THE CROP JOURNAL 5 (2017) 43–51

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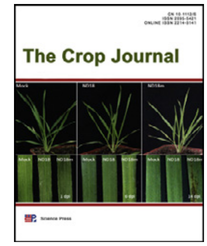

Maize kernel weight responses to sowing date-associated variation in weather conditions

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ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 9 July 2016
Accepted 18 September 2016
Available online 24 September 2016

Keywords:
Maize
Sowing date
Weather conditions
Kernel weight
Grain filling

ABSTRACT

Variation in weather conditions during grain filling has substantial effects on maize kernel weight (KW). The objective of this work was to characterize variation in KW with sowing date-associated weather conditions and examine the relationship between KW, grain filling parameters, and weather factors. Maize was sown on eight sowing dates (SD) at 15–20-day intervals from mid-March to mid-July during 2012 and 2013 in the North China Plain. With sowing date delay, KW increased initially and later declined, and the greatest KW was obtained at SD6 in both years. The increased KW at SD6 was attributed mainly to kernel growth rate (G_{mean}), and effective grain-filling period (P). Variations in temperature and radiation were the primary factors that influenced KW and grain-filling parameters. When the effective cumulative temperature (AT) and radiation (R_a) during grain filling were 950 °C and 1005.4 MJ m^{-2}, respectively, P and KW were greatest. High temperatures (daily maximum temperature [T_{max}] > 30.2 °C) during grain filling under early sowing conditions, or low temperatures (daily minimum temperature [T_{min}] < 20.7 °C) under late sowing conditions combined with high diurnal temperature range ($T_{max-min}$ > 7.1 °C) decreased kernel growth rate and ultimately final KW. When sowing was performed from May 25 through June 27, higher KW and yield of maize were obtained. We conclude that variations in environmental conditions (temperature and radiation) during grain filling markedly affect growth rate and duration of grain filling and eventually affect kernel weight and yield of maize.

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in China and plays a significant role in ensuring food security. Although grain yield in maize is determined mainly by kernel number (KN) per unit area [1], variation in the weight of kernels can also affect crop yield [2]. However, dry matter accumulation of the kernel may be strongly affected by growth conditions, especially stresses (temperature, drought,

Abbreviations: SD, sowing date; AT, effective cumulative temperature; R_a, cumulative solar radiation; T_{mean}, daily mean temperature; T_{max}, daily maximum temperature; T_{min}, daily minimum temperature; P_r, cumulative precipitation; KW, kernel dry weight; W_{max}, the increased kernel weight at the maximum grain-filling rate; P_f, the effective grain-filling duration; G_{mean}, the mean kernel growth rate; R_0, the initial grain-filling potential; G_{max}, the maximum kernel growth rate; D_{max}, date of maximum kernel growth rate.

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Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.

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http://dx.doi.org/10.1016/j.cj.2016.07.002

precipitation, etc.) during the grain-filling period [3–6] caused by climate change across northern China [7,8]. To guarantee a stable maize yield, it is thus important to understand the impacts of weather conditions during grain filling period on dry matter accumulation in kernels and final kernel weight (KW) of maize.

Dry matter accumulation in kernels depends on grain-filling parameters such as kernel growth rate and duration of linear grain filling [6,9]. Many studies have investigated the relationship between grain filling and environment. It has been suggested that the temperature is the main climatic factor influencing grain filling and that the optimum temperature during maize grain filling is 27–32 °C [10]. However, the temperature at this period is often higher than 32 °C, resulting in loss of grain yield [11]. A high temperature of 35 °C during the grain-filling period may cause kernel abortion [12], and a low temperature of 10 °C for 5 days in succession may limit the increase of KW [13]. Light intensity too is one of the most important environmental factors in the growing period of maize and might influence the formation of maize yield and quality [14,15]. Shading treatment during grain filling could limit kernel development and affect the achievement of maximum weight [16], as a decrease in starch was observed in kernels subjected to low light intensity after silking [17–19]. Drought stress during grain filling can markedly shorten grain filling duration and thereby limit the increase of kernel weight [4,20]. However, the growth environment of maize can be changed by sowing at different stages, exposing the crop to different environmental conditions during grain filling [21–23]. Cirilo and Andrade [21] suggested that, under the local climatic conditions (Balcarce, Argentina), with a delayed sowing date, radiation and thermal time during the grain-filling period decreased, leading finally to decreased maize kernel weight. Li et al. [24] reported that with a delay of sowing date at Shihezi, Xinjiang Uygur Autonomous region, China, grain filling rate and final kernel weight decreased.

Sowing in stages enables researchers to examine the effects of different weather conditions on maize growth in natural fields [21,22,25–27], reduces the experimental period, and removes spatial and temporal disparities in soil fertility, varieties, cultivation technology, and other factors. The objectives of this study were (i) to examine the effects of sowing date-associated variation in weather conditions on KW and grain filling by sowing on eight dates from mid-March to mid-July in the North China Plain, (ii) and to quantify the relationship of weather factors with KW and grain filling parameters to provide a reference for similar maize production areas throughout the world.

2. Materials and methods

2.1. Site description

A field experiment was conducted during the 2012 and 2013 maize growing seasons at Xinxiang Experimental Station, Chinese Academy of Agricultural Sciences (35°11′30″ N, 113°48′ E), located in Xinxiang county, Henan province. This region is in the temperate zone with a continental monsoon climate, and the annual mean temperature, cumulative temperature above 10 °C, sunshine hours, and precipitation are 14 °C, 4647.2 °C, 2323.9 h, and 573.4 mm, respectively. The soil type of this site is clay loam (ISSS Classification, International Soil Science Society), with 13.1 g kg^{-1} organic matter, 64.3 mg kg^{-1} available nitrogen, 15.4 mg kg^{-1} available phosphorus, 121.3 mg kg^{-1} available potassium, and pH 8.3.

2.2. Experimental design

Sowing was performed every 15–20 days from mid-March to mid-July, such that the earliest and latest dates suitable for sowing maize at the test sites were included. The eight sowing dates were March 25, April 10, April 25, May 10, May 25, June 12, July 1, and July 20 and are defined as SD1, SD2, SD3, SD4, SD5, SD6, SD7, and SD8, respectively. Table 1 lists the weather conditions for each sowing date during the maize grain growth period at the study site.

The early-maturing hybrid ZD958, the most widely grown cultivar in the North China Plain, was chosen for this study. Maize was planted at a density of 67,500 plants ha^{-1} at spacings of 0.4 m and 0.8 m. Each plot was 10 m long and 4.8 m wide and consisted of 8 rows. A randomized complete block design with three replications was used in each experiment. Before sowing, the plots were finely cultivated and irrigated and basal fertilizer was applied at the rate of 225 kg N ha^{-1}, 173 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1}. Additional nitrogen fertilizer (138 kg N ha^{-1}) was applied at the 12th leaf stage (V12). The fertilizer application amounts were based on existing levels of N, P, and K determined from soil tests to ensure no nutrient deficiency. Irrigation was applied two or three times during the maize growing season, depending on rainfall. The amount of irrigation water applied ranged from 50 to 75 mm based on soil moisture and crop water requirements. All experimental fields were well managed and weeds, diseases, and insect pests were well controlled.

2.3. Weather data

Daily weather data for the experimental site [daily mean temperature (MT), daily maximum temperature (T_{max}), daily minimum temperature (T_{min}), precipitation, and sunshine hours] during the maize growing season in 2012 and 2013 were recorded (Chinese Meteorological Administration, 2013).

The ≥10 °C cumulative temperature is the sum of daily mean temperature during the period in which daily mean temperature is above 10 °C for every day [28].

Solar radiation was calculated using the following equation (Eq. 1) [29]:

$$\text{Solar radiation } Q = Q_0(a + bS/S_0) \quad (1)$$

where Q is total solar radiation, Q_0 is climatologically radiation, S is actual sunshine hours, S_0 is possible sunshine hours, S/S_0 is percentage of sunshine, and a and b are correction coefficients.