EFFECTS OF CLIMATIC CHANGE ON PHENOLOGICAL TRAITS IN THE SPANISH ATLANTIC COAST

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Abstract

Climatic change has impact on animals and plants, including crops and food production at global scale and the effects are variable at local scales. Our objectives were to find out which climatic parameters have changed along years and their effects in living beings and, particularly, in maize. We made regression analyses in order to investigate the variation of several climatic parameters along 40 years in an Atlantic Spanish location, their effects on several phenological traits and on maize performance. We found that maximum yearly temperature increased at a rate of 0.08 degrees per year while minimum yearly temperature decreased at a rate of -0.08. Six phenological traits varied significantly along the years, namely, the swift (*Apus apus*) advanced its migration, the swallow (*Hirundo rustica*) delayed its migration, the fig (*Ficus carica*) leaves fall earlier, the orange (*Citrus sinensis*) and the chestnut (*Castanea sativa*) trees and the vine (*Vitis vinifera*) flowered earlier while the willow (*Sambucus nigra*) flowered later. Most climatic variables affected few phenological traits and only maximum yearly temperature affected five phenological traits. Mean maize (*Zea mays* L.) yield did not follow a linear variation along years. Therefore, there was significant climatic variation towards more extreme temperature conditions and irregular effects on temperature and rainfall, and these climatic changes had significant effects on living beings. The relative importance of the clime in each season is related to the vegetative state of the plants and the life cycle of the animals. Particularly spring clime had more significant effects although the seasonal effects varied for each living organism; being summer clime less important for maize performance.

Resumen

El cambio climático tiene un impacto en animales y plantas, incluyendo cultivos y la producción de alimentos a escala global y los efectos son variables a escala local. Nuestros objetivos eran conocer qué parámetros climáticos han cambiado a lo largo de los años y sus efectos sobre los seres vivos y, en particular, sobre el maíz. Realizamos análisis de regresión para investigar la variación de varios parámetros climáticos a lo largo de 40 años en una zona del Atlántico español, sus efectos sobre varios rasgos fenológicos y sobre el rendimiento del maíz. Descubrimos que la temperatura máxima anual aumentó a un ritmo de 0,08 grados por año, mientras que la temperatura mínima anual disminuyó a un ritmo de -0,08. Seis rasgos fenológicos variaron significativamente a lo largo de los años, en concreto, el vencejo (*Apus apus*) adelantó su migración, la golondrina (*Hirundo rustica*) retrasó su migración, las hojas del higo (*Ficus carica*) caen antes, el naranjo (*Citrus sinensis*), el castaño (*Castanea sativa*) y la vid (*Vitis vinifera*) florecieron antes, mientras que el sauce (*Sambucus nigra*) floreció más tarde. La mayoría de las variables climáticas afectaron pocos rasgos fenológicos y sólo la temperatura máxima anual afectó cinco rasgos fenológicos. El rendimiento medio del maíz (*Zea mays* L.) no siguió una variación lineal a lo largo de los años. Por tanto, hubo una importante variación climática hacia condiciones de temperatura más extremas y efectos irregulares sobre la temperatura y las precipitaciones, y estos cambios climáticos tuvieron efectos significativos sobre los seres vivos. La importancia relativa del clima en cada estación está relacionada con el estado vegetativo de las plantas y el ciclo vital de los animales. Particularmente el clima primaveral tuvo efectos más significativos, aunque los efectos estacionales variaron para cada organismo vivo; el clima de verano es menos importante para el rendimiento del maíz.

Key words: climatic change; global warming; stress; maize

Introduction

Climate has been changing for a long time; but the rate of change has increased more than what can be explained only by natural causes. Climatic change affects crops and living conditions at large scale and poses a consistent treat to food security and agriculture production (Saleem et al. 2024). Several evidences support a negative impact of climate change on crops and food production at global scale (Lobell and Field 2007; Parry et al. 2004) and varying results at regional scale (Olesen and Bindi 2002; Piao et al. 2010). In a World study of possible effects of climatic change, Lobell et al. (2008) concluded that South Asia and Southern Africa can suffer negative impacts on several important crops and that uncertainties vary widely by crop. Lobell et al. (2011) found that in most cropping regions temperature trends from 1980 to 2008 exceeded one standard deviation and global maize and wheat production declined by 3.8 and 5.5%, respectively. Climatic phenomena are becoming more extreme and variable altering life in unpredictable ways and having nonlinear effects on specific crops or agricultural systems. According to Olesen and Bindi (2002), climatic change is expected to benefit agricultural systems in Northern Europe and hamper them in Southern Europe. However, Southern Europe is a heterogeneous region with diverse climatic conditions varying from the humid and cold Atlantic coast to the warm and dry Mediterranean area.

In order to deal with a complex problem, we can take a comprehensive approach or focus in a particular case of study, as the maize breeding program carried out in the Misión Biológica de Galicia (CSIC). In previous studies, Malvar et al. (2005) evaluated a diallel among maize populations in Spain and France and identified cold temperature at early stages as the main environmental factor affecting yield; Butrón et al. (2004) evaluated 49 maize hybrids in five locations characterized by different levels of corn borer natural infestation and yield decreased with decreased mean daily minimum temperature and average humidity; and Romay et al. (2010) evaluated the effects of climatic variables in a large set of Spanish maize populations at three Spanish locations during three years and found out that the main climatic covariates for yield were some temperature-related variables. The main climatic covariates for yield were days with mean temperature over 15 °C and maximum temperature in September, but were not consistent across locations. Romay et al. (2010) concluded that if yield stability should be a breeding goal and yield stability depends on several climatic variables mainly related to high temperatures.

In the present study, we focus in a single location for a 40-year period of climatic data, phenological variables, and maize crop. The objectives are to find out which climatic parameters have changed along the years and their effects in living beings and, particularly, in maize performance.

Materials and Methods

Climatic data were obtained from the weather station located in the experimental field of the research institute Misión Biológica de Galicia (CSIC) located in Pontevedra (42º 24' 20'' N, 8º 38' 48'' W, 20 masl) during 40 years between 1967 and 2006 (figure 1). Climatic data consisted on total, mean and maximum yearly rainfall; maximum, minimum and mean yearly temperatures; total, mean and maximum rainfall of each month; mean of the maximum and of the minimum temperatures, and maximum, minimum and mean temperatures of each month.

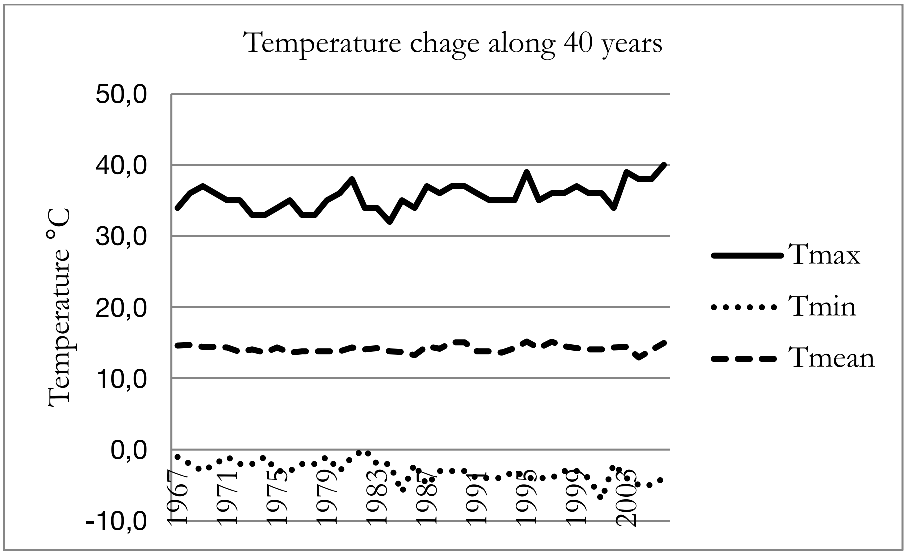

Figure 1. Temperature variation between 1967 and 2006 in Pontevedra (Northwest of Spain).

Regression analyses were made with each climatic and phenological trait as dependent variable and years as independent variable by using the PROC REG of SAS (SAS Institute 2008). Lineal regression was calculated for maize traits from each set on years. Then, multiple regression analyses with the stepwise method ($P = 0.05$) were carried out for each phenological trait as dependent variable and the climatic traits as independent variables. Furthermore, multiple regressions with stepwise method were calculated for each maize trait from each set of hybrids on the climatic traits.

Results and Discussion

Regressions of climatic variables during 40 years showed that the clime is becoming more extreme, i.e. maximum yearly temperature increased at a rate of 0.08 degrees per year while minimum yearly temperature decreased at a rate of -0.08 (table 1). Also mean temperatures increased in April, May, and June and decreased in October and November. Moreover, maximum temperatures increased in February and in spring while minimum temperatures decreased in autumn and winter. There was also a reduction of rain in February and an increase in August and October. Non-significant trends suggest that temperatures might be increasing in winter, spring and summer and rainfall might be decreasing in summer and autumn.

Our data show that the clime is becoming more extreme at a slow rate. Temperatures increase in winter, spring, and summer, while rainfall decrease in summer and autumn. Increase in mean yearly temperature was not significant. Contrarily, average temperatures have been reported to raise 0.74 ± 0.19 °C from 1906 to 2005 and are predicted to increase 1.8–4.0 °C by the end of the 21st Century (IPCC 2007). At regional scale, this global trend has some fluctuations, for example, Berner et al. (2013) found that mean summer temperatures increased 1 °C from 1938 to 2009 in Siberia, though there was no significant trend in growing year precipitation or climate moisture index. Zhang et al. (2013) found that the climatic change trends in China showed that the diurnal temperature difference and sunshine hours were declining and stated that this type of climatic change trend might further negatively affect winter wheat production in the future. Traore et al. (2013) found in southern Mali that minimum daily air temperature increased on average by 0.05 °C per year during 40 years; maximum daily air temperature remained constant, seasonal rainfall varied largely across years but had no significant change over that period, and the rainfall distribution changed.

Seven phenological traits varied significantly along the years, specifically, the swift advanced its migration, the swallow delayed its migration, the fig leaves fall earlier, the orange and the chestnut trees and the vine flowered earlier while the willow flowered later (table 1). In order to find out the possible climatic causes of these significant changes, multiple regression analyses were carried out and showed that as many as 26 climatic variables affected the flowering of vine and as few as 4 affected the migration of the swallow (table 2). The climatic variables affecting each of the phenological traits were diverse; most of them affected only one of the phenological traits, some of them affected two or three and only “maximum yearly temperature” affected five phenological traits, namely migration of the swift, and flowering of the orange tree, the chestnut tree, the willow, and the vine. Most effects were small, but for each phenological trait there was one climatic variable with $R^2 >$ 0.20, being the largest one the negative coefficient of maximum rainfall in January over flowering of the willow ($R^2 = 0.435$). The other large effects were the negative effect of maximum yearly temperature on flowering of the chestnut tree ($R^2 = 0.363$), its negative effect on migration of the swift (0.247), and its negative effect on flowering of wine (0.267), the positive effect of the mean of the maximum temperatures in May on migration of the swallow (0.319), the negative effect of maximum temperature in June on fall of fig leaves (0.247), and the negative effect of maximum temperature in December on flowering of orange tree (0.231) (table 2).

Table 1. Significant linear regression coefficients of climatic and phenological traits on 40 years: 1967 to 2006.

Climatic trait	Adjusted R^2	b ± SE[a]
Maximum yearly temperature (°C)	0.24	0.080±0.022
Minimum yearly temperature (°C)	0.39	-0.080±0.016
Total rainfall (mm) in February	0.12	-3.848±1.562
Total rainfall (mm) in August	0.13	1.237±0.472
Total rainfall (mm) in October	0.20	5.439±1.669
Mean rainfall (mm) in February	0.11	-1.356±0.556
Mean rainfall (mm) in August	0.13	0.398±0.153
Mean rainfall (mm) in October	0.20	1.756±0.538
Maximum rainfall (mm) in August	0.13	4.686±1.825
Maximum rainfall (mm) in October	0.20	10.983±3.392
Mean of maximum temperatures (°C) in January	0.13	0.047±0.018
Mean of maximum temperatures (°C) in February	0.21	0.098±0.029
Mean of maximum temperatures (°C) in April	0.29	0.095±0.023
Mean of maximum temperature (°C) in Mai	0.30	0.135±0.032
Mean of maximum temperature (°C) in June	0.21	0.088±0.026
Mean of maximum temperatures (°C) in July	0.08	0.043±0.021
Mean of maximum temperatures (°C) in October	0.08	-0.088±0.042
Mean of minimum temperatures (°C) in January	0.28	-0.095±0.023
Maximum temperature (°C) in February	0.20	0.139±0.042
Maximum temperature (°C) in April	0.24	0.142±0.039
Maximum temperature (°C) in May	0.19	0.138±0.043
Maximum temperature (°C) in June	0.22	0.104±0.030
Minimum temperature (°C) in February	0.25	-0.090±0.024
Minimum temperature (°C) in March	0.09	-0.052±0.023
Minimum temperature (°C) in October	0.12	-0.100±0.040
Minimum temperature (°C) in November	0.08	-0.060±0.029
Minimum temperature (°C) in December	0.10	-0.060±0.026
Mean temperature (°C) in April	0.13	0.049±0.019
Mean temperature (°C) in May	0.20	0.078±0.024
Mean temperature (°C) in June	0.14	0.049±0.018
Mean temperature (°C) in October	0.09	-0.076±0.034
Mean temperature (°C) in November	0.08	-0.058±0.029
Phenological trait		
Migration of the swift (days[b])	0.49	-0.785±0.137
Migration of the swallow (days)	0.17	0.337±0.121
Fall of fig leaves (days)	0.40	-0.643±0.136
Flowering of orange tree (days)	0.44	-0.716±0.133
Flowering of chestnut tree (days)	0.49	-0.624±0.105
Flowering of willow (days)	0.26	0.494±0.147
Flowering of vine (days)	0.36	-0.444±0.096

[a] Coefficient of regression and standard error
[b] Days from the first of January

Table 2. Significant regressions of phenological traits on climatic traits along 40 years (1967 to 2006) using a stepwise method with selection limit for entry of variables at p=0.10.

Variable	Adjusted R^2	b ± SE[a]
Migration of swift		
Maximum yearly temperature (°C)	0.247	-3.284±0.599
Maximum yearly rainfall (mm)	0.090	-0.048±0.006
Mean of minimum temperatures (°C) in December	0.090	4.068±0.442
Mean of minimum temperatures (°C) in October	0.087	1.214±0.445
Mean rainfall (mm) in May	0.083	-0.324±0.037
Minimum rainfall (mm) in May	0.083	3.031±0.530
Total rainfall (mm) in October	0.065	0.035±0.006
Minimum temperature (°C) in April	0.041	2.411±0.550
Total rainfall (mm) in January	0.035	0.026±0.007
Maximum rainfall (mm) in July	0.034	-0.028±0.007
Minimum temperature (°C) in June	0.031	-2.794±0.823
Minimum temperature (°C) in July	0.026	1.798±0.585
Maximum temperature (°C) in May	0.016	-0.738±0.377
Migration of swallow		
Mean of maximum temperatures (°C) in May	0.319	3.341±0.690
Mean of maximum temperatures (°C) in February	0.162	1.445±0.410
Mean of minimum temperatures (°C) in June	0.068	-2.735±1.029
Maximum temperatures (°C) in May	0.079	-1.140±0.475
Fall of fig leaves		
Maximum temperature (°C) in June	0.247	-2.343±0.458
Maximum temperature (°C) in August	0.127	-0.100±0.011
Mean rainfall (mm) in August	0.128	0.895±0.143
Minimum temperature (°C) in June	0.075	3.925±0.716
Maximum temperature (°C) in November	0.055	1.282±0.290
Maximum temperature (°C) in October	0.088	0.014±0.003
Mean of maximum temperatures (°C) in April	0.059	-5.458±0.914
Mean temperature (°C) in April	0.075	5.473±1.292
Maximum rainfall (mm) in December	0.035	0.013±0.004
Mean temperature (°C) in January	0.026	-2.662±0.833
Total rainfall (mm) in September	0.014	-0.025±0.013
Flowering of orange tree		
Maximum temperature (°C) in December	0.231	-3.833±0.568
Minimum yearly temperature (°C)	0.181	5.410±0.844
Mean rainfall (mm) in January	0.116	0.093±0.026
Minimum temperature (°C) in July	0.101	-3.908±0.773
Maximum rainfall (mm) in November	0.070	-0.018±0.006

Maximum yearly rainfall (mm)	0.054	0.028±0.008
Maximum temperature (°C) in January	0.043	-1.251±0.481
Maximum rainfall (mm) in July	0.023	0.014±0.008
Flowering of chestnut tree		
Maximum yearly temperature (°C)	0.363	-2.585±0.530
Maximum rainfall (mm) in October	0.146	-0.013±0.003
Mean of maximum temperatures (°C) in January	0.079	-2.046±0.672
Mean of minimum temperatures (°C) in May	0.078	3.317±0.848
Mean of maximum temperatures (°C) in December	0.041	1.879±1.074
Mean of maximum temperatures (°C) in August	0.037	1.143±0.480
Mean rainfall (mm) in November	0.032	-0.037±0.020
Flowering of willow[b]		
Maximum rainfall (mm) in January	0.435	-0.034
Total yearly rainfall (mm)	0.134	0.019
Minimum temperature (°C) in July	0.097	3.795
Mean temperature (°C) in February	0.077	-5.077
Minimum temperature (°C) in May	0.045	3.738
Total rainfall (mm) in January	0.034	-0.106
Mean rainfall (mm) in February	0.031	0.111
Maximum temperature (°C) in November	0.025	-0.672
Maximum rainfall (mm) in September	0.020	0.042
Mean rainfall (mm) in September	0.018	-0.305
Mean of maximum temperatures (°C) in February	0.016	2.977
Minimum temperature (°C) in March	0.011	-2.352
Mean temperature (°C) in September	0.010	2.368
Mean yearly temperature (°C)	0.010	2.811
Maximum temperature (°C) in June	0.007	-0.010
Maximum temperature (°C) in February	0.001	-0.277
Maximum rainfall (mm) in November	0.002	0.004
Maximum rainfall (mm) in August	0.001	0.004
Minimum temperature (°C) in August	0.0002	0.226
Mean of maximum temperatures (°C) in September	0.0001	-0.379
Flowering of vine		
Maximum yearly temperature (°C)	0.267	-1.810±0.010
Total rainfall (mm) in March	0.080	0.015±0.0002
Minimum temperature (°C) in December	0.063	0.041±0.011
Minimum temperature (°C) in April	0.047	2.097±0.009
Mean temperature (°C) in January	0.055	-2.394±0.011
Mean temperature (°C) in November	0.035	-3.385±0.014
Maximum temperature (°C) in November	0.044	1.520±0.009
Total rainfall (mm) in December	0.053	0.024±0.0002
Mean of maximum temperatures (°C) in May	0.030	-1.515±0.008

Mean rainfall (mm) in August	0.014	0.122±0.001
Maximum rainfall (mm) in June	0.014	-0.012±0.0001
Maximum temperature (°C) in September	0.006	-0.901±0.006
Minimum temperature (°C) in February	0.006	-0.691±0.008
Maximum yearly rainfall (mm)	0.004	0.009±0.0001
Maximum temperature (°C) in April	0.004	-0.165±0.007
Mean temperature (°C) in March	0.004	-2.162±0.010
Mean of minimum temperatures (°C) in September	0.001	1.207±0.015
Minimum temperature (°C) in June	0.001	0.555±0.016
Maximum temperature (°C) in June	0.001	-0.292±0.008
Mean temperature (°C) in October	0.001	-0.449±0.011
Mean rainfall (mm) in November	0.0004	1.834±0.168
Minimum yearly temperature (°C)	0.0003	0.128±0.015
Maximum temperature (°C) in July	0.0002	0.142±0.007
Mean temperature (°C) in April	0.0002	-0.303±0.017
Maximum rainfall (mm) in March	0.0001	0.002±0.0001
Total rainfall (mm) in November	0.0001	-0.610±0.056

[a] Coefficient of regression and standard error
[b] The standard error was close to zero

Some of the animals had modified their migration patterns, particularly the swift that advanced its migration and the swallow that delayed its migration. Accordingly, Ambrosini et al. (2011) found that the migration patterns of common house-martin (*Delichon urbica*) and common swift were affected by climatic change; particularly, swift was primarily affected by the vegetation index. Rubolini et al. (2007) also found that climatic change alters the migration pattern of some birds, particularly, the swift and the swallow significantly advanced arrival dates, but other species did not show any significant temporal trend. They concluded that birds respond differentially to climate variability and some species adapt to rapidly changing climatic conditions.

Most climatic variables affected only one of the phenological traits and some of them affected two or three. Maximum yearly temperature affected migration of the swift, and flowering of the orange tree, the chestnut tree, the willow and the vine. Most effects were small, except for maximum rainfall in January that positively affected flowering of the willow and maximum yearly temperature that affected negatively flowering of the chestnut tree. Other effects were not negligible. Spring climatic variables had the largest effects, followed by the summer and the autumn, while the winter had the lowest effects probably due to the high or low activity of plants and animals during spring or winter, respectively. Therefore, climatic change affecting spring parameters had the largest effects on natural life perturbation and the effects decreased as the seasons advance.

Other authors have reported stronger climatic change and extensive reorganization of ecological communities, such as the conversion of boreal forest to steppe or expansion of forest into tundra in some high-latitude regions (Tchebakova et al. 2010; Pearson et al. 2013). Berner et al. (2013) concluded that plant growth was constrained by both low temperatures and limited moisture availability and that warming enhanced growth.

Mean yield of hybrids from the first set (those evaluated at least in trials during three years) during these 31 years (1975 to 2005) did not follow a linear variation along years. Actually, the highest mean yearly yield was for 1999 (10.04 Mg ha^{-1}) followed by 1996 (9.69), and 1977 (9.49), while the lowest yields were for 1990 (4.27), 2001 (5.01), and 1975 (5.61). Our results show that the effect of the environment of each year on maize yield is stronger than the effect of maize genotypes.

In order to avoid biases on the calculations of environmental effects affecting maize yield, we used the second set of hybrids, which includes only checks evaluated in the trials most of the years. Considering the climatic variables affecting the six maize traits, there were 9 climatic variables with significant effects on grain moisture, 13 on maize yield, 15 on yield index, 11 on days to pollen shedding, 7 to silking, and 9 to anthesis-silking interval (ASI) (Table 3). Some of the climatic variables had significant effects on one single maize trait, while others had effects on several traits; particularly, maximum rainfall in January had negative effects on yield index and positive effects on days to pollen and silking and ASI. Most of the climatic variables with significant effects on maize yield corresponded to autumn while none of the yearly variables had significant effects on yield (Table 2). Contrarily, grain moisture was not affected by autumn clime and the other seasons had a similar effect and yield index was affected mainly by the spring. Finally, flowering time and ASI were affected mainly by winter and autumn clime in variable proportions.

Table 3. Significant regressions of maize phenotypic traits on climatic variables along 31 years (1975 to 2005) using a stepwise method with selection limit for entry of variables at p=0.10.

Variable	Adjusted R^2	b ± SE[a]
Maize grain moisture (%)		
Minimum temperature (°C) in August	0.3062	-0.398±0.123
Total rainfall (mm) in May	0.1496	0.013±0.002
Mean yearly temperature (°C)	0.1136	-1.327±0.442
Minimum temperature (°C) in May	0.0708	-0.639±0.099
Maximum temperature (°C) in April	0.0475	-0.251±0.061
Mean temperature (°C) in September	0.0552	-1.003±0.148
Total rainfall (mm) in February	0.0417	-0.253±0.097
Mean rainfall (mm) in September	0.0254	-0.026±0.008
Mean of minimum temperatures (°C) in July	0.0210	-0.465±0.183
Mean rainfall (mm) in February	0.0231	0.679±0.270
Maize grain yield (Mg ha^{-1})		
Mean rainfall (mm) in October	0.2368	-1.830±0.773
Mean of minimum temperatures (°C) in April	0.1059	0.988±0.081
Mean of minimum temperatures (°C) in February	0.1325	-0.402±0.038
Mean of maximum temperatures (°C) in January	0.1186	-0.518±0.050
Maximum rainfall (mm) in July	0.1007	0.007±0.001
Maximum temperature (°C) in December	0.0823	0.192±0.040
Maximum temperature (°C) in May	0.0424	-0.050±0.025

Mean of maximum temperatures (°C) in December	0.0406	-0.537±0.074
Minimum temperature (°C) in September	0.0632	0.192±0.039
Maximum temperature (°C) in November	0.0111	0.140±0.030
Minimum temperature (°C) in April	0.0140	-0.239±0.059
Maximum rainfall (mm) in November	0.0083	-0.001±0.0004
Total rainfall (mm) in October	0.0087	0.587±0.249
100 × Maize grain yield / grain moisture		
Mean rainfall (mm) in October	0.2088	-0.708±0.036
Maximum rainfall (mm) in July	0.1340	0.353±0.016
Total rainfall (mm) in April	0.0715	-0.514±0.019
Maximum yearly rainfall (mm)	0.0733	-0.186±0.012
Mean temperature (°C) in April	0.0587	43.318±1.867
Maximum temperature (°C) in January	0.0471	-15.485±0.847
Maximum temperature (°C) in May	0.0842	-16.458±0.833
Maximum rainfall (mm) in January	0.0875	-0.189±0.013
Mean of maximum temperatures (°C) in May	0.0470	9.132±1.136
Mean of minimum temperatures (°C) in May	0.0329	-14.058±1.438
Minimum temperature (°C) in July	0.0192	9.845±1.161
Mean of minimum temperatures (°C) in October	0.0059	-10.980±1.775
Mean yearly temperature (°C)	0.0031	16.868±4.100
Minimum temperature (°C) in April	0.0018	6.003±0.937
Maximum rainfall (mm) in March	0.0016	-0.020±0.010
Days to pollen shedding		
Mean of maximum temperatures (°C) in April	0.4552	$-2.017\pm4.5\times10^{-5}$
Maximum rainfall (mm) in January	0.2432	$0.0258\pm5.3\times10^{-7}$
Total rainfall (mm) in December	0.2032	$0.016\pm7.7\times10^{-7}$
Maximum temperature (°C) in December	0.0666	$0.308\pm3.8\times10^{-5}$
Mean of maximum temperatures (°C) in August	0.0234	$-0.437\pm6.2\times10^{-5}$
Minimum temperature (°C) in February	0.0074	$0.380\pm4.0\times10^{-5}$
Maximum rainfall (mm) in December	0.0008	$0.002\pm6.0\times10^{-7}$
Total rainfall (mm) in March	0.0002	$0.001\pm6.5\times10^{-7}$
Maximum temperature (°C) in August	0.0000	$-0.026\pm6.0\times10^{-5}$
Minimum temperature (°C) in August	0.0000	$-0.005\pm6.5\times10^{-5}$
Maximum temperature (°C) in October	0.0000	$-0.002\pm4.7\times10^{-5}$
Days to silking		
Maximum yearly temperature (°C)	0.4739	$-3.306\pm2.7\times10^{-5}$

Maximum rainfall (mm) in January	0.2621	$0.031\pm1.4\times10^{-7}$
Total rainfall (mm) in January	0.2074	$-0.029\pm4.2\times10^{-7}$
Maximum rainfall (mm) in March	0.0376	$-0.004\pm2.0\times10^{-7}$
Maximum temperature (°C) in April	0.0092	$0.557\pm1.4\times10^{-5}$
Mean of maximum temperatures (°C) in January	0.0090	$-0.435\pm1.6\times10^{-5}$
Minimum temperature (°C) in October	0.0007	$0.092\pm2.0\times10^{-5}$
	Anthesis – silking interval	
Minimum temperature (°C) in October	0.4492	$-0.561\pm7.3\times10^{-5}$
Maximum rainfall (mm) in March	0.1751	$-0.010\pm3.8\times10^{-7}$
Minimum temperature (°C) in November	0.1698	$-0.478\pm3.4\times10^{-5}$
Maximum rainfall (mm) in September	0.0839	$0.005\pm6.1\times10^{-7}$
Maximum rainfall (mm) in January	0.0678	$0.006\pm7.9\times10^{-7}$
Minimum temperature (°C) in January	0.0333	$0.366\pm3.6\times10^{-5}$
Maximum rainfall (mm) in February	0.0166	$-0.002\pm5.6\times10^{-7}$
Minimum temperature (°C) in June	0.0041	$0.143\pm6.8\times10^{-5}$
Maximum temperature (°C) in October	0.0002	$-0.039\pm4.7\times10^{-5}$

[a] Coefficient of regression and standard error

Maize yield did not change significantly during 30 years. Traore et al. (2013) found that yields of cotton (*Gossypium hirsutum*), sorghum (*Sorghum bicolor*) and groundnut (*Arachis hypogaea*) in southern Mali had no clear trend over years. However, some researchers have reported that population response to environmental change is not immediate or linear because many wild herbaceous plants are long-lived and often have dormant stages or do not grow during some of the seasons (Ouborg and Eriksson 2004). Crops are also affected by agricultural techniques that change along time. Other reports have shown yield increases due to climatic change in other crops, for example mean soybean yield increased between 1924 and 2010 due to a combination of genetic improvements, agronomic technologies, and climatic changes (Fox et al. 2013). Some studies predict that global change could increase crop production, provided that agronomic adaptations are made for exploiting the potential advantages of the changing conditions (Lobell et al. 2008). Such benefits can occur for some countries as China, while not for others as India or Russia (Lobell et al. 2011). Our results do not show a significant variation of maize yield along years, while Lobell et al. (2011) reported that models indicate a trend to decrease maize yields.

On the other hand, our results show, in accordance with the previous reports, that the effect of the environment of each year on maize yield is stronger than the effect of maize genotypes. Indeed, although maize hybrids have been replaced by new hybrids with higher yield, we did not find a significant yield increase in this period of time. These results are not consistent with the expected superiority of modern hybrids over oldest hybrids although Tollenaar and Lee (2002) stated that modern hybrids have higher yield and stability than the old populations because the breeding programs focused on improvements of yield have also increased stability. Contrarily, Gomes et al. (2000) found that the hybrid with the highest yield was unstable, although they used a three-way cross that was probably less elite than these commercial hybrids. Obviously, stability is not guaranteed among modern hybrids, as shown by Fan et al. (2007), who found that the hybrids with higher yield could be either stable or unstable.

The maize trait most strongly affected by climatic variables was yield index, followed by grain yield and male flowering. Most of the climatic variables with significant effects on maize yield corresponded to autumn probably because of the large yield losses that storms can cause while none of the yearly variables had significant effects on yield. The relative importance of the climatic variables from each season was equilibrated; although summer clime had less significant effects in maize performance altogether and spring had slightly more effects on maize yield and moisture balance.

In a shorter study with a collection of open-pollinated maize populations, Romay et al. (2010) found that the climatic variables with significant effects on yield were rainfall in May, number of days with mean temperature above 15 °C during the growing cycle, mean temperature of June, number of days with mean temperature above 15 °C in April, mean maximum temperature of September, and number of days with mean temperature above 15 °C in July. In that previous study we also found that number of days with mean temperature above 15 °C in April, June, July, September and October with the mean temperature of August and the mean of the maximum temperatures of September can explain all the environmental variation, but only the number of days with mean temperature above 15 °C in April, the mean maximum temperature of September, and the number of days with mean temperature above 15 °C in July explain more than 5% of the sum of squares. These results do not coincide with our current results, probably due to differences in the genotypes and environments involved; actually, in the study reported by Romay et al. (2010), the environmental covariates for yield were not consistent across locations, showing that environmental traits affecting maize performance depended on environment and that general statements can mislead the local details. However, there is a general agreement on the importance of temperature and water balance on maize yield (Argillier et al. 1994; Epinat-Le Signor et al. 2001; Butrón et al. 2004). For other crops, environmental effects are also different; particularly for winter wheat, Zhang et al. (2013) found that sunshine hours and diurnal temperature difference were positively, and relative humidity was negatively related to grain yield of winter wheat. Traore et al. (2013) found a negative effect of maximum temperature, number of dry days, and total seasonal rainfall on cotton yield; therefore, the variation in cotton and maize yields were related to the rainfall distribution within the rainfall season in southern Mali. Waha et al. (2013) stated that in the sub-Saharan Africa, temperature and precipitation are expected to change severely and found that the importance of temperature and precipitation effects on maize yields varies spatially; in some regions the models predict strong negative effects, and in other regions the effects were positive. Berner et al. (2013) predicted that impacts of future climatic change on forests in the arctic area will be influenced by shifts in both temperature and moisture. Liu et al. (2013) found in northern China that durations of sowing to emergence and emergence to silking increased with latitude due to reduction of temperature, while silking to maturity decreased. In China, Zhang and Huang (2013) found that wheat and maize was negatively affected by average temperature and diurnal temperature range and positively in some areas. Haris et al. (2013) using simulations to study the impact of climate change found that wheat yield decreased whereas the yield of maize increased and duration of both crops decreased with higher temperatures in sub humid environments. Chen et al. (2012) identified rainfall larger positive effects on maize yield in China than light and temperature and the impact of climatic conditions on maize yield has increased more rapidly as time advances during the last decade in China.

Conclusions

Along these 40 years we found a significant climatic variation towards more extreme temperature conditions and irregular effects in the clime of diverse months and seasons. Moreover, climatic variables had significant effects on living beings affecting birds' migration and plants' phenological development and maize performance in particular. Changes in spring clime had more significant effects although the seasonal effects varied for each living organism, summer clime being less important for maize performance.

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