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Relay strip intercropping of oat with maize, sunflower and mung bean in semi-arid regions of Northeast China: Yield advantages and economic benefits

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ABSTRACT

Intercropping is a sustainable agriculture system that provides an alternative pathway to combat environmental deterioration due to excessively intensive agriculture. However, relay strip intercropping patterns have rarely been practiced in the semi-arid regions of Northeast China. Therefore, two years of field experiments of oat/maize, oat/sunflower, and oat/mung bean relay strip intercropping were conducted to determine the optimal yields and economic patterns. Treatments included sole crops of oat, maize, sunflower and mung bean, as well as three relay strip intercropping patterns consisting of six rows of oat alternating with three rows of maize, sunflower, or mung bean. The land equivalent ratio (LER) of intercrops varied from 1.10 to 1.14, 1.23 to 1.38, and 1.05 to 1.08 for oat/maize, oat/sunflower, and oat/mung bean, respectively. Relay strip intercropping systems presented distinct yield advantages, especially in oat/sunflower. The net incomes of oat/sunflower intercropping were estimated to be ~2000 $ ha^{-1}, which were significantly higher than both sole oat and sunflower. In oat/sunflower intercropping, kernel numbers per ear, ear numbers per meter row of oat and the thousand kernel weight of sunflower in border rows were 16–25%, 23–30% and 10–13% higher than inner row, well as thousand kernel weight of sunflower in border row increased 10–13% than inner rows, respectively. However, no positive border row effects were observed in the oat/maize or oat/mung bean intercropping systems. In conclusion, oat/sunflower relay strip intercropping is the most profitable alternative intercropping pattern in the semi-arid regions of Northeast China.

1. Introduction

Northeast China plays a crucial role in national food security due to intensive agriculture system with high levels of fertilizer and water consumption (Wang et al., 2015b; Yin et al., 2016). With 16% of the total arable land, it supplies 19%, 34% and 16% of the grain, maize and rice production of China (NBS, 2014). Consequently, a series of environmental concerns including desertification, nitrate pollution of groundwater and soil acidification exist, especially in the semi-arid regions of this area (Cao et al., 2008; Ju et al., 2009; Zhang et al., 2009). Therefore, meeting the increasing grain demand and avoiding adverse environmental impacts from intensive agriculture has become a major challenge.

Intercropping is the cultivation of two or more crop species in the same field (Vandermeer, 1989). It was initially practiced to provide a yield advantage and stability, it also provides possible options for the sustainable intensification of agriculture (Lithourgidis et al., 2011). Previous studies focused on nutrient (e.g. nitrogen (N), and phosphorus) (Mei et al., 2012; Gao et al., 2014), photosynthetically active radiation (Wang et al., 2015a), water efficiency (Wang et al., 2015c), and rhizodeposition transfer (Zhang et al., 2015) in intercropping systems. Intercropping systems have been proven to have positive effects on the control of wind erosion, pests and weeds (Chen et al., 2010; Gronle et al., 2015; Liang et al., 2016).

Recently, intercropping has drawn much attention in arid and semi-arid regions of Northwest China, where wheat/maize, crop/tree and legume-based intercropping patterns have been widely practiced. For instance, wheat/maize relay intercropping could increase grain yield

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and soil carbon (C) storage, and enhance resource (e.g. water, C, and N) use efficiency in Gansu Province (Li et al., 2001b; Fan et al., 2013; Cong et al., 2015; Hu et al., 2016). Agroforestry systems combining trees and crops such as jujube/wheat and young walnut/wheat, have been promoted to improve the agricultural output of household farms in Xinjiang (Zhang et al., 2015; Liu et al., 2016). Legume-based intercropping patterns such as switchgrass/milkvetch and alfalfa/Siberian wild rye were practiced in the arid and semi-arid regions of Northwest China for forage production (Xu et al., 2008; Sun et al., 2009). Previous studies mainly focused on traditional row-intercropping systems, which generally require high labor input and are difficult to automate (Feike et al., 2012). However, traditional intercropping patterns declined in practice due to increasing labor costs. Strip intercropping is the cultivation of two or more crops in strips, which has the ability to accommodate machinery, which is a key factor encouraging farmers to practice such patterns.

Strip intercropping could have an important role in sustainably intensified and mechanized agriculture in the semi-arid regions of Northeast China. Since intercropping systems were rarely practiced and reported in Northeast China, an optimal intercropping pattern needs to be selected with generalization and application values. Oat is a short season crop with appreciable economic benefits and adaptabilities on marginal lands (Ren et al., 2007), which has great potential in Northeast China. Moreover, maize, sunflower and mung bean are the most important crops in the local farming systems, which could be potentially combined with oat in intercropping systems. Previously, oat-pea intercropping received more attention and was mainly concentrated on nitrogen use (Cochran and Schlentner, 1995; Neugschwandtner and Kaul, 2015). In this study, yield and economic performance were paid particular attention to determine which combination was sufficient to convince farmers to accept such strip intercropping. Additionally, yield components were quantified to evaluate the border row effects and diagnose the mechanisms underlying system performance. Therefore, we conducted two years of field experiments (1) to evaluate the yield advantages and economic benefits in oat/maize, oat/sunflower, oat/mung bean strip intercropping and the corresponding sole cropping patterns and (2) to quantify the yield components, thus clarifying the contribution of border rows and inner rows to productivity in strip intercropping systems.

2. Materials and methods

2.1. Experimental site description

The experiment was conducted during 2014 and 2015 at the Baicheng Academy of Agricultural Sciences in Baicheng City, Jilin Province, China (45° 37′N, 122° 48′E, 155 m above sea level). The region is a typical semi-arid area with 407 mm annual precipitation that mainly occurs during April to September. It has a temperate, semi-arid and continental climate, with an annual mean temperature of 4.9 °C, 125–135 frost-free days, and up to 2915 °C of effective accumulated temperature. The soil is light Chernozem with 1.12 g kg^{-1} total nitrogen, 17.4 g kg^{-1} organic matter, 12.2 mg kg^{-1} available phosphorus, 102 mg kg^{-1} available potassium, and pH (H_2O) 8.2. The preceding crop of the experiment field was potato. The meteorological data during the crop growing season were presented in Fig. 1.

2.2. Experimental design and field management

A completely randomized block design with three replicates was used in the same field during 2014–2015. The plot size was 10.8 m wide by 10 m long. The tested cultivars of oat (*Avena sativa* L.), maize (*Zea mays* L.), sunflower (*Helianthus annuus* L.) and mung bean (*Vigna radiata* L.) were “Baiyan 2”, “Zhengdan 958”, “Baikuiza 6” and “Bailv 8”, respectively, based on local agronomic performance. There were seven cropping patterns including the sole cropping of oat, maize, sunflower, and mung bean and strip intercropping of oat/maize, oat/sunflower and oat/mung bean. A schematic illustration of different cropping patterns is shown in Fig. 2. Oat sole cropping was planted with a row spacing of 30 cm, and at a seeding rate of 150 kg ha^{-1}. In addition, sole maize, sunflower and mung bean were planted with a row spacing of 60 cm, and plant spacing of 30, 30 and 10 cm, respectively. Oat and maize (sunflower or mung bean) were planted in alternating 3.6 m wide strips in intercropping systems, which included a 1.8 m wide oat strip of six rows with 0.3 m inter-row distance and a 1.8 m maize (sunflower or mung bean) strip of three rows with 0.6 m inter-row distance, the interspecific row distance was 45 cm. Among intercropping systems, the seeding rate of oat was 75 kg ha^{-1}, and the row and plant spacing of maize (sunflower or mung bean) was in accordance with monocultures. All plots were treated with basal fertilizers, which were evenly distributed and incorporated into the top 20 cm of the soil before crop sowing. Chemical fertilizers were applied at a rate of 150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 50 kg K_2O ha^{-1}. Urea, superphosphate and potassium chloride were used as sources of N, P and K, respectively. Specifically, the dates of sowing were 8 May for oat and maize and 8 June for sunflower and mung bean; the corresponding dates of harvesting were 30 July for oat and18 September for maize, sunflower and mung bean in both years, and the overlap of growing periods is shown in Fig. A.1. All plots were irrigated by flooding during the growing season according to the local field management practices. Flood irrigations were carried out twice for oat, sunflower and mung bean and four times for maize each year (Table A.1). The irrigation amount was 50 mm each time. Weeds were controlled by hand and no application of chemical pesticides for the control of disease and insects was used. Leaf injury or disease symptoms due to disease and insect pest damages were not notable in any of the crop years.

2.3. Data collection

At maturity, the aboveground dry matter was measured after being dried until a balanced weight was reached. The sampling areas for each occasion were two rows 0.6 m long for sole oat and two rows 0.6 m long in both border rows and inner rows for intercropped oat, respectively. Six continuous plants were sampled in both border and inner row for intercropped and sole maize, sunflower and mung bean. All samples were oven-dried at 105 °C for 30 min and then at 70 °C until a constant weight was reached. Grain yield was determined by harvesting two 1.8 m^2 (6 rows, 1 m) for oat and nine plants for maize, sunflower and mung bean in sole cropping and the inner strips of intercropping plots. All samples were air-dried under a platform shelter until the moisture content was 14% and then the samples were threshed for seeds. Finally, yield components including kernel number per plant (ear), thousand kernel weight, grain yield per plant and ear number per meter row were investigated.

2.4. Calculation and statistics

2.4.1. Economic analysis

Economic analysis was conducted to determine the economic feasibility of strip intercropping systems. The total expense including seeds, fertilizers, irrigation, machinery and labor were calculated on the basis of local conditions. Gross income was estimated according to the current price and yield (Table A.2). Since oat straw was sold as winter forage at the price of 96 \$ t^{-1}, we also added this part as gross income. Maize, sunflower and mung bean straws are generally burned and not incorporated into the gross income. Net income was obtained by deducting total costs from the gross income.

2.4.2. Land equivalent ratio

The land equivalent ratio (LER) was used to assess the yield advantage provided by intercropping (Mead and Willey, 1980):