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Research paper

Integration of wheat-maize intercropping with conservation practices reduces CO_2 emissions and enhances water use in dry areas

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ABSTRACT

Crop intensification has been used as a mean to increase crop yield and secure food supplies in developing countries. However, issues about CO_2 mitigation, water consumption, and the overall viability associated with the crop intensification have become a concern. The main objective of this study was to investigate how the yield related environmental factors, i.e. soil CO_2 emission and crop water use would responsed to wheat-maize intercropping with conservation practices. Here we determined crop yield, plant biomass carbon, soil CO_2 emission, and crop water use in various cropping systems. The field experiment was conducted at Wuwei Experimental Station in an arid oasis region (37°57′N, 102°37′E), in 2011 and 2012. Four tillage and crop residue options were applied to wheat-maize intercropping. They were (a) no-till with stubble standing (NTS), (b) no-till with stubble mulching (NTM), (c) reduced tillage with stubble incorporated into the soil (RTS), and (d) conventional tillage without stubble retention (CT). Averaged across two years, wheat-maize intercropping integrated with no-till and stubble mulching yielded 1.6 t ha^{-1} more grains and 7.1 MJ ha^{-1} more energy, while emitted 1.2 t ha^{-1} less soil CO_2 than conventional wheat-maize intercropping; at the same time, the system increased plant biomass carbon by 16%, and enhanced CO_2 emission efficiency per unit of grain yield by 39%, compared with the conventional system. Also, the integrated system decreased soil evaporation by 11%, increased energy yield per unit of water by 19%, and lowered CO_2 emission per unit of water by 9%. Among the wheat-maize intercropping systems evaluated, the treatment with no-till and crop residue mulched on the soil surface had the highest evaluation index at 0.82; this was attributable to the increases of carbon emission efficiency by 48% and water use efficiency by 22%, compared with the conventional system. Wheat-maize intercropping integrated with no-till and stubble retention can be used to increase crop yield efficiently while reducing soil CO_2 emission and enhancing crop water use effectively in dry areas.

1. Introduction

Securing food supplies to meet the need of growing human population presents a significant challenge in the biggest developing countries – China and India (Wanjari et al., 2004; Zhou et al., 2012). Many strategies and farming practices have been developed to alleviate the challenge. One of the most promising and highly productive farming practices is intercropping, where two crop species with contrasting growth habits are planted in alternate rows or in strips on the same field. This cropping system has been increasingly adopted worldwide in recent years as it is efficient in resource use (Willey, 1990; Ofori et al., 1987) and yield improvement (Willey, 1985; Brooker et al., 2015). A number of intercropping systems have been tested in order to meet the primary advantages such as light interception (Szumigalski and Van Acker, 2008; Zhang et al., 2008), soil nutrient sharing (Hauggaard-Nielsen and Jensen 2005; Shen and Chu, 2004), and soil moisture conservation (Fan et al., 2012). Thus, the cropping system is highly expected to close yield gaps between current crop yields and their potentials (Mueller et al., 2012). However, questions remain in regard to how the yield-focused approaches

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may be environmentally-friendly or detrimental (Kim, 2012; Chapagain and Riseman 2015; Epie et al., 2015), especially for the fragile agroecosystems that currently adopted in arid and semiarid environments. Accordingly, developing of some best farming practices are imperative, so that the great pressure of yield related environmental problems can be alleviated (Hu et al., 2015).

Conservation agriculture is considered a system of farming practices, including reduced tillage (RT) or no-till (NT), permanent organic soil cover with crop residues, and crop rotations (Palm et al., 2014). The integration of farming practices in a system has been shown to enhance system productivity (Gan et al., 2013), and reduce soil degradation and solve some production-related problems (Arslan et al., 2014). Conservation agriculture has increasingly been used in developed countries because of its environmental advantages (Al-Kaisi and Yin, 2005). For instance, cropland with conservation tillage often receives minor soil disturbance (Alletto et al., 2010) but reserves a greater amount of carbon retention in the soil (Iqbal et al., 2009). In many circumstances, cropland with conservation practices generates a low CO_2 emission from the soil (Fuentes et al., 2011), while sequestering more carbon in it (Alletto et al., 2010). Furthermore, conservation agriculture practices are often used to minimize soil water loss (Govaerts et al., 2006), increase water infiltration (Kirkegaard et al., 2014), and improve crop water use efficiency (Fan et al., 2012; Plaza-Bonilla et al., 2015). This is a practice vital for farming in dry areas where agriculture is experiencing severe water stress due to water scarcity and warming climate (Altieri et al., 2015).

Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are the two main crops grown in the arid northwest China, where the two crops are usually intercropped together in intensified systems (Qin et al., 2013). As cropland scarcity and remaining arable land deficit are getting more serious recently (Zhou et al., 2012), wheat-maize intercropping is extended in a large scale (Yang et al., 2011). The main focus of this intensified farming system has been on crop yield in the past, but information on the effect of wheat-maize intercropping combined with conservation practices on soil CO_2 emission and water use is limited. In addition, the conflict between food supply and farming viability is becoming a global concern (Tilman et al., 2002). To address the effects on CO_2 emission and water use of this cropping system is of important significance. Therefore, the overall objective of the present study was to determine the yield related environmental factors, i.e. soil CO_2 emission and crop water use of the intensified cropping system. More specifically, we aimed to determine (i) the influence of conservation practices in wheat-maize intercropping systems on grain yield, energy yield and plant biomass carbon; and (ii) the effect of tillage practices on soil surface CO_2 emission and water use of various wheat-maize intercropping system. We tested the hypothesis that intercropping wheat and maize with conservation practices can increase crop yield, optimize water use, and lower soil CO_2 emission simultaneously, compared with conventional tillage.

2. Materials and methods

2.1. Site description

The experiment was carried out in 2011 and 2012 at the Wuwei Experimental Station of Gansu Agricultural University in an arid oasis region (37°57′N, 102°37′E, and 1506 m a.s.l). This station, located in the eastern part of the Hexi Corridor of northwestern China, is in the temperate arid zone in the hinterland of the Eurasia Continent. Long term (1960–2009) average solar radiation is 6000 MJ m^{-2}, annual sunshine duration is >2945 h, annual mean temperature is 7.2 °C with accumulated temperature above 0 °C > 3513 °C and above 10 °C >2985 °C, and a frost-free period of 155 d. Mean annual precipitation is rarely greater than 156 mm, occurring mainly in the summer (Fig. 1), however, annual potential evaporation is greater than 2400 mm. The soil at the experimental site was classified as an Aridisol (FAO/UNESCO, 1988), and some of the properties are presented in Table 1. At the start of the experiment, the total nitrogen (N), Olsen P, and organic matter of the top (0–60 cm) soil was 0.78 g kg^{-1}, 1.14 g kg^{-1} and 14.3 g kg^{-1}, respectively.

2.2. Experimental design and plot management

The experiment was conducted with a randomized, complete block design and with three replicates. A preparatory experiment was conducted in 2010 to create proper wheat straw retention and tillage patterns so as to provide field bases for the implementation of various treatments in the following years (Fig. 2). In 2011, the following conservation farming practices: (a) no-till with 25 cm

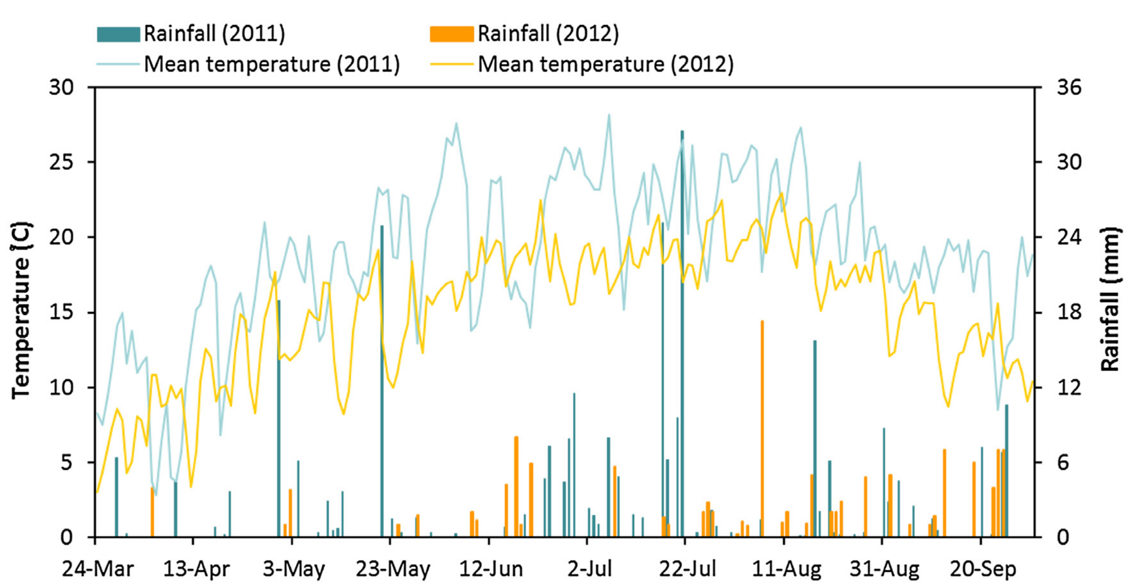

Fig. 1. Mean air temperature and rainfall during the growing season of wheat-maize intercropping in 2011 and 2012, at Wuwei experimental station, northwestern, China.