Variations in cereal crop phenology in Spain over the last twenty-six years (1986–2012)

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Abstract

Over recent years, the Iberian Peninsula has witnessed an increase both in temperature and in rainfall intensity, especially in the Mediterranean climate area. Plant phenology is modulated by climate, and closely governed by water availability and air temperature. Over the period 1986-2012, the effects of climate change on phenology were analyzed in five crops at 26 sites growing in Spain (southern Europe): oats, wheat, rye, barley and maize. The phenophases studied were: sowing date, emergence, flag leaf sheath swollen, flowering, seed ripening and harvest. Trends in phenological response over time were detected using linear regression. Trends in air temperature and rainfall over the period prior to each phenophase were also charted. Correlations between phenological features, biogeographical area and weather trends were examined using a Generalized Lineal Mixed Model approach. A generalized advance in most winter-cereal phenophases was observed, mainly during the spring. Trend patterns differed between species and phenophases. The most noticeable advance in spring phenology was record-ed for wheat and oats, the "Flag leaf sheath swollen" and "Flowering date" phenophases being brought forward by around 3 days/year and 1 day/year, respectively. Temperature changes during the period prior to phenophase onset were identified as the cause of these phenological trends. Climate changes are clearly prompting variations in cereal crop phenology; their consequences could be even more marked if climate change persistsinto the next century. Changes in phenology could in turn impact crop yield; fortunately, human intervention in crop systems is likely to minimize the negative impact.

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1 Introduction

The world produces annually about two billion tons of cereals, i.e., annual grasses whose seeds are traditionally used for human food or livestock feed. Since ancient times, cereals and cereal-based products have provided the main food basis for human civilization. Aided by its geographical location, Spain is a major producer of cereals, chiefly wheat, barley, oats, rye and corn, which account for over 90 % of domestic output; cereal production is a key sector of the national economy (SAAFFM 2013).

A number of biological factors influence plant physiology and phenology, including pests, age and instead other factors. However, the key factor affecting phenology is the weather prevailing during the growing season: temperature, photoperiod and water availability are the most influential weather-related parameters (Schwartz 2003).

In the case of cereal phenology, water availability exerts a major influence on vegetative development, and particularly on emergence (Squeo et al. 1999), while temperature patterns govern the rate of phenological development (Wielgolaski 1999). Although some cereals do not develop inflorescences under favorable photoperiod conditions, unless there is prior exposure to low temperatures (vernalization), the photoperiod remains decisive for flowering induction (Trevaskis et al. 2007). Carbon dioxide is also a key factor for cereal crop development: free-air CO_2 enrichment (FACE) experiments in grasses suggest that elevated CO_2 levels substantially increase photosynthesis, biomass, and yield; phenology is also slightly accelerated in most species under these conditions (Kimball et al. 2002; Ainsworth and Long 2005). However, long-term exposure to elevated CO_2 concentrations can prompt a loss of sensitivity to this gas (Norby et al. 1999). In fact, the last assessment report of the Intergovernmental Panel on Climate Change predicts an initial increase in crop production from the increasing CO_2 concentration for rainfed crop yields, but yield will decline in most European sub-regions at the end of the century (IPCC 2013).

Over recent years, weather conditions worldwide have been undergoing change at unusual speed. Global warming is a scientific fact: average global surface air temperatures have increased by over 0.6 °C between 1951 and 2010, and the increase is very likely to persist over the short term, i.e., into the next century. The past three decades have consecutively been the warmest on record. Spain has witnessed considerable changes in climate, especially in the Mediterranean area (IPCC 2013). The weather on earth is always far from stationary, over the last century there has been a clear increase in the frequency of extreme weather events such as heat waves, heavy rainfall and thunderstorms. Particularly marked weather variations are forecast in Spain, where the annual mean air temperature has increased over the last hundred years by 1.5 °C (Fernández-González et al. 2005). The extent of human influence on recent weather trends is a matter of debate within the scientific community; however, other environmental changes‒such as increased CO_2 emissions or hydrological changes in inland water bodies‒are clearly attributable to human activity. These global changes could affect plants and animals worldwide, and a number of authors have examined their potential impact on cereals (Olesen et al. 2012; Trnka et al. 2014; Vanuytrecht et al. 2014). There is already evidence of some impact on plant phenology, a key bio-indicator (Menzel et al. 2006a; Gordo and Sanz 2009, 2010). These phenological changes are likely to have a wide range of consequences for many ecological processes, and will undoubtedly affect agriculture, forestry, human health and the global economy (Peñuelas and Filella 2001). The most alarming development is the trend towards global warming, given the current uncertainty regarding its future consequences on global biology. Research has identified relationships between climate change and changes in the timing of various phenological events in a range of plant and animal species, the most common finding being that these events are taking place earlier (Menzel et al. 2001, 2006b; Ahas et al. 2002; Penuelas et al.

2002; Bonofiglio et al. 2008; Estrella et al. 2009). Although grasses are thought to display a less marked response to climate change than woody species (Clot 2003), the findings of a number of authors suggest otherwise (e.g., Fitter and Fitter 2002).

Studies in cereals mostly report a gradual bringing-forward of spring and summer phenophases over the last 50 years (Siebert and Ewert 2012; Tao et al. 2012). For example, Chmielewski et al. (2004), in Germany, noted a moderate advance in phenological stages since 1961 for annual crops such as maize and winter rye, while Xiao et al. (2013) observed an advance in post-sowing phases in China over the period 1980-2012. Though some research has also shown a significant shortening of the growing season for annual crops, other studies report the opposite (Williams and Abberton 2004; Sparks et al. 2005; Hu et al. 2005; García-Mozo et al. 2010).

The primary aim of this work was to analyze changes in cereal crop phenological development in Spain during the last 26 years. A secondary objective was to study the relationship between long-term phenological variations and trends registered in rainfall and air temperature during the same period.

2 Materials and methods

The study was carried out at 26 phenological sampling sites located throughout Spain (Table 1) and covered the period 1986-2012. As Table 1 shows, sampling sites were located in a range of different climatic areas. The northern area, falling within the Atlantic biogeographic region, is characterized by the lowest mean temperatures and the highest rainfall; the southern and eastern areas, lying within the Mediterranean biogeographic region, is warmer and drier (Rivas-Martínez et al. 2002).

Five crop species were studied: oats (*Avena sativa* L.), wheat (*Triticum vulgare* L.), rye (*Secale cereal* L.), barley (*Hordeum vulgare* L.) and maize (*Zea mays* L.). Together, these cereals account for over 90 % of national cereal production with individual contributions being 3.9, 26.7, 1.7, 24 and 24.3 %, respectively (SAAFFM 2013).

Phenological and weather data for the 26 sampling sites were obtained from the Spanish Meteorological Agency (AEMET). Daily mean temperatures and daily rainfall were charted over the study period. Phenological data considered in the present study consist of the first day of the year in which a specific phenophase of each species is observed in more than one individual on each monitoring place. Sampling sites are located in cereals crops fields. Monitoring is performed by visual inspection of the sampling site (located on the edge of the crop field) to inside the crop, covering the visual area. To obtain a long time series of phenological data, it is necessary to apply an exhaustive monitoring with enough resolution, which is highly time-consuming. Phenological monitoring is performed routinely during the entire study period by local collaborators of AEMET, with a minimal time resolution of 7 days. This monitoring method was designed to be able to be easily applied routinely during long study periods. Phenophases are identified using the international BBCH code (Zadoks et al. 1974), the following phenophases were studied:

- Sowing date: phenophase 00. Dry seed on sowing date
- Emergence: phenophase 09. Cotyledons break through soil surface
- Flag leaf sheath was swollen: phenophase 45. Flag leaf sheath was swollen (late-boot)
- Flowering: phenophase 59. Inflorescence fully emerged (end of heading)
- Seed ripening: phenophase 92. Seed ripening
- Harvest: phenophase 99. Harvested product

Table 1 Monitoring places with phenological and weather features for each one– *Coordinates*, *Altitude*, annual mean *Temperature*, annual *Rainfall*, *Bio-geographic region*

Name of sampling point	Coordinates		Altitude	Temperature	Rainfall	Bio-geographic region
	X	Y				
San Cristobal	−6.15	43.516667	360	12.2	916	Atlantic
Oneta	−6.65	43.45	330	10.8	986	Atlantic
Salas	−6.25	43.4	239	13.2	833	Atlantic
Oviedo	−5.866667	43.35	339	13	848	Atlantic
Benia de Onís	−4.97	43.34	215	13.2	808	Atlantic
Tineo	−6.4	43.333333	640	11.7	889	Atlantic
Genestoso	−6.383333	43.05	1180	7.2	1083	Atlantic
Borgonya	2.233333	42.066667	521	12.6	790	Mediterranean
Cardedeu	2.35	41.633333	195	15.4	685	Mediterranean
Villanueva de la Sierra	−6.4	40.2	524	14.2	602	Mediterranean
Coria	−6.483333	39.983333	250	16.3	522	Mediterranean
Ciudadela	3.816667	39.916667	20	16.6	633	Mediterranean
Es Marroig	2.733333	39.766667	309	16	558	Mediterranean
La Cabaneta Marratxi	2.75	39.616667	152	16.3	506	Mediterranean
San Vicente de Alcántara	−7.13	39.35	504	15.5	739	Mediterranean
Arroba de los Montes	−4.533333	39.15	615	14.4	471	Mediterranean
Casas de Don Pedro	−5.316667	39.1	385	16.2	460	Mediterranean
Tamurejo	−4.9	38.983333	550	15	504	Mediterranean
Viso del Marqués	−3.562719	38.52148	783	14.6	492	Mediterranean
Feria	−6.55	38.5	680	14.7	649	Mediterranean
Santos de Maimona	−6.38	38.44	541	15.1	623	Mediterranean
Pozoblanco	−4.85	38.366667	649	15.2	611	Mediterranean
Villagarcía de la Torre	−6.066667	38.283333	560	15.1	636	Mediterranean
Huescar	−2.55	37.816667	1100	13.8	455	Mediterranean
Grazalema	−5.35	36.75	823	14	830	Mediterranean
Jimena de la Frontera	−5.45	36.433333	82	17.5	744	Mediterranean

Annual linear trends were calculated for mean monthly rainfall and mean daily temperatures, and also for phenophase timing in all species, at all sampling sites; their significance was determined using the F-test. The average date of onset of each phenophase at each sampling site was recorded. Daily mean temperature and daily rainfall trends were charted over the period prior to the average mean onset of each phenophase.

The generalized linear mixed models (GLMM) approach fixed to normal distribution was used to analyze the influence of the fixed factors biogeographical area, species and specific phenophase, and their combined interactions, on three dependent variables: the average onset date of each phenophase, standard deviation of the onset of each phenophase, and trend in the timing of each phenophase. A GLMM was also used to study the influence of temperature and rainfall trends on phenological trends. Mean temperature and accumulated rainfall trends over 15, 30 and 45 days prior to the average onset of each phenophase were calculated for each sampling site. Statistical analysis and plots were performed using R statistical software (R Core Team 2013) and R package “*lme4*” (Bates et al. 2013).

3 Results

Variations in the onset of all phenophases throughout Spain are shown in Fig. 1a. Cereals are annual grasses sown and harvested during the same crop year. As Fig. 1a shows, oats, wheat, barley and rye (winter cereals) displayed similar phenological development, being sown between October (DOY 273) and December (DOY 365) and harvested between May (DOY 120) and July (DOY 211); maize was sown in spring and harvested in summer/autumn. Emergence took place some weeks after the sowing date, showing a parallel behavior. The phenophases “flag leaf sheath swollen”, “flowering” and “seed ripening” took place in spring for winter grains and in summer/autumn for maize (a summer crop). The variability recorded is attributable to climate differences between sampling sites. Table 2 shows summary parameters for GLMM. In model I, the onset date of each phenophase was significantly influenced by five factors: obviously, the phenophases studied and their interactions determined the date of onset of specific events, but a significant relationship was also observed between species and biogeographical area. No significant relationship was found between the standard deviation of onset date for each phenological event and either biogeographical area or phenophase (models II and III); however, a significant relationship was observed between annual variability in the onset of each phenophase and species.

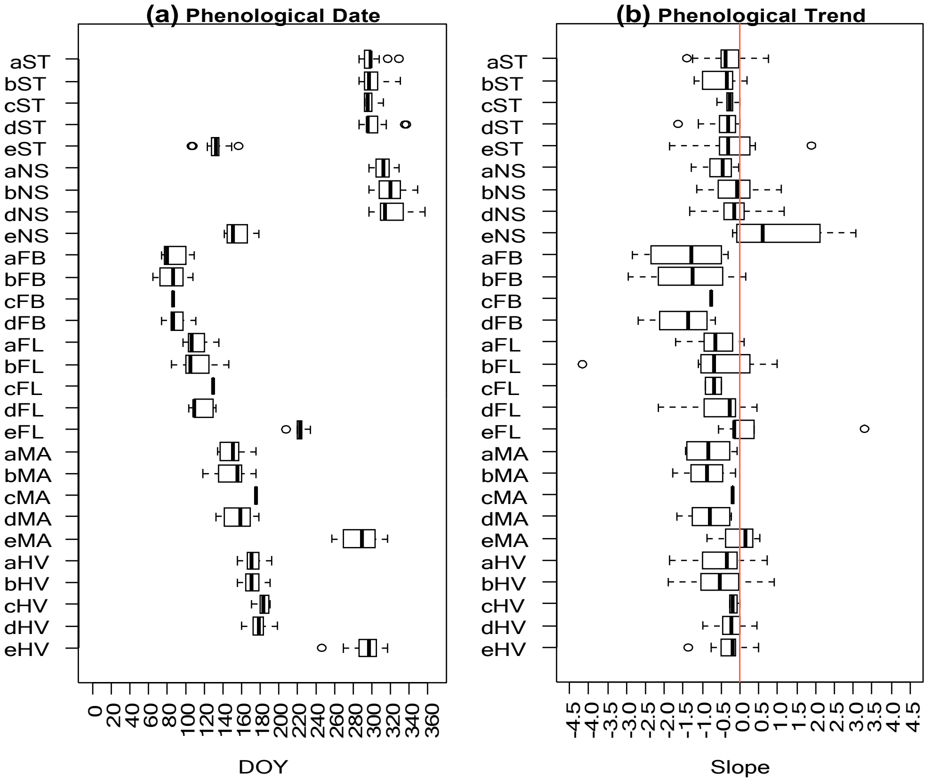

Fig. 1 Boxplots of averaged occurrence of each phenophase (a) and phenology trends (b). Species: oats (a), barley (b), rye (c), wheat (d) and maize (e). Phenophases: sowing date (*ST*), emergence (*NS*), flag leaf sheath swollen (*FB*), flowering (*FL*), seed maturation (*MA*) and harvest (*HV*)

Table 2 Generalized linear mixed model summary parameters. *Model I* (Dependent variable: onset date); *model II* (dependent variable: standard deviation on Onset date) and *model III* (dependent variable: phenological trend). *AIC* Akaike information criterion; *BIC* Bayesian information criterion; *logLik* log-likelihood

Model I					
Dependent variable: onset date					
Model fit summary					
N	AIC	BIC	logLik	Sigma	R^2
218	2108.08	2223.31	−1020.04	27.67	0.91
Sequential hypothesis testing					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Area	1	6954.49	6954.49	9.08	0.0029
Species	4	8612.15	2153.04	2.81	0.0268
Phenophase	5	787561.18	157512.24	205.69	<0.0001
Area: phenophase	4	300610.02	75152.50	98.14	<0.0001
Sp: phenophase	18	254923.54	14162.42	18.49	<0.0001
Residuals	186	142435.03	765.78		
Model II					
Dependent variable: standard deviation on onset date					
Model fit summary					
N	AIC	BIC	logLik	Sigma	R^2
218	1446.48	1561.70	−689.24	6.11	0.22
Sequential hypothesis testing					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Area	1	72.57	72.57	1.94	0.1649
Species	4	929.18	232.29	6.22	0.0001
Phenophase	5	143.63	28.73	0.77	0.5729
Area: phenophase	4	307.70	76.93	2.06	0.0877
Species: phenophase	18	523.13	29.06	0.78	0.7237
Residuals	186	6943.82	37.33		
Model III					
Dependent variable: phenological trend					
Model fit summary					
N	AIC	BIC	logLik	Sigma	R^2
218	689.21	804.44	−310.61	1.08	0.23
Sequential hypothesis testing					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Area	1	0.20	0.20	0.17	0.6822
Species	4	18.95	4.74	4.03	0.0037
Phenophase	5	17.12	3.42	2.91	0.0148
Area: phenophase	4	7.63	1.91	1.62	0.1704
Species: phenophase	18	22.14	1.23	1.05	0.4109
Residuals	186	218.72	1.18		

Phenological trends are summarized in Fig. 1b, being significant trends ($p<0.05$) in 23 % of cases. For winter cereals, an advance was observed at the onset of most phenophases, mainly during the spring (negatives slopes). However, emergence depends on sowing date, emergence date shows a parallel behavior with sowing date with a small delay—sowing date has in average a significant trend of -0.38 and emergence phase has in average a significant trend of -0.26—that means that although emergence date is advancing, the emergence length is softly increasing. However, no significant advance was recorded for maize phenophases; indeed, emergence phenophases displayed a significant delay of 0–3 days/year (slopes range between 0 and 3). As Table 2 shows, no significant relationship was noted between biogeographical area and phenological slope. However, significant differences in trends were observed both between species, the most marked advance in phenophases being recorded for wheat and oats, and between phenophases (model III) The clearest advance was observed for the "Flag leaf sheath swollen" phase taking place between March and May, which advanced by almost 3 days/year at some sites.

Results for linear trend analysis of monthly mean temperatures and monthly accumulated rainfall at the study sites are shown in Fig. 2 Box plots revealed a certain degree of variation in weather trends throughout Spain over the study period. As Fig. 2a suggests, there was a general increase in temperature throughout the year (20 % of significant trends at $p<0.05$), except in February, March, November and December, when a slightly decreasing trend or absence of temperature trend was apparent in some locations. Rainfall trends across Spain

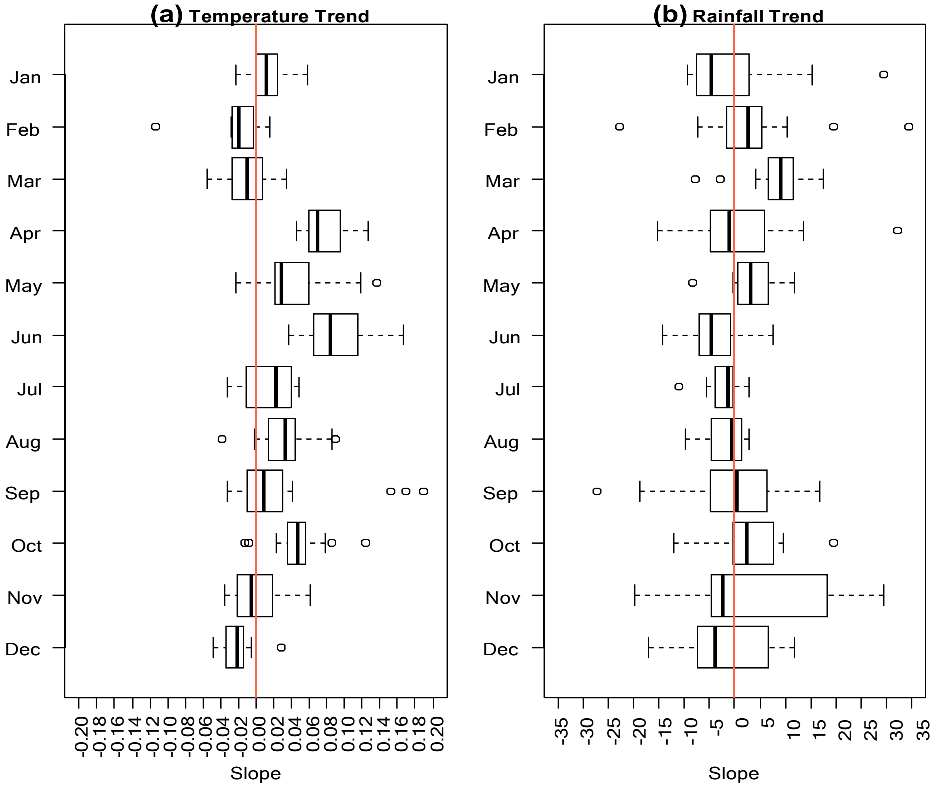

Fig. 2 Weather trends during 1986-2012 in phenological sampling points

were less clear (5 % of significant trends at $p<0.05$); while spring months showed a rising slope, no trend or a slightly decreasing slope was apparent in other months.

Table 3 shows summary parameters for the GLMM performed to determine significant relationships between phenology trends and weather trends. Air temperature trends during the period prior to the onset of each phenophase displayed a significant correlation with phenological trends. Temperature also prompted significant, though differing, effects at different

Table 3 Generalized linear mixed model summary parameters. *Rf* rainfall; *T* air temperature; *AIC* Akaike information criterion; *BIC* Bayesian information criterion; *logLik* log-likelihood

Model IV					
Dependent variable: phenological trend					
Model fit summary					
N	AIC	BIC	logLik	Sigma	R^2
218	696.36	1079.33	−235.18	1.01	0.61
Sequential hypothesis testing					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Phenophase	5	20.19	4.04	3.93	0.0026
Species	4	15.87	3.97	3.86	0.0057
Area	1	0.20	0.20	0.19	0.6616
T(−15 days)	1	11.41	11.41	11.12	0.0012
T(−30 days)	1	5.94	5.94	5.78	0.0179
T(−45 days)	1	4.54	4.54	4.42	0.0379
Rf(−15 days)	1	0.67	0.67	0.65	0.4221
Rf(−30 days)	1	3.52	3.52	3.43	0.0668
Rf(−45 days)	1	0.15	0.15	0.15	0.6992
Phenophase: species	18	13.12	0.73	0.71	0.7944
Phenophase: area	4	7.70	1.93	1.88	0.1200
Phenophase: *T*(−15 days)	5	5.75	1.15	1.12	0.3545
Species: *T*(−15 days)	4	5.21	1.30	1.27	0.2873
Area: *T*(−15 days)	1	0.56	0.56	0.55	0.4615
Phenophase: *T*(−30 days)	5	1.86	0.37	0.36	0.8737
Species: *T*(−30 days)	4	1.19	0.30	0.29	0.8847
Area: *T*(−30 days)	1	7.86	7.86	7.65	0.0067
Phenophase: Rf(−15 days)	5	11.80	2.36	2.30	0.0499
Species: Rf(−30 days)	4	3.53	0.88	0.86	0.4910
Area: Rf(−30 days)	1	1.61	1.61	1.57	0.2127
Phenophase: Rf(−30 days)	5	9.60	1.92	1.87	0.1054
Species: Rf(−30 days)	4	1.73	0.43	0.42	0.7932
Area: Rf(−30 days)	1	0.20	0.20	0.20	0.6561
Phenophase: Rf(−45 days)	5	11.92	2.38	2.32	0.0480
Phenophase: *T*(−30 days)	4	3.00	0.75	0.73	0.5725
Species: *T*(−30 days)	4	0.50	0.13	0.12	0.9742
Phenophase: species: *T*(−30 days)	16	24.88	1.56	1.52	0.1076
Residuals	111	109.83	1.03		

sites. Trends in accumulated rainfall prior to phenophases generally showed no significant correlation with phenological trends, although significant correlations were recorded for some phenophases.

Correlations between significant trends for each phenological time series and trends in air temperature and accumulated rainfall over the 15 days prior to the mean onset of each phenophase at each site are shown in Fig. 3.The advance of the sowing date for winter cereal crops was related to the trend towards increasing rainfall over the previous period. The changing trend in the maize sowing date was more closely correlated with the trend towards increasing temperature over the previous 15 days. Although some correlations were observed between the advance in emergence and increased rainfall, in general, emergence dates showed no significant correlation with weather trends over the previous period, but mirrored the trend shown by sowing date, the two being closely related. Moreover, emergence date has not shown significant trends due to the fact that it is more related with the sowing date.

The most marked advance was recorded for the "Flag leaf sheath swollen" phase, correlating with a trend towards increasing rainfall and air temperature. Advances in flowering date, seed ripening and harvest time in winter cereal crops showed a clear correlation with increases in air temperature over the previous period, while the increase in rainfall appears to have affected other phenophases. Maize phenophases displayed no apparent correlation with weather trends (Fig. 3; Table 3).

4 Discussion

Significant changes in cereal crop phenology trends are recorded in Spain correlated with certain changes in weather trends over the study period. These changes could be of major economic importance, due to their potential direct impact on final crop yields. A generalized advance in most winter cereal phenophases, mainly in spring, was observed for all crops except maize, which registered only a slight advance or even a significant delay in some phenophases. Other studies also report an advance in grass phenophases, with a more marked response in spring than in summer or autumn (Sparks et al. 2000; Beaubien and Freeland 2000; Jaagus and Ahas 2000; Abu-Asab et al. 2001; Sparks and Menzel 2007). A number of authors suggest that perennial crops show a stronger response to climate change than annual crops, due to greater human intervention in the latter (Penuelas et al. 2002; Estrella et al. 2007; Menzel et al. 2006c).

Although the temperature is widely recognized as the main factor influencing grass phenology, photoperiod, rainfall and vernalization time have also been identified as key factors (Schwartz 2003). Changes in these environmental conditions have in some cases been held responsible for changing phenological trends. Heat accumulation models and photoperiod conditions for optimal growth in cereals have for decades been the subject of widespread research (e.g., Danalatos et al. 1994), which has noted that higher temperatures are associated with an increase in the speed of phenological events (Hakala 1998). A number of authors have reported that warmer weather in the preseason months of the year encourages grass growth, with earlier maturation of vegetative and reproductive structures (Emberlin et al. 1994; Penuelas et al. 2002; Cenci and Ceschia 2000). Water availability also has been identified as a key factor for grasses phenology (García-Mozo et al. 2009). Although a correlation has been observed between temperature trends and phenological trends, the interactions of all environmental conditions on the duration of the phenological development of agricultural crops are extremely complex; indeed, some authors consider very unlikely that changes in temperature can be converted directly into changes in crop phenology (Challinor et al. 2009; Craufurd and

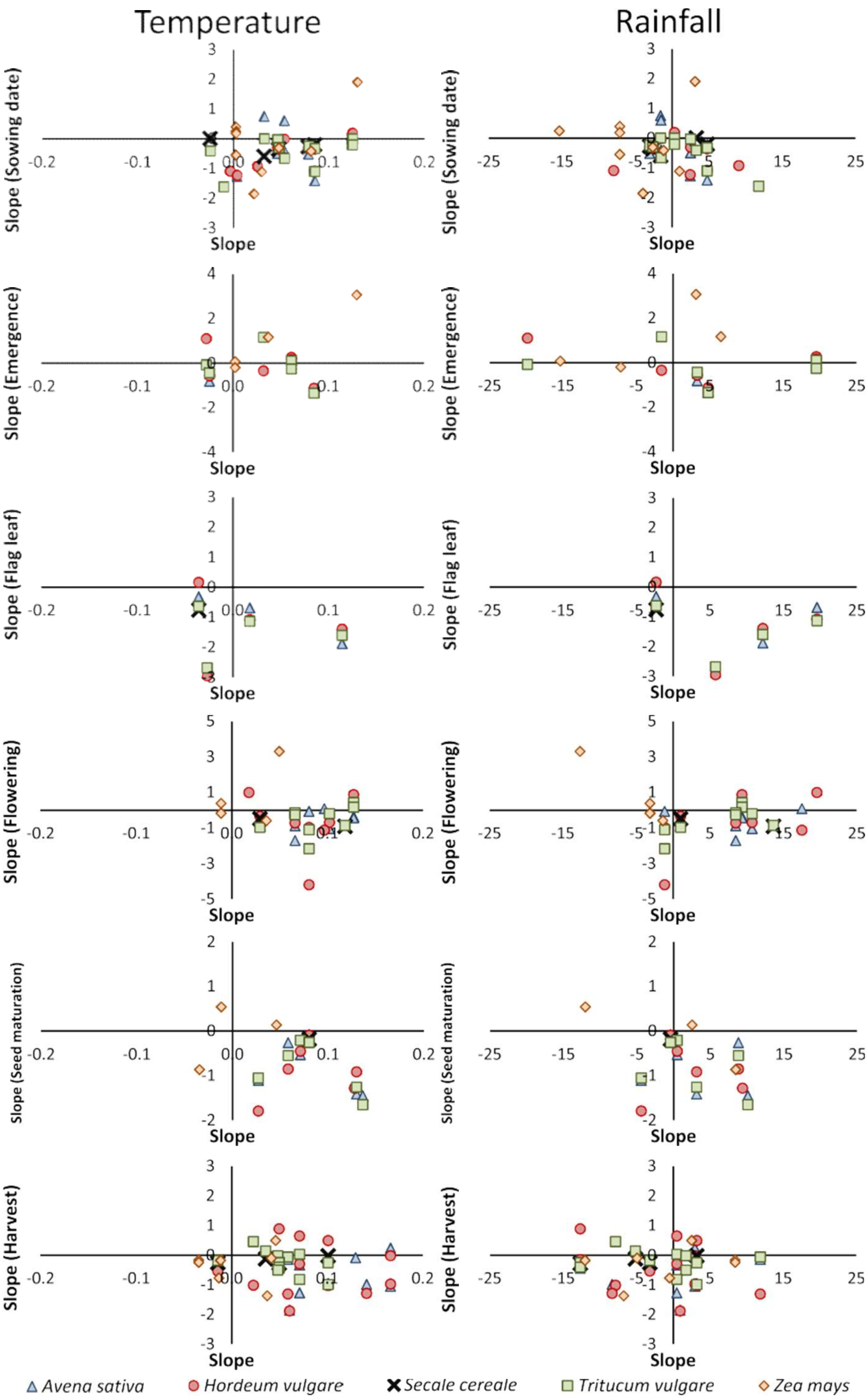

Fig. 3 Relationship between phenological trends and weather trends (1986-2012)

Wheeler 2009). There is also experimental evidence suggesting that increased CO_2 prompts not only an increase in pollen production, mostly due to the increase in the number of flowers or in pollen production/anther, but also the acceleration of vegetative growth in plants (Ziska and Caulfield 2000; Ladeau and Clark 2006). However, the correlation between phenology and CO_2 levels is not reported by all authors (Hakala 1998).

The nature of changes in the timing of phenological events varies depending on the phenophase, and human intervention in one phenophase is likely to influence the timing of all subsequent phenological events, leading to a falsification of statistical trends. Sowing date is strongly influenced by human crop management decisions, while the following phenophase–emergence–is closely linked to sowing. Consequently, time series analyzes of the emergence date yield results similar to those of the preceding phase, as reported by other authors (Menzel 2000; Menzel et al. 2006c). Indeed, we have also observed a parallel behavior between both phenophases with a bigger advance of the emergence than sowing date, which means the soft elongation of emergence length. In agriculture, evidence of changes and their attribution are further complicated by the fact that farmers adapt their strategies to changes in the weather, simultaneously modifying output (van Oort et al. 2012; Rezaei et al. 2013).

The present study recorded a general shortening of the growing season: advance of the sowing date being less marked than that of other phenophases. Similar findings are reported by a number of authors. Siebert and Ewert (2012) found that the growing season for oats in Germany decreased by about 2 weeks between 1959 and 2009, giving rise to earlier onset of other phenological events, as also reported by other studies and for other crops (Menzel et al. 2006a, b, c; Estrella et al. 2007, 2009). In contrast, other authors have recorded a progressively longer growing season. Chmielewski et al. (2004), for example, found that the most marked shift in plant development occurred in very early spring phases and that, while late spring and summer phases also reacted to increased temperatures, trends were generally less pronounced. Other authors maintain that indirect effects of an increase in air temperatures include a prolongation of the growing season (Menzel and Fabian 1999; Chmielewski and Rotzer 2002) and a change in the phenological phases of individual plants, i.e., the sequence of developmental stages.

Flowering is perhaps the most widely studied phenophase in grasses. Certain studies use airborne pollen as a tool for monitoring flowering phenology. General advance in flowering is reported by other authors; however, a number of works report no significant trend in the timing of grass flowering (Leuschner et al. 2000; Damialis et al. 2007). Regarding the length of flowering season, Tormo-Molina et al. (2010) recorded a decrease in duration in Badajoz (Spain) between 1994 and 2008, together with an advance in the flowering onset, no change in maximum flowering date and a delayed end to flowering. By contrast, García-Mozo et al. (2010) reported a lengthening of the pollen season in southern Spain over the period 1982-2008, with an advance in flowering onset and a delay in flowering end. Clot (2003) also recorded a longer grass pollen season in Neuchâtel (Switzerland) between 1979 and 1999, with an advance in flowering onset, but no change in flowering end date.

Although harvest timing is also strongly influenced by human crop-management decisions, other authors report results from harvest date and seed ripening similar to those obtained here. The warming trend recorded between 1959 and 2009 in Germany resulted in an earlier onset of all phenophases in oats and a shortening of most of them; i.e., a 17-day earlier onset of yellow ripeness and a shortening of the “sowing to yellow ripeness” period by 14 days (Siebert and Ewert 2012)

Although no significant relationship was found between biogeographical area and phenological slope, location influenced the average onset of each phenophase. The spatiotemporal variability observed in onset dates may be attributed to the effects of temperature and of day length. Siebert and Ewert (2012) showed that spatial patterns in the phenological development of oat crops in Germany (1959-2009) reflected differences among eco-regions in the onset of developmental events.

The phenological features of living things are not stationary; variations in phenology are usually apparent in the earliest phenological records; however, recent climate trends are prompting more marked variations in phenology worldwide, and cereal crop phenology is being affected by these changes (Mariani et al. 2012). Recent publications predict a decrease in cereal crop production in the Mediterranean area due to extreme high temperatures (Asseng et al. 2014; IPCC 2013). If current weather trends continue into the next century, they could have dire consequences for global biology, with an alarming impact on cereal crop yields, on the global economy and on global power supplies. The advance in most of the phenophases could increase the exposure of crops to extreme events. The increase in weather variability also could increase the interannual variability in crop production or it would produce the modification of traditionally suitable areas for crops.

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