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Straw retention combined with plastic mulching improves compensation of intercropped maize in arid environment

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ABSTRACT

Improving compensation effect of late-maturing crop is a feasible way to increase total productivity of intercropping system. In arid areas, it is unknown whether the compensation can be improved via optimizing management of early-maturing crops. In this study, we developed an improved crop production pattern, i.e., plastic combined with 25–30 cm tall of three straw retention treatments, including straw standing (i.e., NTSS), straw covering (i.e., NTS), or straw incorporated into the soil (i.e., TIS), and one conventional deep tillage treatment without crop straw residue (i.e., CT) for early-maturing wheat in wheat-maize intercropping systems, to determine (i) the compensation effect of dry matter accumulation of intercropped maize after accompanying wheat harvest in different intercropping treatments; (ii) the secondary super-compensation effect (i.e., SCE) of intercropped maize based on dry matter transformation; and (iii) the comprehensive compensation effect of different intercropping systems, in comparison to monoculture maize with conventional treatment (i.e., CTM). The field experiment was conducted in northwestern China from 2009 to 2012. We found that the improved crop production patterns can increase the crop growth rate (i.e., CGR) of intercropped maize after the intercropped wheat was harvested, especially, NTS accelerated the compensation effect of intercropped maize, and shortened the compensation process of the intercropped maize. Straw retention increased contribution rate to grain yield by each organ in maize. Thus the SCE based on contribution to grain yield from leaf increased by 13.7%, increased by 14.9% from stem, and 32.8% from sheath, in comparison with CT treatment; NTS had higher SCE by 10.9%, 11.4%, and 26.2% from leaf, stem, sheath of maize, respectively, than those of NTSS and TIS. These results means that improved systems can improve the grain yield by 73.7% and harvest index by 11.7%, compared with the CTM treatment; NTS was the most productive pattern, boosted the maize grain yield by 16.4% and increased harvest index by 14.8% over intercropping maize with conventional treatment, during the three studied years. We can draw a conclusion that intercropping wheat and maize with straw mulching on the soil surface can be applied as an effective straw management method in improving the super-compensatory effect of late-maturing maize, thus improving total yield in intercropping system in arid oasis areas.

1. Introduction

Multiple cropping with a history of thousand years is a common intensified agriculture in China. Moreover, about a third of all the arable land areas have been used for multiple cropping patterns, producing half of the total grains (Zhang and Li, 2003). Intercropping, one of the most important multiple cropping patterns, has a potential to obtain the higher yield than monoculture pattern mainly due to the improved efficiency of water, light, nutrient, and other resources utilization (Li et al., 2001b; Rowe et al., 2005). Also, intercropping has been confirmed to boost agricultural productivity and to provide a potential biological diversity for the agricultural sustainable development (Chai et al., 2013). It continues to be widely focused not only on the legume-cereal intercropping in tropical regions (Vandermeer, 1992), which is

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a productive and sustainable system, but also employed on the cereal–cereal intercropping in temperate regions (Yin et al., 2015). Such as, wheat-maize intercropping pattern, which was introduced to the oasis irrigation area in northwestern China, in the 1970s, is still a prevailing cropping pattern (Yin et al., 2015), which had contributed a great deal in poverty elimination and food security.

Interspecific interaction is inevitable consequence when the two or more than two crops are grown together (Vandermeer, 1992), it can promote niche differentiation. Interspecific competition can promote the use of different resource. Different crops can utilize a given resource based on time and space (Mehrhoff and Turkington, 1996), and then facilitation appears when one crop promotes the growth of another crops (Callaway, 1995). Complementarity can decrease interspecific competition through resource partitioning between intercrops (Hinsinger et al., 2011). Of course, interspecific competition is bound to weaken the growth of late-maturing crops (i.e., the weaker competition crops) across the co-growth period (Li et al., 2001b); yield advantage of intercropping was attributed to compensation effect of the late-maturing crops which the growth was impaired during the co-growth period (Li et al., 2001a). Therefore, it is urgently important for improving the compensation effect of late-maturity crops through regulating agronomic measures. A key strategy in improving the compensation effect of late-maturity crops is to adopt advanced agricultural techniques in the production of agriculture (Li et al., 2001a). Take effective cultivation measures to improving the compensation effect of late-maturity crops is an important research topic for developing high yield of agriculture, such as the use of conservation tillage, or no tillage with straw retention.

To our knowledge, a suitable soil water thermal environment is conducive to the growth and development of crops (Li et al., 2010; Yin et al., 2016). Therefore, optimizing soil temperature and improving soil moisture are the effective ways to increase crop yield through effective farming practices. In arid oasis agriculture zone, the annual precipitation ranges from 50 to 150-mm, and the annual potential evaporation is greater than 2400 mm, thus, maize production must adopt plastic film mulching measure. In the maize-based intercropping system, maize strip of mulching with plastic can conserve soil water, increase topsoil temperature, and accelerate crop growth and boost crop yields (Ramakrishna et al., 2006). Also, it can promote the accumulation of photosynthetic product in crops, prompt nutrients transfer from stem to the grain, increase the contribution rate to grain, thus improving harvest index (Tiwari et al., 2003; Zhou et al., 2009). However, the higher soil temperature in the root layer at the flowering stage of crops cultivated with plastic can result in leaf and root senescence of crops, thus decreasing crop productivity (Bu et al., 2013), it maybe not conducive to the formation of intercropping compensation effect. Meanwhile, straw retention can effectively keep soil water, reduce soil temperature and water consumption, enhance crop productivity (Huang et al., 2008), in particular, it can optimize dry matter distribution of crops, leading to high harvest index (Baumhardt et al., 2013). Previous research showed that intercropping wheat and maize system with plastic mulch in combination with crop straw retention can optimize soil temperature and improve the use of soil moisture in arid area (Yin et al., 2016). However, an important question is whether this advanced system can increase crop productivity via enhancing compensation effect of the late-maturity crop based on the dry matter accumulation, or even produce the strong super-compensation effect of late-maturing crop based on dry matter translocation? This means the productivity of intercrops higher than that of the monoculture.

With those challenges in mind, we identify plastic mulching and straw retention that have been proven to be successful in the production of crops and we put them together to establish an improved farming pattern, i.e., plastic combined with the return of crop straw to the field, in wheat-maize intercropping patterns. We determined: (i) the compensation effect of dry matter accumulation of maize after wheat harvest in a wheat-maize intercropping system; (ii) the secondary super-compensation effect of intercropped maize based on dry matter translocation; and (iii) the comprehensive compensation effect of different intercropping treatments. Our hypothesis was that this test had a great advantage in increasing translocation rate of vegetative organs to grain, and the secondary super-compensation effect in crop production occurred in intercropped maize after wheat harvest with the improved approach, thus improving maize productivity.

2. Materials and methods

2.1. Site description

The experiment was conducted in 2009–2012 at the Gansu Agricultural University Oasis Experimental Station (37°34′N, 102°94′E). This Experiment Station located in the eastern of Hexi regions of the northwestern China, with the sunshine duration above 2940 h, and the thermal day above 10 °C is about 155 days, which is suitable for the development of intercropping pattern. The averaged annual precipitation is less than 155-mm, however, the potential evaporation is more than 2400-mm. Meanwhile, this region is a typical arid oasis irrigation area, which relies on irrigation for crop production. Therefore, plastic mulching and the return of crop straw to the field measures were applied into crop production for improving water utilization. Water shortage and gradually shrinking area of arable land in that area result in a conflict between crop water requirements and food demand. Therefore, a new planting pattern on intercropping system has been introduced to Hexi Corridor of China. The precipitation (mm) and mean air temperature (°C) during the three studied years of the maize growing season were presented in Fig. 1.

2.2. Experimental design and crop management

A preparatory experiment was carried out in 2009, to form different wheat straw management methods in the field for the implementation of the treatments in 2010, 2011, and 2012. In the testing years, four kinds of straw retention patterns were implemented, and plastic mulch was applied for maize strips before sowing, which formed an advanced pattern with plastic mulching and crop straw (i.e., both plastic and straw were used to mulch on the maize strips). The wheat-maize intercropping was tested in three crop-straw retention systems and a conventional tillage treatment without straw residue. Besides, the conventional treatment was also applied for monoculture maize. In all, there are 5 treatments with 3 replicates constituting a total of 15 plots. Moreover, for improving the compensation effect of intercropped maize after accompanying wheat harvest, four approaches were examined: (i) no tillage with 25–30 cm wheat straw standing on the plots at intercropped wheat harvesting last summer (NTSS); (ii) no tillage with 25–30 cm wheat straw evenly covered the soil surface at intercropped wheat harvesting last summer (NTS); (iii) tillage with 25–30 cm height of intercropped wheat straw incorporated into the soil after wheat harvesting last summer (TIS); and (iv) conventional treatment without straw retention (CT) where deep tillage (30 cm depth) was applied to the plots with wheat straw being removed off the field, the four crop-straw methods were applied into the wheat-maize intercropping systems (Fig. 2). An additional treatment was monoculture wheat with conventional tillage pattern rotated monoculture maize in alternate years (monoculture wheat planted the current year were planted with monoculture maize the following year and vice versa), in order to form conventional