European Journal of Agronomy 96 (2018) 96–107

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Winter and spring night-warming improve root extension and soil nitrogen supply to increase nitrogen uptake and utilization of winter wheat (*Triticum aestivum* L.)

Chenxi Hu[1], Zhongwei Tian[1], Shilu Gu, Hua Guo, Yonghui Fan, Muhammad Abid, Kai Chen, Dong Jiang, Weixing Cao, Tingbo Dai*

Key Laboratory of Crop Physiology Ecology and Production Management of Ministry of Agriculture, Nanjing Agricultural University, Nanjing, Jiangsu 210095, PR China

ARTICLE INFO

Keywords:
Winter wheat
Night-warming
Nitrogen utilization efficiency
Root growth
Soil nitrogen supply
Apparent nitrogen surplus

ABSTRACT

Elucidating the effects of asymmetric warming during winter and spring will help develop a feasible crop management strategy for climate change. Field experiments were conducted using the Yangmai-13 (vernal type) and Yannong-19 (semi-winter type) winter wheat cultivars to investigate the effects of night-warming during winter (warming by 1.47–1.53 °C from tillering to jointing), spring (warming by 1.68–1.77 °C from jointing to booting), and winter + spring (warming by 1.53–1.60 °C from tillering to booting) on plant growth and N utilization in 2014–2016. The results showed that the grain yield, N agronomic efficiency (NAE), and N recovery efficiency (NRE) of both cultivars were highly increased in response to night-warming, which were associated with enhanced dry matter and N accumulation, and winter + spring night-warming resulted in greater increases than winter night-warming and spring night-warming. Furthermore, the increase in pre-anthesis N accumulation was much higher than after anthesis, resulting in a greater increase in post-anthesis dry matter accumulation due to more leaf N distribution at anthesis to support photosynthetic production. Root growth characteristics (i.e., root length, surface area and volume, and root bleeding intensity) were significantly promoted, which favored plant N uptake. Soil urease and protease activity as well as the net N mineralization rate, which are involved in soil N supply capacity, were increased, whereas soil inorganic N content and apparent N surplus were clearly decreased, which indicated that plant N uptake capacity was highly improved in response to night-warming conditions. In conclusion, winter and spring night-warming improve pre-anthesis root growth and N uptake ability to promote plant growth, resulting in increased N utilization efficiency with reduced N fertilizer loss, and winter + spring night-warming has more advantages for N uptake and utilization of winter wheat.

1. Introduction

Warming is a main impact of global climate change. In the past 100 years, the global air temperature has increased by approximately 0.65–1.06 °C, and it is likely to increase by another 0.3–4.8 °C by the end of this century (IPCC, 2014). Global warming causes diurnal warming asymmetry, as the amplitude of the temperature increases in winter and spring are greater than those in summer and autumn, and warming is greater at night than during the day (Lobell, 2007; Zhou et al., 2007; Peng et al., 2013; Suonan et al., 2017). Temperature is a key factor regulating crop development and growth (Lobell et al., 2011). Understanding the impact of asymmetric warming on crop production may facilitate the development of food security strategies that help adapt agriculture to future climate changes.

Numerous efforts have been made to understand the impacts of warming on wheat production. Some studies have suggested that climate warming will decrease wheat yield because warming shortens the length of the wheat growth period, resulting in large declines in biomass production (Lobell and Asner, 2003; Hussain and Mudasser, 2007; You et al., 2009). Others have reported that the production of wheat might benefit from warming because warming increases the number of grains per ear and 1000-grains weight or primary biomass production by stimulating net photosynthesis (Tian et al., 2012; Fan et al., 2015; Zheng et al., 2017). These observations suggest that wheat yield does not always respond consistently to warming.

Nitrogen is the most essential nutrient for wheat growth,

Abbreviations: N, nitrogen; NUE, N use efficiency; NRE, N recovery efficiency; NAE, N agronomic efficiency; NR, nitrate reductase; GS, glutamine synthetase

* Corresponding author.
E-mail address: tingbod@njau.edu.cn (T. Dai).

[1] Both authors equally contributed to this paper.

https://doi.org/10.1016/j.eja.2018.03.008
Received 26 September 2017; Received in revised form 30 January 2018; Accepted 25 March 2018

productivity and grain quality among all nutrients (Fageria and Baligar, 2005). Improved wheat N use efficiency (NUE) would be of economic benefit to farmers and would help reduce environmental contamination associated with excessive inputs of N fertilizer (Stevens et al., 2005; Delin et al., 2008). Root growth is an essential parameter for plant N uptake, and improved root growth helps increase plant N uptake and reduce nitrate leaching loss to the environment (Foulkes et al., 2009; Rasmussen et al., 2015). A few studies have investigated the effects of warming on plant root morphology and activity (Björk et al., 2007; Bai et al., 2010; Yin et al., 2012). For example, Yin et al. (2013) reported that experimental warming increases root length, root biomass, and the root/shoot mass ratio in two coniferous species. Tian et al. (2014) reported that experimental warming increases root dry biomass and root activity of winter wheat at anthesis, resulting in improved plant N uptake. However, most of these studies focused on the entire plant growth period, and little is known about variations in root morphology in the soil profile and root activity of winter wheat in terms of asymmetric warming.

Soil inorganic N is easily absorbed by plants and represents the soil N supply capacity (Liu et al., 2003). Many studies have revealed that warming increases the soil net N mineralization rate, resulting in increased inorganic N content in soil, which helps improve plant N uptake (Butler et al., 2012; Bai et al., 2013; Zhang et al., 2015). Furthermore, soil enzymes play vital roles in the decomposition of soil organic matter and soil nutrient mineralization, and temperature is an important factor determining soil enzyme activity (Gong et al., 2015). Therefore, climate warming is likely to significantly affect soil enzyme activity and consequently alter soil inorganic N content, which will likely change plant N uptake (Baldrian et al., 2013). The most important enzymes involved in soil N cycling are proteases and ureases (Sardans et al., 2008a). Proteases are involved in the first step of N release by hydrolysing the peptide bonds between amino acids as an indispensable step for N uptake by plants. Ureases hydrolyse urea to ammonium and carbon dioxide, and ammonium can be directly absorbed and utilized by plants. Several studies have shown that warming increases soil urease and protease activity because warming increases microbial activity, thus increasing the release of enzymes (Wallenstein et al., 2010; Xu et al., 2010; Liu et al., 2014). Others have reported that warming decreases soil urease and protease activity because warming reduces soil water content, and limited soil water can directly affect enzyme activity (Brzostek et al., 2012; Zhao et al., 2014; Davidson et al., 2015). However, most of these studies were carried out in grassland or forest ecosystems; very few studies are available on the effects of asymmetric warming on the net N mineralization rate and enzyme activity involved in soil N cycling in wheat fields. Wheat mainly grows during the winter and spring seasons, when more warming is anticipated. Therefore, it would be of great practical significance to study the change in NUE of wheat in response to winter and spring night warming.

The objectives of this study were to (1) evaluate the effects of winter and spring night-warming on N uptake and utilization of winter wheat and (2) identify how winter and spring night-warming affect root growth and soil N supply and their relationship to wheat N uptake and utilization. The results are intended to provide a theoretical basis for improving the NUE of wheat under future climate change.

2. Materials and methods

2.1. Experimental design

Field experiments with two wheat cultivars Yangmai-13 (vernal type) and Yannong-19 (semi-winter type) were conducted from 2014 to 2016 in Nanjing (32°04′N, 118°76′E), China. Weather conditions and the initial status of the 0–60 cm soil layer of the experimental site during the wheat growing season are given in Fig. 1 and Table 1 respectively.

The experiment consisted of macro-plot experiment and micro-plot experiment. The macro-plot experiment comprised of a randomized complete block with three replications and four warming treatments, including winter night-warming treatment (WW), spring night-warming treatment (SW), winter + spring night-warming treatment (WSW) and no warming control (NW). The WW, SW and WSW were applied from tillering to jointing (from Dec. 20, 2014 to Mar. 5, 2015 and from Dec. 23, 2015 to Mar. 4, 2016), jointing to booting (from Mar. 6, 2015 to Apr. 6, 2015 and from Mar. 5, 2016 to Apr. 4, 2016), and tillering to booting (from Dec. 20, 2014 to Apr. 6, 2015 and from Dec. 23, 2015 to Apr. 4, 2016), respectively.

Based on the technique of passive night warming (PNW) (Beier et al., 2004; Fan et al., 2015), a removable plastic membrane of manual control was constructed. The warmed plots were covered with the plastic membrane from sunset to sunrise (from around 19:00 to 07:00 on next day). To ensure normal respiration of the crops at night, the plots were provided with proper ventilation. To keep each plot with the same precipitation, the plastic membranes were rolled up at night when it rained or snowed. The warming facility was 3 m × 5 m in area and 2 m in height. Canopy temperatures were automatically recorded using a dual-channel LCD temperature instrument (NZ-LBR-F11, Nanjing Nengzhao Electronic Instrument Co., Ltd., China) after every 10 min interval, whereas, temperatures in 5 cm soil layer were automatically recorded by using a digital data logger (EM 50, Decagon Devices, Inc., USA) at every 10 min interval. The increase in the mean night temperature of canopy and 5 cm soil layer between treatments and the control are given in Fig. 2.

The plot size was 2 m × 4 m and seeding density was 2.25×10^6 seeds ha^{-1} with a spacing of 0.25 m between rows. All plots were supplied with 240 kg N ha^{-1}, 105 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1}, in the form of urea, superphosphate and potassium chloride fertilizers, respectively. 120 kg ha^{-1} N and total P_2O_5 and K_2O were applied before sowing. The remaining N was applied in splits at jointing and booting stages, with 60 kg N ha^{-1} at each stage. Sowing dates were 27 October in 2014 and 4 November in 2015. Fungicides and pesticides were applied at jointing, booting and 10 days after anthesis to control diseases and pests. The precipitation was ample for winter wheat growth, thus, no irrigation was applied during the period of experiments.

The micro-plot experiment was designed same as the macro-plot experiment using Yangmai-13 in 2015–2016. The micro-plots were set within macro-plots by polyvinyl chloride (PVC) tubes with 25 cm diameter and 105 cm height to monitor the root morphology, this method was also used by (Giacomini et al., 2010; Shi et al., 2012a). To keep the micro plots with soil conditions similar to field experiments, soil was dug out and separated into four layers: 0–20, 20–40, 40–60 and 60–100 cm. Soil layer of 20–100 cm was backfilled into the PVC tube in the correct order, followed by watering to consolidate the layers. After that, the PVC tubes were buried into macro-plot with the top edge at 5 cm above the ground. Soil layer of 0–20 cm was backfilled into the PVC tube after mixing basal fertilizer. All micro-plots received same N rate with field experiment.

2.2. Plant and soil sampling and analysis

Three replications of each treatment were sampled at sowing (0 days after sowing, 0 DAS), tillering (44 DAS), overwintering (80 DAS), regreening (112 DAS), jointing (125 DAS, before topdressing), booting (154 DAS), anthesis (168 DAS), filling (182 DAS, 14 days after anthesis) and maturity (206 DAS). Plant shoots were separated into leaves, culms, chaffs, and grains. Fresh samples were first put into the oven at 105 °C for 30 min to deactivate enzymes, and then dried at 70 °C till a constant weight reached for dry weight determination. The dried samples were milled. The total N content of the plant samples was determined using the semi-micro Kjeldahl method (Santos and Boiteux, 2013). Two 2 m long rows (1 m^2) of plants were marked at anthesis in the center of the plots to measure grain yield at maturity.

Soil samples to a depth of 60 cm were separated into three layers: