Effects of various leguminous intercrops on maize yield

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Abstract

Intercropping increases a field's utilization rate and maintains soil fertility. By comparing the single cropping of corn (SCC) with the intercropping of corn with three leguminous crops; i.e., mung bean (CM), black soybean (CB), and peanut (CP), this study investigated the effects of various leguminous intercrops on corn growth and yield. The experiment results indicate that intercropping corn with the mentioned leguminous crops increases the plant height, leaf area, and relative growth rate of the corn. In addition, the average single ear weight was 14.6%, 15.93%, and 22.1% higher in the CB, CM, and CP, respectively, when compared with that in the SCC, suggesting that the intercropping of corn with peanut is most beneficial for corn yield. Moreover, the number of rhizobia in the CP was 4.0 and 5.9 times the numbers in the CM and CB during the harvest period; the highest soil nitrogen content was also found in the CP (147.5 mg/kg), 2.0–2.2 times those in the other arrangements. This suggests that the abundant rhizobia on peanut roots increase the nitrogen content of soil and substantially boost corn yield. Intercropping corn with a leguminous crop thus increases both the growth and yield of the corn; compared with mung bean and black soybean, peanut was discovered to maximize growth and yield benefits as the most profitable intercrop.

KeyWords *corn, leguminous, intercrops, yield*

Abbreviations *SSC- single cropping of corn, CM- intercropping of corn with mung bean, CB- intercropping of corn with black soybean, CP- intercropping of corn with peanut, RGR- relative growth rate, SNC- soil nitrogen content*

Introduction

The world population increased from 6.6 billion in 2006 to 7.3 billion in 2015, an 11.4% increase during this period of approximately ten years (FAOSTST., 2017a). This increasing human population has resulted in a corresponding increase in food demand. The Food and Agriculture Organization of the United Nations deem corn, soybeans, and wheat as essential crops for addressing the food crisis. Statistics show that the global corn output increased from 0.713 billion metric tons in 2005 to 1.037 billion metric tons in 2014, a 45.4% increase (FAOSTST., 2017b). However, this substantial increase in corn output did not reduce the impact of the food crisis. Because the growing world population has resulted in a shortage in food supply and global warming has caused extreme climates that affect crop yield, increasing the volume of crops produced has become an urgent task.

Presently, crops are mainly produced through conventional farming, which tends to use excessive amounts of nitrogen fertilizers. During year after year of farming, considerable numbers of nitrate or sulfate ions accumulate in the soil, which can decrease crop yields by altering the pH of the soil, degrading the soil's structure, reducing soil fertility, and affecting crop growth (Arnhold et al., 2014). Therefore, the amount of nitrogen fertilizer used by farmers must be reduced and the farming model must be changed to retain soil fertility and facilitate sustainable agricultural development.

Intercropping refers to the growing of two or more crops in the same field and season (Andrews and Kassam, 1976). Special attention must be paid to the crop spatial distribution, planting density, ripening period, and growth model to maximize space utilization efficiency and reduce the potential effects of soil fertility on the competitive relationship between the crops (Silva et al., 2009). Studies have demonstrated that leguminous crops have a similar growth model to corn and that intercropping leguminous crops with corn boosts corn yield (Geren et al., 2008; Latati et al., 2016; Li et al., 2016; Mahallati et al., 2015; Mao et al., 2012). Rhizobia in leguminous crops fix free nitrogen in the air to assist corn growth and increase corn yield (Li et al., 2016). Thus, intercropping corn with leguminous crops not only reduces the amount of nitrogen fertilizer required but also maintains soil fertility, which complies with sustainable agricultural development.

The type and breed of an intercrop affects the yield of the main crop. Selecting three leguminous crops (peanut, cowpea, and common bean) as intercrops with corn, Monicah et al. (2009) found that corn yield was significantly higher than those of cowpea and peanut by 43% when a two-by-two staggered arrangement (i.e.,

two rows of corn and two rows of a leguminous crop) was employed. When intercropping two marigold cultivars (kampar and porpar) with the common bean, Sadeghi et al. (2013) observed that the 100-grain weight of the common bean was higher with kampar (46.4 g) than with porpar (37.0 g), suggesting that the intercrop used affects the yield of the main crop.

This study examined the effects of intercropping corn with peanut, mung bean, and black soybean on corn yield and investigated which of these three leguminous crops is most beneficial for corn yield when intercropped with corn.

Materials and Methods

Experimental materials

The experiment was conducted at National Pingtung University of Science and Technology, which located in Pingtung, Taiwan (22°38'N, 120°37'E), during 2016 Mar-Jun. The average temperature was 24.1°C, and mean annual rainfall was 2270 mm. Precipitation during the corn growing season was 474 mm.

Corn, black soybeans, peanuts and mung bean were selected as the experimental material. Corn (super corn-honey 236) purchased from Hisng Nong Seed Co. Ltd.; black soybeans (Tainan 3) and peanuts (Tainan 14) were supported by Tainan District Agricultural Research and Extension Station and mung bean was obtained from the market. Plug trays were used to grow seedlings of corn and leguminous crops in the initial stage. An incubation medium was created by mixing nacrite and peat soil at a ratio of 1:2. After 2 weeks of greenhouse cultivation, the corn and leguminous crops were transplanted to a field.

Cultivation method

A completely randomized design was adopted by replicating each treatment in the experiment twice in a total of eight blocks, each of which had a size of 6 × 2 m2. The corn was planted in single-cropping and intercropping configurations. In the intercropping configuration, two rows of corn were planted with an interrow spacing of 60 cm and intrarow spacing of 30 cm in each block (total plant = 28), next to which two rows of a leguminous crop were planted with an interrow spacing of 60 cm and intrarow spacing of 25 cm in each block (total plant = 24). In the single-cropping configuration, four rows of corn were planted with an interrow spacing of 50 cm and intrarow spacing of 25 cm in each block (total plant = 48).

NPK fertilizer (i.e., containing nitrogen, phosphorous, and potassium) with an N:P:K ratio of 10:5:5 (g) per m2 was applied; two thirds of this amount was used as the base dressing and the rest as the top dressing. The top dressing was applied at two time points: (1) at the stage of cultivation and banking and (2) when the corn had entered the heading and blooming stage.

Agronomic traits

At Week 11, the corn plants had reached the heading stage, where their plant height stopped increasing dramatically. . Ten of the corn plants were sampled from each block for an agronomic trait investigation.

Leaf area was measured using the following equation:

Leaf area = L × W × A

L: leaf length; W: leaf width; A: coefficient (0.75) (Mokhtarpour et al., 2010)

Relative growth rate

The relative growth rate (RGR) of the corn plants was measured at Week 6. In each block and for each treatment, two corn plants were sampled from the six plants present. The aboveground portions of the corn plants were harvested and dried in an oven at 65 °C; their dry weight was measured 1 week later. The following equation, the RGR equation (Vazin, 2012), was employed to calculate the RGR of these plants:

$$\boldsymbol{RGR} = \frac{1}{W} \mathrm{X} \frac{dW}{dT} \ (\mathrm{g\ g^{-1}\ d^{-1}})$$

W: corn dry weight; $\frac{dW}{dT}$: variation in corn dry weight per unit time.

Corn yield

Ten corn plants were sampled from each block to determine the corn yield. Only two ears of corn were retained from each plant. After corn had ripened, the average weight of a single ear with subtending leaves was measured and the 100-grain fresh weight was determined by collecting the corn grains.

Analysis of nitrogen content in soil

To analyze the nitrogen content in the soil, the corn plants were sampled at two time points: (1) at the silking stage, which indicates the start of head growth, and (2) at the harvest stage, when corn growth had ceased.

The method used to analyze the soil nitrogen content (SNC) was modified according to the method of Winnick (1942) and performed using Conway's microdiffusion method. Soil samples were collected, left to dry naturally, and filtered using a 20 mm filter; 10 g of a soil sample

was placed into a 250 mL flask. After 100 mL of 10% potassium chloride was added to the flask, the mixture was rotated at 150 rpm for 1 hour; 100 mL of filtrate was then collected through a Whatman No. 2 filter paper. A Conway diffusion cell was filled with 0.5 g of zinc powder and 0.5 g of ferrous sulfate; 20 mL of the clarified filtrate was collected and added to the cell. A diffusion cup containing 4 mL of 2% boric acid absorption liquid was placed into the central chamber of the cell, after which 10 mL of 10 N NaOH was quickly added to the cell. Another diffusion cell was used to immediate cover the top of the current cell. The cells were left to stand for 3–5 days for further titration. The titration was performed using 0.002 N sulfuric acid standard solution; the titration value was recorded and employed in the calculation using the following formula:

$$\text{Soil inorganic nitrogen (total inorganic nitrogen \%)} = \frac{\text{Titration value} \times \text{Concentration of sulfuric acid standard solution} \times \text{Molecular weight of nitrogen} \times \text{Quantitative volume}}{\text{Sample volume} \times \text{Soil sample weight}} \times 100$$

Statistical analysis

Differences between the samples were analyzed through analysis of variance and Fisher's least significant difference procedure.

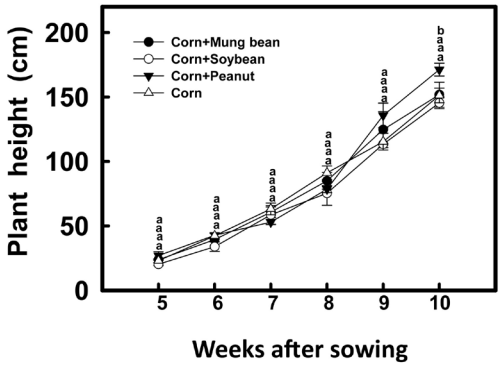
Results and Discussion

Corn plants were planted using the flowing combinations: single-cropping of corn (SCC), intercropping of corn with mung bean (CM), intercropping of corn with black soybean (CB), and intercropping of corn with peanut (CP). By comparing these treatments, this study examined the effects of intercropping on corn growth and yield and investigated which of the three leguminous intercrops was most beneficial for corn yield.

Effects of leguminous intercrops on the plant height and leaf area of corn

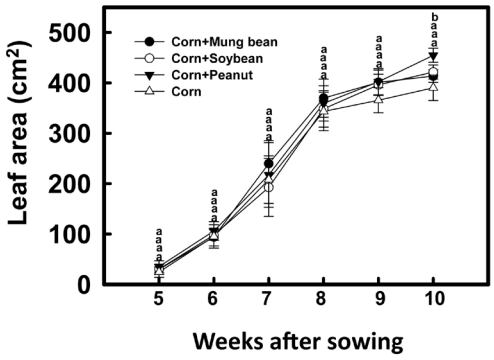
Single cropping leads to light interception because all plants are growing in the same pattern, thus deceasing photosynthetic efficiency (Vandermeer, 1989; Gao et al., 2013). From an ecological perspective, competition among a single crop for environmental resources is higher than that among various crops (Mahallati et al., 2015). Therefore, single cropping affects crop growth owing to competition for the same nutrients. Generally, excessive chemical fertilizer is employed to solve nutrient deficiency problems when single cropping is used. Excessive and long-term chemical fertilizer use gradually acidifies the soil, destroys its colloid structure, degrades its properties, reduces its fertility, and ultimately

Figure 1 - The effect of various leguminous intercrops on maize height. Maize seedlings were grown in a greenhouse for 2 weeks, then transplanted to the field. The plant height was measured during 5 to 10 weeks after sowing. Bars show means ± SE. Values with same letter are not significant by LSD testing at the 5% level.



decreases crop yield (Chung et al., 2006; Arnhold et al., 2014). Intercropping can avoid soil acidification and prevent a decrease in soil fertility. By comparing the single cropping of corn with the intercropping of corn with three leguminous crops, in this study the plant height and leaf area of the corn were measured from Week 5. In Weeks 5–9, no significant differences in plant height and leaf area were discerned between the single-cropped and intercropped corn (Figures 1-2). However, at Week 10, the average height of corn was 171 cm in the CP, significantly higher than those in the CM (151 cm), CB (145 cm), and SCC (151 cm) (Figure 1).

Figure 2 - The effect of various leguminous intercrops on maize leaf area. Maize seedlings were grown in a greenhouse for 2 weeks, then transplanted to the field. The leaf area was measured according to method and material. Bars show means ± SE. Values with same letter are not significant by LSD testing at the 5% level.



Comparison of the corn leaf area demonstrated that, at Week 10, the average leaf area was 454 cm^2 in the CP, significantly higher than those in the CM (413 cm^2), CB (421 cm^2), and SCC (390 cm^2) (Figure 2). These data indicate that corn plant height and leaf area were larger in the CP than in the other arrangements.

Effects of various leguminous intercrops on corn RGR

At Week 5, the soil was cultivated and banked and the first top dressing was applied. Starting at Week 6, the RGR of the corn plants was calculated and analyzed. In Weeks 7–9, no significant differences in plant height and leaf area were discerned for the different configurations. However, at Week 10, the RGR of the corn in the CP (0.4 g) was significantly higher than those in the CB (0.33 g), CM (0.30 g), and SCC (0.23 g), which resulted in the lowest RGR (Figure 3). These data suggest that intercropping corn with leguminous crops increases the RGR of corn; among all the intercrops used, CP yielded the highest RGR.

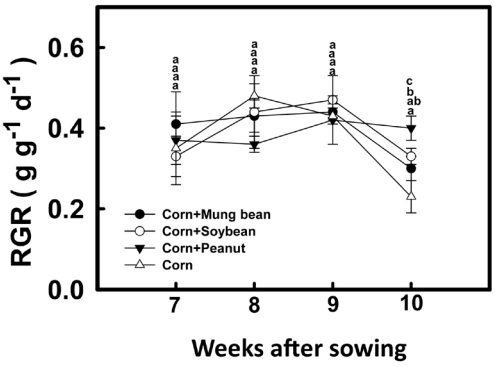


Figure 3 - The effect of various leguminous intercrops on relative growth rate (RGR) of maize. Maize seedlings were grown in a greenhouse for 2 weeks, then transplanted to the field. RGR was measured during 6 to 10 weeks after sowing. Bars show means ± SE. Values with same letter are not significant by LSD testing at the 5% level.

Effects of various leguminous intercrops on corn yield

Intercropping requires consideration of plant distribution, plant density, ripening period, and growth pattern (Silva et al., 2009). Numerous studies have recommended the intercropping of corn with leguminous crops as the optimal configuration (Geren et al., 2008; Latati et al., 2016; Li et al., 2016; Mahallati et al., 2015; Mao et al., 2012). In the present study showed that the effects of single cropping and intercropping arrangements on single ear weight (SEW) and 100-grain fresh weight were examined (Table 1). The average SEW of the corn was 278 g, 276 g, and 294 g in the CM, CB, and CP, respectively, all higher than that in the SCC (251 g). These data demonstrate a higher average SEW in the CP than in the other arrangements. However, no significant SEW differences were detected between the CM and CB configurations.

Table 1. The effect of various leguminous intercrops on maize yield.

	Weight of a single ear[1] (g)	Fresh weight of a hundred seeds (g)
Corn	251.4 ± 11.6 a[2]	28.6 ± 2.9 a
Corn+Mung bean	278.7 ± 15.3 b	34.0 ± 2.1 b
Corn+Soybean	276.4 ± 13.4 b	32.8 ± 2.4 ab
Corn+Peanut	294.3 ± 16.7 b	36.7 ± 1.5 c

(1) The data is shown by means ± standard error.
(2) Values with same letter are not significant by LSD testing at the 5% level.

The highest 100-grain fresh weight was reported for the CP (36.7 g), followed by the CM (34.0 g), CB (32.8 g), and SCC (28.6 g) (Table 1). Intercropping with a leguminous crop thus boosts the 100-grain fresh weight of corn; among all the intercrops, the CP yielded the highest 100-grain fresh weight

Effects of various leguminous intercrops on nitrogen content in soil

The intercropping of corn with peanut facilitated both corn growth and an increase in yield. Thus, whether the three leguminous crops altered the SNC and thereby affected corn yield was further investigated.

The symbiosis of rhizobia with leguminous roots fixes free nitrogen in the air to the soil. In the experiment, the number of rhizobia on the corn plants was calculated starting from Week 11 (i.e., start of the heading stage) and ending at Week 14 (i.e., start of the harvest). Figure 4 suggests that, at Week 11, the number of rhizobia on the peanut crop was 291, 3.5 and 4.2 times the numbers on the mung bean and black soybean crops, respectively. The number of rhizobia on the peanut crop increased with time; at Week 14, the number of rhizobia on the peanut crop was 550, 4.0 and 5.9 times of the numbers on the mung bean and black soybean crops, respectively.

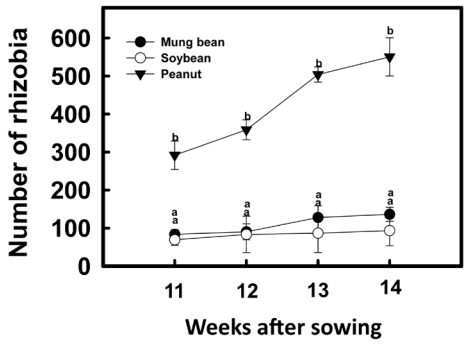


Figure 4 - The number of rhizobia in various leguminous. After maize heating, the number of rhizobia of different legumes crops was calculated during 11 to 14 weeks after sowing. Bars show means ± SE. Values with same letter are not significant by LSD testing at the 5% level.

To further understand whether the number of rhizobia affects SNC, SNC analysis was conducted after the silking stage and harvest period. Figure 5 indicates that, after the silking stage, the highest SNC was reported in

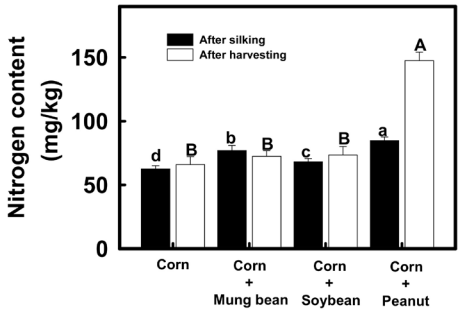


Figure 5 - The effect of various leguminous intercrops on soil nitrogen content . Soil nitrogen content was measured after flowering and harvesting; respectively. Bars show means ± SE. Values with same letter are not significant by LSD testing at the 5% level.

the CP (84.7 mg/kg), followed by the CM (77.0 mg/kg), CB (68.1 mg/kg), and SCC (62.6 mg/kg). SNC analysis conducted after the harvest period indicated that the highest SNC was identified in the CP (147.5 mg/kg), 2.0–2.2 times those in the other configurations (Figure 5). No significant SNC differences were discerned between the CB, CM, and SCC arrangements.

Studies have indicated that the nitrogen fixing effect of soybean increases corn yield by facilitating the growth of corn roots, eliminating competition for nutrients, increasing photosynthetic efficiency, and boosting dry matter accumulation (Latati et al., 2016). Authors stated that the intercropping of corn with peanut increases the number of microorganisms in the soil and enhances the availability of nitrogen and phosphorus in soil by increasing the activity of soil urease and phosphate monoesterase, thereby increasing the amount of chlorophyll and microorganisms on corn plants (Latati et al. 2016). The results of the present study also confirmed that the abundant rhizobia on peanut roots increase the nitrogen content of soil (Figures 4-5) and ultimately increase corn yield (Table 1).

The findings of this research suggest that intercropping corn with a leguminous crop increases both the growth and yield of corn; compared with mung bean and black soybean, peanut maximizes growth and yield benefits and results the most profitable intercrop.

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