Europ. J. Agronomy 64 (2015) 67–77

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Effects of increased day and night temperature with supplemental infrared heating on winter wheat growth in North China

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ARTICLE INFO

Article history:
Received 31 August 2014
Received in revised form
17 December 2014
Accepted 29 December 2014
Available online 9 January 2015

Keywords:
Growth
Development
Aboveground biomass
Winter wheat yield
Plant height
Climate change
Minimum temperature

ABSTRACT

The main future challenge is to feed 9 billion people under a changed climate, and the projected increase in global temperature will affect, negatively or positively, future wheat production depending on the geographical location. Temperature is a key factor in crop growth, development and yield. Global temperatures are rising asymmetrically with the daily minimum temperature rising faster than the daily maximum temperature. The objectives of this study are to evaluate wheat biomass growth, development, yield and harvest index under whole day and night time temperatures increased by 2.5 °C in field conditions. The field experiment was carried out during three growing seasons (2008/09, 2009/10, and 2010/11) in Hebei Province, which is the main wheat region of the North China Plain. The experiment was carried out using a warming system with infrared radiation lamps suspended 2.3 m above the ground which increased the mean air temperature by 2.0–2.5 °C . The treatments were: (1) ambient control (CK: not warmed), (2) higher night temperature (HNT: warmed from 19:00 to 7:00), and (3) higher day–night temperature (HDNT: warmed from 9:00 to 17:00 and 19:00 to 7:00). Each treatment was replicated four times for a total of 12 plots ($2 \times 4\,m^2$ each) in a randomized complete block design for the growing season 2009/10 and 2010/11 and 5 times in 2008/09. Results of this study, showed that overall wheat biomass increased by 30% and yield by 20% under heating conditions with the highest relative increase for the cold year (2009/10). Grain yield under control treatments, for the cold year, decreased by 37% because the number of days of minimum temperature below 0 °C increased by 14 days. Overall, the different warming timing (night-time only versus day–night) did not cause any significant difference in yield and biomass increase. However, as an overall pattern, warming increased aboveground biomass, grain yield, plant height and panicle numbers, but decreased harvest index. In conclusion, wheat growth and yield were significantly increased by artificial warming indicating that a warming in such area of China has potential benefits to current wheat cultivars. Higher temperatures changed the ratio of beginning/length of overwintering causing a significant change in stem numbers.

1. Introduction

Warming of the climate is unequivocal, most of the observed increase in global average temperature since the mid-20th century is very likely due to increase in anthropogenic greenhouse gas concentration (IPCC, 2013). The main future challenge is to feed 9 billion people under a changed climate, as the future increase in global temperature will affect, negatively or positively, future wheat production depending on the geographical location.

In the last decade, wheat breeding programs have been engaged on increasing wheat resistance to disease and abiotic stresses, with little attention to increase yield potential (Reynolds et al., 2012; Reynolds and Borlaug, 2006). The breeding for increasing yield under changing climate needs to take into account several points such as the improvement of plant structure in order to minimize lodging, better adaptations of the reproductive processes, and increase of crop biomass via modification of the radiation use efficiency (Reynolds et al., 2012). The correlation between biomass and yield is known and has been used in the past to develop high yield wheat cultivars (Waddington et al., 1986). Crop biomass is a function of photosynthesis and respiration, with both processes influenced by temperature (Peng et al., 2004).

Temperature is a key factor in crop growth and development. At higher temperatures, plants will accelerate development causing a

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http://dx.doi.org/10.1016/j.eja.2014.12.012

reduction in growth which often translates into lower yields. Global temperatures are rising asymmetrically with the daily minimum temperature rising faster than the daily maximum temperature (Easterling et al., 1997; Karl et al., 1993; Vose et al., 2005). Therefore, night-time or daytime warming has different impacts on crop growth. Whilst the latest IPCC (2013) report concluded that such fast rising of minimum temperature was lower than that previously thought, Peng et al. (2004) and Lobell and Ortiz-Monasterio (2007) showed the negative effects of raising minimum temperatures on grain yields. These findings were also supported by numerous controlled environments studies (Ahmed et al., 1993; Morita et al., 2002; Mutters and Hall, 1992; Prasad et al., 2008).

Simulation and empirical studies have studied crop responses to the changes of daily mean temperatures (Baigorria et al., 2008; Lobell and Field, 2007; Lobell and Ortiz-Monasterio, 2007; Peng et al., 2004; Rosenzweig and Parry, 1994), but other studies considered the different effects of daytime and night-time warming (Lobell and Ortiz-Monasterio, 2007; Peng et al., 2004).

The quantification of maximum and minimum temperatures impacts on crops is not consistent between studies (Lobell and Ortiz-Monasterio, 2007) as crops are grown in different environments. Greenhouse and open-top chamber (OTC) experimental studies have evaluated the effects of temperature changes on crops, but the average daytime temperature increases are much greater than the night-time increases, which is inconsistent with the asymmetric characteristic of global warming (Baker and Allen, 1993; Klein et al., 2005; Norby et al., 1997). Experiments using free air temperature increase (FATI) (Nijs et al., 1996) are also used to study plant responses to global warming at field scale (Kimball, 2005; Luo et al., 2009; Ottman et al., 2012; Wan et al., 2009; Xia et al., 2010). Previous, FATI studies have evaluated the impacts of warming on grassland biomass (Luo et al., 2009; Wan et al., 2009) and more recently on wheat and rice growth and yield (Dong et al., 2011; Fang et al., 2010; Ottman et al., 2012; Tian et al., 2012). Future wheat production depends on the geographical location and crop varieties, whether in China or elsewhere in the world (Li et al., 2014; Mishra et al., 2013; Porter and Gawith, 1999). For example in south China, it has been found that an increase of 1.5 °C increased the winter wheat yield because of the mitigation of minimum temperatures and earlier anthesis (Tian et al., 2014).The objectives of this study were to evaluate wheat biomass growth, development, yield, and harvest index under heating regimes for the day and night-time.

2. Materials and methods

2.1. Site description

The experiment was carried out during three growing seasons (2008/2009, 2009/2010, and 2010/2011) at the Gucheng Agrometeorological Experimental Center of the China Meteorological Administration in Dingxing County, Hebei Province, North China Plain (39°08′N, 115°40′E, 15.2 m a.s.l.). The site was located within the main winter-wheat producing area in North China Plain. The mean annual temperature was 11.7 °C, the mean yearly precipitation was 551.5 mm, the mean annual sunshine 2659 h, and average frostless period 187 d. The soil was typical Haplic Luvisol (FAO) with a pH of 8.1 and a bulk density of 1.35 g cm^{-3}.

2.2. Experimental design

The field experiment was carried out using a FATI warming system similar to the system located at Great Plain Apiaries, USA and described in details by Wan et al. (2002). Further details of the heating system for the experimental location can be found in Fang et al. (2013). The system simulated environmental warming with infrared radiation lamps suspended 2.3 m above the ground in downwards-facing stainless-steel semi-circular mirror reflectors which enhanced the efficiency of radiation lamps (Fig. 1). Heaters in the warming treatments were set at a radiation input of ~1500 W from sowing to harvest. Fig. 1 shows intensive frost of the ambient control and no frost in the warming plots, indicating the efficacy of the heating system. However, at night the infrared heating requirement to achieve any set degrees of warming is comparatively very small. High wind speeds decreased the efficiency of the heaters (Kimball, 2005), but at this site the average wind speed for the three growing season was about 2.4 m s^{-1}, and might have partially decreased the efficiency of the heaters.

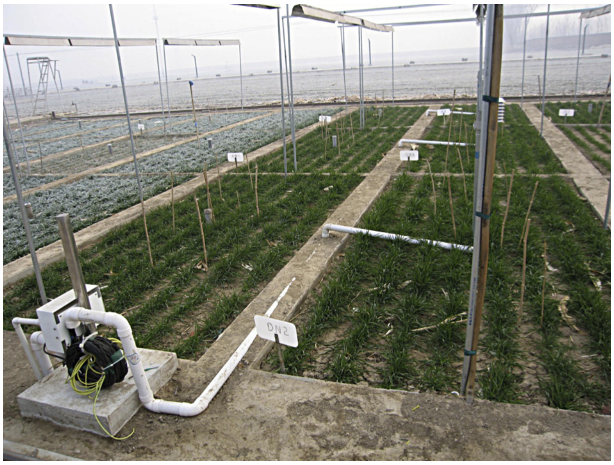

Fig. 1. Plots with artificial warming and control (no artificial warming) under a frost event on 12th December 2008 at Hebei province, China. Intensive frost in ambient control plots showed in upper-left side of the picture and no frost in the waming plots showed in center-right.

The treatments were: (1) ambient control (CK: not warmed), (2) higher night temperature (HNT: warmed from 19:00 to 7:00), and (3) higher day–night temperature (HDNT: warmed from 9:00 to 17:00 and 19:00 to 7:00). Each treatment was replicated four times for a total of 12 plots (2×4 m^2 each) in a randomized complete block design for the growing seasons 2009/10 and 2010/11, and they were replicated 5 times in 2008/09. Each plot was separated between each other by 2 m. In each control plot (CK), “dummy” heaters of the same shape and size as the infrared heaters were used to obtain the shading effect. The warming began at sowing and continued through to grain harvest.

2.3. Air and soil temperature measurement

Each plot was equipped with a set of automatic thermometer sensors (Model HC2S3-L, Campbell Scientific Inc., Logan, Utah, USA) to record air temperature within the canopy. The sensors were mounted inside of a naturally ventilated radiation shield (type 439101, Feingerätebau K. Fischer GmbH, Germany), protected from direct sunlight. They were put at 2/3 of the canopy height between two consecutive rows. They were adjusted as the crop grew to keep the ratio constant throughout the growing season.

Soil temperature was measured at a soil depth of 20 cm using factory calibrated thermometer sensors (HMP107, Campbell Scientific Inc., Logan, Utah, USA) in each plot. Temperatures were recorded once every minute throughout the growing seasons. Daily soil temperatures were averaged on an hourly basis from seeding to ripening (GS00–GS99) (Zadoks et al., 1974). The daily air temperature near the canopy was averaged on an hourly basis from the 1st March to ripening (GS99). Before March, the plants were too small and the thermometers were too close to the soil surface; therefore, the mean air temperature was used as a metric.