Highland Barley Phenological Trends and Their Driving Factors in Menyuan County, Qinghai Province, 1980-2015: Postprint

Authors: Yan Yingcun, Zhao Quanning, Wang Zhe, Dou Qingfang

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Abstract

Using phenological data of highland barley and concurrent temperature and precipitation data from the agricultural meteorological station in Menyuan County, Qinghai Province from 1980 to 2015, this study analyzed the trends and driving factors of highland barley phenology in Menyuan County, Qinghai Province under the background of climate change. The results show that: sowing, emergence, and jointing stages showed a delaying trend, while the remaining phenological stages exhibited an advancing trend. Specifically, the sowing stage was significantly delayed at a rate of 2.65 d/10a, while the tillering and heading stages were significantly advanced at rates of 4.78 d/10a and 2.30 d/10a, respectively. The climate factors that significantly influenced highland barley phenology were temperature, precipitation, and accumulated temperature. When the active accumulated temperature above 0°C before sowing increased by 1°C · d and precipitation during this period increased by 1 mm, the sowing stage was delayed by 0.252 d; when the accumulated temperature stably passing 0°C increased by 1°C · d, the tillering stage was advanced by 0.026 d; and when the minimum temperature in April increased by 1°C, the heading stage was advanced by 1.890 d. Since the 1990s, abrupt changes have occurred in the delayed sowing, advanced tillering and heading stages, and increased driving factors. The abrupt changes in phenological stages and driving factors were basically synchronous, indicating that climate warming on the Qinghai Plateau is the dominant factor driving the changes in highland barley phenology.

Full Text

Preamble

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Analysis of Highland Barley Phenophase Change Trend and Driving Factors in Menyuan County, Qinghai Province During 1980–2015

YAN Yingcun[1,2,*], ZHAO Quanning[1], WANG Zhe[1], DOU Qingfang[3]
[1] Qinghai Province Institute of Meteorological Sciences, Key Laboratory of Disaster Prevention and Mitigation in Qinghai Province, Xining 810001, China
[2] Menyuan County Meteorological Bureau of Qinghai Province, Haibei 810399, China

Abstract

Using highland barley phenophase data and parallel temperature and precipitation records from the Menyuan Agricultural Meteorological Station in Qinghai Province from 1980 to 2015, this study analyzed the phenological change trends of highland barley and their driving factors under climate change in Menyuan County, Qinghai Province. The results indicated that sowing, seedling, and jointing stages tended to be delayed, while most other phenophases advanced. The sowing stage was significantly delayed by 2.65 days per decade, whereas the tillering and heading stages advanced by 4.78 days per decade and 2.30 days per decade, respectively. The climatic factors that significantly affected highland barley phenophases were temperature, precipitation, and accumulated temperature. When the accumulated temperature before sowing increased by 1°C · d and precipitation increased by 1 mm, sowing was delayed by 0.252 days. When the stable accumulated temperature increased by 1°C · d, the tillering stage advanced by 0.026 days, and when the April minimum temperature increased by 1°C, the heading stage advanced by 1.890 days. Since the 1990s, the sowing stage has been delayed while tillering and heading stages have advanced, with driving factors simultaneously increasing. The phenophases and driving factors began to change synchronously, indicating that plateau climate warming in Qinghai was the dominant factor determining phenological changes in highland barley.

Keywords: Menyuan County, Qinghai Province; spring highland barley; phenophase change; driving factors

Introduction

Biological phenological change serves as a comprehensive indicator of environmental changes such as climate. Analyzing phenological changes is of significant scientific importance for evaluating ecosystem responses to recent climate change, determining vegetation carbon uptake periods, and characterizing seasonal exchanges of water and energy between the surface and atmosphere and their feedback effects on global carbon cycles and climate change [1–2]. Highland barley is cultivated throughout the Tibetan Plateau region, including the Tibet

Autonomous Region and Tibetan areas in Qinghai, Sichuan, Yunnan, and Gansu provinces. The proportion of highland barley cultivation increases progressively from the periphery to the interior of the region and with increasing altitude; above 4,200 m, it is the only crop planted [3]. Studying phenological changes in highland barley—the upper limit of crop cultivation on the Tibetan Plateau—and their driving factors is therefore indicative of climate change impacts on crops.

Significant progress has been made in research on natural vegetation phenology under global change [4-15], and crop phenology has also been studied to some extent [16-28]. However, due to the concentrated cultivation area and limited observational data for highland barley, research has primarily focused on meteorological conditions affecting growth, development, and yield [29-32], variety genetics [33-34], culture [35], and fertilization [36-37]. Exploration of highland barley phenophase changes requires strengthening. This paper analyzes phenophase changes and their responses to hydrothermal conditions using highland barley sowing-maturity phenophase data and parallel temperature and precipitation records from Menyuan Station from 1980 to 2015, aiming to provide a scientific basis for crop responses to climate change and highland barley cultivation decisions in Qinghai Province.

1. Study Area Overview

Menyuan Hui Autonomous County is located in northeastern Qinghai Province, bordering Datong and Huiyan counties to the south, Qilian County to the west, and Shandan County of Gansu Province' s Hexi Corridor to the northeast. The county lies between 37.5°-38°N and 102°-102.5°E, with elevations ranging from 2,388 to 5,254 m. The region features typical high-altitude cold-temperate humid climate characteristics: long sunshine hours (2,264.8-2,739.8 h annually), strong solar radiation, large diurnal temperature range (11.6-17.5°C), and an average annual temperature of 0.8°C. Mountainous areas account for 83.1% of the territory, with 16.9% plains. The county has 52,000 hectares of cultivated land and is Qinghai' s largest commercial oilseed base, Tibetan-area highland barley seed production base, and key bee product county. Crops include oilseed rape and highland barley.

1. Data Sources

Highland barley sowing-maturity phenophase, temperature, and precipitation data for Menyuan Station from 1980-2015 were obtained from the Qinghai Provincial Meteorological Information Center. Phenophase observations followed the *Agricultural Meteorological Observation Standards*. Data from 1999-2000 and 2003-2006 were used for specific analyses.

2. Research Methods

Climate tendency rate and cumulative anomaly analysis were used to identify climate change trends. The Mann-Kendall (M-K) test was employed for mutation detection, while correlation coefficient and stepwise regression methods assessed climate impacts.

The climate tendency rate was calculated using linear regression:

For a phenophase time series y_i and year t_i (where $i = 1, 2, ..., n$), the regression equation is:

$$y_i = a + bt_i$$

where b is the regression coefficient representing the climate tendency rate (days/10 years) and a is the regression constant. The cumulative anomaly for year t is calculated as:

$$\Delta y_t = \sum_{i=1}^{t} (y_i - \bar{y})$$

where $\bar{y}$ is the mean value of the agricultural meteorological element. Statistical analyses were performed using SPSS 17.0.

1. Characteristics of Highland Barley Phenophases

Highland barley phenophases include sowing, seedling, three-leaf, tillering, jointing, booting, heading, bloom, milky maturity, and maturity stages .

1. Interannual Variation of Phenophases

Climate tendency rates for each phenophase at Menyuan Station from 1980-2015 showed that sowing, seedling, and jointing stages were delayed, while all other stages advanced. The sowing stage was significantly delayed at 2.65 days per decade, while tillering and heading stages significantly advanced at 4.78 days per decade and 2.30 days per decade, respectively. Milky maturity and maturity stages also advanced, though not significantly .

Cumulative anomaly analysis revealed negative values for sowing and seedling stages but mostly positive values for other phenophases, confirming the advancement trend. Except for three-leaf and milky maturity stages with unclear patterns, most phenophases showed significant quadratic polynomial relationships over time. Using Excel' s LINEST function, parameters for the quadratic curves were calculated, with $F_{0.01}(4, 24) = 4.218$ and $F_{0.01}(2, 26) = 5.526$, indicating highly significant quadratic polynomial changes in most phenophase cumulative anomalies.

2. Mutation Detection of Phenophase Changes

At significance level $\alpha = 0.05$ ($\mu_{0.05} = \pm 1.96$), Mann-Kendall nonparametric tests were performed for phenophases with significant trends. The UF and UB curves showed that since the late 1990s, the sowing stage exhibited a clear delaying trend, with the intersection point indicating a mutation around 2001–2010. The tillering stage showed a significant advancing trend since the early 1990s, with the intersection suggesting a mutation around 2010–2015. The heading stage displayed a significant advancing trend since 2001, with fluctuations indicating possible mutations in 1994 and 2013 [Figure 1: see original paper].

1. Correlation Analysis Between Phenophases and Meteorological Conditions

Correlation coefficients were calculated between the significantly trending phenophases (sowing, tillering, heading) and preceding climate factors (monthly temperature and precipitation). Sowing stage was primarily affected by temperature and precipitation, showing significant positive correlation with accumulated temperature before sowing (0°C and 3°C thresholds) and precipitation. Tillering stage was mainly influenced by February-April mean and maximum temperatures, accumulated temperature, and average temperature during the period, with significant positive correlation with stable accumulated temperature above 0°C and 3°C. Heading stage was affected by April minimum temperature, February-April mean and maximum temperatures, and accumulated temperature, showing highly significant positive correlation with the initial date of stable temperature above 0°C and 3°C, and significant negative correlation with other factors .

2. Stepwise Regression Fitting of Phenophases

Although climate factors at all stages affect highland barley phenophases, the primary drivers are temperature, precipitation, and accumulated temperature. Using SPSS 17.0 stepwise regression:

- Sowing stage delay was significantly correlated with pre-sowing accumulated temperature and precipitation
- Tillering stage advancement was associated with increased stable accumulated temperature (0.026 days per 1°C · d increase)
- Heading stage advancement was associated with increased April minimum temperature (1.890 days per 1°C increase) and precipitation (0.252 days per 1 mm increase) .

The regression equations showed that when pre-sowing accumulated temperature increased by 1°C · d and precipitation increased by 1 mm, sowing was delayed by 0.252 days. When stable accumulated temperature increased by 1°C · d, tillering advanced by 0.026 days. When April minimum temperature increased by 1°C, heading advanced by 1.890 days.

3. Analysis of Climate Factor Changes

Since 1980, the climate factors significantly affecting highland barley phenophases have shown extremely significant increasing trends. Pre-sowing precipitation showed fluctuating decreasing trends, while April minimum temperature showed a significant increasing trend. Mann-Kendall mutation tests revealed clear mutation points around 1994 and 1996 for these climate factors [FIGURE:2, FIGURE:3].

4. Mutation Relationship Between Phenophases and Driving Climate Factors

Highland barley phenophases are sensitive to climate mutations. The start years of phenophase mutations were basically synchronized with climate driver mutations, though sowing and tillering stages showed significant mutations slightly later than their driving climate factors, while heading stage mutations fluctuated .

3. Conclusions and Discussion

3.1 Conclusions

Highland barley phenophases in Menyuan occur from mid-April sowing to early September maturity, with maximum variation of 14–25 days between earliest and latest stages. Over the 35-year period: - Sowing and jointing stages were delayed; all other stages advanced, with tillering and heading showing significant or highly significant trends - Most phenophase cumulative anomalies followed highly significant quadratic polynomial curves over time - Climate warming is the dominant factor determining phenological changes in highland barley - Phenophases and driving climate factors began changing synchronously, indicating sensitive responses to climate change

3.2 Discussion

This study focused on spring highland barley. Varieties have evolved from Menyuan Lianglan to Moduoji and Beiqing, with maturity changing from very early to medium-early. The delayed sowing did not lead to delayed maturity; instead, maturity showed a non-significant advancing trend, suggesting that climate warming-induced phenophase advancement outweighed cultivar effects.

While spring phenophases of Tibetan Plateau grassland plants have advanced and growing seasons extended, crops and grasslands have different phenological response concerns. Grassland studies focus on green-up and withering that affect growing season length, while crops focus on sowing and maturity. The delayed sowing and advanced maturity of Menyuan highland barley demonstrate that climate warming provides more abundant heat resources for agriculture on the Tibetan Plateau, subsequently altering crop phenology.

Notably, although early spring sowing is generally considered beneficial for high yield on the Tibetan Plateau, Menyuan showed delayed sowing with increased temperature and pre-sowing accumulated temperature. Analysis of agricultural meteorological disasters revealed that frost and hail-drought are primary concerns, mainly early frost in May. The positive correlation between sowing date and pre-sowing precipitation suggests sowing changes relate to winter-spring precipitation reduction. However, 0–10 cm soil relative humidity showed significant increasing trends, strongly correlated with autumn precipitation increases that enhance soil moisture storage. Whether delayed sowing after soil thawing is appropriate requires further field experiments, though early sowing clearly helps avoid later frost damage. Current sowing timing suitability warrants additional research.

These findings have positive practical significance for rational utilization of climate resources, agricultural structure adjustment, and cropping system optimization on the Tibetan Plateau.

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Note: Figure translations are in progress. See original paper for figures.