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Research Article

Effects of soil amendments and coverings on the kenaf yield and soil physicochemical properties in saline-alkali land

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Abstract

In order to investigate the effects of various treatments on the growth of kenaf in saline soil, this study employed a comprehensive experimental design incorporating a dual approach of soil amendment and mulching techniques. Soil treatment of saline and alkaline land, as well as biological material mulching treatment after sowing kenaf, were conducted. The growth dynamics of kenaf were assessed before the mid-term investigation, and the harvest period was examined. Soil physicochemical properties were measured and analysed at different periods. The results show that in the analysis of red sesame yield traits, the differences mainly appeared between soil treatments. There is no significant difference between the different mulching treatments within each soil treatment. In the mid-term study, significant differences were observed in kenaf plant height. Plant height was the most affected by soil conditioners, while other yield traits did not show significant variations. During harvest, only stem thickness and dry weight of a single plant did not show significant differences, whereas other yield traits did. The application of soil conditioners resulted in a 58.15% increase in dry hull yield compared to organic fertilizers and a 22.66% increase compared to regular fertilizers. Soil conditioners also led to higher levels of effective phosphorus, quick-acting potassium, organic matter, and total nitrogen throughout the kenaf growth period compared to organic and regular fertilizers. This is beneficial for enhancing soil quality and reducing soil alkalinity. Combined with the results of kenaf yield and soil physical and chemical properties analysis, it has been proven that the application of soil conditioner has the best effect, followed by the application of compound fertilizer, with organic fertilizer treatment being the least effective.

Keywords: kenaf; kenaf production; phosphogypsum; saline-alkali land; soil physicochemical properties

Introduction

Soil salinization, a critical environmental issue affecting agricultural productivity worldwide, is primarily caused by the rise of saline shallow groundwater through capillary action or the application of irrigation water containing salt. This process leads to the concentration of dissolved salts and/or sodium ions at concentrations surpassing the threshold limits on the cation exchange sites within the soil matrix (Talebnejad and Sepaskhah, 2016). This excessive salt concentration disrupts the delicate balance necessary for healthy soil structure and

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function, posing significant challenges to plant growth and ecosystem health. It is a significant issue that hinders the progress of agricultural production and poses a threat to the ecological environment's safety (Mao Qinglian, 2020). Currently, the global saline land area has exceeded 9.55×10^8 hm^2, which is about 10% of the total land area (Zhang Zhimei, 2021). More than 100 countries have been affected by soil salinization, which is still on the rise (Yang, 2022), greatly limiting global crop yield and ecological security, and causing serious economic losses and ecological crises (Shrivastava and Kumar, 2015; Ivushkin, 2019). The results of the second national soil census conducted by the Ministry of Agriculture revealed that the area of saline and alkaline land in China is approximately 3.46×10^7 hm^2, representing 4.88% of the total usable land area of the country (Shi Jianping and Song Ge, 2016). Saline and alkaline land have high pH levels and rich soil colloid content, leading to salinization accompanied by alkalization, low soil organic matter, nutrient content, and trace element deficiency (Navarro-Torre *et al.*, 2023). Nutrients necessary for crops are challenging to absorb and utilize due to the formation of precipitation in the higher soil pH, resulting in crop nutritional deficiencies. This condition is not conducive to farming and impedes agricultural development (Zhou Qiyun, 2021). Therefore, exploring measures to improve saline soil and enhancing production capacity play crucial roles in ensuring the stability of arable land and ecological security (Yu Shuhui, 2017).

Kenaf (*Hibiscus cannabinus* L.) is an annual bast fiber crop of the genus Hibiscus in the family Malvaceae, also known as kenaf and hibiscus hemp. It is characterized by fast growth, strong resistance, wide adaptability, and high saline tolerance (An *et al.*, 2022; Chen *et al.*, 2024). Kenaf fiber has the effect of water absorption, fast water dispersion, and antibacterial and antimicrobial properties, making it recognized as one of the new fiber raw materials that can replace wood (Sapuan, 2018). Kenaf bast fiber has strong tensile strength, soft fibers, and fast moisture absorption and water dispersal. It is an important raw material for the textile and manufacturing industry (Khakifirooz *et al.*, 2012). Kenaf is commonly used in blending with cotton and hemp, and in the production of sacks, linen, linen carpet, rope, kenaf mulch, lightweight composite panels, activated charcoal, fodder, and more. Additionally, it is utilized for soil and water conservation, cultivation substrates, etc. (Liu *et al.*, 2018; Papadopoulou *et al.*, 2014; Chen *et al.*, 2014). The methods of improving saline soil mainly include physical and hydraulic engineering regulation, biological improvement, and chemical conditioning. Physical improvement and water conservancy engineering are highly feasible and effective for improving saline-alkaline land. However, they are costly and their regulatory impact is influenced by soil texture, weather conditions, water quality, and other factors. This makes them unsustainable and challenging to widely implement and popularize (Zhou *et al.*, 2023; Shen *et al.*, 2023). Biological improvement can be achieved by planting salt-tolerant plants and cultivating salt-tolerant microorganisms. However, the time-limited effect on soil quality improvement is poor, and the stability and long-lasting effect on ecosystems remain to be observed (Qian, *et al.*, 2023). Chemical improvement is mainly achieved through the cultivation of salt-resistant plants and cultivating salt-resistant microorganisms. Biological improvement can enhance saline-alkaline land by planting salt-tolerant plants and cultivating salt-tolerant microorganisms. However, the speed of soil quality enhancement is slow, and the long-term stability and impact on ecosystems are yet to be determined (Qian *et al.*, 2023). Chemical improvement primarily decreases soil soluble sodium ion concentration and salinity through methods such as ionic substitution, acid and alkali neutralization, and ionic equilibrium. The commonly used materials for chemical conditioning improvement include gypsum, desulfurization gypsum, ferrous sulfate, humic acid, and furfural slag. However, their costs are very high. Furfural slag, etc., are low-cost, fast-acting, and highly operable materials (Zhao *et al.*, 2021; Sun *et al.*, 2022). However, they also contribute to secondary pollution, which hinders the effectiveness of improving saline-alkaline soils (Fan Wangtao, 2020). Therefore, there is an urgent need for an effective and low-cost saline-alkaline land improvement measure to enhance plant productivity and restore the ecology of saline-alkaline areas (Xu Chenglong, 2020).

In the hemp planting areas in the middle and lower reaches of the Yangtze River, the average temperature in early April can also reach the temperature for seed germination. Due to prolonged low temperature and rainy weather before and after the Qingming Festival, plastic film covering is often used for sowing. The results of the study showed that although film cultivation can reduce irrigation and increase soil temperature, most of the films are polyethylene plastic films, which can damage the soil structure and pollute the environment (Hu *et al*., 2020; Wang *et al*., 2021). It is crucial to address the multifaceted impacts of soil salinization comprehensively. This includes not only detailing the mechanisms leading to salinity buildup but also exploring the implications for soil chemistry, plant physiology, and broader ecological dynamics. Understanding these interconnections is vital for developing effective management strategies to mitigate the adverse effects of salinization on agricultural systems and natural environments.

In order to both effectively improve the quality of saline soils and increase farmers' profitability; a combination of biological and chemical enhancements was used to select kenaf crops with strong saline and alkali tolerance. Organic fertilizer, peat, phosphogypsum, and compound fertilizer were applied for soil improvement. In addition, in conjunction with Zhang *et al*. (2015) the effect of ground cover on the growth and yield of kenaf in different types of saline soils, the topsoil after sowing was treated with rice straw, crushed hemp bone, hemp mulch, and other measures to study their impact on kenaf growth, kenaf yield, and the physical and chemical properties of the soil. The aim was to identify the optimal cultivation measures and methods for kenaf planting, providing technical support for kenaf cultivation. In order to provide a scientific basis for the improvement of saline and alkaline land and to promote the sustainable development of the kenaf industry, it is of great significance.

Materials and Methods

Test materials

Kenaf using the Institute of Bast Fiber Crops Chinese Academy of Agricultural Sciences (IBFC) selected and bred ultra-high yield hybrid combination varieties 'H318'.

Test setup

The experiment consisted of two factors: soil treatment and mulching treatment. A split zone design was implemented, with soil treatment A serving as the main zone (with 3 levels: organic fertilizer A1, soil amendment A2, compound fertilizer A3). Mulching treatment B was designated as the secondary area (with 4 levels: straw B1 - approximately 1 cm thick, broken kenaf B2 - approximately 1 cm thick, hemp mulch B3 - one layer, control B4 - no cover). Each treatment group was randomly arranged and repeated three times, resulting in a total of 36 plots. Protective rows surrounded each cell which had an area of 10 square meters. Straight wide strip seeding method was employed with two cells per plot. Approximately 1850 seeds were sown in each plot. The experimental site was located in Section 14 of Weiken in Xiaoshan District, Hangzhou City, Zhejiang Province under the jurisdiction of the Administrative Committee Office for Agricultural Foreign Comprehensive Development Zone on reserved saline-alkali land. The average values for soil physicochemical and chemical properties prior to sowing were as follows: Alkali hydrolysis N =47.64 mg/kg. available P=32.68 mg/kg. quick available K=140.63 mg/kg. organic matter =9.04 g/kg. total N=0.58 g/kg. pH=7.69. salt content =0.80 g/kg. electrical conductivity =287 .25 μs/cm. Seeding took place on May 26th.

Soil treatment (A): The application rate of organic fertilizer (A1) was 3000 kg/hm^2, with a minimum content of $N+P_2O_5+K_2O \geq 4.0\%$ and organic matter $\geq 30.0\%$ (Guo *et al*., 2020). The soil amendment (A2) consisted of peat and phosphogypsum in a ratio of 4:1, with an application rate of 7500 kg/hm^2 (Zhou et al., 2017; Dou et al., 2024). The control group (compound fertilizer A3) received 750 kg/hm^2 of 16-16-16 compound fertilizer (Chen et al., 2018), with 300 kg/hm^2 applied as base fertilizer during soil tilting, 75 kg/hm^2 at the seedling stage and later stage, and another 300 kg/hm^2 at the middle stage.

Covering material (B): After seeding, straw cover (B1) involved broken straw; broken kenaf cover (B2) utilized broken kenaf rods; hemp mulch cover (B3) employed white non-waterproof hemp mulch; while the control group (B4) remained uncovered.

Table 1. Each processing group schematic table

Processing group	Treatment
A1B1	organic fertilizer +straw
A1B2	organic fertilizer +broken kenaf
A1B3	organic fertilizer +non-waterproof hemp mulch
A1B4	organic fertilizer +control group
A2B1	soil amendment +straw
A2B2	soil amendment +broken kenaf
A2B3	soil amendment +non-waterproof hemp mulch
A2B4	soil amendment +control group
A3B1	control group +straw
A3B2	control group +broken kenaf
A3B3	control group +non-waterproof hemp mulch
A3B4	control group +control group

Experimental investigation

Before the midterm examination, seedlings were observed at 22 days (6.17), 49 days (7.14) prior to the midterm, and 77 days (8.11) after sowing. In each plot, a random selection of 20 representative plants was made for studying growth dynamics, including plant height, dry weight of an individual plant, and aboveground dry biomass production.

Chlorophyll content was concurrently measured with growth dynamics using a chlorophyll meter to determine SPAD values based on 20 leaves per treatment.

During the harvesting period (10.19), a sample of 20 representative plants from each plot was chosen to measure plant height, stem thickness, skin thickness, dry leaf weight, dry stem weight, dry skin weight, dry aboveground biomass of each plant as well as the effective number of plants in each plot for counting and yield calculation.

Subsequently, soil samples were collected from five points within each plot at a depth ranging from 5-20 cm and then dried indoors under light-free conditions.

Soil alkalinity influences levels of dissolved nitrogen, effective phosphorus quick-acting potassium organic matter total nitrogen salt content pH value conductivity; among these factors salt content and conductivity were measured during the seedling stage pre-sowing stage mid-sowing stage and harvesting stage respectively while alkaline dissolved nitrogen effective phosphorus quick-acting potassium organic matter total nitrogen pH were measured during sowing stage and harvesting stage.

Data processing and analysis

The data were preliminarily organized and graphed using Excel 2010, analyzed by Multiple comparisons and ANOVA using SAS 9.1.3, and tested for significance using Duncan's new complex polarity method.

Results

Effects of different treatments on the yield of kenaf before mid-term

From the effects of different soil treatments (A) and mulching treatments (B) on plant height, dry tare weight per plant, and dry aboveground biological yield per plant of red sesame in the pre-middle stage (Table 2), there were no significant effects on dry tare weight per plant and dry aboveground biological yield per plant. However, there were either significant or non-significant effects on plant height. Plant height showed significance in various mulching treatments (B) and different soil treatments, as well as block interactions (A*block) at the seedling stage. However, all other treatments and interactions were not significant. This pattern was consistent in the early and middle stages, except for block interactions (block), which were not significant. Significant effects were observed in all other cases.

In terms of the mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) with organic fertilizer (A1) (Table 3), the plant heights of the mulching treatments at the seedling stage, early stage, and middle stage were significantly different from each other. The minimum plant height at the seedling stage was observed in the control (B4) group, while the differences among the other three mulching treatments were not significant. The plant height in the early stage was the highest in the rice straw mulch (B1) at 147.22 cm, while in the middle stage it was the highest in the hemp mulch (B3) at 211.52 cm. In the early stage, the plant height was highest when using rice straw (B1), and in the middle stage, it was highest with hemp mulch (B3). In terms of dry tare weight per plant, there was no significant difference in the early stage. However, the plants covered with hemp mulch (B3) showed the highest weight in the middle stage, while the differences among the other three mulching treatments were not significant. In terms of aboveground dry biological yield per plant, there was no significant difference among the mulching treatments at the seedling stage, pre-mulching, and mid-term. Regarding the mulching treatments (rice straw B1, crushed hemp bone B2, hemp film B3, control B4) of the soil conditioner (A2), there were significant differences in the height of the plants at the seedling stage, pre-mulching, and mid-term mulching treatments. The smallest height was observed in the control (B4) at the seedling stage 20.51 cm. The differences among the other three mulching treatments were not significant, with the smallest height observed in the crushed hemp bone treatment at the pre-mulching stage. There were significant differences in plant height among the mulching treatments at the seedling, pre-emergence, and mid-term stages. The control (B4) had the smallest height at the seedling stage, while the other three mulching treatments showed insignificant differences. For the dry tare weight per plant, there was no significant difference among the mulching treatments in the early and middle stages. In terms of aboveground dry biological yield per plant, there was no significant difference among the mulching treatments at the seedling stage, in the early stage, and in the middle stage. From the perspective of the mulching treatments of compound fertilizer (A3) (rice straw (B1), crushed hemp bone (B2), hemp mulch (B3), and control (B4)), there was a significant difference in the plant height of each of the mulching treatments at the seedling stage, in the early stage, and in the middle stage. Additionally, at the seedling stage, the control (B4) was the smallest, while the difference among the other three mulching treatments was not significant. The differences among the other three mulching treatments were not significant. In the early stage, straw (B1) and crushed hemp bone (B2) had the highest levels, while in the middle stage, crushed hemp bone (B2) showed the highest levels. In terms of dry tare weight per plant, there was also no significant difference between the mulching treatments in the early and middle stages. For aboveground dry biological yield per plant, there was no significant difference among the mulching treatments at the seedling, pre-midterm, and midterm stages. Taken together, the yield traits of the treatments did not differ significantly before the mid-term.

Table 2. The analysis of influential factors on kenaf yield variation in different periods under various treatment measures

Name	Plant height (cm)			Dry weight of an individual plant(g)		Aboveground dry biomass production (g)		
	22d	49d	77d	22d	77d	22d	49d	77d
A	ns	**	***	ns	ns	ns	ns	ns
B	***	***	***	ns	ns	ns	ns	ns
block	ns	ns	ns	ns	ns	ns	ns	ns
A*B	ns	***	***	ns	ns	ns	ns	ns
A*block	***	***	**	ns	ns	ns	ns	ns

Notes: ***, **and*indicates that the difference is up to 1‰, 1% and 5% significant level

Table 3. Effects of different treatment measures on kenaf yield before metaphase

Name		Plant height (cm)			Dry weight of an individual plant(g)		Aboveground dry biomass production (g)		
		22d	49d	77d	22d	49d	22d	49d	77d
A1	B1	21.88±2.90a	147.22±14.09a	203.60±18.27b	3.43±1.12a	9.62±1.76a	0.38±0.14a	9.42±2.99a	27.60±4.98a
	B2	22.01±2.57a	137.83±11.22b	201.04±24.31b	2.77±0.75a	9.13±1.75a	0.38±0.07a	7.59±2.10a	25.76±5.20a
	B3	22.71±3.05a	134.55±12.37b	211.52±18.40a	2.07±0.64a	10.22±1.55a	0.38±0.07a	6.06±1.63a	28.07±4.14a
	B4	20.15±3.55b	138.27±17.04b	192.51±16.43c	2.77±1.07a	6.14±1.36a	0.33±0.04a	7.80±2.97a	17.24±4.02a
A2	B1	22.53±3.23a	140.58±7.60b	211.47±16.61a	2.53±0.55a	9.46±4.49a	0.37±0.01a	7.10±1.56a	23.13±7.66a
	B2	22.57±2.42a	149.03±9.20a	204.58±17.88ab	3.30±0.61a	7.35±1.01a	0.33±0.05a	8.86±1.62a	19.81±2.73a
	B3	22.26±4.82a	138.08±13.23b	207.99±18.42ab	2.63±0.95a	9.61±2.89a	0.37±0.12a	7.21±2.55a	26.97±8.53a
	B4	20.51±3.75b	136.55±12.10b	201.45±28.78b	2.50±0.69a	9.06±3.05a	0.36±0.07a	8.43±2.38a	25.69±7.92a
A3	B1	22.67±1.70a	140.27±8.96a	189.84±20.98b	2.80±0.10a	7.10±1.15a	0.35±0.04a	7.68±0.39a	20.01±3.03a
	B2	21.92±2.71a	142.85±9.30a	203.54±19.75a	2.90±0.36a	8.79±2.37a	0.34±0.07a	8.07±0.96a	24.49±6.85a
	B3	21.78±5.45a	135.62±8.40b	197.60±24.88ab	2.57±0.76a	8.23±4.71a	0.41±0.16a	7.02±2.26a	23.06±12.62a
	B4	18.70±3.54b	133.52±15.84b	197.33±27.42ab	2.80±0.89a	9.81±4.79a	0.31±0.07a	8.05±2.49a	28.09±13.66a

Effects of different treatments on SPAD values of red flax leaves at different time periods

From the effects of different soil treatments (A), various mulching treatments (B), and their interactions on the SPAD values of kenaf leaves at different time points (refer to Table 5), significant and non-significant effects were observed.

There was no significant difference in leaf SPAD values across mulch treatments with organic fertilizer (A1) and soil conditioner (A2) at seedling and preemergence stages, while significant differences were observed at midterm. There was no significant difference in leaf SPAD values among the mulch treatments at the seedling and midterm stages in the application of compound fertilizer (A3), but a significant difference was observed in the early stage (Figure 1). Taken together, there were differences in leaf SPAD values among the treatments mainly at midterm, but the differences were not significant. The maximum value was observed for each of the mulching treatments with the application of compound fertilizer (A3).

Table 5. Analysis of the influence factors of different treatment measures on the change of SPAD value of kenaf leaves in different periods

Name	22d	49d	77d
A	ns	ns	**
B	*	ns	***
block	ns	*	ns
A*B	ns	ns	**
A*block	**	ns	ns

Notes: ***, **and*indicates that the difference is up to 1‰, 1% and 5% significant level

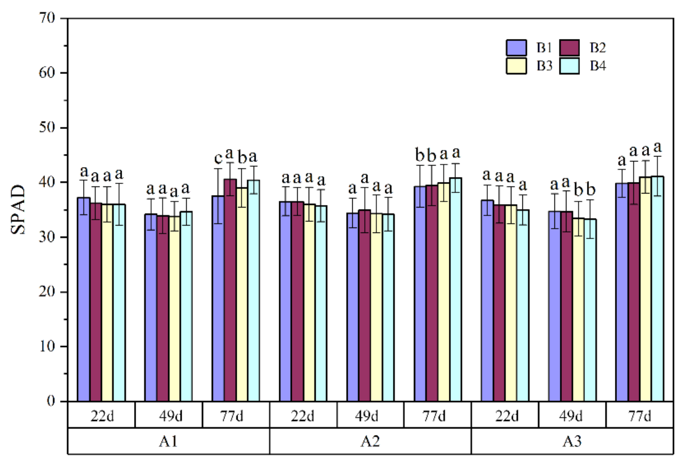

Figure 1. Influence of different treatment measures on SPAD value of kenaf leaves at different periods. Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. (p< 0.05; n = 3)

Effects of different treatments on kenaf yield at harvest time

From the effects of different soil treatments (A), various mulching treatments (B), and their interactions on the yield traits of kenaf at the harvest stage (refer to Table 6), significant and non-significant effects were observed. Analyzed from different soil treatments, there were significant differences, except for stem thickness, single-plant dry biomass weight, and single-plant dry leaf weight, which were not significant. Analyzed from various mulching treatments, there were no significant differences except for plant height and stem thickness, which showed significance. Analyzing different block groups (blocks), no significant differences were found except for plant height and dry leaf weight per plant. When analyzing the effects of various soil treatments and different mulching interactions (A*B), the results were consistent with those of the mulching treatments. From the analysis of different soil treatments and intercropped blocks (A*block), significant differences were observed, except for stem thickness, skin thickness, dry leaf weight of a single plant, and dry skin weight of the plot, which were not significant.

From the application of organic fertilizer (A1) and mulching treatments (rice straw B1, crushed hemp bone B2, hemp film B3, control B4) (Table 7), significant differences were observed in plant height and stem thickness, reached 301.53 cm and 13.81 mm respectively. Among the mulching treatments, crushed hemp bone

(B2) resulted in the largest plant growth. However, there were no significant differences in other yield traits. Similarly, when soil conditioner (A2) was applied as a mulching treatment, significant differences were observed in plant height and stem thickness, but not in other yield traits. Overall, the application of soil conditioner (A2) as a mulching treatment led to significant differences in various plant characteristics, except for plant height and stem thickness. No significant differences were observed for other yield traits. Plant height and stem thickness were the greatest for rice straw (B1) mulch. Among the mulching treatments with compound fertilizer (A3), only plant height showed a significant difference, with plant height being the lowest for rice straw (B1) mulch. The differences were not significant for the other three mulches. Taken together, the application of soil conditioner (A2) treatment was the most effective, while the mulching treatments were not significantly different.

Table 6. Analysis of influencing factors of different treatment measures on kenaf yield change at harvest stage

Name	Plant height(cm)	Stem diameter(mm)	Skin thickness (mm)	Dry bone weight per plant (g)	Dry skin weight per plant(g)	Dry leaf weight per plant (g)	Dry biological yield per plant (g)	Area dry skin weight(kg)
A	***	ns	**	ns	**	ns	*	***
B	**	*	ns	ns	ns	ns	ns	ns
block	*	ns	ns	ns	ns	**	ns	ns
A*B	***	***	ns	ns	ns	ns	ns	ns
A*block	***	ns	ns	*	**	ns	*	ns

Notes: ***, **and*indicates that the difference is up to 1‰, 1% and 5% significant level

Table 7. Effects of different treatment measures on kenaf yield at harvest stage

Name		Plant height (cm)	Stem diameter (mm)	skin thickness (mm)	Dry bone weight per plant (g)	Dry skin weight per plant(g)	Dry leaf weight per plant (g)	Dry biological yield per plant (g)	Area dry skin weight (kg)
A1	B1	285.25±35.78b	12.77±2.10b	1.05±0.17a	35.52±8.70a	21.04±7.71a	7.01±0.42a	63.58±16.54a	2.83±1.20a
	B2	301.53±35.87a	13.81±2.72a	1.15±0.04a	45.07±6.35a	28.54±2.36a	12.38±4.95a	85.99±4.00a	3.15±1.82a
	B3	280.48±43.86b	12.45±2.45b	1.06±0.15a	34.03±6.45a	22.50±4.96a	7.84±4.54a	64.37±11.22a	4.05±0.94a
	B4	286.98±29.38b	12.84±2.49b	1.09±0.11a	37.01±4.04a	25.00±2.50a	9.90±0.83a	71.91±6.14a	4.22±0.25a
A2	B1	327.65±34.09a	14.05±2.17a	1.3±0.07a	49.85±7.72a	33.34±2.82a	16.09±1.89a	99.27±12.42a	5.37±1.07a
	B2	321.53±32.68ab	12.66±2.10b	1.2±0.14a	41.37±10.12a	27.71±6.29a	11.28±0.95a	80.35±17.24a	6.02±0.70a
	B3	322.8±28.6ab	13.69±2.10a	1.3±0.22a	48.66±1.37a	32.29±0.96a	12.65±2.90a	93.6±3.05a	5.63±1.35a
	B4	310.72±40.6b	12.28±2.27b	1.18±0.12a	40.60±7.62a	28.75±3.48a	8.53±4.54a	77.87±15.62a	5.50±0.64a
A3	B1	292.75±41.73b	13.04±2.8a	1.24±0.08a	42.39±5.09a	27.71±4.69a	10.18±7.80a	80.27±17.08a	4.79±1.15a
	B2	316±39.25a	12.59±2.48a	1.15±0.07a	41.73±5.57a	28.33±4.39a	10.73±4.13a	80.79±14.04a	4.75±0.82a
	B3	321.42±48.09a	13.63±2.88a	1.27±0.21a	56.12±16.66a	34.79±10.82a	15.13±9.84a	106.04±37.24a	4.72±0.78a
	B4	310.72±53.47a	12.6±3.16a	1.19±0.25a	48.06±24.37a	31.25±13.05a	13.48±9.95a	92.78±46.89a	4.09±1.54a

Effects of different treatment measures on soil alkaline dissolved nitrogen content at sowing and harvesting stages of kenaf

The application of organic fertilizer (A1) and soil conditioner (A2) in the mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) during the sowing and harvesting periods of alkaline nitrogen did not show significant differences (Figure 2). However, the application of composite fertilizer (A3) in the mulching treatments of alkaline nitrogen showed significant differences in the pre-sowing period but not in the harvest period. The trend changes were consistent across all treatments; they were low before and high after. In general, before sowing, the alkaline dissolved nitrogen content of the soil conditioner (A2) was higher than that of the organic fertilizer (A1) and compound fertilizer (A3). The alkaline dissolved nitrogen content of each mulching treatment with organic fertilizer, soil conditioner, and compound fertilizer was higher than that before sowing at harvest.

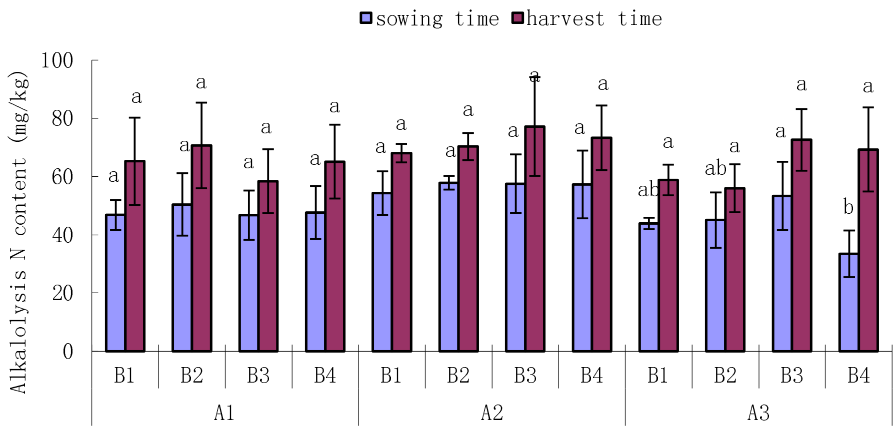

Figure 2. Effects of different treatment measures on soil alkali-hydrolyzed nitrogen at sowing and harvesting stages of kenaf

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. (p< 0.05; n = 3)

Effects of different treatment measures on effective phosphorus content of soil at sowing and harvesting stages of kenaf

The application of organic fertilizer (A1) among the various mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) during the sowing and harvesting periods did not show significant differences in the soil's effective phosphorus content (Figure 3). The mulching treatments with soil conditioner (A2) were significantly different at the planting stage, but not at the harvest stage. The opposite was true for each of the mulch treatments with compound fertilizer (A3) application, which was not significant at planting but significant at harvest. The trend changes were consistent across all treatments, unlike alkaline dissolved nitrogen, which was higher before and lower after. In general, the effective phosphorus (P) content of the soil conditioner (A2) was higher than that of the organic fertilizer (A1) and compound fertilizer (A3) throughout the growth period. The soil's effective phosphorus content with each mulching treatment using the soil conditioner was higher than before sowing during the growth period of red sesame. In contrast, the soil's effective phosphorus content with each mulching treatment using organic fertilizer and compound fertilizer was lower than the average value before sowing at harvest time.

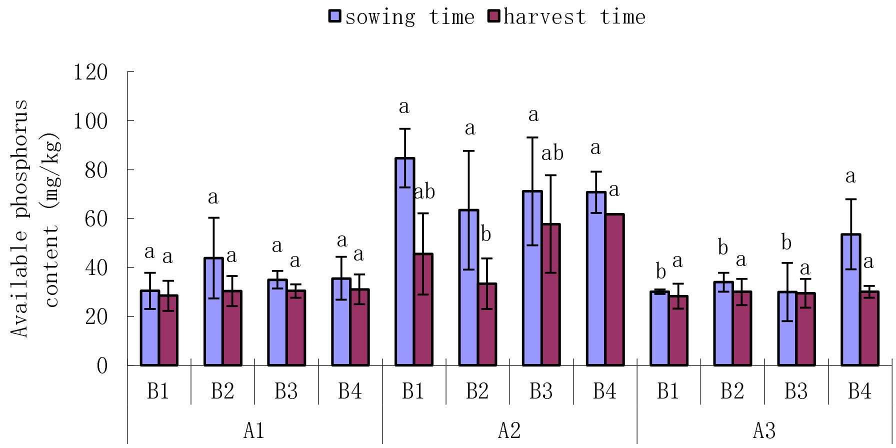

Figure 3. Effects of different treatment measures on soil available phosphorus at sowing and harvesting stages of kenaf

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. (p< 0.05; n = 3)

The effect of different treatments on soil quick-acting potassium content during sowing and harvesting of kenaf

Application of organic fertilizer (A1) and soil conditioner (A2) mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) at the sowing stage significantly affected the soil's fast-acting potassium content (Figure 4); however, there was no significant difference in the harvest. The quick-acting potassium content of the soil in each mulch treatment with compound fertilizer (A3) was significantly different at seeding and harvest. The trends in the treatments varied, showing both higher and lower levels, similar to the pattern observed with effective phosphorus. In general, the soil's effective phosphorus content in soil amendment (A2) was consistently higher than that in organic fertilizer (A1) and compound fertilizer (A3) throughout the growing period. However, the soil's effective phosphorus content in all treatments was lower than the pre-sowing average by the harvesting period.

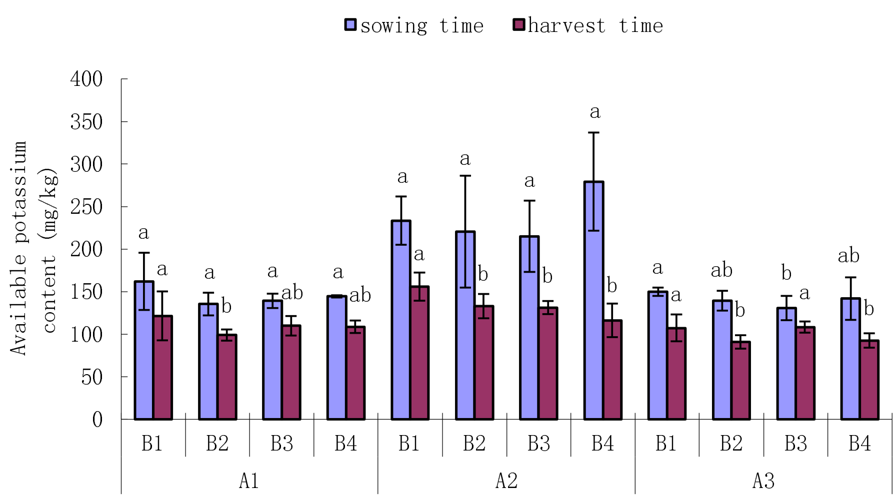

Figure 4. Effects of different treatment measures on soil available potassium at sowing and harvesting stages of kenaf

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. (p< 0.05; n = 3)

The effect of different treatments on the organic matter content of soil at sowing and harvesting stages of kenaf

Different fertilization strategies significantly affect soil organic matter. Application of organic fertilizer (A1) and application of composite fertilizer (A3) in the mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) during the sowing and harvesting periods significantly affect soil organic matter content (Figure 5). And the maximum organic matter content was reached in both B1 treatments at harvest time, 11.47 g/kg and 11.98 g/kg, respectively. The mulch treatments with soil conditioner (A2) application, on the other hand, did not show significant differences at both seeding and harvesting stages. The trend of the treatments varied in the same way as the soil alkaline dissolved nitrogen content, which initially decreased and then increased. Overall, the soil organic matter content of the soil amendment (A2) was consistently higher than that of the organic fertilizer (A1) and compound fertilizer (A3) throughout the growing period. Additionally, the soil organic matter content of all treatments exceeded the pre-sowing average at harvest.

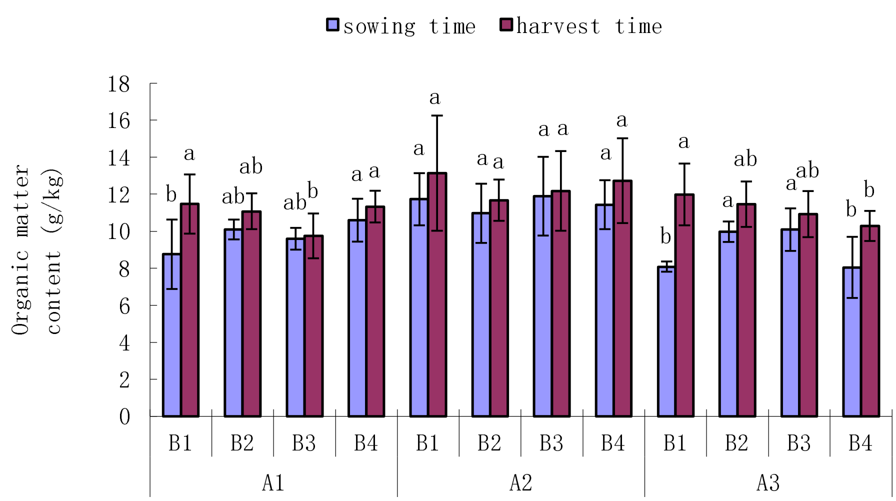

Figure 5. Effects of different treatment measures on soil organic matter content at sowing and harvesting stages of kenaf

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. (p< 0.05; n = 3)

Effects of different treatments on soil total nitrogen content at sowing and harvesting stages of kenaf

Application of organic fertilizer (A1) and various mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) during the sowing and harvesting periods significantly affect the soil's total nitrogen content (Figure 6). The mulch treatments with soil conditioner (A2) were not significantly different at both seeding and harvest. The mulch treatments with compound fertilizer (A3) did not show significant differences in soil total nitrogen content before planting but were significant at harvest. Interestingly, the trend variation in all treatments did not align with soil alkaline dissolved nitrogen, effective phosphorus, quick-acting potassium, and organic matter content. The treatments with organic fertilizer application exhibited high levels before and low levels after, while the treatments with soil conditioner and compound fertilizer application showed low levels before and high levels after. However, in general, the soil nitrogen content of kenaf is higher throughout the growth period when applying soil conditioner (A2) compared to organic fertilizer (A1) and compound fertilizer (A3). Additionally, the nitrogen content is higher than the average value before sowing. The total nitrogen content in the soil was lowest during the harvest period when organic fertilizer was applied.

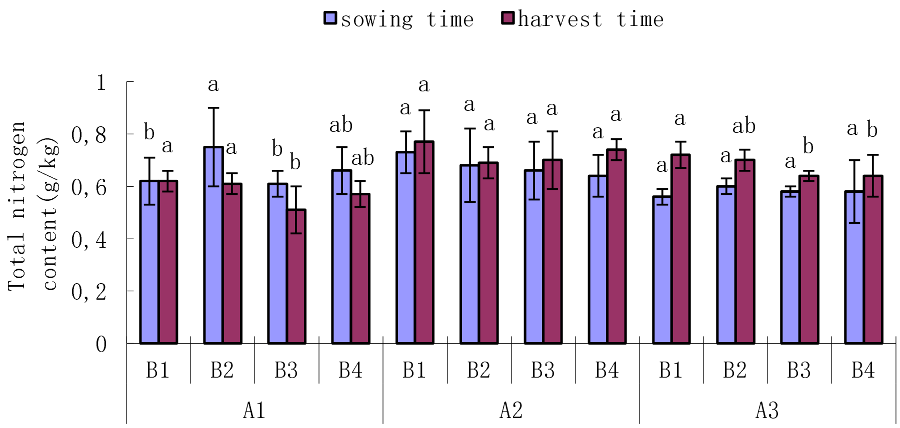

Figure 6. Effects of different treatment measures on soil total nitrogen content at sowing and harvesting stages of kenaf

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. ($p < 0.05$; n = 3)

The effect of different treatment measures on the kenaf sowing and harvesting soil PH value

Application of organic fertilizer (A1) and soil conditioner (A2) in the various mulching treatments (rice straw B1, crushed hemp bone B2, hemp mulch B3, control B4) during the sowing and harvesting periods did not show significant differences in soil pH values (Figure 7). The mulch treatments with the application of compound fertilizer (A3) showed significant differences at sowing but not at harvest. The trend changes differed among all treatments. However, the trend changes were consistent for treatments involving organic fertilizer and compound fertilizer application, both of which showed high values before and low values after straw (B1) application. In contrast, all other mulching treatments exhibited low values before and high values after. The pH values of each mulch treatment with soil conditioner application were low before and high after. Overall, the pH values of the mulching treatments with soil conditioner were the lowest throughout the growing period, dropping below the pre-sowing average. This was followed by the treatments with organic fertilizer, while the treatments with compound fertilizer had the highest pH values. During the harvesting period, the pH values of the treatments with organic fertilizer and compound fertilizer were higher than the pre-sowing average.

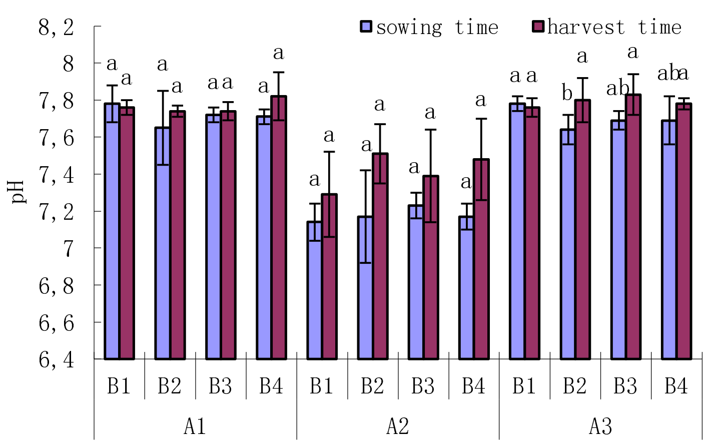

Figure 7. Effects of different treatment measures on soil PH value at sowing and harvesting stages of kenaf

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. ($p < 0.05$; n = 3)

The effect of different treatments on soil salinity at sowing and harvesting stages of kenaf

From the effects of different soil treatments (A), various mulching treatments (B), and their interactions on soil salinity at different stages of kenaf growth (refer to Table 9), both significant and non-significant effects were observed. The trends of all treatments are similar; they initially decreased, then rebounded, and finally decreased again (Figure 8). Taken together, the soil salinity was highest in all treatments when soil conditioner (A2) was applied. The decrease in harvest yield compared to the early stage was also most significant across all treatments. The soil salinity during the early, middle, and harvest stages was lower than that during the seedling stage. However, throughout the entire growth period, the soil salinity was higher than that during the pre-sowing stage. When analyzing the application of organic fertilizer (A1) and composite fertilizer (A3), it was observed that, except for the straw (B1) mulching treatment with compound fertilizer, which had lower soil salinity than the seedling stage, the soil salinity in the middle and harvest stages of each treatment was higher than that in the seedling stage. This suggests that the two soil treatments had an impact on the soil salinity levels. Treatments returned to salt in the middle and late stages.

Table 9. Analysis of the influence factors of different treatment measures on the change of soil salt content in different periods

Name	22d	49d	77d	Harvest time
A	***	***	**	***
B	ns	ns	ns	**
block	ns	ns	ns	**
A*B	ns	ns	**	***
A*block	ns	ns	ns	ns

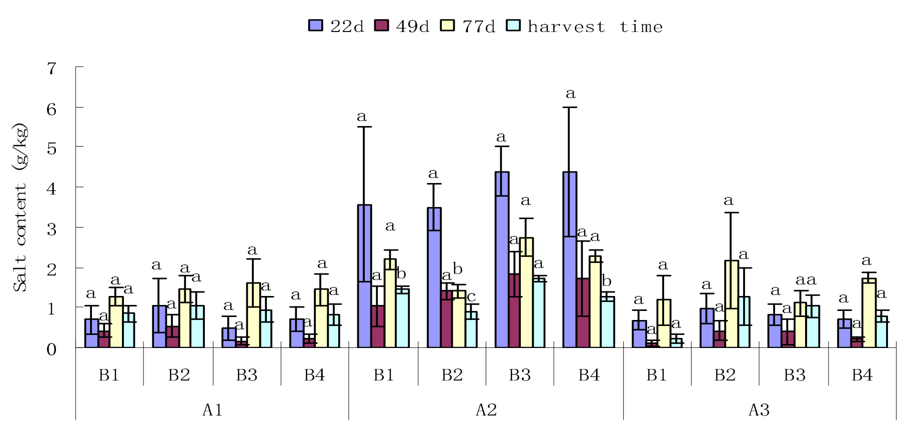

Figure 8. Effects of different treatment measures on soil salt content of kenaf during sowing and harvesting. Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. ($p < 0.05$; n = 3)

Effects of different treatments on soil conductivity at sowing and harvesting stages of kenaf

From the effects of different soil treatments (A), different mulching treatments (B), and their interactions on the soil conductivity of kenaf at different periods (refer to Table 10), similar significant or non-significant effects were observed. The trend change of the treatments is similar to the soil salinity, all of which initially decreased, then rebounded, and finally decreased again (Figure 9). Taken together, the soil conductivity was highest across all treatments when soil conditioner (A2) was applied. The most significant decreases in conductivity during the harvest period compared to the initial period were observed. Additionally, the soil conductivity during the seedling period was higher than in the first, middle, and harvest periods. However, throughout the entire growth cycle of red sesame, the conductivity was higher than that in the pre-sowing period.

Table 10. Analysis of the influence factors of different treatment measures on soil conductivity changes in different periods

Name	22d	49d	77d	Harvest time
A	***	***	**	**
B	ns	ns	ns	ns
block	ns	*	ns	ns
A*B	ns	ns	**	ns
A*block	*	ns	*	ns

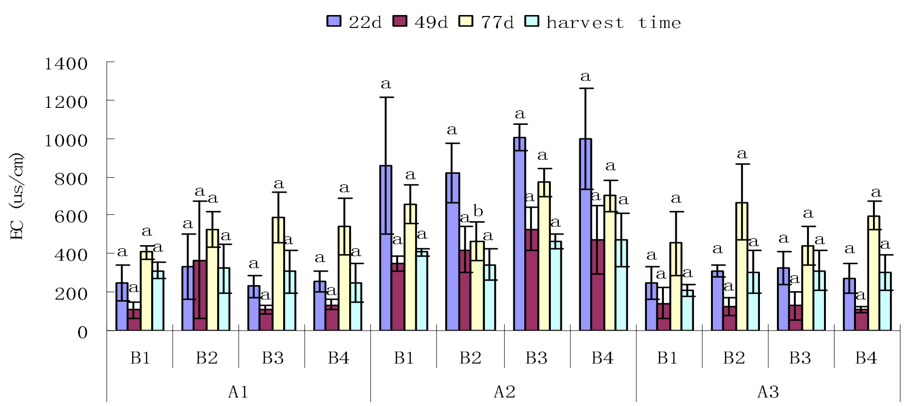

Figure 9. Effects of different treatment measures on soil conductivity of kenaf during sowing and harvesting

Different letters represent the significance under the same fertilizer treatment and different coverage treatments at the same period. ($p < 0.05$; n = 3)

Spearman's Correlation

We explored the Spearman's correlation between soil physicochemical properties and kenaf yield. The results showed that TN, SC, pH, OM and EC were significantly correlated with kenaf yield. Random forest modelling results further indicated that the variation of PH was able to be explained 22.80% by soil properties, with SC and EC being relatively important predictors of its variation. In addition, variation in DBW was able to explain 14.68% by soil properties, where SC was a relatively important predictor of its variation. TN and SC, on the other hand, were able to predict variation in BW.

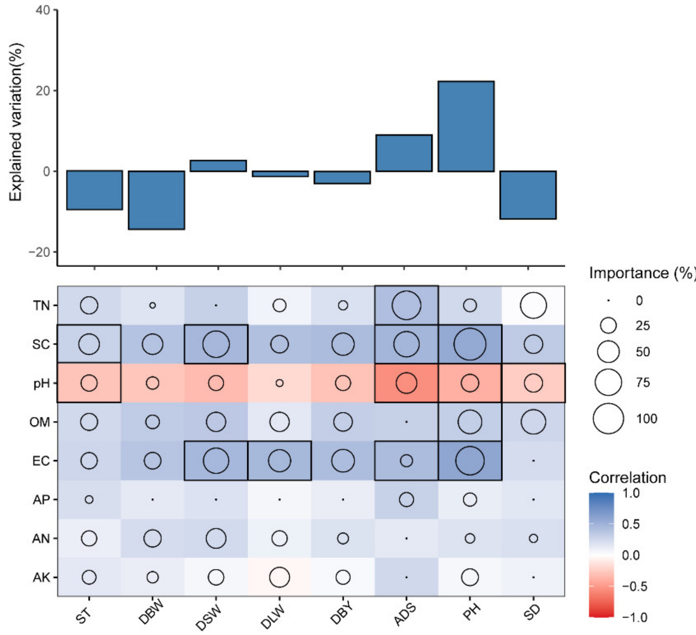

Figure 10. Correlation between soil physicochemical properties and kenaf yield. TN (total nitrogen content); SC (Salt content); OM (organic matter content); EC (electrical conductivity); AP (available potassium); AN (alkali-hydrolyzed nitrogen); AK (available potassium); ST (skin thickness); DBW(Dry bone weigh); DSW (Dry skin weight per plant); DLW (Dry leaf weight per plant); DBY (Dry biological yield per plant); ADS (Area dry skin weight); PH (Plant height); SD (Stem diameter).

Discussion

From the consideration of kenaf yield traits, before the mid-term, the yield traits of the treatments do not differ significantly. There is no significant difference between the dry tare weight of a single plant and the dry biological yield of a single plant above ground. However, at the harvest stage, the dry tare weight of a single plant, the dry biological yield of a single plant above ground, and the dry tare weight of a plot show significant differences. When combined with the SPAD value of leaves of the treatments, the differences are mainly analyzed in the mid-term. This indicates that the growth of kenaf under the various treatments mainly differentiated in the middle and late stages. From the analysis of various soil treatments (A), mulching treatments (B), and their interactions on kenaf during the seedling stage, as well as the first, middle, and harvest periods of yield traits, differences primarily stem from the varied soil treatments, with the soil amendments (A2) treatment demonstrating the most significant effect. Converted with maximum soil conditioner + broken kenaf treatments, the dry hull yield was 6023 kg/hm^2, which was close to 6589 kg/hm^2 of Yang *et al.* (2011) during 2004-2006 in the new kenaf variety area of the whole country, which indicated that the planting improvement measure was feasible. Mulching treatments show minimal impact, which is consistent with Zhang *et al.* (2015) saline mulching treatment on kenaf yield in the first year of the trial.

From a comprehensive consideration of soil nutrients, soil amendments with soil nutrients, in addition to alkaline nitrogen during the harvest period, are not all higher than the application of organic fertilizers and fertilizer mulching treatments. Effective phosphorus, quick-acting potassium, organic matter, and total nitrogen content throughout the entire growth period of kenaf are higher than those from the application of organic fertilizers and fertilizer mulching treatments. This indicates that it can enhance soil nutrient content, improve soil quality, enhance soil permeability, and promote plant growth, aligning with the kenaf yield trait values.

From a comprehensive analysis of soil pH values, the use of soil conditioner to maintain soil pH levels throughout the entire growth period of kenaf is lower compared to the use of organic fertilizer and fertilizer mulching treatments. This finding aligns with Zhou Liming *et al*. (2017), who observed a significant reduction in soil pH values when treating saline soil in Changji with phosphogypsum. This reduction is more favorable for the growth requirements of kenaf and is consistent with the yield characteristics of kenaf. In our study, there was no significant difference in soil pH between the mulch treatments of soil amendment (A2) at both seeding and harvesting stages, but soil pH decreased slightly under this treatment compared to the A1 and A3 treatments. The studies have reported that the application of soil amendments decreases soil pH (Luo *et al*., 2018; Sun *et al*., 2016). However, Li *et al*. (2012) reported that There is also evidence that low rate of gypsum addition had no significant effects on soil pH in saline-alkaline soils in the northwest China.

The soil conditioner used in this test contains phosphogypsum, with calcium sulfate dihydrate ($CaSO_4$-$2H_2O$) as its main component, constituting over 90% (Jia, 2020). When it reacts with sodium carbonate and sodium bicarbonate in saline soil, it produces soluble sodium sulfate. This compound has stable chemical properties, resulting in neutral soil colloid (Li Shouming, 1985). The soil salinity after applying the soil conditioner was higher throughout the growing period compared to before sowing. However, it was lower than during the seedling stage in the pre-growing, mid-growing, and harvesting periods. This difference may be attributed to the reaction of phosphogypsum in the soil conditioner with sodium carbonate and sodium bicarbonate in the soil during the growth of red sesame. The resulting sodium sulfate was likely washed away by rainwater. It is possible that not all of the sodium sulfate generated by the reaction was washed away, as there was a small amount of phosphogypsum impurity salts in the phosphogypsum.

Comprehensive comparative analysis shows that the application of soil conditioner (A2) can effectively enhance the nutrient content of saline soil, decrease soil alkalinity, and increase the yield of kenaf. This is a significant advantage for enhancing the utilization of saline land in the region and improving the quality of arable land.

Conclusions

The results of this study indicate that soil treatment has a significant impact on the yield of kenaf. The dry bark yield of kenaf treated with soil amendments is higher than that treated with organic fertilizer and compound fertilizer. There is no significant effect on kenaf yield among different covering treatments in each soil treatment. The content of available phosphorus, available potassium, organic matter, and total nitrogen in the soil treated with soil amendments is higher than that treated with organic and compound fertilizers throughout the growth period of kenaf, which can improve soil quality and reduce soil alkalinity. Future research will focus on applying different doses of soil amendments to different saline alkali soils, providing scientific basis for the improvement of saline alkali soils.

Authors' Contributions

XA and CC proposed and designed this research. CC and XA collected samples and conducted the experiments. CC and RC analyzed the data. CC, XA and RC wrote the manuscript, and CC, XA and RC corrected the manuscript. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

An X, Chen J, Liu T, Li W, Luo X, Zou L (2022). Transcriptomic and metabolic profiling of kenaf stems under salinity stress. Plants 11: 1448. *https://doi.org/10.3390/plants11111448*

Chen C, Luo X, Li W, An X, Zhu G, Jin G (2018). Effects of kenaf varieties and sowing amount on yield and characters. Zhejiang Agricultural Sciences 59(1):83-85. *https://doi.org/10.16178/j.issn.0528-9017.20180130*

Chen S, Yang H (2014). Special topic on multi-purpose comprehensive utilization and strategic research of hemp. Hunan University Press, Hunan.

Chen J, Zhao H, Zhu A (2024). Key tasks of scientific and technological innovation in China's hemp industry in the new era. Chinese Journal of Hemp Industry 46(1):60-64.

Dou B, Jing H, Li C, Wang W, Zhang W (2024). Study on improvement effect of compound improvers on salinized soil at low-lying farmland in Ningxia Yellow River irrigation area. Chinese Agricultural Science Bulletin 40(7):93-100.

Fan W (2020). Study on soil salinization hazards and improvement methods. Agriculture and Technology 40(23):114-116.

Guo Q, Chen S, Hai L, Yang Y (2020). Study on the effect of different commercial organic fertilizers on saline-alkali soil improvement in Shizuishan City, Ningxia. Agricultural Technology Communication 10:127-130. *https://doi.org/10.3969/j.issn.1000-6400.2020.10.038*

Hu G, Song S, Xiang J, Zhu D, Chen H, Wang Y, ...Zhang Y (2020). Effect of biodegradable film mulching on growth and quality of mechanically transplanted rice (*Oryza sativa* L.). Chinese Journal of Rice Science 34(2):159-170. *https://doi.org/10.16819/j.1001-7216.2020.9081*

Jia R, Wang Q, Feng P (2021). A comprehensive overview of fibre-reinforced gypsum-based composites (FRGCs) in the construction field. Composites Part B: Engineering 205:108540. *https://doi.org/10.1016/j.compositesb.2020.108540*

Khakifirooz A, Kiaei M, Sadegh AN, Samariha A (2012). Studies on chemical properties and morphological characteristics of Iranian cultivated kenaf (*Hibiscus cannabinus* L.): A potential source of fibrous raw material for paper industry in Iran. Research on Crops 13:715-720.

Konstantin I, Harm B, Arnold K, Alim P, Bas K, Luisde S (2019). Global mapping of soil salinity change. Remote Sensing of Environment 231:111260-111260. *https://doi.org/10.1016/j.rse.2019.111260*

Li M, Jiang L, Sun Z, Wang J, Rui Y, Zhong L, Wang Y, Kardol P (2012). Effects of flue gas desulfurization gypsum by-products on microbial biomass and community structure in alkaline–saline soils. Journal of Soils Sediments 12:1040-1053. *https://doi.org/10.1007/s11368-012-0531-z*

Li SM (1985). Improvement and utilization of saline-alkali land. Inner Mongolia People's Press. Hohhot pp 57.

Liu J, Yang J, Yu Y, Xu Z, Zhang X (2018). Preparation and properties of nonwoven hemp mulch film in kenaf. Journal of Textile Science and Engineering 2018(01):142-148.

Luo S, Wang S, Tian L, Shi S, Xu S, Yang F, … Tian C (2018). Aggregate-related changes in soil microbial communities under different ameliorant applications in saline-sodic soils. Geoderma 329:108-117. *https://doi.org/10.1016/j.geoderma.2018.05.023*

Mao Q, Wang S (2020). A brief analysis on the trend of saline-alkali land management in China. Hubei Agricultural Sciences 59(S1):302-306. *https://doi.org/10.14088/j.cnki.issn0439-8114.2020.S1.085*

Navarro-Torre S, Garcia-Caparrós P, Nogales A, Abreu M, Santos E, Cortinhas A, Caperta A (2023). Sustainable agricultural management of saline soils in arid and semi-arid Mediterranean regions through halophytes, microbial and soil-based technologies. Environmental and Experimental Botany 212:105397. *https://doi.org/10.1016/j.envexpbot.2023.105397*

Papadopoulou E, Bikiaris D, Chryssafis K, Wladyka-Przybylak M, Wesolek D, Mankowski J, … Gronberg V (2014). Value-added industrial products from bast fiber crops. Industrial Crops and Products 68:116-125. *https://doi.org/10.1016/j.indcrop.2014.10.028*

Qian S, Zhou X, Fu Y, Song B, Yan H, Chen Z, Lai C (2023). Biochar-compost as a new option for soil improvement: Application in various problem soils. Science of The Total Environment 870:162024. *https://doi.org/10.1016/j.scitotenv.2023.162024*.

Sapuan SM, Ishak MR, Sahari J (2018). Kenaf Fibers and Composites. Taylor and Francis.

Shi J, Song G (2016). China Soil Species Database: A National Soil Dataset Based on the Second Soil Census. Chinese Scientific Data 1(2):1-12.

Shen J, Su G, Lou L, He L, Hu K (2023). Effects of salt washing on soil salinity, nutrient content and vegetable growth in facilities. Chinese Agricultural Science Bulletin 39:69-73.

Shrivastava P, Kumar R (2015). Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences 22(2):123-131. *https://doi.org/10.1016/j.sjbs.2014.12.001*

Sun J, He F, Shao H, Zhang Z, Xu G (2016). Effects of biochar application on *Suaeda salsa* growth and saline soil properties. Environmental Earth Sciences 75:630. *https://doi.org/10.1007/s12665-016-5440-9*

Sun Z, Ge J, Li C, Wang Y, Zhang F, Lei X (2022). Enhanced improvement of soda saline-alkali soil by in-situ formation of super-stable mineralization structure based on CaFe layered double hydroxide and its large-scale application. Chemosphere 300:134543. *https://doi.org/10.1016/j.chemosphere.2022.134543*

Talebnejad R, Sepaskhah A (2016). Modification of transient state analytical model under different saline groundwater depths, irrigation water salinities and deficit irrigation for quinoa. International Journal of Plant Production 10(3):365-389. *https://doi.org/10.22069/ijpp.2016.2903*

Wang W, Bai P, Zhang X (2021). Effects of different mulching films on soil physiochemical properties and spring maize yield in dry land. Shaanxi Journal of Agricultural Sciences 67(03):12-16.

Xu C, Dong L, Lu J, Zhang Y, Cheng M, Cheng M, Ma J (2020). Research progress on soil improvement and resource utilization of coastal saline-alkali land in China. World Forestry Research 33(6):68-73. *https://doi.org/10.13348/j.cnki.sjlyyj.2020.0056.y*

Yu S, Zhou X, Qin J, Chen Z, Guo A, Qin L (2017). Ecological security assessment of coastal saline-alkali land in Hebei Province. Chinese Journal of Eco-Agriculture 25(5):778-786.

Yang J, Yao R, Wang X, Xie W, Zhang X, Zhu W, … Sun R (2022) Research on saline soils in China: history, current situation and prospects. Journal of Soil Science 59(1):10-27.

Yang L, Hu W, Lei C (2011). Study on the adaptability of a new hybrid kenaf H318 with high yield and stress resistance planted in Anhui. Plant Fiber Sciences in China 33(4):165-171. *http://doi.org/10.3969/j.issn.1671-3532.2011.04.001*

Zhao D, Gao S, Zhang X, Zhang Z, Zheng H, Rong K, … Khan S (2021). Impact of saline stress on the uptake of various macro and micronutrients and their associations with plant biomass and root traits in wheat. Plant, Soil and Environment 67. *https://doi.org/10.17221/467/2020-PSE*

Zhou L, Wang H, Cao H, Xu Y (2017). Effect of phosphogypsum on improving saline-alkali cotton field. Rural Science and Technology 2017(11):21-22.

Zhou Q, Zheng Z, Jing Y, Peng S, Chen T, Liu Z, … Li J (2021). Study on soil organic matter content and its relationship with nitrogen, phosphorus and potassium in different soil layers of rice-growing tobacco areas in Southern Hunan. Crop Magazine 37(5):114-119.

Zhou J, Wang Z, Yang F (2023). Research progress on phytoremediation mechanism of saline-alkali soil. Journal of Ecology 1-11.

Zhang Z, Yuan M, Li S, Ji Y, Qiao Y, Tian Y (2021). Study on the improvement effect of different amendments on saline-alkali land in Dongying. Humc Acid 2021(06):15-21. *https://doi.org/10.19451/j.cnki.issn1671-9212.2021.06.003*

Zhang J, Luo X, Jin G, Chen C (2015). Effects of land cover on the growth and yield of kenaf in different types of saline-alkali land. Zhejiang Agricultural Sciences 56(12):1936-1939. *http://doi.org/10.16178/j.issn.0528-9017.20151208*