Effects of Different Planting Patterns on the Growth and Yield of Maize and Soybean in Northwest China

L. Shen¹, X. Y. Wang¹, T. Yang¹, Y. X. Teng¹, T. T. Liu¹, L. H. Li¹ & W. Zhang¹

¹ College of Agriculture, Shihezi University, Shihezi, Xinjiang, China

Correspondence: W. Zhang, College of Agriculture, Shihezi University, Shihezi, Xinjiang 832003, China. E-mail: bluesky2002040@163.com

L. H. Li, College of Agriculture, Shihezi University, Shihezi, Xinjiang 832003, China. E-mail: liluhuashiz@163.com

Received: December 21, 2020      Accepted: February 6, 2021      Online Published: March 15, 2021
doi:10.5539/jas.v13n4p1          URL: https://doi.org/10.5539/jas.v13n4p1

Abstract

Aboveground and belowground interactions are crucial in the over-yielding of intercropping systems. However, the relative effects of aboveground and belowground interactions on yields in maize (Zea mays L.) and soybean (Glycine max) intercropping systems are still unclear. Field experiments, including measurements of plant height, soil-plant analysis development (SPAD) value, photosynthetically active radiation (PAR), root length density (RLD), root volume density (RVD), and grain yield, were conducted in 2018-2019 to analyze the advantages and effects of above-ground and belowground inter-species interactions. This study adopted three different planting patterns: mono-cropping maize (MM), mono-cropping soybeans (MS), and maize-soybean intercropping (IM and IS). This study showed that intercropping promotes the growth of maize and makes maize have a better photosynthetic environment, while the growth of intercropping soybeans is inhibited and the photosynthetic environment becomes worse. In the upper layer (0-40 cm) and close to the plants, the root growth and distribution of intercropped maize increased, resulting in greater root length density and volume density, while the root growth and distribution of intercropped soybean decreased, resulting in lower root length density and volume density. The intercropping increased the maize yield by 18.52-19.8%, and reduced the soybean yield by 55.87-57.44%. The results indicated that intercropping improves the competitiveness of maize and reduces the competitiveness of soybeans. The increase in maize yield made up for the loss of soybean yield and led to an overall significant advantage in the maize-soybean intercropping system.

Keywords: growth, intercropping, maize, PAR, root, soybean, SPAD, yield

1. Introduction

Intercropping is the practice of growing two or more crops in the same field for a significant part of their growing period (Li et al., 2020). A large number of studies have confirmed that reasonable intercropping can utilize above-ground light and heat resources and belowground water and nutrient resources at multiple levels (Fan et al., 2006), improve the utilization rate of natural resources, and result in high yield and stability of crop composite groups (Mei et al., 2012; Raphaël et al., 2010). The most commonly reported is the cereal-legume intercropping system; the most typical example is the intercropping of soybean and maize (Simbine et al., 2018). Maize and soybeans are important food crops in China, and maize-soybean intercropping is a common high-yield planting model in northern China. Due to the low economic benefits of soybeans, China’s soybean planting area has been declining year by year (Yang et al., 2007) and the domestic market supply of soybeans mainly depends on imports. Therefore, while the maize planting area continues to increase, the development of the maize-soybean intercropping planting mode can benefit maize and soybean production.

The relationship between interspecific competition and complementarity is the core of productivity and yield improvement in intercropping systems. It is also the key to the successful operation of intercropping systems (Yin et al., 2020). The competition and complementarity for nutrients, water, and sunlight are the main factors often used to explain the advantages of intercropping. Zhang and Li (2003) reported that belowground interactions and rhizosphere effects between intercropped crops play an important role in the advantages of intercropping. Lv et al. (2014) found that the competition between two crops for nutrition is more important than the competition for sunlight in an intercropping system. Intercrop productivity may be more affected by belowground than...
The spatial distribution of roots and their density in the soil may determine the ability of a crop to acquire the nutrients and water necessary to sustain plant growth. Gao et al. (2010) indicated that the horizontal root growth of the crops was confined to the soil surface and the zone closest to plants. Ding et al. (2020) found that intercropping shallow-rooted pepper with deep-rooted alfalfa (*Medicago sativa* L.) can enhance root nutrient absorption in deep soil layers, increasing N use efficiency and thus reducing NO₃⁻ leaching. When the water absorption space and root distribution of intercropped components are different, this can produce a greater complementary effect compared to intercropped components with similar water absorption space and root distribution (Mu et al., 2013). However, in the maize-soybean intercropping system, the effect of the interaction between the aboveground and the belowground parts on the growth and development of crops in different growth periods has not been extensively researched. It is difficult to obtain relevant data on crop roots as the traditional soil drilling sampling method will cause damage to the root systems and other methods are frequently technically demanding and costly. Therefore, this study carried out related research on the spatio-temporal changes of roots in a maize-soybean intercropping system through studying the minirhizotrons, which allowed us to observe the complete roots, improved our work efficiency, and provided a certain theoretical basis for the development of maize-soybean intercropping in arid areas.

The objectives of this paper were to: (i) investigate the effect of intercropping system on the aboveground and underground parts of maize and soybean at different growth period, and (ii) analyze the effects of intercropping on the yield and yield composition factors of maize and soybean, and judge whether the maize-soybean intercropping has yield advantages.

2. Materials and Methods

2.1 Study Site Descriptions

The maize cultivar ‘Jinnuo 205’ and the soybean cultivar ‘Xinda 1’ were used. Field experiments were conducted in 2018 and 2019 at a location in the Agricultural Experiment Station (45°08′N, 85°36′E) of Xinjiang Shihezi University, China. The mean temperature during the 2018 crop growing season (April-October) was 18.65 °C, the precipitation was 211.7 mm, and the sunshine duration was 2 077.3 h. The average temperature during the crop growing season (April-October) in 2019 was 20.94 °C, the precipitation was 142 mm, and the sunshine hours totaled 1 843.08 h. The soil texture was gray desert soil, the soil bulk density of the plough layer was 1.6 g·cm⁻³, the total nitrogen was 0.890 g·kg⁻¹, the available phosphorus was 0.023 g·kg⁻¹, the available potassium was 0.259 g·kg⁻¹, the alkaline nitrogen was 0.058 g·kg⁻¹, the organic matter was 13.260 g·kg⁻¹, and the pH was 7.3.

2.2 Seeding Treatments

A two-year experiment was conducted with three treatments: (1) maize mono-cropping, (2) soybean mono-cropping, and (3) maize-soybean intercropping. The experimental was a randomized complete block design with three replications. The treatments were applied to the same plots in each year. The plant spacing and row spacing of maize and soybean was 30 cm. Four rows of maize were intercropped with 2 rows of soybean and the area of each test plot was 8.1 m²(4.5 m × 1.8 m). The arrangement between rows is shown in Figure 1-I. Crops were sown on April 24, 2018 and April 26, 2019. The base fertilizer included 300 kg·hm⁻² of diammonium phosphate, 75 kg·hm⁻² of urea and potassium fertilizer, and 45 kg·hm⁻² of urea in the maize spinning period. The experiment adopted the drip irrigation method. The irrigation frequency was once every seven days and the irrigation volume was 675 m³·hm⁻² each time. The data collection time and the corresponding crop growth period are shown in (Table 1).
Table 1. Data measurement time and corresponding growth stages period of Maize and Soybean crops (2018-2019)

| Stage | Date(2018-2019) | Growth stage period       |
|-------|-----------------|---------------------------|
| A     | 20/5, 21/5      | Seedling                  |
| B     | 2/6, 3/6        | Jointing                  |
| C     | 26/6, 28/6      | Tassal                    |
| D     | 14/7, 17/7      | Silking                   |
| E     | 25/7, 27/7      | Milk                      |
| F     | 10/8, 11/8      | Maturity                  |

2.3 Measurement Items and Calculations

The field photosynthetically active radiation was measured at 12 pm on June 26th, 2018 and June 28th, 2019. The LI-250A light meter was used to measure the photosynthetically active radiation in different parts of the crop under different planting modes. Monocropped and intercropped maize crops were measured at three sites: the upper, middle, and lower part of the plants. Monocropped and intercropped soybeans were measured at two sites in the upper part and the middle part. There were five replicates in the experiment, the chlorophyll meter can be used to measure the leaf SPAD value to predict the nitrogen nutrition status of the crop. The SPAD 502 chlorophyll meter was used to measure the relative chlorophyll content of plant leaves. The SPAD value was measured on the three leaves of maize on the cob and the top unfolded leaves of soybean. Each treatment was repeated with six replicates. Six plants were randomly selected for measurement in a monocropping plot.

CI-600 was used to collect images of the field root systems. During sowing, the transparent observation tube was buried in the crop row along the horizontal ground at 45° angle, and the root system of the crops in the first five periods was measured. Each treatment had three repetitions. The scanner collected the crop roots in the soil layers of 0-20 and 20-40 cm. WinRHIZO was used to analyze the root image and calculate the root length density, root volume density, and root surface area. The minirhizotron setting is shown in Figure 1-II.

Each treatment was harvested when the crops were mature. The harvest area was 4 m². Each treatment was repeated three times, and threshing and natural drying were performed uniformly. The grain yield was measured and converted into hectare yield. The land equivalent ratio (LER) was used as an index to measure the yield advantage of intercropping (Willey, 1979), and the calculation formula was:

\[
LER = \frac{Y_{ia}}{Y_{sa}} + \frac{Y_{ib}}{Y_{sb}}
\]

where, \(Y_{ia}\) represents the yield of intercropped maize, \(Y_{sa}\) represents the yield of mono-cropping maize, \(Y_{ib}\) represents the yield of intercropped soybean, and \(Y_{sb}\) represents the yield of mono-cropping soybean. If \(LER > 1\), ...
it indicates that the maize-soybean intercropping system has yield advantage; if \( LER < 1 \), it indicates that the maize-soybean intercropping system has no yield advantage.

2.4 Statistical Analyses

All of the experimental data were managed by Microsoft Excel 2016 and the figures were constructed with Origin Pro 2018. Differences between intercropping systems and years were identified by analysis of variance (ANOVA) using SPSS 19.0 software (SPSS Inc., Chicago, IL, USA). The intercropping effect was estimated for each year individually because of significant year \( \times \) treatment interactions for most of the variables assessed in the current study. The mean values were compared with a least significant difference (LSD) test at the \( (P < 0.05) \) significance level.

3. Results

3.1 Plant Heights

During the two years, the heights of maize and soybean plants increased as the growth period continued, and the plant heights of the crops tended to be stable in the later period of crop growth (Figure 2). Intercropping maize plant heights were significantly increased by 12.85-15.31\%, 9.58-16.08\%, 6.42-10.63\%, and 5.77-11.33\% in comparison with the mono-cropping crop at the tassel, spinning, milk maturity, and maturity stages, respectively in 2018 and 2019 \((P < 0.05)\).

![Figure 2. Dynamic changes of plant heights of maize and soybean under different planting patterns in 2018-2019 \((n = 3)\)](image)

The height of mono-cropping and intercropping soybean plants increased rapidly from the seedling stage to the seed filling stage during the two years. Intercropping soybean plant heights were significantly increased by 14.92-16.76\%, 15.36-16.74\%, 13.61-14.96\%, and 12.79-14.46\% in comparison with the monocropping crop at the flowering and podding, seed filling, mature, and harvest stages, respectively, in 2018 and 2019 \((P < 0.05)\). No significant differences were found at the seedling and flowering stages in both experimental years.

3.2 Photosynthetic Characteristics of Crops

As shown in Figure 3, the soil-plant analysis development (SPAD) value of each treatment maize increased rapidly from the seedling stage to the jointing stage during the two years and reached the maximum during the jointing and tasseling stage, after which the SPAD value gradually decreased. The intercropping maize SPAD value was significantly increased by 14.87\% in comparison with the monocropping crop in the milk maturity period in 2018 \((P < 0.05)\), and the intercropping maize SPAD value was significantly increased by 9.15\% in the tasseling period in 2019. There was no significant difference in SPAD values between monocropping and intercropping maize in other growth periods.
Figure 3. Dynamic changes of maize and soybean soil-plant analysis development (SPAD) values under different planting patterns in 2018-2019 (n = 3)

During the two years, the SPAD value of each soybean treatment increased rapidly from the seedling stage to the flowering stage and reached the maximum in the flowering stage in both years. The intercropping soybean SPAD values were significantly reduced by 9.27% and 12.00% in comparison with the monocropping crop in the flowering and pod stages in 2018 ($P < 0.05$), respectively. The intercropping soybean SPAD value was significantly reduced by 10.21% in comparison with the monocropping crop in the seed filling stage in 2019 ($P < 0.05$). There were no significant differences in SPAD values between monocropping and intercropping soybeans in other growth periods.

Different planting methods significantly affect the PAR between maize and soybean rows (Figure 4). The results of the two-year experiment showed that the maize-soybean intercropping significantly increased the photosynthetically active radiation in the lower and middle parts of maize by 9.63-11.33% and 22.78-36.10% in comparison with the mono-cropping crop in 2018 and 2019 ($P < 0.05$), respectively. However, intercropping significantly reduced the photosynthetically active radiation in the middle and upper parts of soybeans by 8.91-8.64% and 24.01-24.63% in comparison with the mono-cropping crop in 2018 and 2019 ($P < 0.05$) respectively.
Figure 4. Photosynthetically active radiation (PAR) of different parts of crops under different planting modes

3.3 Root Growth and Distribution

With the advancement of the growth period of maize and soybean, the root length density (RLD) value gradually increased (Figure 5). At 0-20 cm depth, there were no significant differences in the RLD values of mono-cropping and intercropping maize between the growth periods of the crop in both 2018 and 2019 (Figure 5A). At 20-40 cm depth, the intercropped maize RLD value was significantly increased by 8.4% and 18.0% in comparison with the mono-cropping crop at the tasseling and spinning stages in 2018 respectively, and the maize RLD value was significantly increased by 22.6% at the tasseling stage in 2019 (Figure 5B). At 0-20 cm depth, the intercropped soybean RLD values were significantly reduced by 16.29-19.10% and 13.35-19.40% in comparison with the mono-cropping soybean at the seed filling and maturity stages respectively, in both 2018 and 2019 (Figure 5C). At 20-40 cm depth, the intercropped soybean RLD value was significantly reduced by 17.34% in comparison with the mono-cropping soybean at the maturity stage in 2019. However, there were no significant differences between mono- and intercropped in each growth period in 2018 (Figure 5D).
Figure 5. Dynamic change of root length density (RLD) value of soybean and maize in 0-40 cm soil layer under different planting patterns in 2018-2019 system in different planting modes

Note. MM: mono-cropping maize; MS: mono-cropping soybeans; IM and IS: maize-soybean intercropping. A: Seedling stage of maize and soybean; B: Jointing stage of maize and flowering stage of soybean; C: Tasseling stage of maize and flowering and podding stage of soybean; D: Spinning stage of maize and seed filling stage of soybean; E: Milk maturity of maize and mature stage of soybean.

As the growth period of maize and soybeans advanced, the root volume density (RVD) value showed a single peak curve that first increased and then decreased (Figure 6). The greatest differences between mono-cropping and intercropping maize RVD values at each soil depth were as follows: at 0-20 cm depth, the maximum RVD values of mono-cropping and intercropping maize appeared at the spinning stage, and the intercropped maize RVD values were significantly increased by 8.92-9.91%, 12.27-15.92%, and 18.65-22.04% in comparison with the mono-cropping crop at the flower pod, seed filling, and harvest stages, respectively, in 2018 and 2019 (Figure 6A). At 20-40 cm depth, the maximum RVD value of monocropping and intercropping maize appeared at the tasseling stage, and the intercropped maize RVD values were significantly increased by 7.08-9.87%, 27.79-36.49% and 27.89-37.33% in comparison with the mono-cropping crop at the flower pod, seed filling, and harvest stages respectively, in 2018 and 2019 (Figure 6B). There were no significant differences in other growth periods.
The differences between mono-cropping and intercropping soybean RVD values at each soil depth were as follows: at 0-20 cm depth, the maximum RVD value of monocropping and intercropping soybeans appeared at the flower pod stage, and the intercropped soybean RVD values were significantly increased by 10.17-13.77%, 1.06-14.19%, and 7.93-22.29% in comparison with the mono-cropping crop at the flower pod, seed filling, and harvest stages in 2018 and 2019 (Figure 6C). At 20-40 cm depth, the maximum RVD value of mono-cropping and intercropping soybeans appeared at the seed filling stage, and the intercropped soybean RVD values were significantly increased by 15.80-19.56%, 21.97-26.82%, and 49.08-50.20% in comparison with the mono-cropping crop at the flowering and podding, seed filling, and mature stages respectively, in 2018 and 2019 (Figure 6D). There were no significant differences in other growth periods.

3.4 System Yield and Yield Composition Factors

Crop yield was significantly affected by planting methods, while the year effect and the effect of its interaction with planting patterns were not significant (Table 2). The most significant differences between maize yield and yield composition factors under mono-cropping and intercropping were as follows: intercropped maize 1000 grain weight and yield were significantly increased by 7.73-8.48% and 18.52-19.8% in comparison with the mono-cropping crop in 2018 and 2019 respectively. There was no significant difference in the panicle number per plant and the number of grains per spike between mono-cropping and intercropping maize in the two years. In relation to soybean yield and yield composition factors the most significant differences under mono-cropping and intercropping were as follows: There was no significant difference in the number of seeds per pod in mono-cropping and intercropping soybeans during the two years of experiments. However the intercropped soybean number of pods per plant, 1000-grain weight, and yield were significantly reduced by 34.51-35.45%.
13.34-16.45%, and 55.87-57.44% in comparison with the mono-cropping crop in 2018 and 2019, respectively. The two-year intercropping land equivalent ratio (LER) was calculated as 1.61-1.64 > 1 by Equation (1) (Willey, 1979), indicating that the intercropping system was advantageous.

### Table 2. Crop yield and yield composition factors under different planting patterns in 2018-2019

| Years | Treatment          | No. of panicle·plant⁻¹ | No. of pod·Plant⁻¹ | No. of seeds·spike⁻¹ | 1000 grain weight (g) | Yield (kg·hm⁻²) |
|-------|--------------------|-------------------------|--------------------|----------------------|-----------------------|----------------|
| 2018  | Mono-cropping maize | 1.67±0.47 a             | 188±5.72 a         | 404.33±3.40 a        | 4969.41±127.68 a      | 4969.41±127.68 a |
|       | Intercropping maize | 1.67±0.47 a             | 195±5.35 a         | 438.60±1.72 b        | 5953.36±130.54 b      | 5953.36±130.54 b |
| 2019  | Idem               | 1.33±0.47 a             | 188.33±1.25 a      | 407.1±1.96 a         | 4950.3±115.49 a       | 4950.3±115.49 a |
|       | Idem               | 1.67±0.47 a             | 195±1.63 a         | 438.57±3.96 b        | 5866.95±123.84 b      | 5866.95±123.84 b |
| 2018  | Mono-cropping soybean | 36.67±2.05 b           | 2.67±0.47 a        | 242.6±7.03 a         | 1457.27±82.90 a       | 1457.27±82.90 a |
|       | Intercropping soybean | 23.67±3.30 a           | 2.67±0.47 a        | 202.7±1.79 b         | 643.11±49.29 b        | 643.11±49.29 b |
| 2019  | Idem               | 37.67±1.7 b             | 2.67±0.47 a        | 234.95±2.08 a        | 1525.82±43.41 a       | 1525.82±43.41 a |
|       | Idem               | 24.67±2.05 a            | 2.33±0.47 a        | 203.6±4.28 b         | 649.34±67.77 b        | 649.34±67.77 b |

### 3.5 Correlation Between Different Indicators of Crop Growth Stages and Yield

The Pearson correlation coefficient was obtained through correlation analysis of crop height, SPAD, RLD, RVD value and crop yield under different growth periods (Table 3). Throughout the growth period of the crop, the yield of maize was positively correlated with plant height, SPAD, RLD and RVD value. Soybean yield is negatively correlated with plant height, and positively correlated with other indicators. And the indicators that are significantly related to crop yield mostly occur in the middle and late stages of crop growth. Indexes that are highly correlated with maize yield are plant height and RLD, and indexes that are relatively correlated with soybean yield are plant height, RLD and RVD value.

### Table 3. Pearson correlation coefficient between different indicators of crop growth stages and yield

| Crops  | Index             | Stage | A      | B      | C      | D      | E      | F      |
|--------|-------------------|-------|--------|--------|--------|--------|--------|--------|
| Maize  | Plant height      | A      | -0.063 | 0.176  | 0.995**| 0.958* | 0.959* | 0.937  |
|        | SPAD              | B      | 0.548  | 0.441  | 0.72   | 0.509  | 0.905  | 0.929  |
|        | RLD (0-20cm)      | C      | 0.367  | -0.978*| 0.997**| 0.987* | 0.985* | 0.922  |
|        | (20-40cm)         | D      | 0.989* | 0.037  | 0.894  | 0.994**| 0.922  |        |
|        | RVD (0-20cm)      | E      | -0.444 | -0.148 | 0.718  | 0.699  | 0.848  |        |
|        | (20-40cm)         | F      | 0.125  | 0.533  | 0.559  | 0.906  | 0.849  |        |
| Soybean| Plant height      | A      | -0.445 | -0.854 | -0.994**| -0.984*| -0.982*| -0.996**|
|        | SPAD              | B      | 0.51   | 0.7    | 0.513  | 0.89   | 0.959* | 0.435  |
|        | RLD (0-20cm)      | C      | 0.989* | 0.037  | 0.894  | 0.994**| 0.922  |        |
|        | (20-0cm)          | D      | -0.923 | -0.972 | 0.715  | 0.992**| 0.895  |        |
|        | RVD (0-20cm)      | E      | -0.61  | 0.573  | 0.82   | 0.57   | 0.715  |        |
|        | (20-40cm)         | F      | 0.16   | 0.338  | 0.921  | 0.965* | 0.992**|        |

**Note.** A: Seedling stage of maize and soybean; B: Jointing stage of maize and flowering stage of soybean; C: Tasseling stage of maize and flowering and podding stage of soybean; D: Spinning stage of maize and seed filling stage of soybean; E: Milk maturity of maize and mature stage of soybean; F: Maturity stage of maize and harvest stage of soybean.

* Significant at 5% (P < 0.05); ** Significant at 1% (P < 0.01).

### 4. Discussion

The intercropping of maize and soybeans is a weak competition system. Interspecific facilitation in maize-soybean intercrops may be due to increased efficiency of resource use (Hamel et al., 1991) and the compensatory distribution of root systems (Gao et al., 2010). To reduce interspecific competition, intercropped species are
separated in the time of absorption and utilization of water, nutrients, and other resources and there are differences in the utilization of resources in different niches, resulting in intercropping advantages (Xia et al., 2013).

The results of this study indicated that intercropping promotes the height of maize and soybean, and the plant height of maize is positively correlated with yield, while the plant height of soybean is negatively correlated with yield. In intercropping systems, shorter crops suffer shading from taller crops, thus increasing plant height and decreasing yield (Wu et al., 2016).

In the early stage of crop growth, the crop is in the vegetative growth stage, and the biomass is supplied to the roots, stems and leaves of the crop. In the middle and late stages of the crop growth, the vegetative growth transitions to reproductive growth, so that the biomass is supplied to the grains and the growth rate of the plant height decreases (Na et al., 2018). In addition, in the early stage of soybean growth, since the degree of shading from maize plants to soybean plants was not obvious, there was no significant difference in the height of soybeans under monocropping and intercropping modes. As the growth period advanced, the degree of shade from maize to soybeans increased and the taller maize gained a competitive advantage in the maize-soybean intercropping system. As a result, the shaded soybeans intercepted less incident radiation. In full sunlight, the proportion of biomass distributed to the leaves was significantly higher than the petioles and stems. However, under shade, the proportion of biomass distributed to the leaves was lower than the stems. Soybean showed a significant stem elongation response under shaded, leading to the production of less biomass and reduced grain yield (Wu et al., 2017).

The chlorophyll content of crop leaves is closely related to nitrogen content and the chlorophyll meter reading is positively related to the chlorophyll content (John, 1983; Hallik, et al., 2009). Nitrogen (N) is critical for the growth and development of crop plants. While most plant species depend on the uptake of soil N to satisfy their needs, certain clades, most notably the legumes, are capable of fixing N via a symbiotic relationship with rhizobia bacteria (Carranca, 2013). This fixed N may benefit not only the legumes but also companion/subsequent crops. The results of this study indicated that the SPAD values of maize and soybean increased rapidly and reached the maximum in the early growth period, after which the SPAD values of crops gradually decreased (Figure 3). This was due to the transition of crops from vegetative growth to reproductive growth and nitrogen transfers from vegetative organs such as leaves to reproductive organs such as grains, resulting in a decrease in the SPAD value of leaves (Wang et al., 2014). Compared with monocropping, intercropping increased the SPAD value of maize and decreased the SPAD value of soybean. As the degree of shade on soybeans was higher, the SPAD value was lower (Liu et al., 2016).

PAR refers to the solar radiation spectrum with a wavelength of 400-700 nm, which can be absorbed by green plant leaves and used for photosynthesis (Mizoguchi et al., 2014). Previous studies demonstrated that photosynthesis is the basis for yield formation, and 90% of dry matter comes from photosynthesis (Gaju et al., 2016). Changes in PAR are related to the effects of species, varieties, planting methods, and row spacing. The planting patterns of maize-soybean intercropping systems can induce changes in the microclimate environment, particularly in the light intensity and the spectral properties of the soybean canopy with its lower layer (Awal et al., 2006). The different planting patterns of intercropping may change the light environment of the system and the interaction on the ground to intercept more light, and mutual shading significantly affects the productivity of intercropping (Midmore et al., 1988; Cao, 2010). The results of this study indicated that compared with monocropping, intercropping significantly increased the PAR in the lower and middle parts of maize, and the PAR of the soybean in monocropping planting and intercropping varied significantly because the incident light reflected and absorbed by maize leaves reduced the amount of incoming PAR that was available for the soybean seedlings in intercropping conditions, resulting in a decrease in PAR in the middle and upper intercropping soybeans (Figure 4). Similarly, Lv et al. (2014) reported that taller maize plants in an intercropping system affect the light environment of a shorter species, such as soybean.

The crop growth and final yield of an intercropping system are closely related to the spread of roots, which determines the uptake and utilization of water and nutrients. Maize has a stronger resource competitive advantage than soybean. Intercropping can expand the vertical and horizontal spatial niche of crop roots, that is, expand the crop's water and nutrient niche, and increase the effective space for crops to absorb nutrients (Yong et al., 2012). Gao et al. (2010) reported that the roots of the two are mainly distributed in the 0-30 cm soil layer during the intercropping of maize and soybeans. This study showed that the RLD value difference between monocropping and intercropping maize began to increase gradually after the jointing stage. The growth of roots in the 20-40 cm soil layer of intercropped maize expanded the vertical niche of the maize root system. Yong et al. (2018) showed that the intercropping of maize and beans expanded the niche of the maize root system in the horizontal and vertical directions, and the root length density and root surface area were positively correlated with nitrogen absorption. In the intercropping system of maize and soybeans, intercropping soybeans promoted the growth of...
maize through nitrogen fixation. Nitrogen uptake promotes the vigor of maize root systems (Bethlenfalvay et al., 1991). After the flowering and pod stage, the difference in RLD value of monocropping and intercropping soybeans began to gradually increase. Intercropping inhibited the growth of soybean roots in the 0-40 cm soil layer, and the root system in the 0-20 cm soil layer was more inhibited, making the soybean roots spread horizontally. From the RVD value, can be found that in the 0-40 cm soil layer, there was no significant difference in the RVD value of crops in the early stage of growth between monocropping and intercropping, while in the middle and late stages of growth, the RVD values of intercropped maize were significantly increased and intercropped soybean RVD values were significantly reduced in comparison with the monocropping crop. In the later stage of crop growth, due to the gradual decrease of crop irrigation and the transition from vegetative growth to reproductive growth of crops, the biomass of crop roots gradually decreases, resulting in a decrease in root volume density. Yin et al. (2014) reported that the growth of intercropped soybeans was significantly inhibited at the seedling stage, which is inconsistent with the results of this study. This study suggested that in the middle and late stages of crop growth, soybean photosynthesis preferentially supplies stem elongation, which seriously affects and inhibits the growth of the underground part of soybean plants.

The yield of cereal crops is determined by the number of panicles, grain number per spike and grain weight. The coordinated development of these three yield components is an important basis for obtaining high yields. Anderson et al. (1986) and Krarup and Davis (1970) proposed that leguminous crops yield could be expressed as the product of number of pods, seeds per pod and seeds weight. Lesoing et al. (1999) reported that maize yields were increased compared with inside rows in strip-intercrop soybeans of varying plant heights when intercropped. Shading of the legume was also reported for reducing seeds weight in legumes both in intercrop and sole crop as seeds filling becomes source limited if photosynthesis is reduced (Neugschwandtner & Kaul, 2014). Monti et al. (2016) reported that the intercropping system affected the pod setting stages in pea causing a large reduction in number of pods per plant and pea grain. This study showed that intercropping increases the thousand-grain weight of maize, thereby increasing the yield of intercropping maize. Intercropping reduces the number of pods·plant\(^{-1}\) and the thousand-seed weight of soybeans, resulting in lower soybean yields. This study believes that the main reason for the reduction of soybean production by about 50-60% is that the shading of soybeans by maize will reduce the formation of soybean photosynthesis, and the lack of nutrients required for the growth of flowers and pods has led to the fall of soybean flowers and pods, which seriously affected soybean production. Pearson correlation analysis shows that the main factors of crop yield formation are mostly distributed in the middle and late stages of crop growth. And the LER of the maize-soybean intercropping was 1.61-1.64, indicating that maize and soybean intercropping had planting advantages.

5. Conclusions

The aim of this study was to gain an understanding of how intercropping agronomic practices will affect the growth and yield of maize and soybean in Northwest China. Our results show that the intercropping system makes the maize form a better photosynthetic environment, and promotes the growth of the aboveground and deep root system of maize. The photosynthetic environment of intercropping soybeans becomes more severe, which inhibits the growth of soybeans and the growth of soybean roots. The intercropping system increases the weight of maize kernels and increases the yield of maize, while the intercropping system affects soybean pod formation, resulting in a large reduction in the number of pods per plant, and reducing the thousand-seed weight of soybeans, resulting in a decrease in soybean yield. In 2018 and 2019, the land equivalent ratio was 1.61 and 1.64, the benefits are significant. And improved field management in the middle and late stages of crop growth may further increase the productivity of the intercropping system.

Acknowledgements

This work was financially supported by the National Natural Science Foundation of China (Project Nos. 31460335 and 31560376).

References

Anderson, W., Haglund, W. A., Eaton, G. W., & Fraser, F. (1986). Sequential yield component analysis of processing peas. *HortScience*, 21, 103-105.

Awal, M. A., Koshi, H., & Ikeda, T. (2006). Radiation interception and use by maize/peanut intercrop canopy. *Agricultural & Forest Meteorology, 139*, 74-83. https://doi.org/10.1016/j.agrformet.2006.06.001

Bethlenfalvay, G. J., Reyes-Solis, M. G., Camel, S. B., & Ferrera-Cerrato, R. (1991). Nutrient transfer between the root zones of soybean and maize plants connected by a common mycorrhizal mycelium. *Physiologia Plantarum, 82*, 423-432. https://doi.org/10.1111/j.1399-3054.1991.tb02928.x
Cao, D. W. (2010). Effects of shading on morphology, physiology and grain yield of winter wheat. *European Journal of Agronomy, 33*, 267-275. https://doi.org/10.1016/j.eja.2010.07.002

Carranca, C. (2013). Legumes: Properties and Symbiosis. In A. H. Camisão & C. C. Pedrosa (Eds.), *Symbiosis: Evolution, Biology and Ecological Effects* (pp. 177-188). Animal Science, Issues and Professions, Nova Science Publishers, New York.

Chen, G. P., Gao, J. L., Zhao, M., Dong, S. T., Li, S. K., Yang, Q. F., … Zhao, J. R. (2012). Distribution, yield structure, and key cultural techniques of maize super-high yield plots in recent years. *Acta Agron Sin, 38*, 80-85. https://doi.org/10.3724/SP.J.1006.2012.00080

Ding, Y., Huang, X., Li, Y., Liu, H., & Di, H. (2020). Nitrate leaching losses mitigated with intercropping of deep-rooted and shallow-rooted plants. *Journal of Soils and Sediments, 21*, 364-375. https://doi.org/10.1007/s11368-020-02733-w

Fan, F., Zhang, F., Song, Y., Sun, J., Bao, X., & Guo, T. (2006). Nitrogen fixation of faba bean (*Vicia faba* L.) interacting with a nonlegume in two contrasting intercropping systems. *Plant & Soil, 283*, 275-286. https://doi.org/10.1007/s11104-006-0019-y

Gaju, O., Desilva, J., Carvalho, P., Hawkesford, M. J., Griffiths, S., & Greenland, A. (2016). Leaf photosynthesis and associations with grain yield, biomass and nitrogen-use efficiency in landraces, synthetic-derived lines and cultivars in wheat. *Field Crops Research, 193*, 1-15. https://doi.org/10.1016/j.fcr.2016.04.018

Gao, Y., Duan, A., Qiu, X., Liu, Z., Sun, J., & Zhang, J. (2010). Distribution of roots and root length density in a maize/soybean strip intercropping system. *Agricultural Water Management, 98*, 199-212. https://doi.org/10.1016/j.agwat.2010.08.021

Ghosh, P. K., Tripathi, A. K., Bandyopadhyay, K. K., & Manna, M. C. (2009). Assessment of nutrient competition and nutrient requirement in soybean/sorghum intercropping system. *European Journal of Agronomy, 31*, 43-50. https://doi.org/10.1016/j.eja.2009.03.002

Hallik, L., Kull, O., ülo Niinemets, & Aan, A. (2009). Contrasting correlation networks between leaf structure, nitrogen and chlorophyll in herbaceous and woody canopies. *Basic & Applied Ecology, 10*, 309-318. https://doi.org/10.1016/j.baae.2008.08.001

Hamel, C., Furlan, V., & Smith, D. L. (1991). N2-fixation and transfer in a field grown mycorrhizal corn and soybean intercrop. *Plant & Soil, 133*, 177-185. https://doi.org/10.1007/BF00009190

John, R. E. (1983). Nitrogen and Photosynthesis in the Flag Leaf of Wheat (*Triticum aestivum* L.). *Plant Physiology, 72*, 297-302. https://doi.org/10.1104/pp.72.2.297

Krarup, A., & Davis, D. W. (1970). Inheritance of seed yield and its components in a six-parent diallele cross in peas. *J. Am. Soc. Hortic. Sci., 95*, 795-797.

Lesoing, G. W., & Francis, C. A. (1999). Strip intercropping effects on yield and yield components of corn, grain sorghum, and soybean. *Agronomy Journal, 91*(5), 807-813. https://doi.org/10.2134/agronj1999.915807x

Li, H. W., Jiang, D., Wollenweber, B., Dai, T. B., & Cao, W. X. (2010). Effects of shading on morphology, physiology and grain yield of winter wheat. *European Journal of Agronomy, 33*, 267-275. https://doi.org/10.1016/j.eja.2010.07.002

Li, S. W., Evers, J. B., Werf, W., Wang, R., & Ma, Y. (2020). Plant architectural responses in simultaneous maize/soybean strip intercropping do not lead to a yield advantage. *Annals of Applied Biology, 177*(2). https://doi.org/10.1111/aab.12610

Liu, T., Liu, W. G., Ren, M. L., Du, Y. L., Deng, Y. C., & Zou, J. L. (2016). Effects of shade degrees on photosynthesis and lodging resistance degree of different shade tolerance soybean. * Scientia Agricultura Sinica, 49*, 1466-1475.

Lv, Y., Francis, C., Wu, P. T., Chen, X. L., & Zhao, X. N. (2014). Maize-soybean intercropping interactions above and below ground. *Crop Science, 54*, 914-922. https://doi.org/10.2135/cropsci2013.06.0403

Mei, P. P., Gui, L. G., Wang, P., Huang, J. C., Long, H. Y., & Christie, P. (2012). Maize/faba bean intercropping with rhizobia inoculation enhances productivity and recovery of fertilizer p in a reclaimed desert soil. *Field Crops Research, 130*, 19-27. https://doi.org/10.1016/j.fcr.2012.02.007
Midmore, D. J., Berrios, D., & Roca, J. (1988). Potato (Solanum spp.) in the hot tropics V. Intercropping with maize and the influence of shade on tuber yields. *Field Crop Research, 18*, 159-176. https://doi.org/10.1016/0378-4290(88)9006-8

Mizoguchi, Y., Yasuda, Y., Ohtani, Y., Watanabe, T., Kominami, Y., & Yamanoi, K. (2014). A practical model to estimate photosynthetically active radiation using general meteorological elements in a temperate humid area and comparison among models. *Theoretical & Applied Climatology, 115*, 583-589. https://doi.org/10.1007/s00704-013-0912-2

Monti, M., Pellicanò, A., Santonoceto, C., Preiti, G., & Pristeri, A. (2016). Yield components and nitrogen use in cereal-pea intercrops in mediterranean environment. *Field Crops Research, 10*, 379-388. https://doi.org/10.1016/j.fcr.2016.07.017

Mu, Y., Chai, Q., Yu A., Yang C., Qi W., Feng F., & Kong, X. (2013). Performance of wheat/maize intercropping is a function of belowground interspecies interactions. *Crop Science, 53*(5), 2186-2194. https://doi.org/10.2135/cropsci2012.11.0619

Na, M. I., Cai, F., Zhang, Y., Ruipeng, J. I., & Zhang, S. (2018). Differential responses of maize yield to drought at vegetative and reproductive stages. *Plant, Soil and Environment, 64*(6), 260-267. https://doi.org/10.17221/141/2018-PSE

Neugschwandtner, R. W., & Kaul, H. P. (2014). Sowing ratio and N fertilization affect yield and yield components of oat and pea in intercrops. *Field Crops Research, 155*, 159-163. https://doi.org/10.1016/j.fcr.2013.09.010

Raphaël, P., Christian, W., Winfried, V., Weigelt, A., Roscher, C., & Attinger, S. (2010). Diversity Promotes Temporal Stability across Levels of Ecosystem Organization in Experimental Grasslands. *PLoS ONE, 5*, e13382. https://doi.org/10.1371/journal.pone.0013382

Simbine, M. G., Baijukya, F. P., & Onwonga, R. N. (2018). Intermediate maturing soybean produce multiple benefits at 1:2 maize:soybean planting density. *Journal of Agricultural Science, 10*(9), 29. https://doi.org/10.5539/jas.v10n9p29

Wang, X. W., Yang, W. T., Miao, J. Q., Wan, J. R., & Nie, Y. P. (2014). Effects of maize-soybean intercropping and nitrogen fertilizer on yield and agronomic traits of maize. *Acta Ecologica Sinica, 34*, 5275-5282. https://doi.org/10.5846/stxb201405090927

Willey, R. (1979). Intercropping its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstracts, 32*, 1-10.

Wu, Y., Gong, W. Z., Yang, F., Wang, X. C., Yong, T. W., & Yang, W. Y. (2016). Responses to shade and subsequent recovery of soya bean in maize-soya bean relay strip intercropping. *Plant Production Science, 19*, 206-214. https://doi.org/10.1080/1343943X.2015.1128095

Wu, Y., Gong, W., & Yang, W. (2017). Shade inhibits leaf size by controlling cell proliferation and enlargement in soybean. *Scientific Reports, 7*(1), 9259-10. https://doi.org/10.1038/s41598-017-10026-5

Xia, H. Y., Wang, Z. G., Zhao, J. H., Sun, J. H., Bao, X. G., & Christie, P. (2013). Contribution of interspecific interactions and phosphorus application to sustainable organization and productive intercropping systems. *Field Crops Research, 154*, 53-64. https://doi.org/10.1016/j.fcr.2013.07.011

Yong, T. W., Yang, W. Y., Xiang, D. B., & Chen, X. R. (2012). Effects of different cropping modes on crop root growth, yield, and rhizosphere soil microbes’ number. *The Journal of Applied Ecology, 23*(1), 125-132.
Zhang, F., & Li, L. (2003). Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant & Soil*, 248(1-2), 305-312. https://doi.org/10.1023/A:1022352229863

**Copyrights**

Copyright for this article is retained by the author(s), with first publication rights granted to the journal. This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).