Europ. J. Agronomy 72 (2016) 70–79

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Planting density and sowing proportions of maize–soybean intercrops affected competitive interactions and water-use efficiencies on the Loess Plateau, China

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ARTICLE INFO

Article history:
Received 8 April 2014
Received in revised form
30 September 2015
Accepted 1 October 2015
Available online 22 October 2015

Keywords:
Competition dynamics
Intercropping
Water equivalent ratio
Leaf area index
Relative growth efficiency

ABSTRACT

In field trials on the Loess Plateau, China, in 2012–13, maize (*Zea mays* L.) and soybean (*Glycine max* L.) were sole cropped and intercropped at three densities and with three sowing proportions. Maize was generally more growth efficient for biomass accumulation than soybean during the entire growth interval, as assessed using the relative efficiency index (REI_c). However, most of sowing proportion at each density displayed a trend of decreased growth with development. Throughout the growth period, the dry matter production and leaf area index (LAI) of maize increased as the plant density increased irrespective of whether it was grown as a sole crop or as an intercrop. However, the effect of increasing cropping density was less obvious for soybean. The LAI values of the sole crop treatment for both maize and soybean were greater than that of the intercropping system, indicating that the presence of maize and soybean together suppressed the respective growth of the two crops. At the final harvest, land equivalent ratios (LER) of 0.84–1.35 indicated resource complementarity in most of the studied intercrops. Complementarity was directly affected by changes in plant densities; the greatest LER were observed in 2 rows maize and 2 rows soybean intercrops at low density. The water equivalent ratio (WER), which characterized the efficiency of water resource use in intercropping, ranged from 0.84 to 1.68, indicating variability in the effect of intercropping on water-use efficiency (WUE).

1. Introduction

Intercropping is the simultaneous cultivation of two (or more) crops together on the same piece of land. Intercropping results in greater yield and less variation in yield compared to sole crops (Willey, 1979). This increased yield, particularly under low input conditions, is frequently attributed to resource complementarity, in which component crops use limiting resources more efficiently due to different temporal, spatial, or phenological characteristics (Li et al., 2013). Inter- and intraspecific competition, the availability of environmental resources and the sowing proportion and density of the component crops influenced the degree of resource complementarity, the total yield, the relative contribution of the individual components (Hauggaard-Nielsen et al., 2006; Vanermeer, 1989). For example, Umar (2006) reported that intercrops of grain sorghum (*Sorghum bicolor* L. Moench) and groundnut (*Arachis hypogaea* L.) achieved larger relative yield advantages when grown under drought than they did when kept well-watered. Determination of the optimum plant population density necessary for optimal yield is a major agronomic goal. Compared with sole crops, intercrop components may utilize resources more efficiently. Therefore, the optimum plant density in intercrops outweigh the optimum density in sole crop (Willey and Osiru, 1972). At the mean time, the optimum plant density and sowing proportion at one site may not be applicable to other locations because of regional variations in weather (precipitation, solar radiation, temperature, etc.) and soil properties (organic matter, nitrogen, phosphorus, potassium, soil water hold capacity, etc.). The sowing proportions of intercrop components are sown may be of great significance in determining yield of cereal–legume intercrops (Mao et al., 2012;

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http://dx.doi.org/10.1016/j.eja.2015.10.001
1161-0301/

Ofori and Stern, 1987). Therefore, plant density and sowing proportions are commonly used to achieve potential yield of intercrops in dry land production (Ijoyah and Fanen, 2012).

Willey and Osiru (1972) determined that a higher density of component crops in intercropping resulted in greater intercrop advantages in a maize–bean intercrop. Crop density significantly affects the competitive dynamics between intercrop component crops because dominance is always enhanced by increasing intercrop density. The variables involved (e.g., proportion of the legume or cereal species) may alter the competitive dynamics between component species and indicated their variations (positive effect) in determining yield and production efficiency (Ijoyah and Fanen, 2012). For instance, one stand of maize (*Zea mays* L.) alternated with one stand of soybean (*Glycine max* L.) gave the greatest intercrop yield in maize–soybean intercrop. Intercrop competition studies based on a single, final harvest of crops have hypothesized that competitive strength or the measures of performance are constant throughout most of the growing season (Andersen et al., 2007). However, species interactions are a complex process involving variable nutrient environments, space and time.

However, the reported effects of plant density, row spacing, the distance between plants and crop proportion on water-use efficiency (WUE) have been inconsistent. A number of studies have reported that WUE was reduced under intercrops by crop proportion (Gao et al., 2009). Mao et al. (2012) discovered that the sowing proportions had a significant effect on water use in intercropping and that WUE varied from 0.87 to 1.16, indicating variability in the effect of intercropping on WUE. However, these studies primarily involved full irrigation. Research studies on the effects of plant density and crop proportion on WUE in rain-fed dryland agriculture are scarce. It is essential to understand how intercropping to offset water limitations influences crop growth and water utilization to optimize water management in arid regions.

Maize and soybean are the most common grain crops on the Loess Plateau, which has a typical semi-arid monsoon climate (Bu et al., 2013). Despite the potential for irrigation, most of the available water for crop growth in semi-arid regions originates from limited precipitation. Therefore, limited water resources are the major constraint on crop production (Rockström et al., 2007).

The aim of this study was to determine the effects of the sowing proportions of maize and soybean and the population density in maize–soybean intercrops on (1) the temporal dynamics of competitive interactions, (2) the potential yield advantages and WUE, and (3) the final yield in intercrops compared to sole crops.

2. Materials and methods

2.1. Study area

The study was conducted during the 2012 and 2013 growing seasons at the Changwu experimental station in the Loess Plateau agricultural center (35.12 N, 107.40 E, 1200 m above sea level). This location is within the dry farming zone with 582 mm of mean annual rainfall from 1957 to 2013 (73% rainfall during May–September). The annual mean temperature is 9.7° C. The soils are Cumuli-Ustic Isohumosols according to Chinese Soil Taxonomy (Gong et al., 2007). The soil physic-chemical characteristics (average) of the sites were as follows for the 2012 and 2013 growing seasons: organic matter 11.8 g kg^{-1}, total nitrogen 0.87 g kg^{-1}, available phosphorus 14.4 mg kg^{-1}, exchangeable potassium 144.6 mg kg^{-1}, and inorganic nitrogen 3.15 mg kg^{-1}. The climatic data for the two growing seasons of the experiment are provided in Fig. 1. Precipitation during the growth period was recorded at the research station.

2.2. Experimental design and field management

The experimental plots were arranged factorially in a randomized complete block design with three blocks. The experimental treatments: there were three planting densities (maize (*Z. mays* L. cv. Zhengdan 958) densities of 45,000, 90,000 and 135,000 plants ha^{-1} for low, medium and high density; soybean (*G. max* L. cv. Zhonghuang 24) densities of 90,000, 210,000 and 330,000 plants ha^{-1} for low, medium and high density), each density included five sowing proportions: sole-cropped maize (M) and soybean (S), three maize–soybean intercrop treatments included (1/2) maize + (1/2) soybean (M2S2, 2 rows of maize and 2 rows of soybean), (1/3) maize + (2/3) soybean (M2S4, 2 rows of maize and 4 rows of soybean) and (2/3) maize + (1/3) soybean (M4S2, 4 rows of maize and 2 rows of soybean) (only for 2013). Each block included a total of 12 and 15 crop treatments for 2012 and 2013, respectively (Fig. 2).

The land was manually cleared and ridged. Each plot was 6 m × 4 m and contained four ridges. The gross land area (17 × 147 m) was 0.25 ha with 1 m between blocks.

The sowing season for the experiment was late April. Maize and soybean were sowed on 25th April in 2012; maize and soybean were sowed on 20th April in 2013. Two seeds each were sown for maize and were thinned to one plant per stand at 28 and 24 days after planting (DAP) in 2012 and 2013, respectively. Four seeds each were sown for soybean and were thinned to two plants per stand at 17 and 24 DAP in 2012 and 2013, respectively.

All crops were sown at a spacing of 50 cm (inter-row) apart. Maize was sown 44, 22 and 15 cm apart (intra-row spacing) to achieve population densities of 45,000, 90,000 and 135,000 plants ha^{-1}, respectively. Soybean was sown 44, 19 and 12 cm apart (intra-row spacing) to achieve population densities of 90,000, 210,000 and 330,000 plants ha^{-1}, respectively.

Mixed-base fertilizer NP was applied to soybean and maize by spreading the fertilizer 5 days before planting to supply 90 kg N and 150 kg P_2O_5/ha; this was achieved by mixing 196 kg urea + 266 kg $Ca(H_2PO_4)_2 \cdot H_2O$/ha. In addition, 67.5 kg/ha N was applied to maize stands twice by drilling at 60 DAP and 80 DAP to supply 147 kg/ha urea, as recommended for local cultivation. The water supply for each treatment came solely from natural rainfall. Manual weeding was conducted at five and eleven weeks after planting, respectively.

2.3. Sampling and measurements

The standard developmental stage system was used to identify the vegetative stage (VS, from seedling emergence to silking for maize and to flowering for soybean) and the reproductive stage (RS, from silking and flowering for maize and soybean to physiological maturity) of the entire growing season (Ritchie et al., 1993). Three harvests were conducted during the experimental period, and the plants were cut just above the soil surface. The first harvest was performed at the V6 growth stage in maize (44 days after sowing) and the corresponding V3 stage in soybean. The second harvest (90 days after sowing) was performed close to the silking growth stage in maize (stage R1), which corresponds to R4 in soybean. The last harvest (155 days after sowing) was performed at physiological maturity (stage R6) in maize and soybean (stage R8).

Four measurements for leaf area index (LAI) were conducted during the experimental period. The first measurement was performed at the V6 growth stage in maize and the corresponding V3 stage in soybean. The second measurement was performed at V12 growth stage in maize and the corresponding V6 stage in soybean. The third measurement was performed at R1 stage in maize and the corresponding R4 stage in soybean. The fourth measurement was performed at the R3 growth stage in maize and the corresponding R6 stage in soybean. The LAI was measured using a Plant Canopy Analyzer (Li-2200, LiCor Inc., Lincoln, NE, USA).