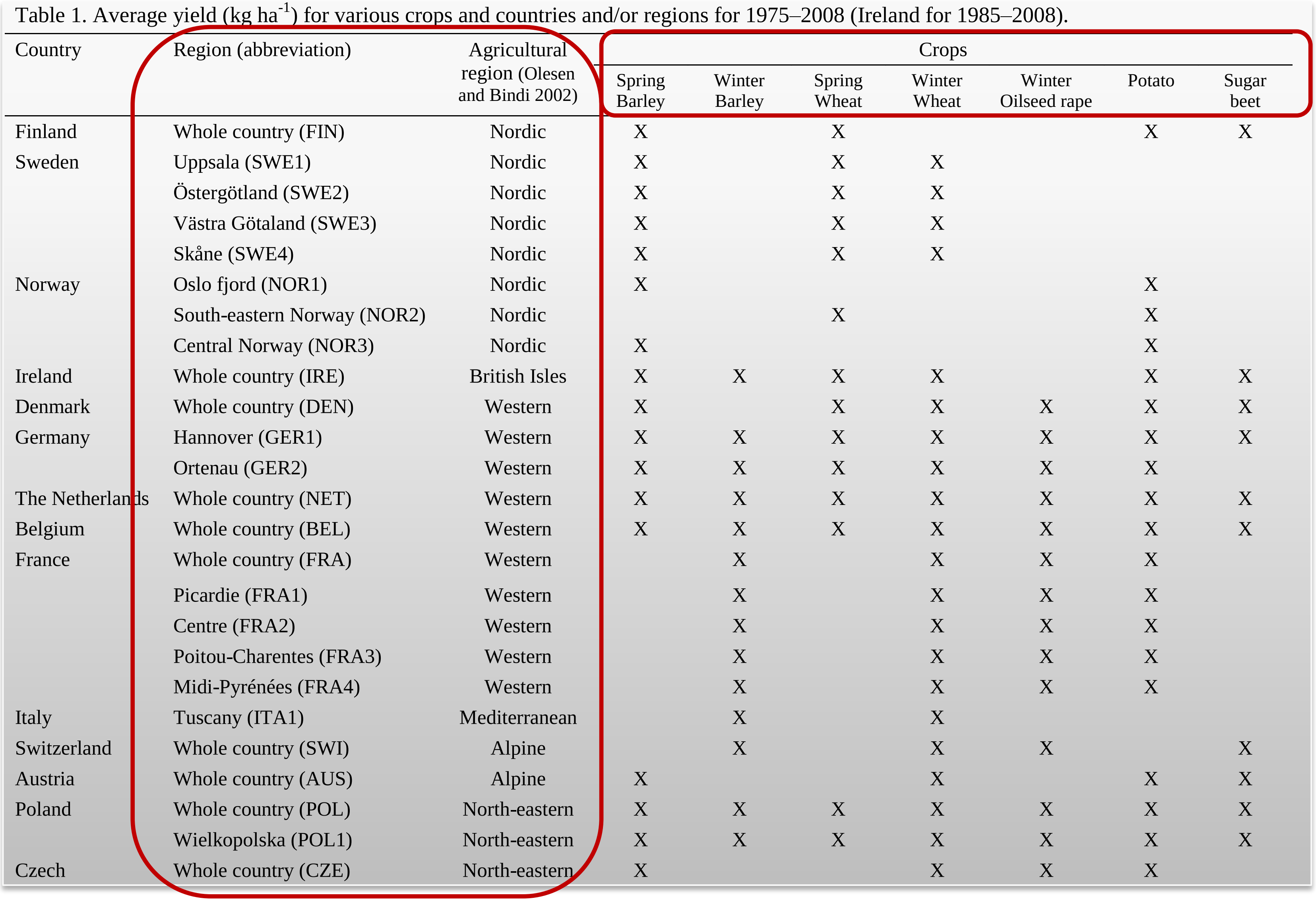


Table 1. Average yield (kg ha^{-1}) for various crops and countries and/or regions for 1975–2008 (Ireland for 1985–2008).

Country	Region (abbreviation)	Agricultural region (Olesen and Bindi 2002)	Crops						
			Spring Barley	Winter Barley	Spring Wheat	Winter Wheat	Winter Oilseed rape	Potato	Sugar beet
Finland	Whole country (FIN)	Nordic	X		X			X	X
Sweden	Uppsala (SWE1)	Nordic	X		X	X			
	Östergötland (SWE2)	Nordic	X		X	X			
	Västra Götaland (SWE3)	Nordic	X		X	X			
	Skåne (SWE4)	Nordic	X		X	X			
Norway	Oslo fjord (NOR1)	Nordic	X					X	
	South-eastern Norway (NOR2)	Nordic			X			X	
	Central Norway (NOR3)	Nordic	X					X	
Ireland	Whole country (IRE)	British Isles	X	X	X	X		X	X
Denmark	Whole country (DEN)	Western	X		X	X	X	X	X
Germany	Hannover (GER1)	Western	X	X	X	X	X	X	X
	Ortenau (GER2)	Western	X	X	X	X	X	X	
The Netherlands	Whole country (NET)	Western	X	X	X	X	X	X	X
Belgium	Whole country (BEL)	Western	X	X	X	X	X	X	X
France	Whole country (FRA)	Western		X		X	X	X	
	Picardie (FRA1)	Western		X		X	X	X	
	Centre (FRA2)	Western		X		X	X	X	
	Poitou-Charentes (FRA3)	Western		X		X	X	X	
	Midi-Pyrénées (FRA4)	Western		X		X	X	X	
Italy	Tuscany (ITA1)	Mediterranean		X		X			
Switzerland	Whole country (SWI)	Alpine		X		X	X		X
Austria	Whole country (AUS)	Alpine	X			X		X	X
Poland	Whole country (POL)	North-eastern	X	X	X	X	X	X	X
	Wielkopolska (POL1)	North-eastern	X	X	X	X	X	X	X
Czech	Whole country (CZE)	North-eastern	X			X	X	X	

Growing area effects on yield variability?

- Growing area for each crop was monitored
  - To identify the major changes in area
  - To analyze whether area was associated with yield variability (e.g. through less intensive production systems in the case of a drastically reduced crop area)
- Changes in area were slow to develop
  - In general all major changes took from 10 to 30 years
- To identify long-term changes:
  - The study period was divided into four sub-periods of equal duration (1975–1983, 1984–1991, 1992–1999, 2000–2008)
  - Yield variability and average growing area were calculated for all sub-periods
- The hypothesis was: if growing area systematically changed from period to another, yield variation within that period followed a parallel pattern
- Graphical examination did not reveal any clear associations between these patterns

Determining relative yield deviation

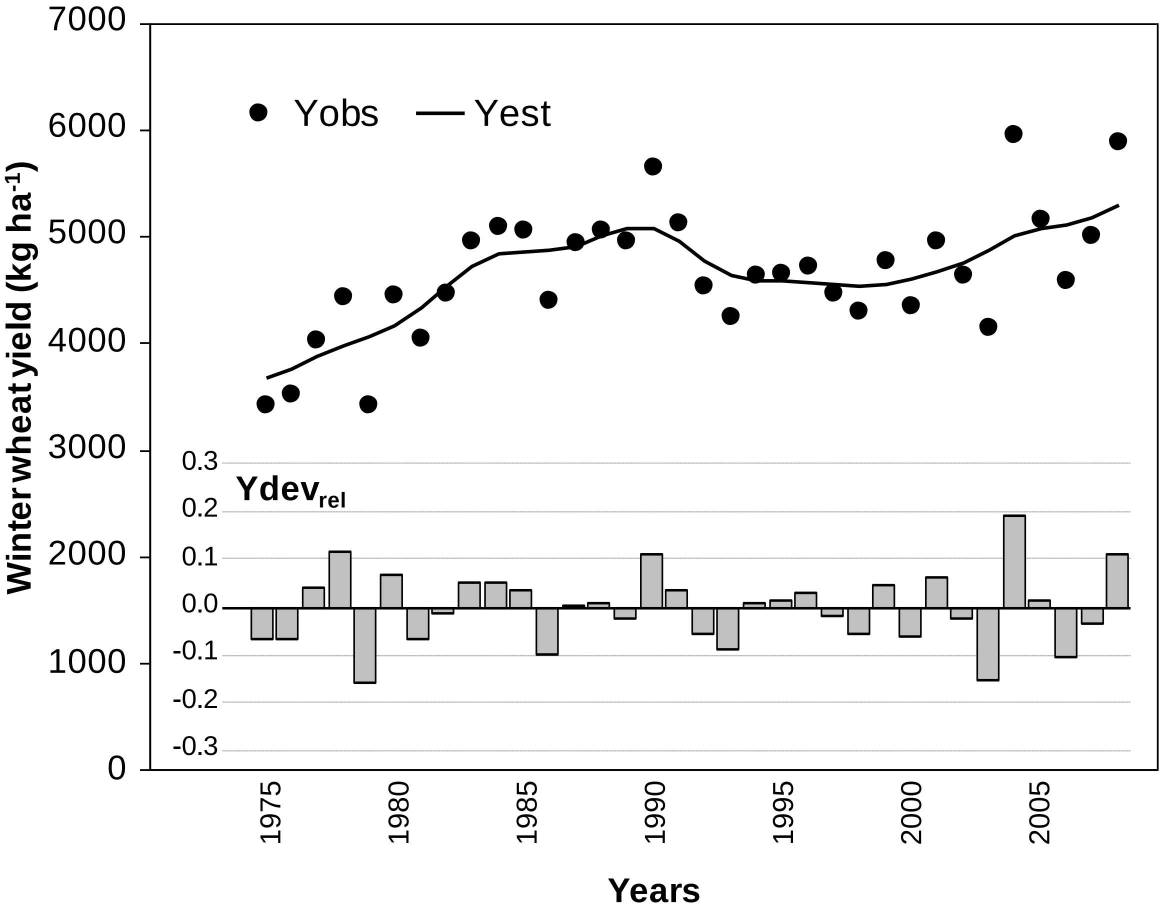


Figure. An example of the values of observed (Yobs) and estimated (Yest) yields (upper graph) and relative yield deviation ($Ydev_{rel}$, lower graph) for winter wheat yields in the Czech Republic. The estimated yields were obtained by applying a 10-year Gauss filter: de-trending effectively captures the long-term component of the crop yield fluctuation. The outputs of the process are values for residuals ($Ydev_{rel}$) that describe inter-annual variability in yield over a 30-year period in region/country.

Relative yield deviations

Relative yield deviations were determined for each crop in each country by comparing the observed yield in each year with an estimated de-trended yield:

$$Ydev_{rel} = (Yobs - Yest) / Yest$$

Example: range of Ydev$_{rel}$

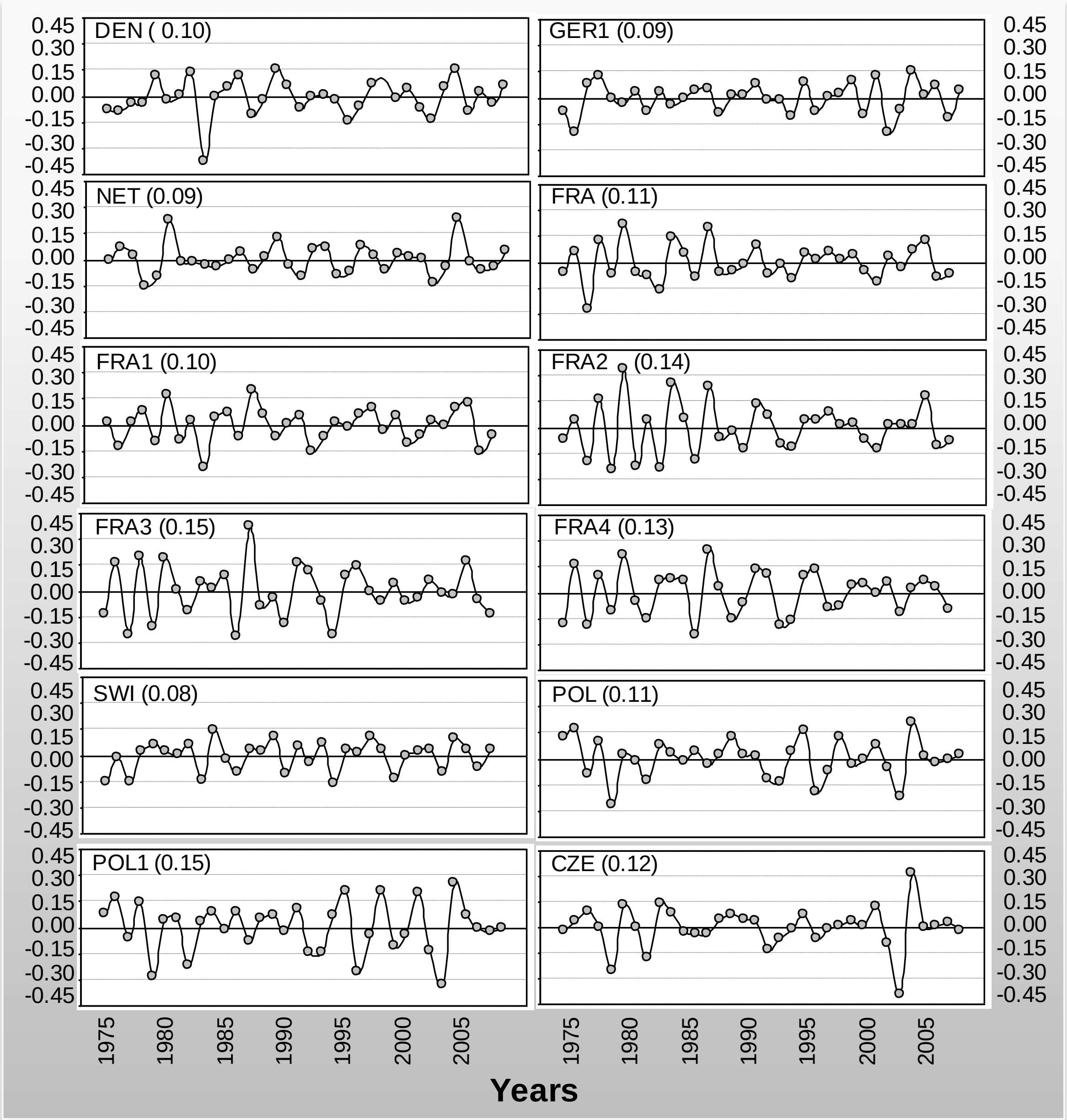


Figure: Range of relative yield deviations for winter oilseed rape in different countries and/regions from 1975 to 2008. Standard divisions are in parentheses.

Meteorological variables

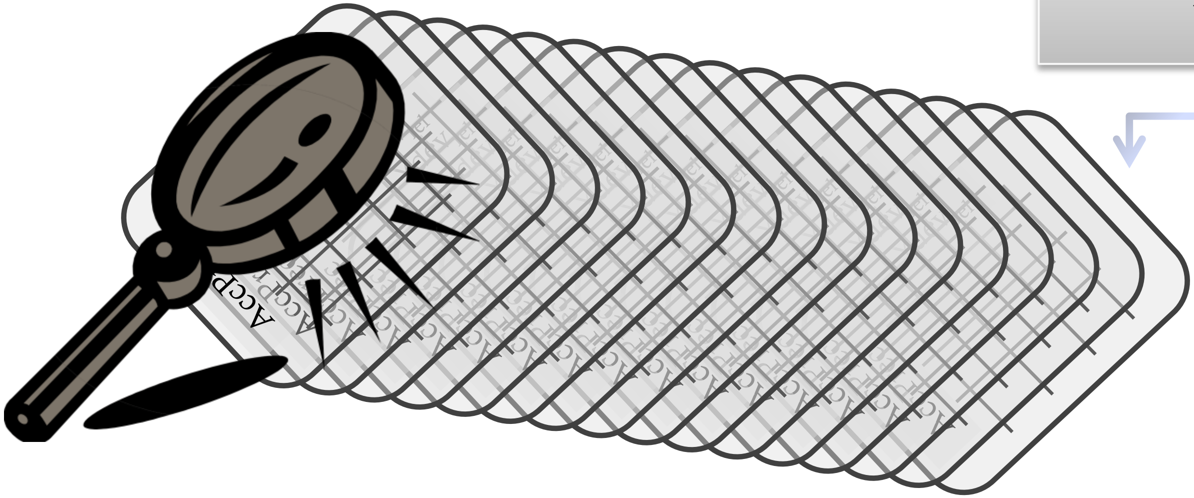
- The JRC-MARS meteorological database (>5000 stations)
    - Station data was interpolated onto a regular mesh (25×25 km grid)
    - To aggregate the meteorological data into national level, a particular procedure was developed taking in account the percentage of arable land present in each grid
- Meteorological variables used were monthly mean values for Tmin, Tmax, Tmean, SolRad, AccPrec and ETo
- Typical timings for major phenophases was determined for each crop and country
    - Timing and duration of major growth phases differ markedly depending on region
    - Crops also differ considerably in responsiveness depending on growth stage
    - It was not possible to time phenophases for individual years
- Meteorological variables for different phenophases were calculated using weighted means
    - If a period was from mid June to mid August, weights were 0.25, 0.50 and 0.25 for June, July and August, respectively

Statistical procedures: single region

- Associations between Ydev$_{rel}$ and means for meteorological variables for each main growth phase of the crop were characterized for each region:
  - Years were ranked according to Ydev$_{rel}$ and then classified into three groups, each representing 33% of the years (groups with the most negative, medium and the most positive Ydev$_{rel}$ values)
  - Similar classification was carried out for each meteorological variable
- Classification was followed by production of 3 × 3 contingency tables (crop by crop, country by country and phenophase by phenophase)
- Kappa Statistics were used to measure the associations between each two variable combinations (Ydev$_{rel}$ *vs.* meteorological variable)
  - Kappa coefficient is +1 when there is complete agreement between two variables
  - When the observed agreement exceeds chance agreement, kappa is positive, with its magnitude reflecting the strength of agreement
  - Kappa is negative when the observed agreement is less than chance agreement
- Cochran-Mantel-Haenszel Statistics were used to test statistical significance of non-zero correlation
  - The levels of weather and Ydev$_{rel}$ were at ordinal scale

Statistical procedures: commonalities

- A multiway table was stratified by country and Cochran-Mantel-Haenszel Statistics were used to reveal the most general commonalities among associations



3 × 3 contingency table for
one crop
one phenophase
one region

Statistical procedures: commonalities

- A multiway table was stratified by country and Cochran-Mantel-Haenszel Statistics were used to reveal the most general commonalities among associations
- Yield responses to weather variables were estimated using a simple linear regression analysis
  - Means and standard deviation of regression slopes of countries were calculated
  - Coefficients of determination were calculated over all countries
  - Relationships between weather variables and $\mathrm{Ydev}_{\mathrm{rel}}$ were not linear for all countries: the model resulted in a crude average that at times slightly underestimated the relationship
- Graphical methods were used to check assumptions of regression analysis

Main findings: general

- Coincidence of variation in yield and meteorological variables was especially frequent and systematic for the vegetatively propagated potato crop
  - It is likely that yields of seed producing crops are more responsive to brief stresses and constraints when they occur at critical development stages, and are without ability to compensate for them subsequently

Linear regression between relative yield deviations ($Ydev_{rel}$) and meteorological variables for potato and sugar beet determined over all countries and regions in Europe. T_{mean}, T_{min} and T_{max}, mean, minimum and maximum temperature (ºC); SolRad, solar radiation (1000 × kJ m^{-2} d^{-1}); AccPrec, accumulated precipitation (mm); ETo, evapotranspiration (mm d^{-1}). Coefficient of determination (R^2) is measured over all countries, while S.D. indicates the deviation depending on country. Average slope indicates the response of crop yield (%) to one unit change in meteorological variable.

Meteo-parameter	Potato		Potato		Sugar beet	
	Planting to tuber emergence		Tuber emergence to harvest		Sowing to harvest	
	Average slope	S.D. (R^2)	Average slope	S.D. (R^2)	Average slope	S.D. (R^2)
T_{mean}	1.17	1.65 (0.05)	–2.96	2.47 (0.17)	1.52	3.15 (0.10)
T_{min}	1.42	1.72 (0.05)	–2.67	2.68 (0.10)	1.00	2.08 (0.04)
T_{max}	0.88	1.58 (0.06)	–2.53	2.14 (0.21)	1.63	3.33 (0.13)
SolRad	0.31	2.20 (0.05)	–2.68	3.30 (0.19)	1.65	3.50 (0.10)
AccPrec	0.002	0.099 (0.04)	0.119	0.132 (0.08)	–0.035	0.142 (0.04)
ETo	2.67	9.09 (0.06)	–9.62	11.12 (0.23)	6.74	16.72 (0.12)

Main findings: temperature

- This approach was successful in capturing the central role of elevated temperatures in causing yield perturbations in Europe
  - But our method likely underestimated the degree of crop response
- Harmful effects of elevated temperatures were recorded
  - For pre-heading yield determination period for spring and winter barley and spring wheat
  - For post-heading period for spring barley and winter barley and wheat
  - For flowering and seed-filling phases in winter oilseed rape
- Due to many other factors that have caused variation in historical yields and also due to use of large, pooled datasets, the recorded effects of elevated temperatures on yields were moderate
  - A 3°C increase in temperature resulted at most in 7% yield reduction in cereals during grain-filling and 10% in oilseed rape during seed-filling when averaged over all countries

Main findings: temperature

- In potato, prior to tuber initiation, lower mean and maximum temperatures as well as solar radiation were associated with yield penalties
- At tuber formation increases in any of the temperature variables were associated with a yield penalty
  - 3°C increase in temperature with 8% yield losses
- In sugar beet, higher temperatures favored yield formation

Main findings: precipitation

- Coincidence of variability in yields and precipitation events that often holds over very limited time periods (especially regarding heavy rains), were less often captured with these large scale datasets that accumulated precipitation over each major phenophase
- Harmful effects of increased precipitation were frequently recorded for:
  - Spring barley and wheat at seedling emergence phase
  - Winter oilseed rape at flowering and seed filling
  - Winter barley, spring and winter wheat during grain filling
- Potato tuber formation was constrained by reduced precipitation
  - Especially in western and north-eastern agricultural regions where increases in precipitation favored tuber yield formation.

Main findings: precipitation

- By using large-scale datasets we were not able to demonstrate any consistent and obvious effects of severe drought periods on yield variability across Europe
    - Negative associations between solar radiation and Ydev_{rel} at the pre-heading yield determination phase in winter barley could reflect some harmful effects of drought
    - Field crop production in Europe can range from being entirely rain-fed to frequently irrigated, which evidently hampers capture of drought effects

Conclusion

Despite substantial contribution of scientific and technological developments in breeding, crop management and cropping systems, as well as socio-economic changes in Europe to historical yield trends (and despite use of pooled datasets), commonalities across Europe in variation in yield and climate was demonstrated

Thank you!