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Effects of alfalfa intercropping on crop yield, water use efficiency, and overall economic benefit in the Corn Belt of Northeast China

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A B S T R A C T

The proper choice of a planting pattern is a key issue in the Corn Belt of Northeast China (CBNC) for national grain security and increasing the incomes of farmers. Field experiments were conducted from 2014 to 2016 in Lishu County, Jilin Province, China in order to evaluate alfalfa intercropping within the context of a uniform planting density of corn. The four treatments included corn monoculture (nC) as the control, 3-row corn intercropping with 3-row alfalfa cultivation (3C/3A), 3-row corn intercropping with 5-row alfalfa cultivation (3C/5A), and alfalfa monoculture (nA). Corn–alfalfa intercropping did not affect soil moisture in 2014. In 2015, the relative soil water content of the 3C/5A treatment was lower than that of the nC treatment, and the relative soil water content of the 3C/3A treatment was higher than that of the nC treatment. Biomass and yield under the 3C/5A treatment were greater than those under the nC treatment in a normal year (2014) and a wet year (2016). Biomass water use efficiency and net revenue under the 3C/5A treatment were similar with those under the nC treatment. Net revenue of the 3C/5A treatment was 14% higher than that of the nC treatment in a dry year (2015). Biomass, biomass water use efficiency, and net revenue under the 3C/5A treatment were higher than those under the 3C/3A treatment. The 3C/5A treatment was an effective planting pattern over the 3 years, with a total net revenue 443 USD ha^{-1} higher than that of the nC treatment. The nA treatment's biomass and biomass water use efficiency were less than those of the nC treatment, but its economic benefit was highest among all treatments, with a total net revenue 2510 USD ha^{-1} higher than that of the nC treatment. Therefore, planting alfalfa as a monoculture or as part of a 3C/5A intercropping system is recommended to improve soil fertility and the development of animal husbandry while financially benefiting farmers.

1. Introduction

The Corn Belt of Northeast China (CBNC) is a vitally important grain production area and the largest commodity grain supply base in China. It accounts for one third of the total area of the country and about 35% of the total corn production (*Zea mays* L.) in China with 78 million Mg of corn grain yield (National Bureau of Statistics of China, NBSC, 2016). However, the long-term continuous cultivation of corn monoculture has caused many problems in local agricultural production, such as an overly simple ecological system structure, unbalanced soil nutrients, worsening soil-borne diseases, pest outbreaks, and other epidemics (Yu et al., 2006; Zhao et al., 2006). Furthermore, decreasing corn prices in recent years have reduced farmers' enthusiasm for cultivating corn. Moreover, in order to develop animal husbandry rapidly, more and higher quality forage is required, which necessitates that less agricultural land is dedicated to corn production.

Alfalfa (*Medicago sativa* L.) is a perennial, deep-rooted, leguminous forage crop and is commonly used as a high-quality feed with high forage yield potential, good nutritional quality, high adaptability, and high protein content (Li et al., 2007). Its cultivation can also conserve soil and water and increase soil fertility (Liu et al., 2009a). In the United States Corn Belt, planting alfalfa is common (Kanwar et al., 2005; Yost et al., 2012), but while alfalfa–corn rotation has been widely used in the US, alfalfa–corn intercropping has rarely been used (Kanwar et al., 2005; Cela et al., 2011; Yost et al., 2012).

Intercropping has long been practiced in many parts of the world (Anil et al., 1998). In China, intercropping systems are used in more than 33 million hectares of cultivated land (Zou and Li, 2002). Intercropping systems, especially intercropping of cereal crops and leguminous crops, have many advantages, such as increasing crop yield (Zhang et al., 2007a), enhancing land use efficiency (Dhima et al., 2007; Gao et al., 2010), improving pest and disease control (Banik et al., 2006; Vasilakoglou et al., 2008), and increasing the use of light, water, and nutrients (Javanmard et al., 2009). Current research on intercropping has focused on the intercropping of annual leguminous crops (e.g., soybean) and cereal crops, and there are a few references to

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the intercropping of perennial leguminous crops (e.g., alfalfa) and annual crops (Smith and Carter, 1998; Chen et al., 2003; Liu et al., 2009b; Zhang et al., 2011a; Nassiri Mahallati et al., 2015; Wang et al., 2016). For example, Smith and Carter (1998) similarly found that alfalfa–corn intercropping increased crop yield and economic benefit when compared with corn monoculture. Chen et al. (2003) showed that yields from alfalfa–corn intercropping were lower than those from cultivating only corn. Zhang et al. (2011a) showed that 5:2 intercropping patterns (i.e., an alfalfa: corn row ratio of 5: 2) presented the most stable yield advantage during a 2-year experiment in the Huang–Huai–Hai Plain of China, but the economic benefit and land use rate of intercropped land areas increased, which could effectively alleviate the tradeoffs between grain cultivation and animal husbandry. Liu et al. (2009b) also showed that alfalfa–corn intercropping increased corn yield, but the rate of increase depended on the spatial and temporal patterns of intercropping. Wang et al. (2016) suggested that alfalfa–corn intercropping yields were lower than those of corn monoculture, but that the economic benefit was higher than that of growing corn monoculture.

The present research on alfalfa–corn intercropping was conducted with the same spatial configuration in terms of number of rows of corn as under a regime of corn monoculture. Moreover, few intercropping experiments have been conducted by replacing rows of corn plants with rows of alfalfa. As such, the objectives of this study were to (i) investigate the corn growth and soil water status in the corn monoculture and intercropping systems, (ii) clarify the alfalfa growth and soil water status in the alfalfa monoculture and intercropping systems, (iii) evaluate the crop biomass, water consumption, WUE_B and economic benefit in the intercropping and their corresponding monoculture systems. This study will provide valuable information for selecting planting modes in the process of structural adjustment of the CBNC.

2. Materials and methods

2.1. Experimental site

The field experiments were conducted from 2014 to 2016 at the Lishu Experiment Station of China Agricultural University in Lishu County, Jilin Province, which is located in the center of the CBNC (43.3° N, 124.4° E, and altitude 196 m). The experimental site is located in the north temperate zone and has a semi-humid continental monsoon climate. Table 1 summarizes the climatic characteristics. The precipitation during the growing season from early May to the end of September was 463, 307, and 661 mm in 2014, 2015, and 2016, respectively, and the mean precipitation (1980–2012) during the growing season was 485 mm (Fig. 1). The soil is a fine-silty, mixed, superactive, mesic Cryrendoll soil that was formed from alluvial deposits. Table 2 summarizes the soil characteristics.

The precipitation years were classified according to the precipitation anomaly percentage [PAP, (actual precipitation-average precipitation)/average precipitation × 100%] and were divided into dry (PAP < −15%), normal (−15% ≤ PAP ≤ 15%), and wet (PAP > 15%) precipitation years (Standardization Administration of the People's Republic of China, 2008). Total precipitation during the 2014, 2015, and 2016 growing seasons from early May to the end of September were 463 (PAP = −1%, normal year), 307 (PAP = −35%, dry year), and 661 mm (PAP = 41%, wet year), respectively (Fig. 1). In 2014, May, June, and September were wet months, while July and August were dry months. In 2015, May was a wet month, while July and September were dry months. In 2016, July was a dry month, while May, June, and September were wet months.

Table 1
Climate characteristics of the study site.

Item	Value
Average annual temperature (°C)	5.9
Annual total sunshine (h)	2679
Annual cumulative temperature (> 10 °C)	3078
Annual precipitation (mm)	573
Frost-free period (d)	142
Mean annual pan evaporation (based on 1986–2008 data) (mm)	808

2.2. Experimental design and field management

The four experimental treatments of farming system included corn monoculture (nC), alfalfa monoculture (nA), 3-row corn intercropping with 3-row alfalfa cultivation (3C/3A), and 3-row corn intercropping with 5-row alfalfa cultivation (3C/5A). Both monoculture and intercropped corn had a row spacing of 60 cm, and alfalfa monoculture had a row spacing of 30 cm. Alfalfa in the 3C/3A treatment had a row spacing of 30 cm while the interrow spacing under the 3C/3A treatment for corn and alfalfa was 30 cm. Alfalfa in the 3C/5A treatment had a row spacing of 20 cm while the interrow spacing of the 3C/5A treatment for corn and alfalfa was 20 cm. The intercropping treatments with corn had one out of four rows replaced by three rows of alfalfa (3C/3A) or five rows of alfalfa (3C/5A). The overall corn density under the intercropping treatment was uniform in the monoculture treatment. The arrangement of each treatment is shown in Fig. 2. All plots were arranged in a randomized complete block design with three replicates and a 1.0 m buffer zone between plots. Every plot was 9.6 m wide and 16 m long. All plots were ploughed to a depth of 15 cm with a rotary cultivator (1GKN-160, Yungang Rotary Tillage Machinery Co., Ltd, Lianyungang, China) before sowing in the spring of 2014.

The corn cultivar grown was 'Liangyu 66.' Seeds were planted manually at a depth of 5 cm using a hole-driller on May 3, 2014, May 5, 2015, and May 8, 2016. Both alone and intercropped corn were planted to a density of 60,000 plants ha^{-1}. Corn was harvested on Sept. 26, 2014, Sept. 26, 2015, and Sept. 30, 2016. All corn plots (including intercropped corn) received compound fertilizer (Jilin Longyuan Agricultural Production Materials Group Co., Ltd, China) at 260 kg N ha^{-1}, 112 kg P_2O_5 ha^{-1}, and 112 kg K_2O ha^{-1} before seedling. The alfalfa cultivar was 'Gongnong 1.' Seeds were sown by hand at a seeding density of 20 kg ha^{-1} (the thousand-grain weight was 2.39 g) at a depth of 2 cm on May 3, 2014. Alfalfa was harvested two, four, and three times in 2014, 2015, and 2016, respectively. All alfalfa plots (including intercropped alfalfa) were given the same fertilizer as corn plots in 2014, while in 2015 and 2016, all alfalfa plots (including intercropped alfalfa plots) received 50 kg ha^{-1} of N as urea, 125 kg ha^{-1} of P_2O_5 as calcium superphosphate, and 70 kg ha^{-1} of K_2O as potassium sulfate at the alfalfa greening date.

2.3. Measurements and calculations

The volumetric soil water content was measured using TDR (TRIME-PICO IPH, IMKO, Ettlingen, Germany) with 20-cm-long probes. An access tube (a 2-m-long PVC tube, with a 44-mm outer diameter, 42-mm inner diameter, and a steel cutting shoe) was installed at each measurement location using an auger. Two tubes were installed in the corn monoculture and alfalfa monoculture treatments, and three tubes were installed in the alfalfa–corn intercropping treatments, respectively. For the cropping only plots, tubes were situated in the interrow spaces and along the crops rows, and the two-point average represents the soil volume water content under the monoculture treatments. For the intercropping plots, tubes were situated at the center of the corn strip and at the center of the alfalfa strip. The volumetric soil water content was measured every 7 days and before and after the rainfall events throughout the growing seasons of 2014, 2015, and 2016.

The soil water storage in the soil profile was calculated using the equation

$$SW = \sum_{i=1}^{n} \theta_i \times Z_i \quad (1)$$