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Impacts of Various Herbicide Concentrations on Weed Control Effect and Crop Yield in Soybean and Corn Strip Intercropping Systems

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Abstract [**Objectives**] To identify the optimal combination of herbicide concentrations appropriate for soil closed weeding in the soybean and corn intercropping system in Zhongwei City. [**Methods**] Two herbicides, 96% (S)-metolachlor and 75% thifensulfuron methyl, were selected for this experiment. A no-herbicide treatment served as the control, and five concentration gradients of the herbicides were established. Prior to sowing, the soil underwent a closed weeding treatment. The impacts of various herbicide concentration combinations on growth indicators, weed control effect, and the yields of soybean and corn across various treatments were analyzed. [**Results**] The tested combinations of herbicide concentrations did not result in significant phytotoxicity to soybean and corn seedlings. Furthermore, as the herbicide concentrations increased in each treatment, treatments D and E demonstrated the most effective weed control effect. Specifically, 40 d post application, the plant control effect and fresh weight control effect reached 97.25% and 98.03% for treatment D, and 97.25% and 98.24% for treatment E, respectively. Additionally, the yields of both soybean and corn showed significant increases. [**Conclusions**] Considering the overall output-input ratio in this region, treatment D, comprising 96% (S)-metolachlor at 1 650 mL/hm^2 and 75% thifensulfuron-methyl at 48 g/hm^2, can be identified as the herbicide concentration combination that provides the most effective weed control effect in the soybean and corn strip intercropping system.

Key words Soybean and corn strip intercropping, Closed weeding, Control effect, Yield

1 Introduction

In 2022, China implemented the promotion of a soybean and corn strip intercropping system to ensure national food production security and to consolidate and enhance the yield and self-sufficiency rate of soybeans and oilseeds. This initiative aims to increase soybean harvests by adding an additional growing season while maintaining stable corn production[1]. Compared to traditional post-emergence weeding, closed weeding entails the application of herbicides after sowing but prior to seedling emergence, resulting in the formation of a "pesticide film" on the soil surface. When weeds emerge from the soil, their growth is inhibited upon contact with this "herbicide film". Additionally, this method prevents damage to soybeans and corn that may occur due to improper herbicide use during post-emergence weeding[2]. However, under the soybean and corn strip intercropping system, the weed population in the field is considerably more diverse compared to monoculture planting. The application of a single herbicide is insufficient to achieve effective weed control effect, and prolonged use of a single herbicide increases the risk of weed resistance development[2]. Studies have demonstrated that the combined application of various herbicides can effectively broaden the control spectrum of each herbicide, improve their efficacy, and reduce the dosage, frequency, and cost of application[3]. In this experiment, two herbicides—96% (S)-metolachlor and 75% thifensulfuron methyl—were applied in combination to evaluate the weed control effect and phytotoxicity across various concentration combinations in a soybean and corn strip intercropping system. The objective was to identify the optimal herbicide concentration combination suitable for this intercropping system in the study region.

2 Materials and methods

2.1 Overview of the test site The experiment was conducted in 2024 in Yongkang Town, Shapotou District, Zhongwei City, Ningxia, encompassing an area of 0.28 hm^2. The soil under investigation was classified as sandy loam, characterized by a pH of 7.44, organic matter content of 14.06 g/kg, total nitrogen concentration of 0.87 g/kg, total phosphorus concentration of 0.96 g/kg, total potassium concentration of 19.4 g/kg, available phosphorus concentration of 22.5 mg/kg, available potassium concentration of 121.33 mg/kg, and hydrolyzable nitrogen concentration of 95.33 mg/kg.

2.2 Materials The soybean variety tested was Chengdou 6, and the corn variety was Xianyu 1611. A soybean-to-corn row ratio of 4 : 4 was employed. Soybeans were sown in four rows with a row spacing of 30 cm and a plant spacing of 7 cm (one seed per hole), resulting in an approximate density of 124 500 plants/hm^2. Corn was planted in four rows arranged in alternating wide and narrow rows; the spacing between the two central rows was 70 cm, while the spacing between the outer rows was 40 cm. Plant spacing was 12 cm, achieved through single-seed precision sowing, yielding an approximate density of 1.125 million plants/hm^2. The spacing between soybean and corn rows was maintained at 70 cm, and the total width of the soybean-corn production unit was

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380 cm. The chemicals tested were 96% (S)-metolachlor, manufactured by Shandong Binong Technology Co., Ltd., and 75% thifensulfuron methyl, produced by Anhui Fengle Agrochemical Co., Ltd.

2.3 Experimental design Two herbicides applicable to both soybeans and corn—96% (S)-metolachlor and 75% thifensulfuron methyl—were selected for combination. Various dosage gradients were established in closed weeding experiments to identify the optimal herbicide dosage combination suitable for the soybean corn strip intercropping system in this region. Herbicides were applied in a closed system 2 to 3 d prior to sowing. Immediately following application, shallow soil mixing was performed to a depth of 4–6 cm to ensure even incorporation of the herbicide into the soil. A no-herbicide treatment served as the control (CK). Two test herbicides were combined to establish five treatment groups, designated A, B, C, D, and E, each replicated three times (Table 1). Apart from variations in herbicide dosages, all other agricultural practices were uniformly applied across treatments. Throughout the entire growth period, only pre-emergence closed weeding was conducted, with no subsequent weed control measures implemented.

Table 1 Experimental design for different dosages of 96% (S)-metolachlor and 75% thifensulfuron methyl

Treatment	96% (S)-metolachlor mL/hm^2	75% Thifensulfuron methyl//g/hm^2
CK	0	0
A	1 200	39
B	1 350	42
C	1 500	45
D	1 650	48
E	1 800	51

2.4 Investigation items and methods

2.4.1 Safety investigation. The uniformity of the seedlings, their growth conditions, the normality of the leaves and leaf color, and the presence of any symptoms indicative of phytotoxicity—such as dwarfism, necrotic spots, chlorosis, and deformities—were assessed at 10, 20, and 30 d after the emergence of soybean and corn plants.

2.4.2 Investigation of control effect. The weed control conditions for each treatment were assessed on the 20th and 40th d following application, as well as after harvest. A sample area of 0.25 m^2 was selected, with five randomly selected points evaluated per treatment. The number of weed plants and their fresh weights were recorded, and the plant control effect and fresh weight control effect were calculated.

Plant control effect (%) = (Number of weed plants in the blank control area – Number of weed plants in the treatment area)/Number of weed plants in the blank control area × 100% (1)

Fresh weight control effect (%) = (Fresh weight of weeds in the blank control area – Fresh weight of weeds in the treatment area)/Fresh weight of weeds in the blank control area × 100% (2)

2.4.3 Yield survey. The yield measurement method involved actual measurement. At harvest, five sampling points were selected along the diagonal of each plot, with each point encompassing an area of 1 m^2. Actual harvesting and measurement were conducted at these points, and the yield was converted to kg/667 m^2. The yield increase rates for both the treatment and control areas were calculated.

2.5 Data analysis The data were processed using Microsoft Excel 2003 software and statistically analyzed with DPS v3.11 software.

3 Results and analysis

3.1 Safety The emergence rates and safety of soybeans and corn were assessed on the 10th, 20th, and 30th days after emergence. The results indicated no significant differences in emergence rates or plant heights of soybean and corn among the treatments ($P \leq 0.05$). Additionally, leaf morphology and coloration remained normal, suggesting that the herbicide combinations applied in each treatment did not exhibit any apparent phytotoxic effects on soybean and corn plants (Table 2).

Table 2 Effect of various herbicide concentrations on the safety of soybeans and corn

Crop	Treatment	Emergence rate//%	Plant height//cm			Leaf coloration
			10 d after emergence	20 d after emergence	30 d after emergence	
Soybean	CK	94.37 a	7.25 a	15.84 a	37.38 a	Green
	A	95.47 a	6.89 ab	14.38 a	37.58 a	Green
	B	95.80 a	7.19 a	14.43 a	37.30 a	Green
	C	95.53 a	6.35 b	14.49 a	36.92 a	Green
	D	95.43 a	7.16 a	14.40 a	37.78 a	Green
	E	96.43 a	7.01 ab	15.40 a	37.00 a	Green
Corn	CK	95.43 a	19.60 ab	29.60 a	45.64 a	Green
	A	94.47 a	20.08 a	31.70 a	45.24 a	Green
	B	96.33 a	18.65 ab	32.00 a	45.44 a	Green
	C	95.57 a	18.49 b	29.27 a	47.43 a	Green
	D	95.87 a	18.91 ab	26.66 a	45.73 a	Green
	E	95.63 a	19.67 a	27.87 a	43.64 a	Green

NOTE Different lowercase letters in the same column denote statistically significant differences. The same below.

3.2 Control effect As presented in Table 3, at 20 and 40 d after application and following harvest in the soybean field, treatments D and E exhibited the most effective plant control effect and fresh weight control effect, with these effects being significantly greater than those observed in the other treatments ($P \leqslant 0.05$). At 20 d after application, no significant differences were detected between treatments B and C regarding plant control effect and fresh weight control effect in the soybean field ($P \geqslant 0.05$). Nonetheless, both treatments differed significantly from treatment A. At 40 d after application, no significant differences were observed in plant control effect among treatments A, B, and C in the soybean field. Similarly, the fresh weight control effect did not differ significantly between treatments B and C; however, a significant difference was noted between treatments A and C. After harvest, significant differences in plant control effect were detected between treatment C and both treatments A and B, and there was a significant difference in fresh weight control effect between treatments A and C.

Table 3 Weed control effect in soybean fields treated with various herbicide concentrations %

Treatment	20 d after application		40 d after application		After harvest	
	Plant control effect	Fresh weight control effect	Plant control effect	Fresh weight control effect	Plant control effect	Fresh weight control effect
CK	–	–	–	–	–	–
A	77.11 c	66.00 c	81.89 b	75.50 c	78.54 c	67.87 c
B	81.02 bc	69.27 bc	86.39 b	76.95 bc	80.62 c	74.27 bc
C	85.80 b	76.69 b	90.88 b	83.68 b	87.37 b	81.79 b
D	96.09 a	98.58 a	97.25 a	98.03 a	98.04 a	99.07 a
E	96.09 a	98.59 a	97.25 a	98.24 a	98.04 a	99.07 a

3.3 Yield As shown in Table 4, both the number of pods per plant and the number of grains per pod generally increased with rising herbicide concentrations. The 100-grain weight was highest in treatments D and E, measuring 28.50 and 28.18 g, respectively; the difference between these two treatments was not statistically significant, although both differed significantly from the other treatments. Treatments D and E also exhibited the highest converted yields, at 84.15 and 84.12 kg, respectively, whereas the control treatment yielded the lowest at 59.15 kg, with significant differences compared to the other treatments. Additionally, the yield increase rate tended to rise with increasing herbicide concentration, reaching its peak in treatments D and E at 42.27% and 42.22%, respectively.

Table 4 Effect of different herbicide concentrations on soybean yield

Treatment	Number of plants plants/667 m^2	Number of pods per plant//individual	Number of grains per pod//individual	100-grain weight//g	Converted yield kg/667 m^2	Yield increase rate//%
CK	8 068.91	19.65	1.91	22.98 d	59.15 d	–
A	8 419.73	20.08	1.90	24.83 cd	67.67 c	14.40
B	8 419.73	19.92	1.88	25.63 bc	68.62 c	16.02
C	8 419.73	20.58	1.94	26.70 abc	76.22 b	28.87
D	8 068.91	20.96	2.05	28.50 ab	84.15 a	42.27
E	8 419.73	20.75	2.01	28.18 a	84.12 a	42.22

As presented in Table 5, the number of corn kernels per spike generally exhibited an increasing trend with rising herbicide concentrations. The 100-grain weight was highest in treatment D, measuring 39.46 g, and this value differed significantly from those of the other treatments. The converted yields were greatest in treatments D and E, at 1071.78 and 1073.35 kg, respectively, while the control group had the lowest yield of 947.31 kg, showing significant differences compared to the other treatments. Additionally, the yield increase rate tended to rise with increasing herbicide concentration, with treatments D and E demonstrating the highest increase rates of 13.14% and 13.30%, respectively.

Table 5 Effect of different herbicide concentrations on corn yield

Treatment	Number of spikes individual/667 m^2	Number of kernels per spike individual	100-grain weight//g	Converted yield kg/667 m^2	Yield increase rate//%
CK	4 561.63	682.00 a	36.14 cd	947.31 c	–
A	4 491.45	720.00 a	34.93 d	959.83 bc	1.32
B	4 561.63	681.33 a	36.84 bc	973.35 bc	2.75
C	4 421.27	744.00 a	37.47 bc	1 047.44 abc	10.57
D	4 491.45	710.67 a	39.46 a	1 071.79 ab	13.14
E	4 561.63	744.00 a	37.21 b	1 073.35 a	13.30

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public welfare forest compensation or specialized forest tending subsidies. Through the formalization of management and protection contracts, responsibilities can be explicitly assigned to local administrative units such as towns and villages, forest rangers, or professional cooperatives, thereby operationalizing the principle of "those who manage and protect shall benefit". This approach not only enforces accountability for management and protection but also incentivizes engagement at the grassroots level and among forest farmers. Consequently, it facilitates a balanced approach between construction and management, ensuring that biological firebreak forest belts consistently deliver their ecological and fire prevention functions over the long term.

5 Conclusions

The establishment of biological firebreak forest belts is a vital ecological security barrier project. Through the evaluation process, the system identifies significant issues related to seedling survival, tree species composition, structural integrity, subsequent management and maintenance, as well as archives management. Addressing these challenges necessitates systematic optimization across three dimensions: concepts, technologies, and mechanisms. Only through rigorous scientific planning, precise construction, stringent supervision, and the innovative establishment of a long-term management and protection mechanism can each kilometer of forest belt be transformed into a robust and reliable green firewall. Ultimately, this approach will facilitate the development of an efficient, stable, and sustainable forest fire prevention system, thereby providing a solid foundation for safeguarding regional forest resources and the accomplishments of ecological construction.

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4 Conclusions and discussion

During the experiment, the investigation of certain indicators was slightly delayed due to weather conditions, which had some impact on the test results. However, the effect of different herbicide concentration combinations on various weed species was not significantly affected. The variations in herbicide concentrations across treatments did not result in significant differences in the emergence rates or safety indicators of corn and soybeans compared to the control. This suggests that the herbicide concentrations used in each treatment were relatively safe for the growth of both crops. As the concentration of herbicides increased in each treatment, the effect of weed control in soybean fields exhibited an upward trend. Treatments D and E demonstrated the most effective results. Specifically, 40 d after application, the plant control effect and fresh weight control effect were 97.25% and 98.03% for treatment D, and 97.25% and 98.24% for treatment E, respectively. No significant difference was observed between treatments D and E. Furthermore, the yields of soybeans and corn treated with herbicides were higher than those of the control group. This difference can be attributed to the absence of herbicide application in the control group, where weeds competed with the crops for essential resources such as nutrients, light, and water, thereby creating an environment that was detrimental to crop growth[4]. In this study, as the concentration of herbicides increased, the highest converted yields of soybeans and corn were observed in treatments D and E. Specifically, the soybean yields in treatments D and E were 84.15 and 84.12 kg/667 m^2, respectively. The corn yields for treatments D and E were 1 071.79 and 1 073.35 kg/667 m^2, respectively, with no significant differences observed between the two treatments. Considering the overall input and output, this region can identify treatment D as the optimal combination of herbicide concentrations for weed management in the soybean and corn strip intercropping system. This treatment significantly improves weed control effect and crop yield in the soybean and corn strip intercropping system, effectively addressing the prevalent issue of "incomplete weed suppression" in soybean and corn strip intercropping production in Zhongwei City.

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