Effects of Different Bandwidth Configurations on Yield and Economic Benefits of Maize - Soybean Relay Strip Intercropping

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Abstract To identify the optimal maize - soybean relay strip intercropping pattern for the northern margin of the Jianghan Plain, a field experiment was conducted in 2025 at the experimental base of Huangji Town, Xiangzhou District, Xiangyang City, Hubei Province. Maize variety Zhengdan 958 and soybean variety Zhongdou 46 were used as test materials. Seven relay strip intercropping patterns with different bandwidths and row ratios were designed, with sole maize as the control (CK), and the effects of different configurations on crop growth period, agronomic traits, yield, and economic benefits were systematically analyzed. The results showed that different bandwidth configurations had no significant effect on the maize growth period, but significantly influenced the system equivalent yield and comprehensive economic benefits. Sole maize (treatment 1, CK) gave the highest equivalent yield of 7 725 kg/hm^2. Among the relay strip intercropping patterns, treatment 7 (M-S7, bandwidth of 2.8 m, maize-to-soybean row ratio of 2 : 4, maize density 35 700 plants/hm^2, soybean density 285 720 plants/hm^2) showed the best overall performance, achieving an equivalent yield of 7 200 kg/hm^2 and a total system economic benefit of 20 661 yuan/hm^2, with the economic benefit being significantly higher than that of sole maize and the other relay strip intercropping treatments. In conclusion, the treatment 7 (M-S7) pattern balances stable maize yield with increased soybean yield, demonstrates outstanding comprehensive production benefits, and is suitable for extension and application in Xiangyang City and similar ecological zones of the Jianghan Plain.

Key words Maize; Soybean; Relay strip intercropping; Yield; Economic benefit

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Maize is the largest grain crop in China, serving multiple purposes as food, feed, and industrial raw material[1], and occupies a core position in ensuring national food security and supporting the feed industry. Soybean is an important oilseed and protein crop and also a major food crop in China, with its consumption ranking first in the world[2-3]. Although China's soybean production is currently on a steadily rising trend, the demand for soybean in the domestic market remains huge, and the enormous gap between production and demand makes China heavily dependent on the international market[4]. There is a pronounced supply - demand contradiction in both the domestic soybean and maize markets, where domestic production can hardly meet the large demand[5]. The annual soybean import rate in China is as high as 83%, and the maize import rate is 1.8%. Therefore, increasing the production of soybean and maize is an extremely urgent and important task[6].

As the essence of traditional Chinese agriculture, intercropping, relay cropping, and multiple cropping can not only increase the multiple cropping index, grain yield, and farmers' income, but also effectively alleviate problems such as high input with high yield, low nutrient use efficiency, and environmental pollution. Combined with alternate-year crop rotation, a rotational effect can be achieved, playing an important role in the development of modern agriculture[7]. Currently, as one of the important patterns of relay strip intercropping, maize - soybean relay strip intercropping is an effective way to alleviate land competition and improve land use efficiency. Through rational allocation of bandwidth and row ratio, a synergistic effect of stable maize yield and increased soybean yield can be realized[8]. Existing studies have shown that a reasonable bandwidth and row ratio configuration can improve the leaf area index and radiation use efficiency of crops, delay leaf senescence, promote crop nutrient uptake and accumulation, and enhance the land equivalent ratio, population yield, and economic benefits[9]. When the maize-to-soybean row ratio is 2 : 4, the maize and soybean yields are 8 267.7 and 1 939.7 kg/hm^2, respectively, and the planting pattern performs best with the highest economic benefits, achieving the goal of harvesting an extra season of soybean without reducing maize yield[10].

China has a vast territory, and the climatic conditions, soil characteristics, and cropping systems vary greatly among different ecological zones, which can lead to differences in crop yields. The adaptability of existing patterns in Xiangyang City still lacks systematic research. Therefore, this experiment was carried out at Huangji Town, Xiangzhou District, Xiangyang City, to investigate the effects of different bandwidth configurations on the yield and economic benefits of a maize - soybean relay strip intercropping system, and to identify a locally suitable optimized pattern, so as

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to provide a theoretical basis and technical support for the extension and application of maize – soybean relay strip intercropping technology.

1 Materials and methods

1.1 Overview of the experimental site The experiment was conducted in 2025 at the experimental base in Huangji Town, Xiangzhou District, Xiangyang City, Hubei Province (32°15′ N, 112°08′ E, altitude of 105 m). The area has a subtropical monsoon climate, with an annual average temperature of 15.8 ℃, an annual precipitation of 820 mm, and a frost-free period of 240 d. It is yellow-brown soil. The 0 – 20 cm of topsoil had an organic matter content of 13.2 g/kg, total nitrogen of 0.85 g/kg, available phosphorus of 12.3 mg/kg, and available potassium of 115 mg/kg. The soil fertility was moderate, and the preceding crop was winter wheat.

1.2 Plant materials Maize variety: Zhengdan 958; soybean variety: Zhongdou 46. Both are widely promoted local cultivars with strong adaptability and reliable yield stability.

1.3 Experimental design The experiment was laid out in a single-factor randomized complete block design with seven treatments and three replications. The plot area was 28 m^2. The strip width, row ratio, and planting density for each treatment were as follows:

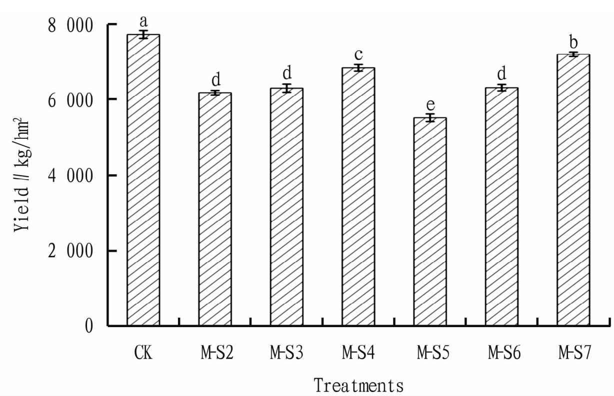
Treatment 1 (CK): sole maize, bandwidth of 1.0 m, maize planted in a single row, density of 67 500 plants/hm^2; treatment 2 (M-S2): bandwidth of 1.2 m, maize-to-soybean row ratio of 1 : 2, maize density of 45 000 plants/hm^2, soybean density of 225 000 plants/hm^2; treatment 3 (M-S3): bandwidth of 1.6 m, maize-to-soybean row ratio of 1 : 2, maize density 42 000 plants/hm^2, soybean density of 240 000 plants/hm^2; treatment 4 (M-S4): bandwidth of 2.0 m, maize-to-soybean row ratio of 2 : 2, maize density of 39 000 plants/hm^2, soybean density of 255 000 plants/hm^2; treatment 5 (M-S5): bandwidth of 2.4 m, maize-to-soybean row ratio of 2 : 3, maize density of 36 750 plants/hm^2, soybean density of 270 000 plants/hm^2; treatment 6 (M-S6): bandwidth of 2.4 m, maize-to-soybean row ratio of 2 : 4, maize density of 36 750 plants/hm^2, soybean density of 285 000 plants/hm^2; treatment 7 (M-S7): bandwidth of 2.8 m, maize-to-soybean row ratio of 2 : 4, maize density of 35 700 plants/hm^2, soybean density of 285 720 plants/hm^2.

Field management followed local conventional practices, with uniform fertilization, irrigation, and pest and disease control.

1.4 Measurements and methods Growth period: the dates of sowing, emergence, jointing, tasseling, grain filling, and maturity were recorded for maize. Agronomic traits: at maize maturity, plant height, ear height, ear length, ear diameter, kernels per row, and 100-kernel weight were measured. Yield: maize and soybean were harvested and weighed separately, and the yields were converted to per-hectare yields based on plot area. The system equivalent yield was then calculated. Economic benefit: the output value of maize and soybean was calculated based on the market prices of the current year. After deducting the costs of seeds, fertilizers, pesticides, labor, *etc.*, the net return per hectare (yuan/hm^2) was calculated.

2 Results and analysis

2.1 Effects of different planting patterns on maize yield Different planting patterns had a significant effect on maize yield in the maize – soybean relay strip intercropping system (Fig. 1). The equivalent yield of CK was the highest, reaching 7 725 kg/hm^2, which was significantly higher than that of all other relay strip intercropping treatments ($P < 0.05$). Among the relay strip intercropping treatments, M-S7 achieved the highest equivalent yield of 7 200 kg/hm^2. The yields of M-S2, M-S3, and M-S6 were 6 180, 6 300, and 6 315 kg/hm^2, respectively, without significant differences among them, indicating they belonged to the same level. M-S5 had the lowest yield, at only 5 520 kg/hm^2. Overall, sole maize showed a prominent yield advantage due to the highest population density. Among the relay strip intercropping patterns, the M-S7 treatment exhibited the best yield stability.



Note: The different lowercase letters indicate significant differences ($P<0.05$).

Fig. 1 Maize yield under different treatments

2.2 Effects of different planting patterns on maize growth period and agronomic traits As shown in Table 1, maize in all experimental treatments was uniformly sown on April 15, with seedling emergence on April 17, giving a 2 d period from sowing to emergence. The jointing, tasseling, and maturity stages occurred on May 15, June 6, and July 30, respectively. Based on the calculations, the total growth period of maize was 106 d in all treatments, with identical progression from sowing to maturity. The relay strip intercropping configurations had no significant effect on maize phenology.

As shown in Table 2, plant height, ear height, rows per ear, kernels per row, ear weight (with husk), ear weight (without husk), ear length, and ear diameter of maize did not differ significantly among treatments ($P > 0.05$). Among these traits, plant height ranged from 207.7 to 215.7 cm; ear height from 85.6 to 99.0 cm; rows per ear from 14.3 to 16.3 rows; kernels per row from 29.5 to 33.3 kernels; ear weight (with husk) from 123 to 155 g; ear weight (without husk) from 120 to 151 g; ear length from 13.3 to 15.1 cm; and ear diameter from 14.5 to 15.2 cm; none of these indices showed significant differences among treatments. The 100-kernel weight, as one of the core yield components, exhibited some variation across treatments. Specifically, M-S4 had the highest 100-kernel weight of 31.5 g, which was significantly greater than that of M-S2 (26.5 g) and M-S7 (27.1 g) ($P < 0.05$), but did not differ significantly from CK, M-S3, M-S5, and M-S6.

Overall, the configurations of bandwidth and row ratio in relay strip intercropping had little effect on vegetative growth and ear development of maize; only the 100-kernel weight differed significantly. The M-S4 treatment achieved a 100-kernel weight of 31.5 g, which was significantly higher than that in most other treatments, indicating superior kernel plumpness.

Table 1 Maize growth period under different treatments

Treatment	Sowing date	Emergence date	Jointing date	Tasseling date	Maturity date	Total growth period//d
CK	04-15	04-17	05-15	06-06	07-30	106
M-S2	04-15	04-17	05-15	06-06	07-30	106
M-S3	04-15	04-17	05-15	06-06	07-30	106
M-S4	04-15	04-17	05-15	06-06	07-30	106
M-S3	04-15	04-17	05-15	06-06	07-30	106
M-S6	04-15	04-17	05-15	06-06	07-30	106
M-S7	04-15	04-17	05-15	06-06	07-30	106

Table 2 Yield components of maize under different treatments

Treatment	Plant height//cm	Ear height//cm	Rows per ear//rows	Kernels per row//kernels	Ear weight with husk//g	Ear weight without husk//g	100-kernel weight//g	Ear length//cm	Ear diameter//cm
CK	211.8 a	85.6 a	16.3 a	31.9 a	134 a	131 a	28.2 ab	14.2 a	14.6 a
M-S2	215.7 a	98.5 a	16.0 a	33.0 a	142 a	128 a	26.5 b	15.1 a	15.2 a
M-S3	212.7 a	95.8 a	14.3 a	32.4 a	147 a	128 a	28.6 ab	15.1 a	14.7 a
M-S4	214.3 a	99.0 a	16.2 a	31.4 a	143 a	138 a	31.5 a	13.5 a	15.1 a
M-S5	211.0 a	94.5 a	15.0 a	32.6 a	155 a	151 a	30.4 ab	14.5 a	15.0 a
M-S6	212.5 a	95.7 a	14.3 a	33.3 a	132 a	128 a	28.7 ab	14.0 a	14.5 a
M-S7	207.7 a	97.5 a	15.0 a	29.5 a	123 a	120 a	27.1 b	13.3 a	14.7 a

Note: The different lowercase letters in the same column indicate significant differences ($P<0.05$).

2.3 Economic benefits of different planting patterns The results of economic benefit analysis (Table 3) showed that the output value per hectare of the CK treatment was 17 243.6 yuan/hm^2, with no soybean income, and the total system benefit was 17 244 yuan/hm^2, which was the lowest among all treatments. Owing to the combination of stable maize yield and additional soybean income, the total benefit of all relay strip intercropping patterns was higher than that of sole maize. Among them, the M-S7 treatment achieved the highest total benefit of 20 661 yuan/hm^2, which was significantly higher than that of the other relay strip intercropping treatments, with an increase of 3 417 yuan/hm^2 over sole maize, representing an increase of 19.8%. The total economic benefits of the remaining relay strip intercropping treatments, ranked from high to low, were M-S3, M-S4, M-S6, M-S2, and M-S5, with values of 19 251.0, 18 618.0, 18 309.0, 18 070.5, and 17 368.5 yuan/hm^2, respectively. Compared with sole maize, the corresponding increases were 2 007, 1 374, 1 065, 826.5, and 124.5 yuan/hm^2, representing increases of 11.6%, 8.0%, 6.2%, 4.8%, and 0.7%, respectively. The total economic benefit of the M-S5 treatment was the lowest among all relay strip intercropping patterns, which was mainly attributed to its markedly lower maize economic benefit of 12 573.5 yuan/hm^2. Overall, the economic contribution of soybean in the relay strip intercropping mode effectively supplemented the maize income, enabling the economic benefit of harvesting an extra season of soybean.

Table 3 Economic benefits of maize and soybean under different treatments

Treatment	Economic benefit of maize yuan/hm^2	Soybean yield//kg/hm^2	Economic benefit of soybean yuan/hm^2	Total economic benefit//yuan/hm^2
CK	17 243.6	-	-	17 244.0
M-S2	14 689.1	589.5	3 382.5	18 070.5
M-S3	14 369.7	850.5	4 881.0	19 251.0
M-S4	16 285.7	406.5	2 332.5	18 618.0
M-S5	12 573.5	835.5	4 795.5	17 368.5
M-S6	14 968.4	582.0	3 340.5	18 309.0
M-S7	16 422.5	738.0	4 237.5	20 661.0

As shown by the economic benefit composition of maize and soybean (Fig. 2), the contribution proportions of maize and soybean to the total economic benefit differed considerably among treatments. In the CK treatment, the economic benefit was entirely contributed by maize, accounting for 100%. In the relay strip intercropping treatments, maize contributed 72% – 87% of the total economic benefit, while soybean contributed the remaining 13% – 28%. The maize economic benefit proportions in the relay strip intercropping treatments, in descending order, were M-S4 (87%), M-S6 (82%), M-S2 (81%), M-S7 (79%), M-S3 (75%), and M-S5 (72%).

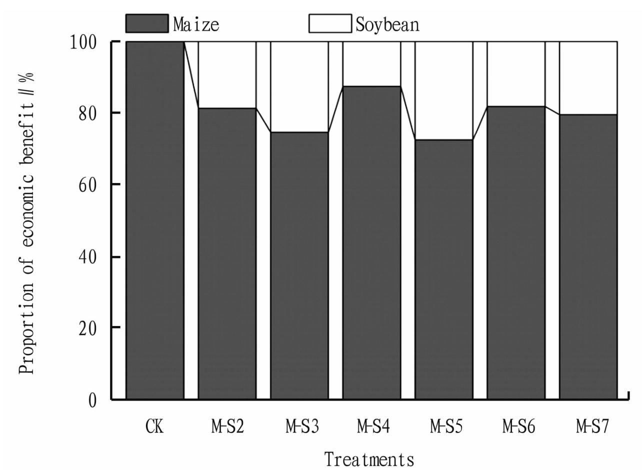


Fig. 2 Economic benefit proportions of maize and soybean under different treatments

3 Discussion

3.1 Effects of different bandwidth configurations on yield of maize – soybean relay strip intercropping Under the ecological conditions of Huangji Town, Xiangzhou District, Xiangyang City, different bandwidth and row ratio configurations had significant effects on the yield and economic benefits of the maize – soybean relay strip relay strip intercropping system. However, they had little influence on the maize growth period and most agronomic traits, indicating that the relay strip intercropping pattern enhances system benefits mainly through spatial arrangement and resource complementarity of crops. Only 100-kernel weight differed among treatments, with the M-S4 treatment achieving the highest value of 31.5 g.

With regard to maize yield, owing to its high population density, the CK treatment exhibited a distinct sole cropping advantage, with an equivalent yield reaching 7 725 kg/hm^2, significantly higher than that of all relay strip intercropping treatments. This reflects the superiority of the high-density sole cropping pattern in stabilizing maize yield. However, the relay strip intercropping patterns achieved enhanced comprehensive benefits through the additional soybean harvest, which is consistent with the resource complementarity effect of "stable maize yield and soybean gain" in maize-soybean relay strip intercropping systems. Under the M-S7 treatment with a bandwidth of 2.8 m and a row ratio of 2 : 4, the maize equivalent yield was the highest, reaching 7 200 kg/hm^2, while the soybean equivalent yield was 738 kg/hm^2. The M-S5 treatment, with a bandwidth of 2.4 m and a row ratio of 2 : 3, had the lowest maize equivalent yield of 5 520 kg/hm^2, possibly due to low resource use efficiency. Although the maize equivalent yield was slightly lower than that of sole maize, the soybean yield effectively compensated for the small reduction in maize yield. Moreover, the nitrogen fixation by soybean root nodules can improve soil fertility and reduce nitrogen fertilizer input, thereby achieving synergistic enhancement of economic and ecological benefits. Some researchers have reported that by setting up eight different wide row spacings for maize, when the row spacing was 1.2 m, the maize yield in 2013 increased by 255.9 kg/hm^2 compared with CK, and the soybean yield reached 706.95 kg/hm^2. It demonstrated that that this experiment not only achieved an extra soybean harvest but also increased maize yield[11].

3.2 Effects of different bandwidth configurations on economic benefits of maize-soybean relay strip intercropping
The economic benefit analysis further confirmed the advantages of the relay strip intercropping patterns. Although the sole maize treatment had the highest maize yield, the relay strip intercropping pattern increased the total economic benefit by 19.8% over sole maize through additional soybean income in the M-S7 treatment. It maintained the highest maize revenue among the relay strip intercropping treatments and also obtained a relatively high soybean yield through a rational row ratio configuration, highlighting the potential economic advantage of relay strip intercropping. In comparison, the M-S3 and M-S5 treatments had relatively high soybean yields but low maize yields, leading to low overall economic benefits; the M-S4 treatment had a high maize yield but a low soybean yield, which also resulted in a low overall economic benefit. Therefore, a rational configuration of bandwidth and row ratio is required to maximize economic benefits. In an experiment with four row ratios, some researchers found that when the maize-to-soybean row ratio was 2 : 4, the maximum additional income compared with sole soybean was 11 707.65 yuan/hm^2, and this pattern had the highest benefit[12], which was consistent with the results of the paper; whereas when the bandwidth was 2.4 m with a maize-to-soybean row ratio of 2 : 3, the economic benefit was the highest[13]. The difference between the optimal configuration reported by those researchers and the paper may be attributed to variations in cultivars, density design, and competition intensity. In addition, the rhizobia in soybean root nodules fix nitrogen, which is beneficial for improving soil nutrients and provides ecological benefits for subsequent crop growth[14–15].

This experiment was only a single-year and single-site study, and the results were greatly influenced by climatic conditions, soil characteristics, and management practices. The long-term stability, mechanization adaptability, and extension potential of relay strip intercropping across different ecological zones still require further validation. Moreover, the effects of different bandwidths

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field is simultaneously facing new development opportunities and also needs to address various practical challenges. Therefore, meteorological departments should improve the channels for the release and transmission of meteorological information, establish a sound information collection and dissemination system, improve the prevention system of rural meteorological disasters, strengthen the training of farmers' meteorological knowledge, strengthen the publicity of knowledge about the prevention and mitigation of meteorological disasters in rural areas and the cultivation of meteorological professionals, promote the standardized and long-term development of meteorological services for agriculture, and contribute meteorological strength to rural revitalization.

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on canopy ventilation and light penetration as well as water and nutrient distribution have not been fully elucidated. Future research could combine light simulation, root distribution analysis, and nutrient use efficiency assessments to further optimize the spatial arrangement of relay strip intercropping, thereby maximizing both stable maize yield and increased soybean income.

In conclusion, this paper verified the feasibility of maize-soybean relay strip intercropping in the northern margin of the Jianghan Plain. The M-S7 treatment pattern performed best in terms of yield and economic benefits, and can be recommended as the preferred pattern for extension in this region. Meanwhile, the results could provide a theoretical basis and technical reference for optimizing relay strip intercropping patterns in different ecological zones.

4 Conclusions

Under the experimental conditions at Huangji Town, Xiangzhou District, Xiangyang City, different bandwidth and row ratio configurations significantly affected the equivalent yield and comprehensive economic benefits of the maize-soybean relay strip intercropping system, but had no significant effect on the maize growth period and most agronomic traits. Among the intercropping patterns, M-S7 (bandwidth of 2.8 m, maize-to-soybean row ratio of 2 : 4, maize density of 35 700 plants/hm^2, soybean density 285 720 of plants/hm^2) showed the best overall performance, ensuring stable maize yield while achieving a marked increase in soybean production. The equivalent yield of the system reached 7 200 kg/hm^2, and the net return reached 20 661 yuan/hm^2, representing an increase of 19.8% compared with sole maize. With its prominent relay strip intercropping advantage, it can be recommended as the preferred pattern for extension and application in Xiangyang City and similar ecological zones of the Jianghan Plain.

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