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STUDY ON STRIP PLANTING TECHNOLOGY OF SORGHUM IN MILDLY SALINE LAND AND ANALYSIS OF THE MECHANISM OF YIELD AND EFFICIENCY INCREASE

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Abstract

Sorghum strip cropping can make full use of light and heat resources and increase the production output value per unit of land. This study conducted sorghum & soybean and sorghum & peanut strip technology trials at the Tie ling experimental base in China for three consecutive years from 2021 to 2023, studied the yield and yield traits under different sorghum & soybean and sorghum & peanut ration patterns, and then proceeded to analyze the economic benefits of different ration patterns. The results showed that sorghum & soybean strip planting mode,"4 sorghum + 4 soybean " is the optimal planting mode, compared with the sorghum clear-cutting, improved the average sorghum plant height, stem thickness, reduced the spike length, and promoted the sorghum's single-plant dry matter accumulation, the sorghum yield per unit area was increased by 11.2 percentage and did not cause a reduction in soybean yields, and to achieve a harmonious symbiosis of soybean and sorghum in the same plot and a season of double harvest. In the sorghum & peanut strip planting pattern, sorghum is kept at 90000 plants per hectare, inter-cropping with peanut can optimise sorghum agronomic traits, improve sorghum yield per unit area, promote sorghum dry matter accumulation, "4 sorghum + 4 peanut" economic benefits are higher than sorghum clear-cutting. Sorghum & soybean and sorghum/peanut are both more conducive to the formation of higher production value under the 4:4 row ratio pattern, which is the optimal ratio.

Key words: Sorghum; Soybean; Peanut; Striped germplasm; Yield increase mechanism

Introduction

Soil salinisation is a global resource and environmental problem that severely constrains crop production. The area of saline soil worldwide has reached 955 million ha, accounting for about 10 % of the total arable land (Ashraf, 2009; Wambua *et al.*, 2017). China is a large saline land country, ranking third in the world in terms of saline land area, with a total area of saline wasteland and saline land affecting arable land of more than 30 million hectares, accounting for about 25 percentage of the country's available land, which is mainly located in Northwest, Northeast, North China, and the coastal region (Wang *et al.*, 2011), so how to develop and make use of saline land has become a key issue that is urgently needed to be solved for agricultural production at the present time.

Sorghum originated from the barren African continent, as a C_4 crop with multiple resistances such as drought resistance, salinity tolerance and barrenness tolerance, it plays an irreplaceable key role in marginal land use and plantation structural adjustment in arid and semi-arid areas (Zou *et al.*, 2020). A large number of studies have concluded that sorghum is not suitable for continuous cropping, especially in saline and alkaline land, where year-round continuous cropping leads to deterioration of plant development, serious pests and diseases, and reduced yield (Li *et al.*, 2017; Li *et al.*, 2021a). Constructing a three-dimensional planting pattern between sorghum and other crops in saline and alkaline land according to their growth characteristics can make full use of light, temperature, water, heat and other resources and maximize the economic value (Gaskell, 2015).

It has been shown that inter-cropping is a traditional agricultural cropping pattern in China. Compared with mono-cropping, inter-cropping has a strong cultivation advantage, which can make use of the reciprocal effect between different crops to make efficient use of natural resources, reduce pests and diseases, and increase crop yields (Alnouri *et al.*, 2016; 2018). It has been shown that the land productivity of maize in saline soil is increased when inter-cropping with equal row ratios, which is a clear advantage of inter-cropping (Cai *et al.*, 2021). Sorghum-soybean inter-cropping with a row ratio of 2:4 has a higher land equivalent ratio, water use efficiency, and nitrogen, phosphorus, and potassium accumulation (Dong *et al.*, 2016). The inter-cropping system causes changes in canopy micro-environment such as light intensity, light quality, temperature and humidity, which in turn affects the morphological construction of the crop and photosynthetic physiological characteristics (Alnour *et al.*, 2016). Research results show that inter-cropping system can improve photosynthesis and nutrient uptake of crops, thus increasing crop biomass and yield, showing strong productivity (Li *et al.*, 2023). Previous studies have shown that in long-term inter-cropping trials of soybean with maize and wheat, the yields of inter-cropped crops were

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significantly higher than those of monocrops by 7.0 % to 33.9 %, and the land-equivalent ratio could reach about 1.5 (Yang *et al*., 2019).

Currently, of the more than 100 major inter-cropping combinations existing in China, inter-cropping between grasses and legumes is the most widely used in agricultural production (Liu *et al*., 2023). Sorghum, as a staple crop in western Liaoning, is still at a preliminary stage of exploration for the types of crops that can be inter-cropped with it. The main common ones in production are sorghum and soybean, sorghum and peanut inter-cropping cultivation mode, but its specific working mechanism is still unclear.

This study takes sorghum and soybean inter-cropping, sorghum and peanut inter-cropping as the research object, through carrying out sorghum & soybean, sorghum & peanut inter-cropping mode research in light saline ecological zone, determining and analyse the changes of sorghum agronomic and yield traits in different inter-cropping row ratios, determining reasonable inter-cropping row ratios, tapping the potential value of inter-cropping of cereal and legume crops, and constructing inter-cropping cropping systems in different regions of our country in accordance with local conditions, which is of great importance for improving land production capacity and dry farming development. It is of great significance to improve the land production capacity and the sustainable development of dry land agriculture by establishing inter-cropping cropping systems for the green development of agriculture in different regions of China according to local conditions.

Material and Methods

Test sites and test materials: Sorghum/soybean and sorghum/peanut strip cropping experiments were conducted from May to October 2021 to 2023 at the experimental base of the Academy of Agricultural Sciences (AAAS) in Tieling City, China (longitude 123.84, latitude 42.29) (Fig. 1). The average temperature during the experiment was 24.7°C (day/night temperature 26.7°C/ 20.1°C), the average humidity was 37.5%, and the average sunshine hours were 8.4 hours.

The soil conditions were salinity 1.89‰, pH 7.9 0.137%, total nitrogen, 0.156% total phosphorus, 2.019% total potassium, 68.218 mg kg^{-1} effective nitrogen, 15.448 mg kg^{-1} effective phosphorus, and 124.625 mg kg^{-1} effective potassium, which were mildly saline.

The test materials included sorghum, soybean and peanut. The sorghum/soybean (G/D) test variety was LiaoNuo10/TieFeng31; the sorghum/peanut (G/H) test variety was LiaoNuo11/TieFa19.

Experimental design: In this study, two groups were set up, G/D and G/H, each group was set up with five treatments, and the planting method and planting density of each treatment are shown (Table 1). Each treatment row was 9.5 m long, and the treatments within the G/D and G/H groups were arranged in sequence in the direction of the vertical ridge, and a 1 m walkway interval was made between G/D and G/H along with the direction of the ridge. G/H was sown with a long-lasting slow-release fertilizer of 750 kg per ha. G/D was manually fertilized, the sorghum planting area with a long-lasting slow-release fertilizer of 750 kg per ha, and the soybean planting area with a low-nitrogen compound fertilizer of 300 kg per ha. G/D was manually fertilized with 750kg per ha of long-lasting slow-release fertilizer in the sorghum planting area and 300 kg per ha of low-nitrogen compound fertilizer in the soybean planting area. In sorghum planting area, 38% atrazine 6000g per ha is sprayed once before seedling, and 50 percentage acid 600g per ha + 38% atrazine 6000g per ha is sprayed once at 3-5 leaf stage. Soybean and peanut planting areas are weeded manually. Field management is the same as conventional field management.

Measurement items and methods: At maturity, sorghum plant height, spike length and stem thickness were measured for each treatment. At maturity, three samples were taken from different crops of each treatment to measure yield, each time the sampling area was 1.2m^2, after natural air-drying, the effective number of spikes and yield per unit area of sorghum in the plot were determined, and the grain weight of a single spike was obtained by calculation, and the weight of a thousand grains of sorghum of each treatment was measured three times repeatedly after the measurement of yield. Three plants were taken from different crops in each treatment during each reproductive period and the dry matter weight of each plant was measured after natural air drying.

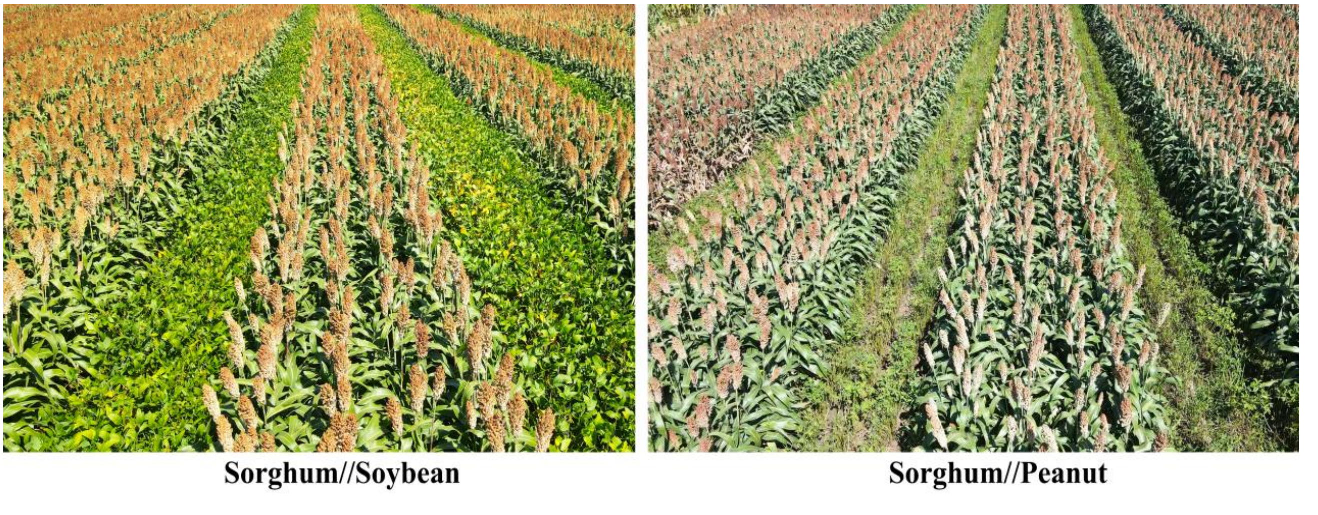

Fig. 1. Sorghum/soybean and sorghum/peanut strip cropping.

Statistics and analysis of data: The experiment was conducted using SPSS 25 software, Excel 2010 and DPS v7.50 data statistical analysis system for graphing and data analysis. Among the statistical analyses multiple comparisons were made using the new complex polar deviation method, $p<0.05$, significant difference; $p<0.01$, highly significant difference.

Results and analyses

Research on quality and efficiency improvement technologies for sorghum/soybean strip cropping

Effect of different sorghum/soybean strip cropping patterns on crop agronomic traits and yield: The agronomic traits of sorghum in different treatments are shown (Table 2) plant height decreased with increasing spacing and spike length increased with increasing spacing.6G+6D and 4G+4D had the same spacing, but sorghum plants in 4G+4D had larger stems and were larger than sorghum clearcuts.

Benefit analysis of different sorghum/soybean strip cropping patterns: A benefit analysis of different sorghum/soybean strip cropping patterns was conducted. The costs and benefits of the treatments are shown (Tables 4 and 5). The 4G+4D planting pattern had the highest economic benefits, with an average increase in income of 975 yuan per ha compared to sorghum individual planting, and an average increase in income of 2115 yuan per ha compared to soybean individual planting, while the other treatments were less economically efficient, with reductions of 16.7 percent and 18.6 percent compared to sorghum individual planting, respectively.

Research on quality and efficiency improvement technologies for sorghum/peanut strip cropping

Effect of different sorghum/peanut strip cropping patterns on crop agronomic traits and yield: The agronomic traits of sorghum in different treatments are shown (Table 6). In the sorghum/peanut strip cropping pattern, the reduced spacing was still able to appropriately reduce sorghum plant height and increase stem thickness. Spike length decreased with reduced spacing. 6G+6H and 4G+4D spacing were the same, but the 6G+6H strip cropping pattern was more suitable for sorghum growth.

Benefit analysis of different sorghum/peanut strip cropping patterns: In Table 8, sorghum/peanut strip planting pattern can promote the growth and development of sorghum and can effectively improve the sorghum yield while maintaining 80000 sorghum plants/ha, and all treatments have improved economic benefits compared with sorghum clear seed. However, the sorghum/peanut strip planting pattern inhibited peanut growth to a certain extent, and there was a significant reduction in yield, especially in the 6G+2H treatment, which reduced peanut yield by 46.99%, while the inhibitory effect of 4G+4H and 6G+H on peanut was smaller, but the economic benefits were lower than that of peanut clear-cut seeding.

Discussion

Yield traits under sorghum & soybean strip cropping techniques: Soil salinity has a greater impact on crop growth and development, and the yields of sorghum, soybean, and peanut in the sorghum inter-cropping model are important discriminatory indexes of the inter-cropping system, and how to seek the optimal combination of them is the key to achieving the overall benefits of the system (Fan *et al*., 2022). Competitive and complementary effects on the use of light, water, nutrients and other resources when inter-cropping grass and legume crops (Liao *et al.*, 2021). Sorghum/soybean strip cropping can expand the light space of the low crop soybean and can also play the role of soybean nitrogen fixation and land nourishment, which is conducive to improving soil conditions and soil fertility. In this experiment, 4G+4D was the optimal treatment, which changed the agronomic traits of sorghum less compared with sorghum clear seeding, and increased sorghum yield, stabilised soybean yield, and effectively improved economic benefits. The main reason for the increase in sorghum yield may be due to the nitrogen fixation of legumes, so that most of the below-ground nitrogen is absorbed and utilised by sorghum, which in turn increases the yieldn (Dong *et al*., 2016). The results are in resounding agreement with the findings of Chang *et al*., (2018) and are also in general agreement with the findings. However, there is a slight difference with the results of (Zai *et al*., 2020).

Yield traits under sorghum & groundnut strip cropping techniques: In terms of inter-cropping sorghum with peanut, Chang *et al.*, *(*2018) showed that when inter-cropping maize and peanut in mildly saline land, maize yield relatively increased, and all peanut had a significant yield reduction (Yang *et al*., 2019). Sorghum yields in the inter-cropping patterns used in this study increased to different degrees, with the highest yields when planted in equal row ratios (4:4), which were stable and consistent from year to year. This result indicated that sorghum was the main crop in sorghum peanut inter-cropping, creating a significant inter-cropping advantage yield, and the significant increase in yield was due to the increase in thousand kernel weight and spike weight. Inter-cropping with peanut and other low crops, sorghum growth and development occupy a certain advantage, inter-cropping to form a composite group can make full use of land resources, land equivalent ratio LER is one of the important indicators to measure the effect of inter-cropping (Fan *et al*., 2022). The study concluded that inter-cropping pattern can increase the land equivalent ratio and land productivity (Alnouri *et al*., 2018; Li *et al*., 2021b). Different inter-cropping row ratio treatments had LER greater than 1, and inter-cropping sorghum land utilisation was higher than that of clear cropping, indicating that inter-cropping can effectively improve land utilisation and increase sorghum yields, which further confirms the above conclusions.

In addition, this study found that net returns were lower in all treatments in the mildly saline sorghum/peanut strip cropping compared to peanut clearcutting, which may be related to differences in peanut prices between seasons of the year and may be due to the shadowing effect between sorghum and peanut under wide-avenged conditions in the Tieling experimental area, which deprived peanut of adequate sunlight and resulted in lower peanut yields in all inter-cropping treatments compared to peanut clearcutting.

Table 1. Experimental treatment names.

Deal with	Sorghum planting density excluding groundnut/ soybean (plants/ha)	Sorghum spacing (cm)	Soybean/peanut planting density (plants/ha)	Soya/peanut growing methods
4G + 4D	90000	9.3	150000	Leave double plants 20cm apart
6G + 6D	90000	9.3		
6G + 2D	90000	13.9		
8G/D	150000	11.1		
8D	-	-		
4G + 4H	90000	9.3	150000	Spacing of plants 10cm apart
6G + 6H	90000	9.3		
6G + 2H	90000	13.9		
8G/H	150000	11.1		
8H	-	-		

Table 2. Agronomic traits of sorghum in different treatments.

Process name	Plant height (m)	Stem thickness (cm)	Spike length (cm)
4G + 4D	1.65 ± 0.03a	2.072 ± 0.102ab	32.2 ± 2.1a
6G + 6D	1.63 ± 0.06a	1.771 ± 0.056c	30.8 ± 2.7b
6G + 2D	1.49 ± 0.01c	2.175 ± 0.096a	34.4 ± 2.5a
8G/D	1.57 ± 0.04b	1.996 ± 0.103b	32.8 ± 1.3a

From Table 3, it is clear that single spike grain weight and thousand kernel weight decreased with decreasing spacing. Compared with 6G+6D, 4G+4D had a better row ratio configuration. Appropriate densification was effective in improving sorghum yield, and 4G+4D had the highest sorghum yield per acre, and the soybean yield differed very little from that of the soybean clear cuts

Table 3. Yield and yield components of different treatments.

Process name	Sorghum plot yield (kg)	Converted clear seed yield (kg/ha)	Number of effective spikes	Grain weight per spike (g)	Thousand grain weight (g)	Soya bean plot yield (g)	Converted clear seed yield (kg/ha)
4G + 4D	1.22a	10166.70a	22.0a	55.45	19.25b	408.70a	3405.91a
6G + 6D	1.12b	9333.45b	22.3a	50.16	18.62c	342.70c	2855.85b
6G + 2D	1.03c	8611.21d	14.0c	73.81	21.88a	355.97b	2966.40b
8G/D	1.10b	9138.90c	17.7b	62.14	19.56b	-	-
8D	-	-	-	-	-	406.50a	225.83a

Figure 2 shows the dry matter weight of different organs of different crops in different treatments at each fertility stage, and the dry matter accumulation of sorghum monocultures was higher in sorghum 6G+2D and 4G+4D at maturity compared to sorghum clear seeding pattern. The sorghum-soybean strip cropping pattern retarded dry matter accumulation in soybean compared to soybean clear cropping pattern in all inter-cropping treatments

Table 4. Individual treatment costs and their components.

Process name	Fertilizer cost (yuan/ha)	Cost of seed use (yuan/ha)	Land rent and field management costs (yuan/ha)	Total cost (yuan /ha)
4G + 4D	1878.75c	721.80b	13500a	16100.70c
6G + 6D	1878.75c	722.25b	13500a	16100.70c
6G + 2D	2345.7b	487.50c	13500a	16333.20b
8G/D	2812.5a	421.95d	13500a	16734.45a
8D	945.02d	937.5a	13500a	15382.50d

Table 5. Treatment benefits and their components.

Process name	Sorghum yield (kg/ha)	Soybean yield (kg/ha)	Production value benefit (yuan/ha)	Government subsidy (yuan/ha)	Total return (yuan/ha)	net income (yuan/ha)
4G + 4D	5083.35c	1702.95b	24616.35b	3150b	27766.35a	11665.80a
6G + 6D	4666.65d	1428.01c	21853.80d	3150b	25003.80b	8903.25d
6G + 2D	6458.40b	741.61d	23454.01c	1575c	25029.01b	8695.95e
8G/D	9138.90a	-	27416.70a	0d	27416.70a	10682.40b
8D	-	3387.45a	18631.05e	6300a	24931.05b	9548.55c

Note: 1. According to the policy requirements of China's Liao Nong Nong [2023] No. 105, the subsidy standard for soybeans was further raised in 2023, and the subsidy standard for soybeans per ha was 5250 yuan higher than that for corn. 2. According to the average subsidy standard of 1050 yuan/ha for corn in the province in 2021, the average subsidy standard for soybeans in 2023 will be about 6300 yuan/ha; according to the local purchase price of sorghum of 4 yuan/kg, the purchase price of soybeans of 5.5 yuan/kg to calculate the benefits of the output value. 3. According to the sorghum fertiliser of 3,150 yuan/tonne and soybean fertiliser of 3,750 yuan/tonne to calculate the cost of fertilisers; according to the local market price of soybean seed of 25 yuan/kg and soybean seed of 2.5 yuan/tonne. kg, soybean seed 37.5kg/ha, sorghum seed 30 RMB/kg, 120000 holes/ha sorghum seed 1.5kg to calculate the cost of seed.4. Sorghum and soybean land rent, field management and other costs are calculated in accordance with the 13500 RMB/ha.

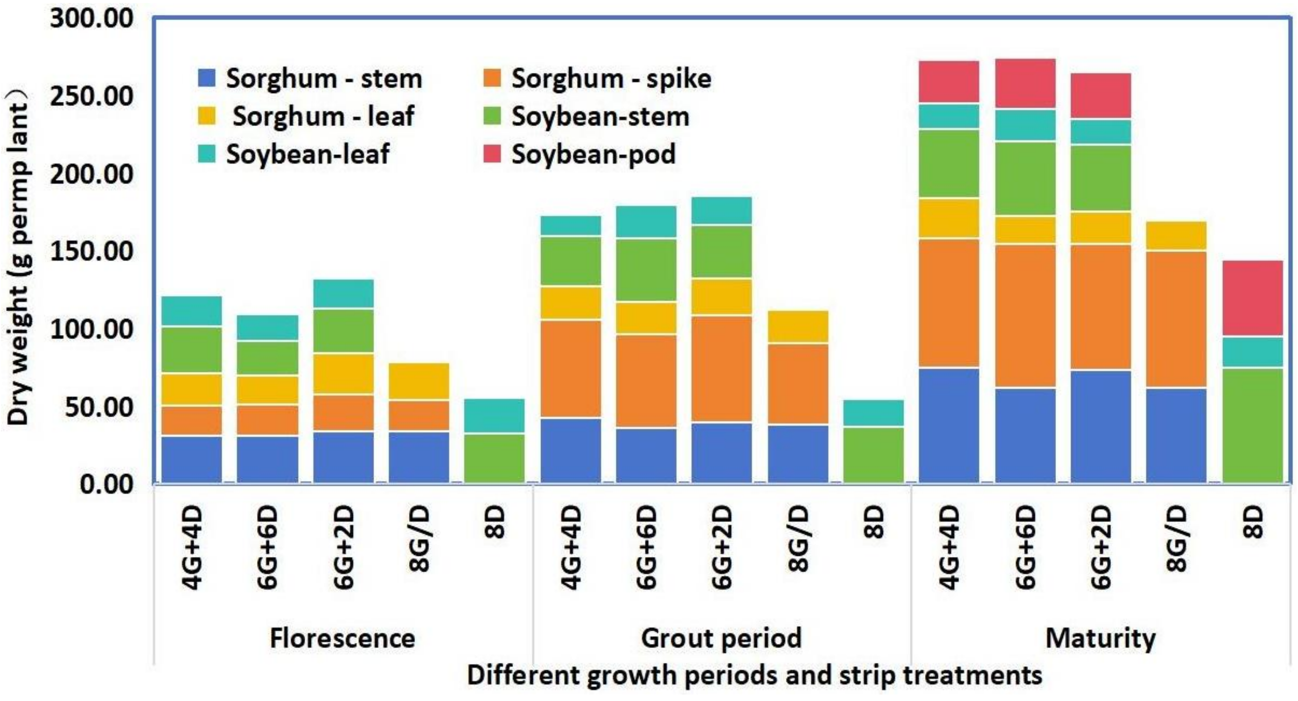

Fig. 2. Dry matter weight of different organs of different crops in different treatments at different fertility stages.

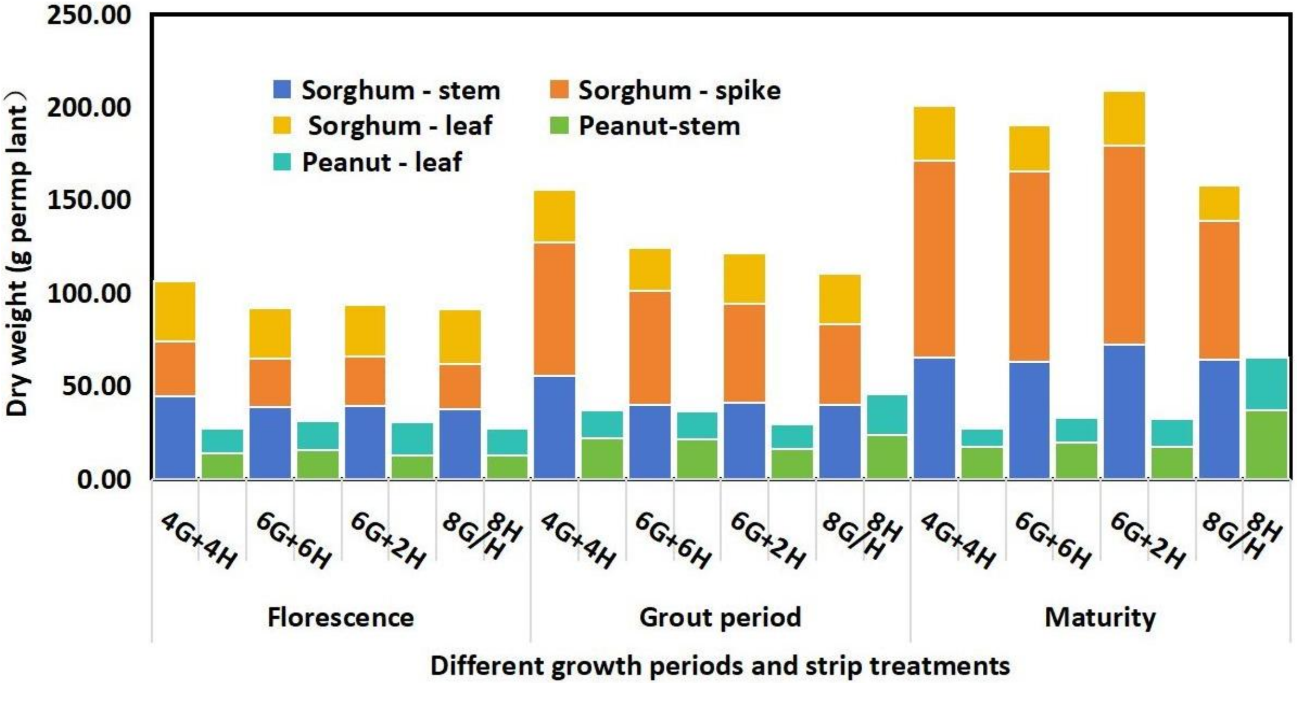

Fig. 3. Dry matter weight of different organs of different crops in different treatments at different fertility stages.

Agronomic traits under strip cropping techniques sorghum & soybean, sorghum & peanut strip cropping techniques: Reasonable population structure is conducive to the growth and development of individual crops and the full utilisation of resources. Reasonable field configuration can reduce individual competition and light loss, resulting in high population yields (Li *et al*., 2021a). Crop plant morphology has a certain degree of plasticity, and changes in the natural growing environment will produce corresponding response mechanisms in agronomic traits (Dong *et al*., 2016; Lei *et al*., 2023). The results of this study showed that sorghum showed a reduction in plant height and an increase in stem thickness when inter-cropped with sorghum & soybean and sorghum & peanut in mildly saline soil, indicating that inter-cropping improved the population ventilation and light transmission conditions of sorghum, a highly dominant crop, and that the excellent field micro-environment laid a good foundation for seed formation.

Dry matter accumulation under strip cropping techniques sorghum & soybean, sorghum & peanut strip cropping techniques: And dry matter accumulation is the basis of economic yield of sorghum and an important indicator of plant organic matter accumulation (Dong *et al*., 2016; Li *et al*., 2017; Liao *et al*., 2021). In this study, under mild saline conditions, the dry matter accumulation of sorghum significantly increased under inter-cropping treatments, which was consistent with the trend of sorghum yield, and the best performance was achieved when planted with a row ratio of 4:4. The significant decrease in sorghum dry matter accumulation could be attributed to the increase in precipitation, decrease in solar radiation and weakening of photosynthesis starting from the tasseling stage of sorghum, leading to a decrease in sorghum dry matter accumulation under all cropping patterns and had a greater effect on sorghum dry matter accumulation in inter-cropping treatments compared to the clear planting.

Table 6. Agronomic traits of sorghum in different treatments.

Process name	Plant height (m)	Stem thickness (cm)	Spike length (cm)
4G + 4H	1.60 ± 0.05a	2.068 ± 0.334b	31.8 ± 2.2d
6G + 6H	1.58 ± 0.07a	2.161 ± 0.158b	34.0 ± 2.6c
6G + 2H	1.40 ± 0.08b	2.363 ± 0.085a	36.4 ± 1.0a
8G/H	1.60 ± 0.05a	1.792 ± 0.201c	35.4 ± 1.9b

It shows the yield and yield components of different treatments, sorghum yield reached maximum under 6G+6H treatment, sorghum clear seed yield was the lowest, and sorghum/peanut strip cropping pattern was effective in increasing sorghum yield (Table 7). The sorghum/peanut strip cropping pattern inhibited peanut growth and development compared to peanut clear seed, and the 6G+6H treatment had the least effect on peanut. The yields of the inter-cropping treatments were reduced by 21.30, 34.12 and 46.99 percentage, respectively, compared with peanut clear seeding

Table 7. Yield and yield components of different treatments.

Process name	Sorghum plot yield (kg)	Converted clear seed yield (kg/ha)	Number of effective spikes	Grain weight per spike (g)	Thousand grain weight (g)	Peanut plot yield (g)	Converted clear seed yield (kg/ha)
4G + 4H	1.42a	11805.60b	20.3a	69.75b	26.62a	311.17b	2593.05b
6G + 6H	1.47a	12250.05a	21.7a	68.19b	20.77c	260.47c	2170.50c
6G + 2H	1.18b	9861.15c	14.3c	82.59a	26.91a	209.57d	1746.45d
8G/H	1.14b	9527.85c	17.7b	64.76c	24.79b	-	-
8H			-	-	-	395.37a	3294.75a

From Figure 3, it can be seen that the sorghum/peanut strip cropping pattern at maturity suppressed dry matter accumulation in the above-ground part of peanut, resulting in peanut yield reduction. The dry matter weight of sorghum plants in different inter-cropping treatments was higher than that of sorghum clear seed, and inter-cropping with peanut could promote dry matter accumulation of sorghum plants

Table 8. Costs and benefits of treatments and their components.

Process name	Sorghum yield (kg/ha)	Peanut yield (kg/ha	Production value benefit (yuan/ha)	Cost of seed use (yuan/ha)	Fertiliser cost (yuan/ha)	Land rent, field management and other costs (yuan/ha)	Net income (yuan/ha)
4G + 4H	5902.80d	1296.60b	31321.95b	1753.20b	2362.5a	13500a	13706.25b
6G + 6H	6125.11c	1085.25c	29770.20c	1753.20b	2362.5a	13500a	12154.65c
6G + 2H	7395.92b	436.65d	26772.03e	1003.21c	2362.5a	13500a	9906.45d
8G/H	9527.85	-	28583.55d	421.95d	2362.5a	13500a	12299.25c
8H	-	3294.75a	34594.95a	3000.05a	2362.5a	13500a	15732.45a

Note: According to the local sorghum purchase price of 3 yuan / kg, peanut purchase price of 10.5 yuan / kg to calculate the output value benefit; sorghum, peanut application of the same kind of fertiliser, according to 3150 / tonne calculation of fertilizer costs; according to the local market price of peanut seed 20 yuan / kg, peanut seed 150kg / ha, sorghum seed 30 yuan / kg, 120000 holes / ha sorghum seed 0.75 kg calculation of the cost of seed; The cost of land rent and field management for sorghum is calculated at RMB13500/ha.

Conclusion

Overall, under mild saline and alkaline environment, sorghum is the dominant crop in sorghum & soybean and sorghum & peanut inter-cropping system, and the reasonable inter-cropping not only improves the plant characteristics, the reasonable canopy structure makes the sorghum photosynthesis and light energy utilisation significantly enhanced, but also significantly improves the productivity of the farmland land with high land utilisation and lays down the good foundation for the transportation of the material production and the construction of the seed grain. Good foundation. Mildly saline land sorghum & soybean, sorghum & peanut inter-cropping are row ratio of 4:4 when the sorghum yield is maximum, cut can obtain relatively high economic benefits.

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