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RESEARCH ARTICLE

Border-rows Effect of Rape (*Brassica napus* L.) Intercropping with Milk Vetch (*Astragalus sinicus* L.)

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Abstract: Border-rows effect is an important research content of intercropping system. Milk vetch-rape intercropping is one of the typical intercropping patterns in southern China. However, research on the border-rows effect is very little, which has affected the application and popularization of the milk vetch-rape intercropping system. In this study, two field experiments were conducted from 2018 to 2020. The effects of monoculture, intercropping and different border-rows on agronomic traits and yield of rape were studied. The results showed that milk vetch had a significant effect on the first border-row of rape. The first border-row of rape diameter of root and secondary effective branch number is significantly higher than second and third border-row, and the rape yield per plant in the first border-row of intercropping milk vetch was 135%, 328%, 257% and 147% higher than that in the second, third, fourth and fifth border-rows respectively. The intercropping with milk vetch enhanced the number of pods per plant in first border-row by increasing the agronomic traits of rape, such as plant height, stem diameter, primary effective branch number and secondary effective branch number. In conclusion, intercropping milk vetch significantly improved the agronomic traits of the first and second border-rows rape, increased the yield of rape. So it is recommended that milk vetch intercropping with two rows rape, which has important guiding significance for the application and promotion of milk vetch-rape intercropping in the future.

Keywords: Border-rows effect; Intercropping; Milk vetch; Rape

1. Introduction

Crop diversification appears to be a critical element to sustain agroecosystems. Intercropping is widely practiced as a mean of increasing productivity and to minimize the risk of total crop failure [1]. Compared with monoculture, reasonable intercropping system can improve agronomic traits and yield of crops. The ecological basis of intercropping advantage has two main aspects: the full utilization of light and heat resources in the overground and the full utilization of water and nutrient resources in the underground [2]. The yield advantage usually comes from the border-row advantage effect of intercropping system.

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Study by Qi et al. [3] on wheat-corn intercropping system found that the edge effects at the first side row were 13.7%, 18.2%, 29.0%, 33.7% higher than the second side row, in sole cropping system, wheat corn intercropping system without root separation, wheat-corn intercropping with root separated by plastic film, wheat-corn intercropping with root separated by nylon, respectively, and the edge effects in the fist side row were 22.5%, 33.9%, 19.4%, 29.8% higher than the third side row in the four treatments respectively. When jujube intercropped cotton, the plant height and leaf area index of side two row cotton increased by 27.44% and 20.73%, respectively, compared with sole cropping [4]. Therefore, exploring the size of the border-row advantage effect of intercropping system can better develop and utilize it, which is of great significance to establish a reasonable intercropping system and ensure the maximum benefit of intercropping [5].

There are various systems of intercropping, such as cereal-bean, cereal-potato, grain-cotton, grain (cotton)-vegetable, etc. Among them, milk vetch-rape intercropping is one of the typical intercropping systems in southern China, which have been reported since the 1950s [6-8]. Milk vetch is the main green fertilizer crop in south China, which can improve soil fertility and soil structure [9]. Rape is one of the important oil crops in China, and the intercropping of milk vetch and rape can not only improve the production efficiency of rape, increase organic fertilizer source, improve soil fertility, but also has good physiological and ecological effects [10-12]. Recent studies found that intercropping milk vetch could not only change the soil microbial characteristics of rape rhizosphere, thereby affecting its soil respiration [13,14], but also reduce the accumulation of cadmium (Cd) and lead (Pb) in rape, reduce the harm of heavy metals to human beings [15]. However, there is still a lack of research on the border-rows effect of milk vetch-rape intercropping, which seriously hinders the development and application of milk vetch-rape intercropping system. This study aims to reveal the influence to yield and agronomic traits of different border-rows of rape, determine the intercropping effect size of every border-row of rape, provide data support to put forward appropriate field configuration mode of milk vetch-rape intercropping, then could provide theoretical basis for the optimization and application promotion of milk vetch-rape intercropping system.

2. Materials and Methods

2.1 Site Description

The experiment was conducted in Jiangxi Agricultural University Science and Technology Park in Nanchang, Jiangxi province, China (28°46′ N, 115°55′ E) from October 2018 to May 2020. The experimental soil type is the typical red soil in south China, the average annual sunshine duration is 1559.9 h, the average annual total sunshine radiation is 102.55 $kJ \cdot cm^{-2}$, the frost-free period is about 269 days, the average annual rainfall is 1658.9 mm, the average annual temperature is 16.5 °C, and the active accumulated temperature ≥10 °C is 5521 °C. The test site is low hill without irrigation condition. The initial soil properties were: pH value was 4.75, organic matter was 23.20 $g \cdot kg^{-1}$, total nitrogen was 1.29 $g \cdot kg^{-1}$, total phosphorus was 0.92 $g \cdot kg^{-1}$ and total potassium was 11.10 $g \cdot kg^{-1}$.

2.2 Experimental Design

Experiment 1: From October 2018 to May 2019, the field experiment was conducted with three treatments (planting methods): (1) Monoculture: monoculture rape, plant spacing 30 cm, row spacing 40 cm (there were 11 rows in each plot and 10 plants in each row); (2) Intercropping: rape planting specifications are the same as monoculture, and milk vetch is sown between rape rows, the amount of milk vetch per strip was 4.5 g; (3) Milk vetch-rape intercropping (the planting ratio is 1:5): milk vetch is sown on both sides of the middle five-row rape (taking the middle five-row rape and milk vetchas the main research object), intercropping rape is divided into first, second and third border-rows), and the amount of milk vetch per strip was 4.5 g (Figure 1). A random block design was used in the experiment, with 3 replicates. There were 9 plots with length of 5.0 m, width of 3.0 m. Each plot was applied with 1.588 kg nitrogen (180 $kg \cdot hm^{-2}$), 1.588 kg phosphate (180 $kg \cdot hm^{-2}$), 1.588 kg potassium (180 $kg \cdot hm^{-2}$). The fertilizer used is Stanley 17-17-17 compound fertilizer. All fertilizers are applied once before sowing.

Experiment 2: From October 2019 to May 2020, a field experiment was carried out to set up an intercropping system of milk vetch and rape. The plot area was 3.0 m×5.0 m, and the rape was planted within the range of 2.0 m×3.0 m in the middle of each plot. The rape was planted by isometric cave seeding with plant spacing of 20 cm and row spacing of 20 cm. Milk vetch was planted within a range of 1.5 m×3.0 m on both sides of the plot, and the seeding amount on each side was 20 g. In this planting method, rape was divided into first, second, third, fourth and fifth border-rows (Figure 2). Fertilization and other field management are same as Experiment 1.

Test varieties: milk vetch variety was “Yujiang Daye”, rape variety of Experiment 1 was “94005 ”(strain), and rape variety of Experiment 2 was “Yangguang 131”.

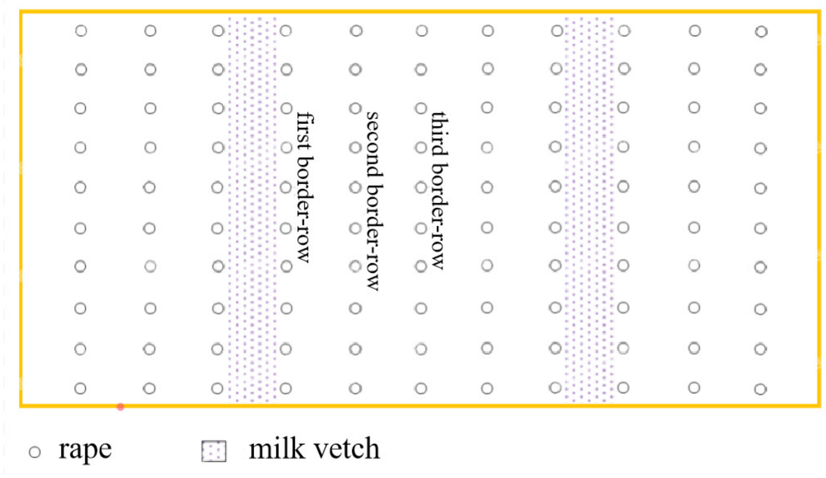

Figure 1. Schematic diagram of experiment design (test 1)

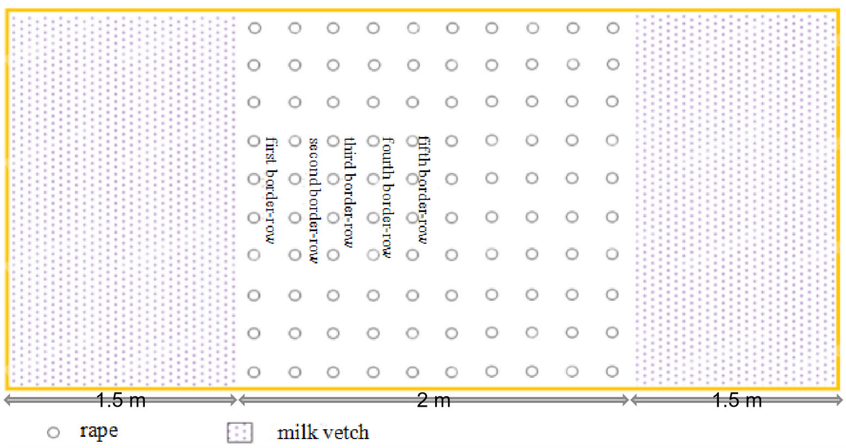

Figure 2. Schematic diagram of experiment design (test 2)

2.3 Measurement Index and Method

Experiment 1: In the rape pod period, the plant height, height of branch point, main inflorescence length of rape were measured by measuring tape, diameter of root was measured by vernier caliper, primary effective branch number and secondary effective branch number were directly counted. Three plants were measured in each plot in monocropping and intercropping, and three plants were measured in each side row in 1-to-5 intercropping of milk vetch rape.

Experiment 2: In the rape pod period, the plant height, diameter of root, sessile leaf number, height of branch point, primary effective branch number and secondary effective branch number and number of pods per plant of rape were measured, the measurement method is the same as Experiment 1. Measure three plants on each side row.

The yield per plant in Experiment 1 and Experiment 2 was measured at the harvest stage.

2.4 Statistical Analysis

Micorsoft Excel 2010 and SPSS 17.0 software were used for data collation and analysis. General Linear Model was used for univariate and one-way ANOVA. Duncan's method was used for multiple comparison.

3. Results and Analysis

3.1 Effects of Different Planting Patterns on Agronomic Characters and Yield of Rape

Different planting patterns have a significant impact on rape agronomic traits (Figure 3). The plant height and secondary effective branch number of rape in intercropping were significantly higher than those in monoculture. For different intercropping border-row, while first and second border-row of rape better agronomic characters, especially in the first border-row. The first border-row of rape plant height and secondary branch number is significantly

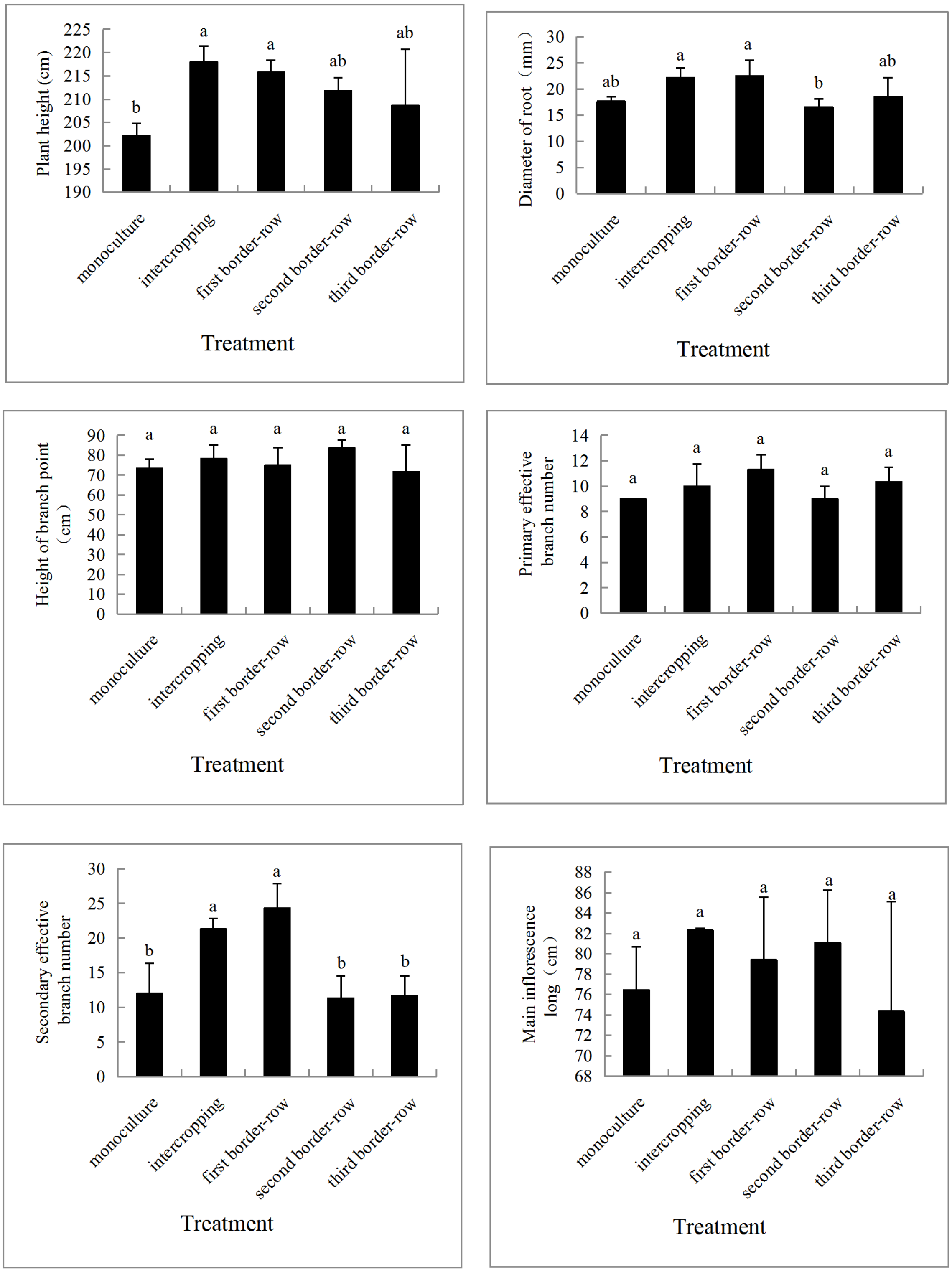

Figure 3. Effects of different planting patterns on agronomic traits of rape (test 1) Values followed by different letters are significantly different at *P*<0.05.

monoculture: monoculture rape; intercropping: milk vetch is sown between rape rows; first, second and third border-rows: milk vetch-rape intercropping with the planting ratio is 1:5.

higher than monoculture, and the diameter of root significantly superior to second border-row, secondary effective branch number is significantly higher than second and third border-row. The results showed that intercropping could improve the agronomic traits of rape, especially in the first border-row.

Different planting patterns also have a great impact on rape yield (Figure 4). The rape yield per plant of intercropping, first, second, third border-rows of rape was decreased in gradient order, and the rape yield per plant of third border-rows was equivalent to monoculture. The rape yield per plant of intercropping was significantly higher than that of monoculture and third border-rows, and the rape yield per plant of first border-row was significantly higher than that of third border-rows. Specifically, the rape yield per plant in intercropping was 119% higher than monoculture, and the rape yield per plant in first border-row was 52% and 119% higher than second and third border-rows. In conclusion, intercropping milk vetch significantly increased rape yield, and the yield effect of intercropping first border-row was more obvious, the second border-rows was second.

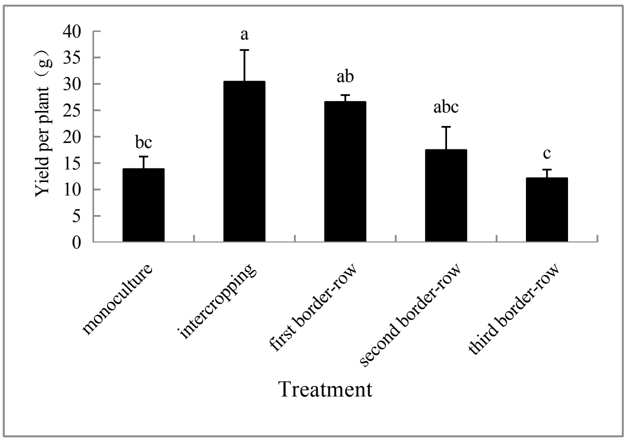

Figure 4. Effects of different planting patterns on yield of rape (test 1)

Values followed by different letters are significantly different at $P<0.05$.

3.2 Effects of Intercropping Milk Vetch on Agronomic Characters and Yield of Rape

Intercropping milk vetch has a great influence on the agronomic traits of different border-rows of rape (Figure 5). In addition to the height of branch point, other agronomic traits of rape were at a high level. The diameter of root, sessile leaf number, secondary effective branch number and number of pods per plant of first border-row were significantly higher than other border-rows, while the height of branch point was the opposite. It was found that all the agronomic traits were at the same level except for first border-row. In conclusion, the effects of intercropping on the agronomic traits of rape were mainly reflected in first border-row, which significantly improved the growth of first border-row of rape, but had no significant effects on other border-rows.

Intercropping milk vetch has different effects on the yield of rape in different border-rows, and has a greater impact on the yield of rape per plant in first border-row (Figure 6). The rape yield per plant in first border-row of intercropping milk vetch was significantly higher than that other border-rows, while the yield per plant in other border-rows was similar, the difference was not significant. Specifically, the rape yield per plant in the first border-row of intercropping milk vetch was 135%, 328%, 257% and 147% higher than that in the second, third, fourth and fifth border-rows respectively. In conclusion, intercropping milk vetch significantly increased the yield of first border-row of rape, but had no effect on other border-rows.

3.3 Correlation Analysis of Yield and Agronomic Traits in Rape

The correlation analysis between yield and agronomic traits of rape with different planting patterns and different border-rows (Table 1) showed that yield per plant of rape was positively correlated with its agronomic traits. The yield per plant was very significant positive correlation with plant height, diameter of root, sessile leaf number, primary effective branch number, secondary effective branch number and number of pods per plant. The number of pods per plant was very significant positive correlation with plant height, diameter of root, sessile leaf number and secondary effective branch number. Secondary effective branch number was very significant positive correlation with plant height, diameter of root, sessile leaf number, was a significant positive correlation with primary effective branch number. Primary effective branch number was very significant positive correlation with plant height, diameter of root. Sessile leaf number was significant positive correlation with diameter of root. Diameter of root was very significant positive correlation with plant height. Combined with the research results in Figure 3 and Figure 5, intercropping of milk vetch can significantly increase the yield of rape in first border-row, mainly because intercropping can increase the plant height, diameter of root, sessile leaves number and secondary effective branch number of rape, and then increase the number of pods per plant, and ultimately increase the yield of rape.

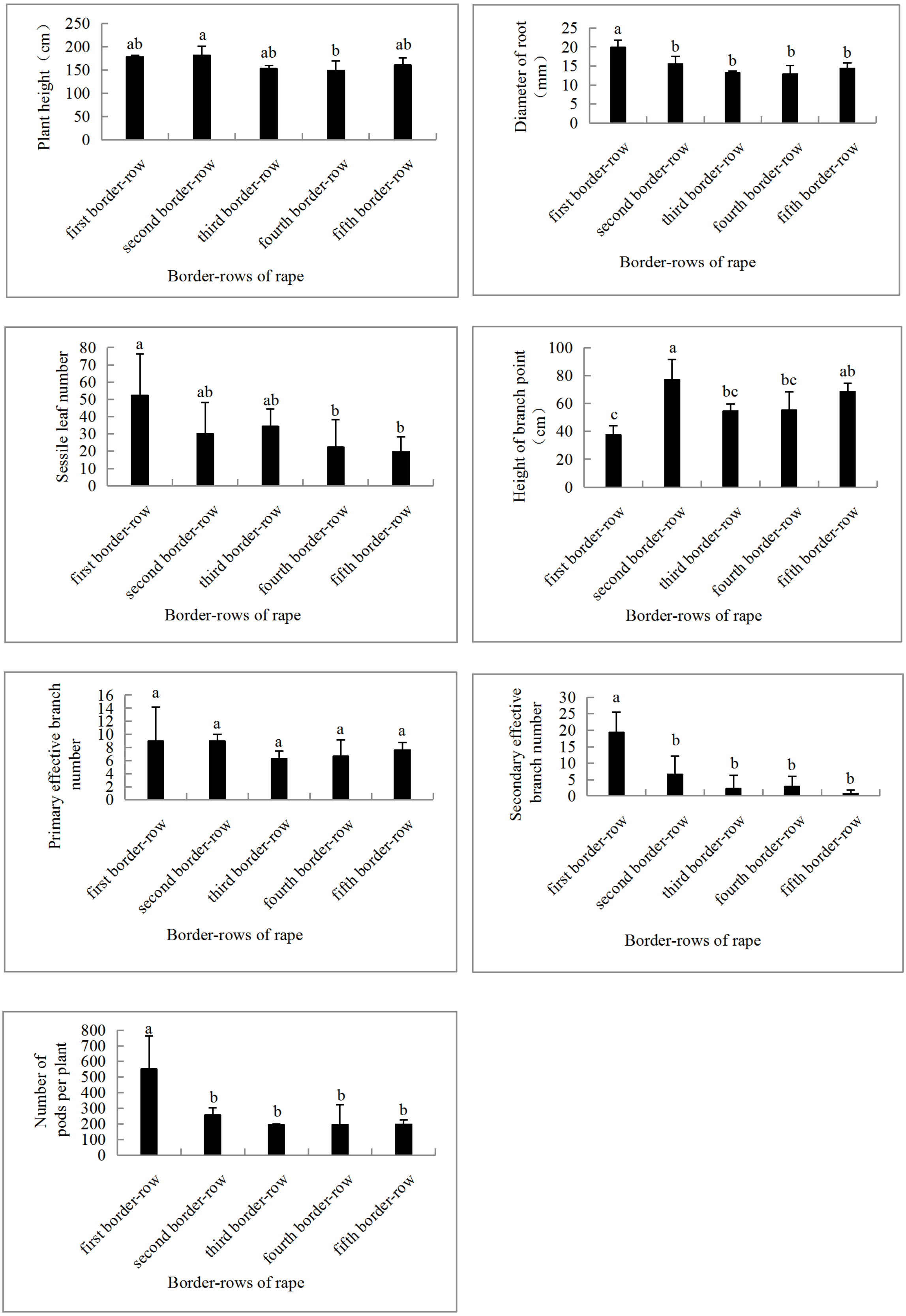

Figure 5. Effects of intercropping Chinese milk vetch on agronomic traits of different border-rows rape (test 2)

Values followed by different letters are significantly different at $P<0.05$.

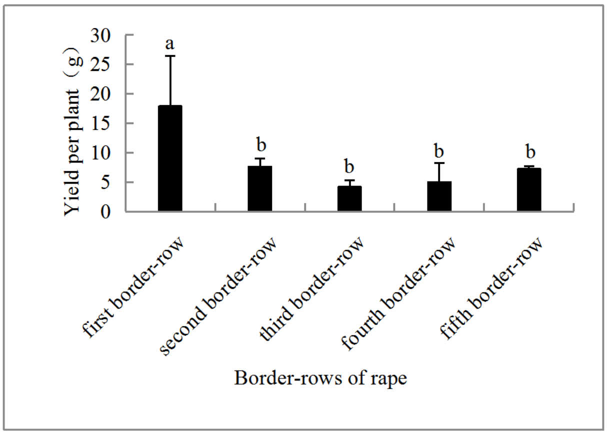

Figure 6. Effects of intercropping Chinese milk vetch on yield of different border-rows rape (test 2)

Values followed by different letters are significantly different at *P*<0.05.

Table 1. Correlation analysis of yield and agronomic traits of rape

Traits	Plant height	Diameter of root	Sessile leaf number	Height of branch point	Primary effective branch number	Secondary effective branch number	Number of pods per plant	Yield per plant
Plant height	1	0.720**	0.230	0.647**	0.596**	0.592**	0.565*	0.705**
Diameter of root	0.720**	1	0.639*	0.198	0.608**	0.850**	0.801**	0.861**
Sessile leaf number	0.230	0.639*	1	–0.512	0.362	0.815**	0.824**	0.692**
Height of branch point	0.647**	0.198	–0.512	1	0.329	–0.033	–0.445	0.294
Primary effective branch number	0.596**	0.608**	0.362	0.329	1	0.513*	0.488	0.652**
Secondary effective branch number	0.592**	0.850**	0.815**	-0.033	0.513*	1	0.872**	0.853**
Number of pods per plant	0.565*	0.801**	0.824**	–0.445	0.488	0.872**	1	0.888**
Yield per plant	0.705**	0.861**	0.692**	0.294	0.652**	0.853**	0.888**	1

* significant at 0.05 level, ** extremely significant at 0.01 level.

4. Conclusions and Discussion

Border-rows effect is an important research content of intercropping system. Intercropping has different effects on different border-rows, especially on first and second border-rows. Our results showed that intercropping with milk vetch only significantly increased the yield of rape, mainly because intercropping increased the plant height, diameter of root, sessile leaves number, secondary effective branch number and other agronomic traits of rape, and then increased the number of pods per plant. Previous studies by Zhou et al. also showed that milk vetch rape intercropping significantly improved the growth of rape and achieved yield increase effect [12]. In recent years, some researchers have further studied the side effects of different intercropping systems. Studies on flax border-rows effect under intercropping of maize flax showed that flax had significant border-rows advantage, which was manifested in the increase of capsule, the improvement of economic coefficient and the significant increase of grain weight in the first border-row compared with the middle border-rows [16]. In the system of maize and wheat intercropping, the border-rows advantage of intercropping wheat is significantly higher than that of monoculture wheat, and the yield of first border-row of intercropping wheat is 18.2% and 33.9% higher than that of second and third border-rows respectively [3]. In the maize/soybean or maize/peanut intercropping system, intercropping maize has obvious border-rows effect on soybean and peanut, which can significantly improve the agronomic traits and yield of crops in first and second border-rows [17]. Intercropping of broad beans and potatoes also had obvious border-rows effect. Under intercropping conditions, the starch content of potatoes in the first border-row was significantly higher than that in the second and third border-rows [18]. Conversely, intercropping also had obvious border-rows effect on broad beans in the first and second border-rows [19]. Under the condition of intercropping spring maize with vegetables, the yield and dry matter quality of spring maize in first and second border-rows were significantly higher than that in third border-row, and the yield was 58.7% and 40.8% higher than that in third border-row respectively [20]. In this study, the rape yield per plant in the first border-row of intercropping milk vetch was 135%, 328%, 257% and 147% higher than that in the second, third, fourth and fifth border-rows respectively (Figure 6), it is similar to the above results.

For the milk vetch-rape intercropping system, milk vetch is a leguminous crop, which can provide some nutrients for rape through biological nitrogen fixation [21]. The root exudates of milk vetch can affect the growth of rape, and their complementary ecological niches broaden the utilization space of nutrients in rape [22]. So intercropping milk vetch could improve rape yield, which was further proved by the results of this study. In this intercropping system, milk vetch is the inferior crop and rape is the dominant crop. In addition to the nitrogen fixation effect of leguminous (milk vetch), the improvement of soil microenvironment of rape is also an important reason [23]. Studies have found that in wheat and corn intercropping system, wheat side row advantage is affected more by the underground part than the above part [24], and in garlic intercropping system, the root nodules amount of side row fava bean is 80.06% higher than that in middle row [25]. In this study, intercropping with milk vetch had a significant effect on first border-row of rape, which may be due to the close distance between first border-row and milk vetch, and the rhizosphere interaction was stronger than other border-rows. In addition, intercropping of milk vetch changed Characteristics of microbial community structure in rhizosphere soil of rape [13]. And there was a co-evolution-like relationship between the plant and soil microbes that facilitates plant growth by optimizing the nutritional benefits provided by plant-associated microbes [26]. Maybe intercropping of milk vetch could change the structure characteristics of soil microbial community in the rhizosphere of rape, especially in first border-row, which was more conducive to the plant growth and increased the yield of rape.

It was found that milk vetch only had a significant effect on intercropping first border-row of rape. Intercropping of milk vetch increased the number of pods per plant by increasing plant height, diameter of root, sessile leaves number and secondary effective branch number of rape. In general, when configuring the intercropping system of milk vetch and rape in the future, it is recommended to intercrop milk vetch and two rows of rape, which ensure the planting density of rape and obtain higher rape yield.

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Conflict of Interest

There is no conflict of interest.

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