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Plastic film mulch increased winter wheat grain yield but reduced its protein content in dryland of northwest China

Laichao Luo[b], Zhaohui Wang[a,b,*], Ming Huang[b], Xiaoli Hui[b], Sen Wang[b], Yue Zhao[b], Hongxia He[b], Xiang Zhang[b], Chaopeng Diao[b], Hanbing Cao[b], Qingxia Ma[b], Jinshan Liu[b]

[a] State Key Laboratory of Crop Stress Biology in Arid Areas, Northwest A&F University, Yangling 712100, Shaanxi, China
[b] Key Laboratory of Plant Nutrition and Agri-Environment in Northwest China, Ministry of Agriculture, Collage of Natural Resources and Environment, Northwest A&F University, Yangling 712100, Shaanxi, China

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ABSTRACT

Plastic film mulch has been proved of great potential to enhance crop productivities in drylands, but there is still lacking insight into its underlying changes in crop grain nutritional quality. Therefore, field experiments were conducted to investigate the effects of different soil surface managements on grain yield and its protein content of winter wheat in 2014–2016 at different fertilizer input levels under no mulch and plastic film mulch at seven sites in dryland of the Loess Plateau in northwest China. Compared with no mulch, overall average grain yield was significantly increased by 13.7%, but its protein content was decreased by 7.8% with plastic film mulch. Apart from the dilution effects caused by the much more increase of grain yield, the decreased N remobilization from vegetative parts to grain and the lowered crop N uptake from soil during grain filling stage were found to be the main reasons, when the overall average of N remobilization efficiency, N harvest index and post-anthesis N uptake was respectively decreased by 16.0%, 5.7% and 24.0%. However, the winter wheat grain protein content was observed to increase more quickly with the N rate increase under plastic film mulch, compared to no mulch. This provides opportunity to increase the grain protein content under plastic film mulch to the same level of no mulch by increasing the N fertilizer application rates, and an estimation of optimal N application rates for winter wheat grain yield and its protein content was computed under plastic film mulch in drylands.

1. Introduction

Global grain production was reported to have to increase by 70% till 2050 to meet with the increasing food demand due to continuously increasing population (Tilman et al., 2002; Tester and Langridge, 2010). Dryland covers approximately 80% of the cultivated land of the word, and contributes about 60% of total food production (World Water Assessment Programme, 2009). Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide. Similarly, wheat is also the main staple food crop in China, especially in northwest dryland, where is the main wheat cropping area with around 4.35 million hectares of wheat sowing annually, accounting for 19.2% of its total crop land area (Li et al., 2009). Therefore, in order to ensure future food security, the crop production in drylands is urgently required to excavate its potential to sustainably increase its yield (Godfray et al., 2010; Khan et al., 2009).

As a typical rainfed farming area, the annual rainfall of Northwest dryland in China is around 300–600 mm, of which 60%–70% is concentrated in the summer fallow from July to September (Li et al., 2000; Tian et al., 2003), and low water availability is usually the major limiting factor restricting crop productivity. In order to tackle this problem, plastic film mulch has become a widely used technique in dryland (Li and Wang, 2006; Kasirajan and Ngouajio, 2012), and the plastic film usage amount and the covering areas increased dramatically with the growth rate of 56.1% and 50.3% between 2002 and 2012 (NBS, 2016). In recent years, many studies reported the mechanism of yield increase under plastic film mulch, and found that in the arid and semiarid areas, plastic film mulch significantly increased the soil water storage by 36–72 mm (Fan et al., 2005; Liu et al., 2009; Wang et al., 2016), and evapotranspiration by 24–71 mm (Li et al., 2004; Xie et al., 2005) for wheat or spring maize. Li et al. (2013) also found that plastic film mulch significantly reduced the soil water loss by 75 mm through evaporation and improved the crop transpiration by 78 mm in spring-maize cropping system. Simultaneously, plastic film mulch was observed to increase soil temperature by 2–9 °C (Wang et al., 2009a; Liu et al., 2014; Li et al., 2007), decrease the period of emergence by eight

* Corresponding author at: College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, Shaanxi, China.
E-mail address: w-zhaohui@263.net (Z. Wang).

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days, and increase growth stage from seedling to maturing up to 6–13 days (Li et al., 1999; Zhao et al., 2014; Khalil et al., 2014; Liu and Siddique, 2015). In addition, plastic film mulch was also able to increase the quantities of soil microbial groups by 17.2%–67.0% and biomass by 30.3%-51.8% (Song et al., 2002; Wang et al., 2009b), promote the soil nutrient transformation and its availability (Müller et al., 2009; Jiang and Xie, 2009; Zhou et al., 2012). Therefore, the average yield was reported to be increased by 770–1655 kg ha^{-1} for wheat (Niu et al., 2004; Qin et al., 2015), 734 kg ha^{-1} for maize (Zhang et al., 2011), 915 kg ha^{-1} for sunflower (Zhao et al., 2016), 4160 kg ha^{-1} for ginger (Thankamani et al., 2016) and 16165 kg ha^{-1} for potato (Qin et al., 2014).

However, in modern intensive agricultural production, not crop yield but also its quality has attracted more and more attentions, especially the grain protein content for cereal crops (Shewry, 2007; Kumar et al., 2011; Chen et al., 2015). Therefore, the protein supply quantity from wheat in China has been increased by 4.3% from 2003 to 2013, and contributing 25.0% protein uptake of human where wheat flour is the main stable food material (FAOSTAT, 2016). In Germany, when the durum wheat grain protein content higher than 14% is demanded by local flourmill, and farmers can make more income for their increased grain protein (Sieber et al., 2015). Grain protein content is also an important factor for food-making quality. Grain with protein content higher than 13% is required for bread-making, and that at least higher than 12% can be used for blending in the UK (Snape et al., 1993). In China, strong gluten wheat used to make bread, steamed bread, dumplings, and instant noodles is required to have a grain protein content around 12.5% to 14.0% (Termoplastics, 2013). Hence, high protein content is important for the nutritional and food-making quality of wheat grain. Therefore, how to achieve a high wheat grain yield simultaneously with high protein content is of importance for the global food and nutritional security.

Previous researches have concentrated on the effect or mechanism of wheat yield improvement, little work has been reported on the effect of plastic film mulch on grain quality in dryland, especially the grain protein content. Nevertheless, our previous six-year long field study observed that plastic film mulch significantly decreased wheat grain protein content by 8.1% (He et al., 2016a). The cause for the reduced wheat grain protein content by plastic film mulch, and how to regulate the grain protein content under plastic film mulch in dryland, are still unclear. Therefore, the objectives of this study were to: (1) identify whether the wheat grain protein content can also be reduced by plastic film mulch in different sites of the dryland wheat growing regions, (2) determine N accumulation before anthesis and its remobilization in wheat and post-anthesis N uptake during grain filling stage affected by plastic film mulch, (3) examine whether the decreased grain protein content could be rebuilt by reasonably increasing the N fertilizer application rates in dryland.

2. Materials and methods

2.1. Locations for field experiment

Field experiments were carried out in two consecutive years, 2014–2015 and 2015–2016, at seven sites with two sites respectively in Shanxi and Shaanxi, and three sites in Gansu province (Table 1), across an area about 3474.8 km (34°43′ to 36°23′ N, 107°07′ to 111°35′ E) in the northwest dryland area, the Loess Plateau of China, where is typically one crop harvest a year with a semiarid continental climate. The main cropping system is winter wheat and summer fallow, and the growing season of winter wheat is from late September to late June or early July in next year. Annual precipitation is 550 mm, and nearly 60% rainfall occurs in the summer fallow season from July to September (Fig. 1). Soils at the experiment sites are classified as silt loam according to the USDA texture classification system (Soil Survey Staff, 1998), and initial main chemical properties of the top 0–20 cm soil are shown in Table 1. Since local farmers are usually over applying N fertilizer, nitrate-N accumulated in 1.0 m soil was averaged to be as high as 218.7 kg ha^{-1} at wheat sowing at Yujiagong in 2014.

2.2. Field experimental design and management

Field experiments were carried out on effects of soil surface management on wheat grain yield and its protein content at each site, with the crop grown under plastic film mulch and no mulch at different fertilizer input levels. For plastic film mulch treatment, wheat was sown with sowing-mulching all-in-one machine, and the plastic film used to mulch the soil surface was of the thickness of 0.008 mm (He et al., 2016b; Huang et al., 2017). For no mulch, wheat was sown with the disc drills machine.

In Shanxi, two levels of 120 and 150 kg N ha^{-1} were applied on the basal of 150 kg P_2O_5 ha^{-1} in Tongcheng, and 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 37.5 kg K_2O ha^{-1} in Liujiayuan. In Shaanxi, five levels of 0, 60, 120, 180 and 240 kg N ha^{-1} were applied on 100 kg P_2O_5 ha^{-1} in Yujiagong, and 150 kg N ha^{-1} and 105 kg P_2O_5 ha^{-1} in Dingjia. In Gansu, three levels of 90, 120 and 150 kg N ha^{-1} on 120 kg P_2O_5 ha^{-1} were applied in Pingxiang, and 150 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1} in Yongqing and Changhe. Urea (N 46%) was used for N, calcium superphosphate (P_2O_5 12%) for P, and potassium chloride (K_2O 60%) for K. All the fertilizers were evenly applied to soil surface and incorporated into top 20 cm soil with rotavator at sowing. Wheat cultivars were all the widely used local cultivars, and they were all sowing at the right date with the proper rates and harvested at maturity as shown in Table 2. During growing season, the crop was grown on natural precipitation with non-supplemental irrigation at all sites, and chemicals were used for controlling weeds, pests and diseases as the product guidelines.

2.3. Sampling and laboratory analyses

Plant samples were collected at anthesis (GS 61) and maturity (GS 92) (Zadoks et al., 1974). During each sampling event, 100 plants from each plot were randomly selected, and the roots were cut off at the joint of root and stem, then the aboveground plant was separated into straw (including stems and leaves), ear at GS 61, and glume and grain at GS 92 by hand-threshing after air-drying. Sub-samples around 20% fresh weight of the samples were weighted and heat-treated at 105 °C for 30 min (de-enzyme), dried at 65–70 °C to a constant weight, weighted to obtain dry weight. Then, the dried samples were smashed by the ball milling machine (MM410, Retsch Company, Germany). In addition, appropriate amounts (0.20–0.25 g) of the ground samples were used to determine the total N concentration by the H_2SO_4-H_2O_2 method, and measured with a high resolution digital colorimeter auto analyzer 3 (AA3, SEAL Company, Germany). Grain protein content was calculated as nitrogen concentration multiplied by 5.7. The grain protein content was expressed based on dry weight.

At maturity, plants were harvested manually from four areas of 1.0 m^2 in the middle of each plot to measure grain yield. After air-drying, the grain were threshed by threshing machine and then weighed. Subsamples of 80 g grain were oven-dried at 105 °C for 30 min, and then at 65 °C for 48 h to calculate dry weight. Grain yield was expressed on the dry weight.

2.4. Calculation methods

Parameters, as N accumulation, N remobilization, N remobilization efficiency, N harvest index and post-anthesis N uptake were calculated as reported by Cox et al. (1986) and Masoni et al. (2007), as:

N accumulation (kg ha^{-1}) = Dry matter at anthesis or maturity × N content at anthesis or maturity

N remobilization (kg ha^{-1}) = N accumulation in aboveground plant parts at anthesis – N accumulation in vegetative parts (stem leaves,

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