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Warming impacts on winter wheat phenophase and grain yield under field conditions in Yangtze Delta Plain, China

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ABSTRACT

A five-year experiment with Free Air Temperature Increase facility was conducted to investigate the actual responses of winter wheat phenophase and yield to warming in Yangtze Delta Plain, China. Air temperature increase of around 1.5 °C in wheat canopy advanced crop phenophases significantly, leading to a reduction in length of the entire growth period by 10 days ($P < 0.05$). This reduction was mainly found in the length of pre-anthesis phase, while the length of post-anthesis phase was prolonged slightly. Warming increased grain yield by 16.3% ($P < 0.05$) whereas no significant effects were found on the aboveground biomass. Warming tended to increase the numbers of productive spike and filled grain and the harvest index. The areas of flag leaf and total green leaf at anthesis and the 1000-grain weight were 36.0, 19.2 and 5.9% higher in the warmed plots than the un-warmed control ($P < 0.05$), respectively. Warming stimulated the filling rate of inferior grain ($P < 0.05$), while the rate of superior grain stayed almost unchanged. The above evidences suggest that anticipated warming may facilitate winter wheat production in East China.

1. Introduction

More than 20% of the world's food consumers depend on wheat (*Triticum aestivum* L.) which is produced on an area of over 200 million hectares worldwide (Ortiz et al., 2008). And winter wheat area accounts for more than 80% of this total, and it is typically grown in the seasons of winter and spring where warming is mainly anticipated. China is the largest country of winter wheat production, and more than 70% of Chinese winter wheat is sown in the eastern provinces. Meanwhile, the mean air temperature in the 2000s was about 1.5 and 0.7 °C higher than during the 1980s and 1990s, respectively, and is expected to increase with about 1.2–2.0 °C by 2050 in China (Chavas et al., 2009). Thus, to learn the impacts of anticipated warming on winter wheat growth in East China will greatly facilitate the development of strategies leading to future food security in China and even in the world.

To date, our knowledge on the impacts of climatic changes on wheat remains quite uncertain in China. For example, Xiao et al. (2008) reported that the interaction of warming temperature and changed rainfall might lead to an increase of 3.1% in wheat yields at a low altitude and of 4.0% at a high altitude in China by 2030. With a method of crop-specific panel data analysis, however, You et al. (2009) found that a 1.0°C increase in wheat growing season might reduce grain yield by about 3–10%. Similarly, with a modeling approach, Chavas et al. (2009) reported that the aggregate potential productivity of winter wheat might increase 24.9% if with CO_2-fertilization effect and might decrease 2.5–12% if without CO_2-fertilization effect in East China. Recently, models that link crop yields to weather indicated that China wheat production might decline by 5.5% (Lobell et al., 2011). Thus, further evidences from field observations are essential to decrease the uncertain in the assessment of warming impacts on wheat production.

Many experiments have been conducted on actual crop responses to warming (Porter and Gawith, 1999; Ortiz et al., 2008; Aronson and McNulty, 2009). Most of the experiments, however, were performed at a plant or plant community scale under controlled conditions, rather than at a crop system scale *in situ* (Aronson and McNulty, 2009). Moreover, exiting warming experiments mainly focused on low or high temperature stress during crop key phenophases, only few were performed over an entire growth cycle with anticipated air temperature increase level

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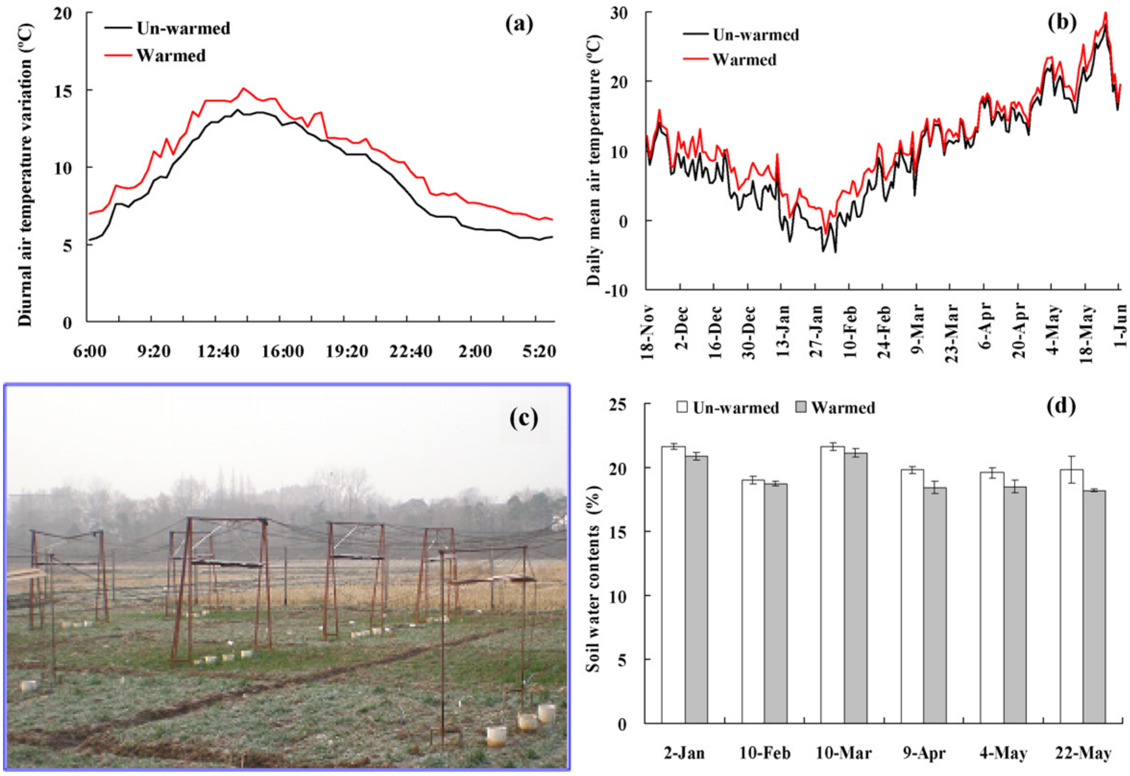

Fig. 1. Diurnal air temperature variation in the jointing stage on 2008/3/6 (a) and daily mean air temperature variation during the entire growth cycle (b) of wheat canopy, the picture of FATI facility (c) and the variations of soil moisture at 0–20 cm layer (d) in the growing season of 2008–2009.

(Nijs et al., 1996; Kimball and Conley, 2009). Evidences provided from previous experiments might not fully represent the realistic impacts of future warming, and further field experiments with an entire growth cycle at a crop system scale are essential. Yangtze Delta Plain is one of the major regions of winter wheat cropping area in China, and Nanjing city is a typical region of this plain. We, therefore, conducted a five-year field warming experiment since 2004 with a facility of Free Air Temperature Increase (FATI) in Nanjing, Jiangsu province. Our objectives were to investigate the actual responses of winter wheat phenophase, biomass production and grain yield to anticipated warming under field conditions.

2. Materials and methods

2.1. Experiment site description

Field experiments were conducted from the winter of 2004 to the summer of 2009 at the Experimental Station of Jiangsu Academy of Agricultural Sciences, Nanjing, Jiangsu Province, China (32°02′N, 118°52′E, 11 m above the sea level). The station is situated in the subtropical monsoon climatic zone. The mean annual temperature is 16.7 °C, and the annual precipitation is 1050 mm with 1900 sunshine hours and 237 frost-free days. The approximate time of sunrise in May is around 5:15 am. The precipitation is ample for winter wheat growth in normal years, thus, the field is not irrigated. The cropping pattern of this winter wheat system has remained almost unchanged for over 1000 years. Its climate and cropping patterns are typical in East China. The soil at the experimental site is a brunisolic silt loam soil (an Alfisols in USA-ST) with sand, silt, and clay respectively 0.5, 75.3 and 24.2%. Other relevant soil properties are: soil organic C 8.2 g kg^{-1}; total N 2.6 g kg^{-1}; total P 0.6 g kg^{-1}; total K 14.0 g kg^{-1}; available P 166.2 mg kg^{-1} and available K 165.0 mg kg^{-1}.

2.2. Experimental design

The field warming system was constructed according to the design of FATI facility located at the Great Plain Apiaries, USA (Wan et al., 2002). The field experiment used a randomized block design with three replicates of warmed with all-day time and un-warmed control (Fig. 1). In each warmed plot, a single 180 cm × 20 cm infrared heater (Jiangsu Tiande special light source Co. Ltd., China) was suspended 1.5 m above the ground. In the un-warmed control plot, a 'dummy' heater of the same shape and size was suspended at the same height to simulate the shading effects of the heater (Fig. 1). Distance to adjacent plots was approximately 5 m to avoid heating contamination between treatments. The warming treatment was started on the sowing date and maintained to the harvest date for an entire growth cycle. Although each plot was 6 m × 5 m in size, this FATI facility can only provide about a 2 m × 2 m sampling area with uniform and reliable warming effects. All samples and field measurements were done in the 4 m^2 area on a plot by plot basis.

2.3. Crop management

The cultivar of Yangmai 11 (*Triticum aestivum* L. cv Yangmai 11) tested in this experiment is a major local cultivar with high yield potential. Standard agronomic practices commonly performed in this area were followed. Seeds were manually sown in November at a density of 225 plants m^{-2} with a row space of 20 cm. Crops were harvested in May or June in the next year on a plot by plot basis depending on the maturity dates of each treatment. The fertilizer applications of N, P and K in each plot were 225, 75 and 75 kg ha^{-1}, respectively. The total P and K and 50% N were applied as basal dressing two days prior to sowing. The other 50% N was applied as side dressing at early tillering in the beginning of March. In order to keep the same regimes of agronomic management between the treatments, all fertilizers