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Wheat straw mulching offset soil moisture deficient for improving physiological and growth performance of summer sown soybean

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ABSTRACT

In North-west china, the soybean (*Glycine max* L. Merr.) is grown in June, when the climate is dry, and soil has limited moisture contents. Moisture deficiency limits the soybean biomass. We studied the effects of wheat straw mulching and nitrogen on soybean growth, physiology and soil properties in three-year field experiments. The treatments included three straw mulching i.e. S1 (0 kg ha^{-1}), S2 (3000 kg ha^{-1}) and S3 (6000 kg ha^{-1}), and three nitrogen rates i.e. N1 (0 kg N ha^{-1}), N2 (21.6 kg N ha^{-1}), and N3 (27 kg N ha^{-1}). Full mulching (S3) significantly increased moisture retention (7.4%) and decrease soil temperature (3.0%) in 0–20 cm soil depth, increased photosynthesis, SPAD-value, leaf area, leaf area index, growth, and soybean grain yield (20.8%) over no-mulching (S1). The S3 improved the roots mass, nodules number and weight than S1. The application of 27 kg N ha^{-1} or 100% N fertilizer (N3) had significantly increased photosynthesis, SPAD-value, growth, and biomass and seed yield of soybean over no-N application (N1). It was concluded that using straw mulching (6 Mg ha^{-1}) can change the soil hydrothermal regime for provision of favorable condition for soybean growth when 27 kg N ha^{-1} was used in semi-arid condition of North-west China.

1. Introduction

Soybean (*Glycine max* L. Merr.) is one of the important edible and oilseed crops of China. It is mostly grown in water deficient and marginal land in most parts of the world. Soybean beside soil fertility improvement also has valuable nutritional values for human being. Likewise, it contributes 48.2-60% to the world-oilseed acreage (USDA, 2016). It fix about 50–300 kg N ha^{-1} in a year, representing a major contribution (Keyser and Li, 1992). During 2014–15, soybean was globally cultivated on 118.2 million hectares of land, having average production of 2699 kg ha^{-1}, and grain yield 319 million tones (USDA, 2016).

Soybean is a N fixing crop thus requires less N fertilizer. However, in North-west China, excessive N fertilizers are used for most of the crops (Li et al., 2008). The average usage of N fertilizer (~450 kg ha^{-1}) had increased the chance of nitrate pollution of the ground water in the irrigated areas of North-west China (Li et al., 2005). This nitrate leaching was around 227 kg NO_3– N ha^{-1} in 0–90 cm soil layer at crop harvest stage (Cui et al., 2006), and expecting to be increase with future N application. Thus, N fertilization is widely accepted as a source of water pollution, but at the same time it is needed for mineral N availability for the plants in a variety ecosystem of the world (Khan et al., 2018). It was evident from the long term excessive use of N fertilization that excess use or long term application of N caused accumulation of residual N in north China (Fan et al., 2003; Ju et al., 2006). Therefore, recently, more discussing and important issue is the N cycling in agroecosystem and need more consideration from scientists in China (Chuan et al., 2015).

The use of crop residues as mulching materials is an important management tools to pose positive effects on soil and crop growth (Akhtar et al., 2018a, b). Surface straw mulching retained more rain water and also had positive response on soil water content by controlling evaporation loss (Ali et al., 2018; Ghosh et al., 2006) and hence decreased the soil temperature due to low thermal conductivity (Ali et al., 2018) and aggregation of soil particles (Jordán et al., 2010; Kesik et al., 2010). Since most of the precipitation occurs in between July and September in the study area, as thus it is expected that mulching will conserve greater moisture content and will fulfill the crop water

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requirements. Soil surface mulching also protect the soil against crusting by promoting soil stability (Govaerts et al., 2007) and thus increase soil porosity (Muhammad et al., 2018) and oxygen diffusion rate. Mulching improves the soil biotic activity of earthworms (Lal, 2015), other soil fauna, soil structure and quality up to a greater extent (Döring et al., 2005; Govaerts et al., 2007).

Previous studies mainly focused on soil bulk density, nutrient status, chemical properties, soil enzymes, and grain yield in response to mulching techniques (Akhtar et al., 2018a, 2018b). However, limited information is available on crop photosynthetic rate and its relationship with soybean grain/straw yield principally in semi-arid region when wheat straw was used as mulching material with variable amount of N. It is well known that chlorophyll is the basic material for plant photosynthesis, and its quantity determine the rate of photosynthetic (Zhang et al., 2013). The improvement of leaf photosynthetic characteristics has a significant impact on crop growth and development, dry matter accumulation, and final grain yield (Makino, 2011). It was supposed that mulching will improve the soil properties, and will also mineralized to provide N, thus different rate of N was interactively added along with straw mulching in a three years field experiment with objectives (i) to clarify the trend changes of soybean net photosynthetic rate, chlorophyll content, dry matter accumulation, root variables and yield with increasing straw mulching/nitrogen rates (ii) to study the correlations between the photosynthetic rate and yield (iii) to identify the changes in soil moisture and soil temperature in response to these management alternative and its impact on seed and biomass yield.

2. Materials and methods

2.1. Experimental site

The experimental site (34°12′N and 108°07′E) is situated within North-west China, Yangling, Shaanxi Province. The area is 520 m above sea level. Mean annual temperature and precipitation are 12.9 °C and 660 mm, respectively. Most of the precipitation occurs between July–September. The soil is classified as Lou soils. The soil nutrients and water contents were measured before the start of experiment. The experimental site has soil organic carbon (1.12%), available N (26.5 mg kg^{-1}), available P (10.2 mg kg^{-1}), available K (132 mg kg^{-1}), total N (0.52 g kg^{-1}), total P (0.49 g kg^{-1}) and soil water content (8.7 mm). The climatic data during growth period is presented in Table 1.

2.2. Experimental design

Three wheat straw mulching treatments i.e. S1 (0 kg ha^{-1}), S2 (3 Mg ha^{-1}), S3 (6 Mg ha^{-1}) and three nitrogen rates N1 (0 kg ha^{-1}), N2 (80% or 21.6 kg N ha^{-1}), N3 (100% or 27 kg N ha^{-1}) were established since 2010 in wheat-soybean rotation. The experimental design was split plot with straw mulching in main plot, and nitrogen rates in subplot with three replications. After five years of treatments imposition, in 2015 the harvested wheat residue was chopped into 3–5 cm consecutively for three years (2015–17) and mulched on soil surface. The mulched wheat residue contains 0.5% N, 0.1% P, 1.0% K and 47% C.

Table 1
Mean monthly air temperature and rainfall during growing season 2015–2017.

Growing Months	Air temperature (°C) Year			Rainfall (mm) Year		
	2015	2016	2017	2015	2016	2017
June	22.9	24.9	24.7	81.3	81.4	69
July	26.6	27	30.2	50.3	122.3	64.7
August	24.3	27.1	25.2	71.2	15.9	203.2
September	20	20.7	20.5	84.1	94.7	270.4

The summer soybean (*Glycine max* L.) common cultivar 'dongdou 339′ was planted at seed rate of 60 kg ha^{-1} on 5 June 2015, 7 June 2016, and 5 June 2017. The sowing depth (5 cm) was kept contestant, and planting was made with no tilt planter machine. The row spacing was 45 cm and plant spacing was 5 cm. The plot size was 13 × 8.25 m. The experimental field was not plowed before sowing of soybean crop. Diammonium phosphate (DAP) was used as a source of nitrogen fertilizer and was applied during mid of July each year. Manual weeding was conducted when required during the field experiments. Irrigation of 120 mm was provided during mid of July each year.

2.3. Observations and measurements

The net photosynthetic rate (NPR) was measured by a portable photosynthesis system (LI-6400, LI-COR, Lincoln, Nebraska, USA) at trifold, flowering initiation and pod developmental stages of soybean. Soybean growth variables were measured at trifold, flower initiation and pod developmental stages. In each plot, five plants were selected and were dug out at 0– 0.3 m soil layers with a soil block, and keep in meshed plastic bag, and to remove the soil from plant roots these bags were kept in running water for ~1 h. Afterward, the aerial and roots parts were separated. At trifold, flower initiation and pod developmental stages, the nodules were separated from roots and were counted. Similarly, from the stem and branches, all the leaves were detached, and leaf area was determined using a leaf area meter (Model LI-COR-3100). The nodules, roots and aerial parts were kept in the hot-air oven at 70 ± 2 °C until constant weights, and dry weights were measured. From the measured leaf area, the leaf area index was computed as total leaf area of five plants/total ground area occupied by five plants. Dry matter accumulation (DMA) and crop growth rate (CGR) were calculated following the formula proposed by Hunt (1978). The SPAD value (index of leaf chlorophyll content) were measured using a SPAD 502 m (KonicaMinolta, Inc., Tokyo, Japan) at trifold, flower initiation and pods development stages (Schepers et al., 1992). Soil temperature and gravimetric soil moisture contents were determined in 0–20 cm soil layer at pod developmental stages.

In each plot, randomly five plants were selected and were harvested for measuring yielding characteristics. Afterwards, all pods of these five plants were counted and were averaged. Pods were threshed, 100 seeds from each plot were counted, dried in sun for four days and in oven at 70 °C for two hours, and weighed to record seed weight. All plants from 3.5 × 1.5 m with a repeat of three times were harvested separately for measuring the biomass and grain yields. These plants were threshed by a mechanical thresher, cleaned, and sun dried for four days and weighed to record grain yield, and was adjusted for 14% moisture content.

2.4. Statistical analysis

For each variable, the mean values were calculated and for the comparison of different treatments, an analysis of variance (ANOVA) was used. The means were compared by the least significant difference (LSD) test. The statistical analyses were performed using SPSS 20.0. In this study, straw mulching and nitrogen rates were considered as fixed and main factors; year is repetitive factor while replication as random factor. The interaction effects, wherever founded significant were also calculated and presented.

3. Results

3.1. Net photosynthetic rate and Leaf-SPAD value

The net photosynthetic rate varied significantly among the year, straw mulching and nitrogen rates (Table 2). The net photosynthetic rate at trifold (22.3% and 17.3%) was higher in 2017 and 2016, respectively than 2015 (Table 2). No significant differences for net