EFFECTS OF DIFFERENT IMPROVEMENT MEASURES ON HYDROTHERMAL CARBON AND COTTON (*GOSSYPIUM HIRSUTUM* L.) YIELD IN SALINE-ALKALI SOIL

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Abstract. In order to explore the effects of different improvement measures on hydrothermal carbon and cotton (*Gossypium hirsutum* L.) yield of saline-alkali soil in Xinjiang, China, four treatments were applied: biochar (B, 20 t·ha^{-1}), desulfurization gypsum (D, 35 t·ha^{-1}), straw mulching (S, 16 t·ha^{-1}) and control (CK). The results showed that the soil moisture content in 0-20 cm and 20-40 cm deep soil layers under the three improved treatments was significantly higher than that of the control throughout the whole growth period. The spatial distribution pattern of soil water in each treatment profile showed the characteristics of lower wet and upper dry. Compared with CK, the improved treatments showed good warming and heat preservation effects, both showed warming effect at low temperature and cooling effect at high temperature. The three improvement measures could increase the content and density of soil organic carbon, among which the application of biochar was the most significant, and the density of organic carbon was 17.46% higher than that of the control. Compared with the control, the yield increase rate of cotton in treatment B was the highest, up to 32.28%. In conclusion, the application of 20 t·ha^{-1} biochar is suitable for soil improvement in the process of cotton planting in saline farmland in Xinjiang, China.
Keywords: *salinized soil, hydrothermal condition, organic carbon, yield, improved measures*

Introduction

Cotton (*Gossypium hirsutum* L.) planting in Xinjiang plays an important role in China's cotton production (Hou et al., 2021). In 2013, the cotton planting area in Xinjiang was 1.80×10^6 ha, accounting for 36.7% of the national cotton planting area, with a total output of 3.52×10^6 t, accounting for 55.9% of the total cotton output in China (Zong et al., 2021). The region has a dry climate, sparse rainfall, strong evaporation, and serious soil salinization (He et al., 2018). In 2005, the area of salinized cultivated land in Xinjiang reached 1.62×10^4 ha, accounting for 32.1% of the total cultivated land area (Wang et al., 2020). Soil salinization leads to the continuous reduction of farmland soil water and fertilizer conservation capacity and agricultural productivity, which seriously restricts the sustainable development of agriculture in Xinjiang, China (Tan et al., 2018). Therefore, it is urgent to apply appropriate soil improvement products to conserve water and fertilizer.

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In recent years, the research on the effect of different improvement products on saline-alkali soil has attracted extensive attention (Zhai et al., 2016; Zhao et al., 2018; Zhu et al., 2020; Zhou et al., 2021). For example, biochar contains organic carbon and has porous structure and large surface area (Liang et al., 2021). After being applied to the soil, it can effectively increase the content of soil organic carbon and improve its nutrient absorption and water holding capacities of the soil (Cui et al., 2021). Therefore, it is widely used in soil remediation and agricultural production. He et al. (2020) and Zhao et al. (2020) showed that the application of biochar had a good effect on improving soil water permeability and permeability and improving soil fertility. Desulfurized gypsum, as coal-fired desulfurization waste, is an economic and environment friendly soil conditioner, which has been proved to be an effective saline alkali soil improvement product (Zhang et al., 2021). Hammerschmitt et al. (2021) showed that desulfurization gypsum could improve soil physical and chemical properties, increase salinized soil organic matter and crop yield. Straw mulching can not only reduce environmental pollution and increase soil carbon pool, but also improve the water, fertilizer, gas and heat status of soil (Wang et al., 2018). A large number of studies have shown that straw mulching can improve soil properties, inhibit water evaporation, improve soil water holding capacity (Wang et al., 2021), effectively stabilize the change of ground temperature and increase the content of soil organic carbon (Ma et al., 2019).

At present, there are many studies on the improvement effect of single measure on saline alkali soil, while there are few reports on the comprehensive analysis and comparison of hydrothermal carbon and cotton yield of saline-alkali soil by selecting different improvement measures at the same time. In view of this, this paper carried out a field experiment in Shaya County, Aksu Prefecture, Xinjiang, China, to explore the effects of three common improvement measures of biochar (B), desulfurization gypsum (D) and straw mulching (S) on the hydrothermal carbon environment of saline-alkali soil and cotton yield, in order to determine more suitable soil improvement measures for improving the hydrothermal conditions of saline-alkali soil in arid areas and provide scientific basis and technical support for improving soil fertility and cotton yield.

Materials and methods

Overview of test area

The experiment was conducted in Shaya County (41°25'N, 84°47'E) in Aksu Prefecture, Xinjiang, China. This region is located in the south of the middle section of Tianshan Mountain, the north edge of Taklimakan Desert and the middle reaches of Tarim River, with an altitude of 946-1050 m. Moreover, the region is far from the sea, the East, South and West are surrounded by deserts, and the ecological environment is relatively fragile. In addition, the region is a typical continental warm temperate arid climate, with annual precipitation of 57.44 mm, evaporation of 2756 mm, average temperature of 11.32℃, annual sunshine number of 2965 h, wind speed of 2.54 $m \cdot s^{-1}$, and frost-free period of 148 days (Liang et al., 2020). Before the experiment, the physical and chemical properties of the initial soil were determined. The soil in the study area (0-40 cm) was sandy loam (63.32% sand, 34.23% silt, 2.45% clay) saturated water content was 0.396 $cm^3 \cdot cm^{-3}$, wilting water content was 0.048 $cm^3 \cdot cm^{-3}$, field water capacity was 0.203 $cm^3 \cdot cm^{-3}$ (Chen et al., 2018; Liang et al., 2019).

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Test materials

The biochar selected in the test was prepared by pyrolysis of corn straw used by Xinjiang Carbon Biotechnology Co., Ltd., China, the results for many years showed that the best application rate in the field was 20 t·ha^{-1} (Liang and Shi, 2021). The desulfurized gypsum was selected from the South Thermal Power Plant of Xinjiang Tianfu Energy Co., Ltd., China, and the optimal application rate was 35 t·ha^{-1} according to the principle of ion exchange reaction (Wang et al., 2017). The locally harvested corn straw cut into small sections of about 5 cm by hay cutter was selected, and the application rate was 16 t·ha^{-1} (Tan et al., 2017).

Experimental design

The test was conducted in April to October 2019 and 2020. Various modifiers were applied to the soil surface in April 2019 and evenly mixed with the topsoil soil with a rotary cultivator. The main sampling date was April to October 2020. A single factor completely randomized block design was adopted. Using the field test method, 4 treatments were set as follows: CK (blank control without any soil improvement measures), B (biochar, 20 t·ha^{-1}), D (desulfurized gypsum, 35 t·ha^{-1}) and S (straw mulching, 16 t·ha^{-1}). Each treatment area was 30 m^2 (6 m long and 5 m wide), with 3 replicates. Cotton was planted by drip irrigation under the film. The cotton was cultivated by drip irrigation under film, and the cultivation mode was 1 film, 2 tubes and 4 rows, which the plant and row distance were 0.10 m and 0.20 m, respectively. The field management level in the later stage of treatment was the same. Conventional irrigation was adopted in the whole growth period of cotton, and the irrigation amount was consistent with the actual production. The irrigation quota of cotton growth period was 5250 m^3·ha^{-1}, the irrigation period was 7-10 days, and the total irrigation time was 10 times. The soil conditions of the test site before the test were shown in *Table 1*.

Table 1. *The condition of soil in the study area*

pH	Electric conductibility (dS·m^{-1})	Bulk density (g·cm^{-3})	Total salt content (g·kg^{-1})	Available phosphorus (mg·kg^{-1})	Available potassium (mg·kg^{-1})	Alkali-hydrolyzed nitrogen (mg·kg^{-1})	Organic matter (g·kg^{-1})
8.32	1.58	1.64	5.15	8.75	218.45	50.74	14.32

Investigate items and methods

Soil moisture content

At stages 13, 55, 61, 79 and 89 in BBCH scale for cotton, soil drill was used for multi-point collection of soil samples in different treatments. The sampling depth was 0-100 cm, and every 20 cm was a layer. After each layer of soil was mixed evenly, it was brought back to the laboratory, drying for 8 h to dry state under the constant temperature of 105°C, and then the soil mass moisture content was calculated.

Soil temperature

The soil temperature was measured by a WH55-405330 curved tube geothermometer (Dongfang Chemical Glass (Beijing) Technology Co., Ltd, China) for 3 consecutive days in each growth period. The soil temperature at the depth of 5, 15, 25 and 35 cm of the soil

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layer was read every 2 hours from 08:00 to 20:00 every day, and finally the average value was obtained.

Soil organic carbon content

At stages 13, 55, 61, 79 and 89 in BBCH scale for cotton, different treatments were sampled in 0-20 cm and 20-40 cm soil layers according to the multi-point method. The soil samples were crushed and mixed, dried and ground naturally, and the content of soil organic carbon was determined by potassium dichromate volumetric method. The organic carbon density of the *i* soil layer and the total organic carbon density of soil profile were calculated as *Eq.1* and *Eq.2*, respectively (Patton et al., 2019).

$$D_{SOCi} = C_i D_i E_i / 100 \quad \text{(Eq.1)}$$

$$D_{SOCt} = \sum_{i=1}^{n} D_{SOCi} = \sum_{i=1}^{n} C_i D_i E_i / 100 \quad \text{(Eq.2)}$$

where, D_{SOCi} represents the organic carbon density of the *i* soil layer, kg·m^{-2}. D_{SOCt} represents the total organic carbon density of the soil profile, kg·m^{-2}. C_i represents the content of soil organic carbon of the *i* soil layer, g·kg^{-1}. D_i represents the soil bulk density of the *i* soil layer, g·cm^{-3}. E_i represents the thickness of the *i* soil layer, cm. *n* represents the number of soil layers.

Cotton yield measurement

On September 18, 2020, the cotton yield under each treatment in the experimental plot of the study area was measured. 3 sample points were taken from each community. 11 lines were taken from each sample point to measure the line spacing and calculate the average line spacing. 21 plants in one row were randomly selected from each sample point to measure the plant spacing and calculate the average plant spacing. 3 rows were randomly selected from each sample point, 10 plants in each row, a total of 30 plants, and the number of bolls was investigated. 100 bolls were collected randomly at each sample point to weigh them after drying and calculate the average single boll weight. Cotton yield was calculated by the average line spacing, plant spacing, number of bolls per plant and average single boll weight.

Data processing and analysis

Data processing were carried out with Microsoft Excel 2016. The analysis of variance was performed by SPSS 20.0 statistical software. One-way ANOVA and LSD were used to test the significance of multiple comparison differences (α=0.05).

Results

Dynamic change characteristics of soil moisture content during cotton growth period

The dynamic changes of soil moisture content in 0-20 cm and 20-40 cm soil layers during the cotton growth period of each treatment were shown in *Fig. 1*. At stage 13 in BBCH scale for cotton (S1), plants were short and water consumption was low. The soil moisture content of CK treatment at 0-20 cm and 20-40 cm was lower than that of B and

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S treatments, while there was no significant difference between CK and D ($p > 0.05$) in 20-40 cm soil layer. At stage 55 in BBCH scale for cotton (S2), the growth indexes of cotton gradually increased, and the soil moisture content decreased due to water consumption. There was significant difference between the three improved treatments and the control ($p < 0.05$), while there was no significant difference between B and D treatments ($p > 0.05$), indicating that each improved measure had a good moisture conservation effect. The budding stage was the key period of cotton growth, and the appropriate water was more conducive to its growth and development. At stage 61 in BBCH scale for cotton (S3), the increase of soil moisture content in 0-20 cm soil layer B was the largest, up to 24.39%, and there was no significant difference between the three improved treatments and the control in 20-40 cm soil layer ($p > 0.05$). At stage 79 in BBCH scale for cotton (S4), the soil moisture content of each treatment in each soil layer was significantly different from that of the control ($p < 0.05$). At stage 89 in BBCH scale for cotton (S5), crop water consumption decreased in the mature stage, resulting in little change in soil moisture content. In 0-20 cm soil layer, B and S treatment were significantly higher than CK by 17.56% and 15.85%, respectively ($p < 0.05$). There was no significant difference between D treatment and CK ($p > 0.05$). In 20-40 cm soil layer, B treatment was significantly higher than CK ($p < 0.05$), with an increase of 16.00%, while there was no significant difference between D and S treatments ($p > 0.05$).

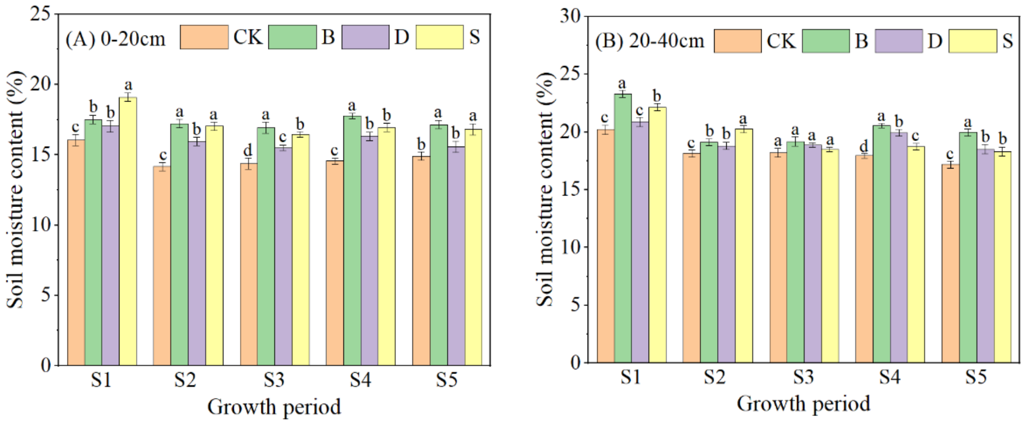

***Figure 1.** Dynamic changes of soil moisture content in different treatments during whole growth period. CK represents blank control without any soil improvement measures, B represents biochar 20 t·ha^{-1}, D represents desulfurized gypsum 35 t·ha^{-1}, and S represents straw mulching 16 t·ha^{-1}. S1, S2, S3, S4 and S5 represent stages 13, 55, 61,79 and 89 in BBCH scale for cotton, respectively. The error lines represent the standard variance, and different lowercase letters represent significant differences among treatments in the same soil layer ($p < 0.05$)*

Profile distribution characteristics of soil moisture content

The spatial distribution characteristics of soil moisture in 0-100 cm soil layer under different treatments within 110 days of cotton growth period were analyzed (*Fig. 2*). It could be seen that the spatial distribution characteristics of soil moisture in 0-40 cm soil layer of was obvious ($p < 0.05$), and the soil moisture content of each improved treatment was higher than that of CK. In the 40-100 cm soil layer, the soil moisture content fluctuated among the treatments, and there was no obvious law between treatments

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(p> 0.05). At stage 13 in BBCH scale for cotton, the soil moisture content of 0-100 cm soil layer of each treatment was higher, and the soil moisture content of 0-100 cm soil layer of CK treatment was lower than that of B, D and S treatment. At stage 55 in BBCH scale for cotton, the soil moisture content of 0-40 cm soil layer of each improvement treatment was generally higher than that of the control, and the effect of 10-20 cm soil layer was the most obvious (p< 0.05). The order of soil moisture content from large to small was B > S > D > CK. At stage 61 in BBCH scale for cotton, the soil moisture content of each treatment was higher than that of CK. At stage 79 in BBCH scale for cotton, the moisture content contour of 10-30 cm soil layer of B treatment was dense, which reflected that the soil moisture content gradient was large and changed violently in space. The soil moisture content was significantly higher than that of CK treatment, with a maximum increase of 80.47%. In addition, the spatial distribution pattern of soil moisture in each treatment profile showed the characteristics of lower wet and upper dry, but the spatial distribution position and soil moisture content of dry and wet soil layer between different treatments were less different (p> 0.05).

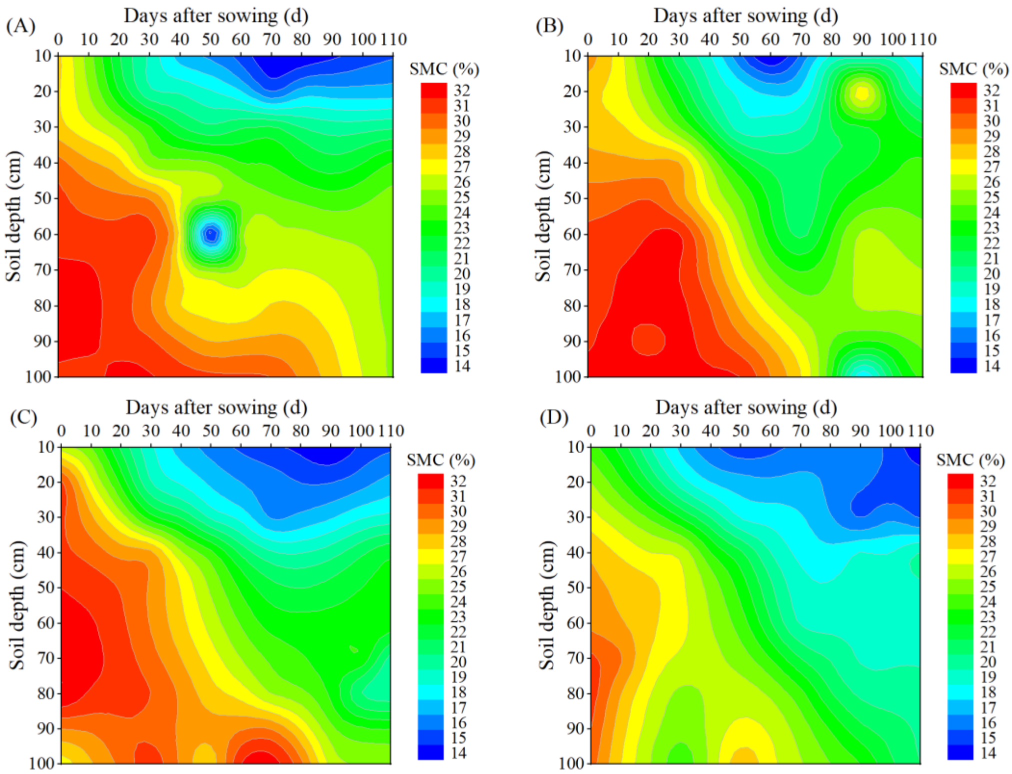

Figure 2. *Spatial distributions of soil moisture under different treatments. A represents the spatial distributions of soil moisture under biochar 20 t·ha^{-1}, B represents the spatial distributions of soil moisture under desulfurized gypsum 35 t·ha^{-1}, C represents the spatial distributions of soil moisture under straw mulching 16 t·ha^{-1} and D represents the spatial distributions of soil moisture under blank control without any soil improvement measures. SMC represents soil moisture cotton*

Effects of different improvement measures on soil temperature

The changes of soil multi-day average temperature in different growth stages of different treatments were shown in *Table 2*. At stage 13 in BBCH scale for cotton (S1),

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the heat preservation effects of treatment B and treatment D were the same. The depth temperature of each soil layer had no significant difference (p> 0.05), while they were higher than that of CK. There was a significant difference between treatment S and CK at the depth of 25 cm (p< 0.05). At stage 55 in BBCH scale for cotton (S2), D and S treatment had the same heat preservation effect, and the soil temperature at 15 cm was significantly higher than CK, increased by 2.5℃ and 2.44℃, respectively (p< 0.05). Compared with the control, B, D and S treatments could effectively improve the soil temperature in the early stage of cotton growth, make cotton emerge in advance and provide good soil temperature conditions for early growth. At stage 61 in BBCH scale for cotton (S3), the soil temperature of treatment B, D and S at the depth of 5-25 cm was 0.02-1.3℃ lower than that of CK, and the external temperature corresponding to this growth stage reached the peak value of the whole year. At stage 79 in BBCH scale for cotton (S4), due to the decrease of temperature at this time and the influence of physiological activities such as transpiration during plant growth, the relative humidity near the ground increased, resulting in the decrease of soil temperature. The thermal insulation effect of treatment B and D was equivalent, and the difference between treatment S and CK in 5-15 cm soil layer was significant (p< 0.05). At stage 79 in BBCH scale for cotton (S5), treatment B, D and S were significantly different from CK at 25 cm soil layer (p< 0.05), with an increase of 1.85℃, 1.74℃ and 1.89℃, respectively.

Table 2. *Comparison of soil temperature in different growth stages of cotton under different treatments*

Treatment	Soil depth (cm)	Soil temperature in different growth stages of cotton				
		S1(℃)	S2 (℃)	S3 (℃)	S4 (℃)	S5 (℃)
CK	5	21.32b	22.90a	26.23a	18.40b	15.11a
	15	20.90a	21.20b	25.11a	17.90b	14.11b
	25	19.31b	20.34a	23.60a	17.02a	13.22b
	35	19.21a	20.05a	21.06a	16.23a	13.22a
B	5	23.35ab	24.21a	25.13a	20.34ab	16.41a
	15	22.57a	22.79ab	23.85a	18.51ab	15.32ab
	25	21.90a	22.23a	23.01a	17.38a	15.07a
	35	20.86a	21.47a	21.04a	16.41a	14.25a
D	5	23.12ab	23.97a	26.20a	20.21ab	15.25a
	15	22.36a	23.70a	24.16a	18.14ab	15.07ab
	25	22.01a	22.12a	23.58a	18.08a	14.96a
	35	20.57a	21.04a	21.53a	17.18a	13.59a
S	5	23.80b	24.36a	26.01a	21.31a	16.21a
	15	22.41a	23.64a	24.02a	20.26a	15.73a
	25	21.80a	22.30a	22.90a	18.13a	15.11a
	35	21.03a	22.08a	21.46a	17.62a	14.27a

CK represents blank control without any soil improvement measures, B represents biochar 20 t·ha^{-1}, D represents desulfurized gypsum 35 t·ha^{-1}, and S represents straw mulching 16 t·ha^{-1}. S1, S2, S3, S4 and S5 represent stages 13, 55, 61,79 and 89 in BBCH scale for cotton, respectively. The different lowercase letters represent significant differences among treatments in the same soil layer (p< 0.05)

Effects of different improvement measures on soil organic carbon content

The variation characteristics of soil organic carbon content in 0-20 cm and 20-40 cm soil layers of each treatment in the whole growth period were shown in *Fig. 3*. In 0-20 cm soil layer, the content of soil organic carbon in treatment B and D was significantly higher than CK at stage 13 in BBCH scale for cotton (S1) (p< 0.05), with an increase of 52.58%

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and 24.96%, respectively. There was no significant difference between treatment S and CK ($p > 0.05$). In 20-40 cm soil layer, only treatment B was significantly higher than CK ($p < 0.05$), with an increase of 17.34%. At stages 55 (S2) and 61 (S3) in BBCH scale for cotton, the content of soil organic carbon in 0-20 cm soil layers treated with B, D and S increased by 52.22%, 27.12%, 15.72% and 36.90%, 16.85% and 20% respectively compared with CK. In 20-40 cm soil layer, the maximum increases of treatment B, D and S compared with CK were 29.42%, 18.18% and 19.37%, respectively. At stage 79 in BBCH scale for cotton (S4), the soil organic carbon content of each treatment was significantly different from that of CK in 0-20 cm and 20-40 cm soil layers, with an increase of 12.95- 47.12% ($p < 0.05$). At stage 89 in BBCH scale for cotton (S5), the soil organic carbon content of B and S treatment increased by 15.92% and 16.90% respectively in 0-20 cm soil layer, while the increase of D treatment was not significant ($p > 0.05$). In 20-40 cm soil layer, the soil organic carbon content of B, D and S treatment increased by 26.22%, 15.18% and 10.05%, respectively.

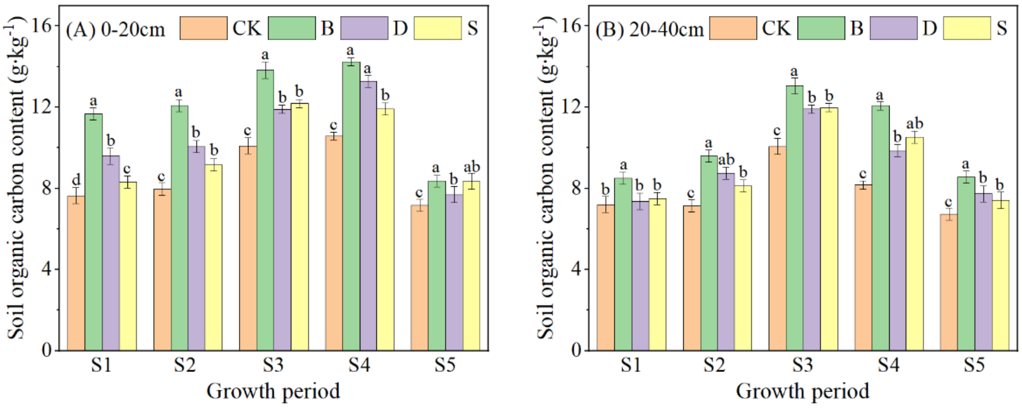

Figure 3. *Dynamic changes of soil organic carbon content under different treatments. CK represents blank control without any soil improvement measures, B represents biochar 20 t·ha^{-1}, D represents desulfurized gypsum 35 t·ha^{-1}, and S represents straw mulching 16 t·ha^{-1}. S1, S2, S3, S4 and S5 represent stages 13, 55, 61,79 and 89 in BBCH scale for cotton, respectively. The error lines represent the standard variance, and different lowercase letters represent significant differences among treatments in the same soil layer ($p < 0.05$)*

Changes of soil organic carbon density under different improvement measures

The total density of soil organic carbon in different soil layers of each treatment was higher than that of CK ($p < 0.05$, *Table 3*). The total density of soil organic carbon in 0-40 cm soil layer of CK, B, D and S treatments were 3.77, 4.43, 4.12 and 4.00 kg·m^{-2} respectively. Among them, B treatment was significantly higher than CK treatment ($p < 0.05$), with an increase of 17.46%. There was no significant difference among B, D and S treatments ($p > 0.05$). In 0-20 cm soil layer, the fluctuation range of soil organic carbon density among treatments was 1.93-2.19 kg·m^{-2}, in which treatment B and D were significantly higher than CK ($p < 0.05$), with an increase of 10.80% and 13.46% respectively. In the 20-40 cm soil layer, the fluctuation range of soil organic carbon density among treatments was 1.84-2.24 kg·m^{-2}. Among them, treatment B was significantly higher than other treatments ($p < 0.05$), 21.64%, 12.99% and 13.86% higher than CK, D and S, respectively. The soil organic carbon density between treatments D and S remained at the same level. The content of soil organic carbon in 0-20 cm soil layer

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was higher than that in 20-40 cm soil layer, indicating that the improvement measures were the main reason for the change of soil organic carbon density.

Table 3. *Soil organic carbon density under different treatments ($kg·m^{-2}$)*

Treatment	Soil depth (cm)		Total
	0-20	20-40	
CK	1.93b	1.84b	3.77b
B	2.02ab	1.97b	4.00a
D	2.19a	2.24a	4.43a
S	2.14a	1.98b	4.12a

CK represents blank control without any soil improvement measures, B represents biochar 20 $t·ha^{-1}$, D represents desulfurized gypsum 35 $t·ha^{-1}$, and S represents straw mulching 16 $t·ha^{-1}$. The different lowercase letters represent significant differences among treatments in the same soil layer ($p< 0.05$)

Effects of different improvement measures on cotton yield

The cotton yield under different improvement measures was shown in *Table 4*. Compared with CK, different improvement measures could promote the cotton yield and single boll weight, and the increase of each treatment was significantly different from that of the control ($p< 0.05$). Under different treatments, the single boll weight of cotton remained between 5.93-8.07 g. The single boll weight and yield of B, D and S treatments were significantly higher than CK ($p< 0.05$), with an increase of 36.10%, 29.67%, 25.11% and 32.28%, 30.68% and 21.94%, respectively, and there was no significant difference among the three treatments ($p> 0.05$). The heat preservation effect of each treatment at the seedling stage was significantly better than that of the blank treatment, which could lead to early emergence. The soil moisture content and organic carbon content effectively increased after the application of modifier, which promoted the growth and development of cotton. Therefore, the yield of each improved treatment was better than that of the blank treatment.

Table 4. *Effects of different improvement measures on cotton yield*

Treatment	Single boll weight (g)	Yield ($kg·ha^{-1}$)	Yield increase rate (%)
CK	5.93b	4212b	
B	7.42a	5136a	21.94
D	8.07a	5572a	32.28
S	7.69a	5504a	30.68

CK represents blank control without any soil improvement measures, B represents biochar 20 $t·ha^{-1}$, D represents desulfurized gypsum 35 $t·ha^{-1}$, and S represents straw mulching 16 $t·ha^{-1}$. The different lowercase letters represent significant differences among treatments in the same soil layer ($p< 0.05$)

Discussion

Effects of different improvement measures on soil moisture content and soil temperature

Water and heat conditions are the key factors affecting crop emergence rate, growth and development and improving crop yield (Yang et al., 2018a), while saline-alkali soil has hardened structure and poor ability of soil moisture and fertilizer conservation (Yan

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et al., 2021). Our results showed that the application of biochar, desulfurization gypsum and straw mulching could improve the soil moisture (*Fig. 1*) and temperature (*Table 2*) in varying degrees, and play the role of moisture conservation and heat preservation. In general, biochar treatment has better water retention and water holding capacity. Especially in the seedling stage, cotton plants are short, roots are shallow and transpiration is small. Evaporation between soil particles have become the main reason for soil water loss. At this time, biochar treatment can significantly increase soil water content, which mainly because biochar can increase soil porosity and improve soil water holding capacity. This is consistent with the research results of He et al. (2020) and Wu et al. (2019a). Desulfurized gypsum can also improve soil moisture content to a certain extent, mainly because it contains high valence ions, which can enhance soil ion adsorption capacity, improve soil aggregate structure and water holding capacity (Li and Wang, 2018). Straw mulching treatment can significantly increase soil moisture content in the early growth stage, and the increasing effect slightly weakened in the later stage. The main reason is that in the later stage, the cotton leaves grow luxuriantly, shading the soil, and plant transpiration is the major factor for the decrease of soil moisture content. In the later stage, the temperature gradually increases, the straw mulching enhances the ventilation capacity of the soil, and the plant water demand increases, which gradually reduces the moisture of the straw itself. Under the condition of drip irrigation, the amount of irrigation is not enough to offset the soil evaporation and crop water absorption. It leads to the decrease of soil moisture content in straw mulching treatment, which is basically consistent with the research results of (Xiao et al., 2019). Through the contour map of soil moisture content (*Fig. 2*), it could be intuitively found that this water retention phenomenon was more significant in biochar treatment. Most of the reasons are due to poor soil water holding capacity and leaching loss of soil organic matter (Bohara et al., 2019). Therefore, the application of biochar in saline-alkali soil can effectively alleviate this contradiction.

Different improvement measures could significantly regulate soil temperature (*Table 2*). Considering the whole growth period, the three improvement measures could improve the soil temperature to a certain extent. The main reason is that the biochar itself is black and the desulfurization gypsum is light gray (Nifong et al., 2019). After adding the improvers to the soil, the heat absorption capacity of the soil could be enhanced, so as to improve the soil temperature. This is consistent with the research results of Yang et al. (2018b). On the other hand, the porous structure of biochar may provide a favorable place for the survival of microorganisms (Shi et al., 2022). Microorganisms will release a lot of heat during their activities, thus increasing the soil temperature (Pagnossa et al., 2020). In addition, our results found that the improvement measures had the effect of increasing temperature and heat preservation in the early growth stage, which could promote the emergence, growth and development of cotton, and had a certain cooling effect in the highest temperature stage, so as to avoid the harm of high temperature and better regulate the soil temperature. The temperature regulating effect of each treatment was mainly in the soil layer of 5-25 cm and weakened at 35 cm. The reason may be that the soil surface temperature is greatly affected by solar radiation and added improvement measures, and with the increase of soil depth, the impact on soil temperature gradually decreases (Tian et al., 2019).

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Effects of different improvement measures on soil organic carbon

Farmland soil organic carbon pool is an active component in soil and the basis of high and stable yield of crops (Guo et al., 2020). Our results showed that the application of different improvement measures could improve the content of soil organic carbon (*Fig. 3*) and the total density of organic carbon (*Table 3*), among which the effect of biochar was the best. Due to the good effect of moisture conservation and heat preservation, biochar improves the soil structure, and the negative charge could increase the soil cation exchange capacity and reduce the soil nutrient loss (Razzaghi et al., 2020). Yuan et al. (2019) showed that the application of biochar could increase the content of soil total organic carbon and was conducive to the fixation of soil carbon, which was consistent with the results of our study. Desulfurized gypsum uses Ca^{2+} to replace Na^{+}, improves soil aggregate structure and contains a large number of trace elements, which can increase soil organic carbon content by changing soil physical and chemical properties (Liu et al., 2021). In addition, the soil organic carbon under desulfurization gypsum treatment was higher than that of straw mulching treatment. The reason may be that desulfurization gypsum reduces the degree of saline-alkali stress by reducing the soil salt content, which increases the effect of fertilizing salinized soil (Yonggan et al., 2020). It was also found that the content of soil organic carbon in the surface soil was higher, and the content of soil organic carbon decreased with the increase of soil depth. The reason may be that the change of soil organic carbon content in 0-20 cm plough layer is mainly affected by improvement measures, which further shows that improvement measures are very helpful to improve soil organic carbon.

Effects of different improvement measures on cotton yield

Compared with the control, the three improvement measures can significantly improve the yield and single boll weight of cotton (*Table 4*), and the yield increase rate of biochar is the highest, up to 32.28%, which is mainly due to the best water and fertilizer retention ability of biochar to soil in the whole growth period, so as to significantly improve the yield of cotton. This is similar to the research results of Wu et al. (2019b). Cao et al. (2019) showed that desulfurization gypsum has a significant effect on improving soil properties and increasing crop yield. Ma et al. (2019) found that straw mulching can significantly improve crop yield. Our results showed that the yield of desulfurized gypsum and straw mulching to the field increased by 30.68% and 21.94%, respectively, compared with the control, which was similar to the above results.

Biochar and straw are important measures to promote farmland sustainable development and resource recycling, and have broad research prospects (Xiu et al., 2019). As a waste of coal desulfurization, desulfurized gypsum is considered to be one of the soil improvement measures with economic, environmental protection and fast remediation rate (Zhang et al., 2021). Some studies have also shown that desulfurization gypsum should be combined with organic fertilizer and farming measures, and the effect is more remarkable (Febrisiantosa et al., 2018). This experiment mainly applied three different improvement measures in in Shaya County, Aksu Prefecture, Xinjiang, China, to study the effects of saline-alkali soil hydrothermal carbon and cotton growth. The results show that biochar treatment can better create good hydrothermal conditions, increase soil organic carbon and greatly improve cotton yield.

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Conclusions

1) The three improved treatments had good water storage effect. The application of biochar increased the most, up to 24.39%, desulfurization gypsum could stably increase the soil moisture content in the whole growth period, while straw mulching could significantly increase the soil moisture content in the early growth period.

2) In the whole growth period, the three improvement measures had a good stabilizing effect on the soil temperature of 5-25 cm soil layer, showing warming effect at low temperature and cooling effect at high temperature.

3) The three improvement measures could increase soil organic carbon content and organic carbon density, and the effect of applying biochar was the most significant, and the increase of straw mulching treatment was the smallest.

4) The three improvement measures could improve the yield and single boll weight of cotton. The application of biochar treatment had the highest yield, followed by desulfurization gypsum treatment, and the straw mulching treatment may have the lowest yield due to the short application life and the straw has not been fully decomposed. Therefore, the long-term effects of the improvement measures on saline-alkali soil and cotton growth need pay attention to and study in the future.

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REFERENCES

[1] Bohara, H., Dodla, S., Wang, J. J., Darapuneni, M., Acharya, B. S., Magdi, S., Pavuluri, K. (2019): Influence of poultry litter and biochar on soil water dynamics and nutrient leaching from a very fine sandy loam soil. – Soil and Tillage Research 189: 44-51.

[2] Cao, Y., Gao, Y., Li, J., Tian, Y. (2019): Straw composts, gypsum and their mixtures enhance tomato yields under continuous saline water irrigation. – Agricultural Water Management 223: 105721.

[3] Chen, W., Jin, M., Ferré, T. P. A., Liu, Y., Xian, Y., Shan, T., Ping, X. (2018): Spatial distribution of soil moisture, soil salinity, and root density beneath a cotton field under mulched drip irrigation with brackish and fresh water. – Field Crops Research 215: 207-221.

[4] Cui, Q., Xia, J., Yang, H., Liu, J., Shao, P. (2021): Biochar and effective microorganisms promote Sesbania cannabina growth and soil quality in the coastal saline-alkali soil of the Yellow River Delta, China. – Science of The Total Environment 756: 143801.

[5] Febrisiantosa, A., Ravindran, B., Choi, H. L. (2018): The effect of co-additives (Biochar and FGD Gypsum) on ammonia volatilization during the composting of livestock waste. – Sustainability 10(3): 789-795.

[6] Guo, L., Fu, P., Shi, T., Chen, Y., Zhang, H., Meng, R., Wang, S. (2020): Mapping field-scale soil organic carbon with unmanned aircraft system-acquired time series multispectral images. – Soil and Tillage Research 196: 104477.

[7] Hammerschmitt, R. K., Facco, D. B., Drescher, G. L., Mallmann, F. J. K., Ono, F. B., Zancanaro, L. (2021): Limestone and gypsum reapplication in an oxisol under no-tillage promotes low soybean and corn yield increase under tropical conditions. – Soil and Tillage Research 214: 105165.

[8] He, H., Wang, Z., Guo, L., Zheng, X., Zhang, J., Li, W., Fan, B. (2018): Distribution characteristics of residual film over a cotton field under long-term film mulching and drip irrigation in an oasis agroecosystem. – Soil and Tillage Research 180: 194-203.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_18211835

[9] He, K., He, G., Wang, C., Zhang, H., Xu, Y., Wang, S., Hu, R. (2020): Biochar amendment ameliorates soil properties and promotes Miscanthus growth in a coastal saline-alkali soil. – Applied Soil Ecology 155: 103674.
[10] Hou, X., Fan, J., Hu, W., Zhang, F., Yan, F., Xiao, C., Cheng, H. (2021): Optimal irrigation amount and nitrogen rate improved seed cotton yield while maintaining fiber quality of drip-fertigated cotton in northwest China. – Industrial Crops and Products 170: 113710.
[11] Li, J., Wang, J. (2018): Integrated life cycle assessment of improving saline-sodic soil with flue gas desulfurization gypsum. – Journal of Cleaner Production 202: 332-341.
[12] Liang, J., Shi, W., He, Z., Pang, L., Zhang, Y. (2019): Effects of poly-γ-glutamic acid on water use efficiency, cotton yield, and fiber quality in the sandy soil of southern Xinjiang, China. – Agricultural Water Management 218: 48-59.
[13] Liang, J., He, Z., Shi, W. (2020): Cotton/mung bean intercropping improves crop productivity, water use efficiency, nitrogen uptake, and economic benefits in the arid area of Northwest China. – Agricultural Water Management 240: 106277.
[14] Liang, J., Shi, W. (2021): Cotton/halophytes intercropping decreases salt accumulation and improves soil physicochemical properties and crop productivity in saline-alkali soils under mulched drip irrigation: A three-year field experiment. – Field Crops Research 262: 108027.
[15] Liang, J., Li, Y., Si, B., Wang, Y., Chen, X., Wang, X., Chen, H., Wang, H., Zhang, F., Bai, Y., Biswas, A. (2021): Optimizing biochar application to improve soil physical and hydraulic properties in saline-alkali soils. – Science of The Total Environment 771: 144802.
[16] Liu, S., Liu, W., Jiao, F., Qin, W., Yang, C. (2021): Production and resource utilization of flue gas desulfurized gypsum in China-A review. – Environmental Pollution 117799.
[17] Ma, L., Kong, F., Wang, Z., Luo, Y., Lv, X., Zhou, Z., Meng, Y. (2019): Growth and yield of cotton as affected by different straw returning modes with an equivalent carbon input. – Field Crops Research 243: 107616.
[18] Nifong, R. L., Taylor, J. M., Moore, M. T. (2019): Mulch-derived organic carbon stimulates high denitrification fluxes from agricultural ditch sediments. – Journal of Environmental Quality 48(2): 476-484.
[19] Pagnossa, J. P., Rocchetti, G., Ribeiro, A. C., Piccoli, R. H., Lucini, L. (2020): Ultrasound: Beneficial biotechnological aspects on microorganisms-mediated processes. – Current Opinion in Food Science 31: 24-30.
[20] Patton, N. R., Lohse, K. A., Seyfried, M., Will, R., Benner, S. G. (2019): Lithology and coarse fraction adjusted bulk density estimates for determining total organic carbon stocks in dryland soils. – Geoderma 337: 844-852.
[21] Razzaghi, F., Obour, P. B., Arthur, E. (2020): Does biochar improve soil water retention? A systematic review and meta-analysis. – Geoderma 361: 114055.
[22] Shi, Y., Liu, T., Yu, H., Quan, X. (2022): Enhancing anoxic denitrification of low C/N ratio wastewater with novel ZVI composite carriers. – Journal of Environmental Sciences 112: 180-191.
[23] Tan, S., Wang, Q., Xu, D., Zhang, J., Shan, Y. (2017): Evaluating effects of four controlling methods in bare strips on soil temperature, water, and salt accumulation under film-mulched drip irrigation. – Field Crops Research 214: 350-358.
[24] Tan, S., Wang, Q., Zhang, J., Chen, Y., Shan, Y., Xu, D. (2018): Performance of AquaCrop model for cotton growth simulation under film-mulched drip irrigation in southern Xinjiang, China. – Agricultural Water Management 196: 99-113.
[25] Tian, Y., Cui, L., Lin, Q., Li, G., Zhao, X. (2019): The sewage sludge biochar at low pyrolysis temperature had better improvement in urban soil and turf grass. – Agronomy 9(3): 149-156.
[26] Wang, S. J., Chen, Q., Li, Y., Zhuo, Y. Q., Xu, L. Z. (2017): Research on saline-alkali soil amelioration with FGD gypsum. – Resources, Conservation and Recycling 121: 82-92.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_18211835

[27] Wang, J., Zhang, Y., Gong, S., Xu, D., Juan, S., Zhao, Y. (2018): Evapotranspiration, crop coefficient and yield for drip-irrigated winter wheat with straw mulching in North China Plain. – Field Crops Research 217: 218-228.
[28] Wang, X., Wang, H., Si, Z., Gao, Y., Duan, A. (2020): Modelling responses of cotton growth and yield to pre-planting soil moisture with the CROPGRO-Cotton model for a mulched drip irrigation system in the Tarim Basin. – Agricultural Water Management 241: 106378.
[29] Wang, X., Wang, J., Wang, J. (2021): Seasonality of soil respiration under gypsum and straw amendments in an arid saline-alkali soil. – Journal of Environmental Management 277: 111494.
[30] Wu, X., Wang, D., Riaz, M., Zhang, L., Jiang, C. (2019a): Investigating the effect of biochar on the potential of increasing cotton yield, potassium efficiency and soil environment. – Ecotoxicology and environmental safety 182: 109451.
[31] Wu, Z., Zhang, X., Dong, Y., Li, B., Xiong, Z. (2019b): Biochar amendment reduced greenhouse gas intensities in the rice-wheat rotation system: six-year field observation and meta-analysis. – Agricultural and Forest Meteorology 278: 107625.
[32] Xiao, L., Zhao, R., Kuhn, N. J. (2019): Straw mulching is more important than no tillage in yield improvement on the Chinese Loess Plateau. – Soil and Tillage Research 194: 104314.
[33] Xiu, L., Zhang, W., Sun, Y., Wu, D., Meng, J., Chen, W. (2019): Effects of biochar and straw returning on the key cultivation limitations of Albic soil and soybean growth over 2 years. – Catena 173: 481-493.
[34] Yan, F., Zhang, F., Fan, J., Hou, X., Bai, W., Liu, X., Pan, X. (2021): Optimization of irrigation and nitrogen fertilization increases ash salt accumulation and ions absorption of drip-fertigated sugar beet in saline-alkali soils. – Field Crops Research 271: 108247.
[35] Yang, J., Mao, X., Wang, K., Yang, W. (2018a): The coupled impact of plastic film mulching and deficit irrigation on soil water/heat transfer and water use efficiency of spring wheat in Northwest China. – Agricultural Water Management 201: 232-245.
[36] Yang, Y., Yu, K., Feng, H. (2018b): Effects of straw mulching and plastic film mulching on improving soil organic carbon and nitrogen fractions, crop yield and water use efficiency in the Loess Plateau, China. – Agricultural Water Management 201: 133-143.
[37] Yonggan, Z., Yan, L., Shujuan, W., Jing, W., Wu, L. (2020): Combined application of a straw layer and flue gas desulphurization gypsum to reduce soil salinity and alkalinity. – Pedosphere 30(2): 226-235.
[38] Yuan, P., Wang, J., Pan, Y., Shen, B., Wu, C. (2019): Review of biochar for the management of contaminated soil: Preparation, application and prospect. – Science of the Total Environment 659: 473-490.
[39] Zhai, Y., Yang, Q., Wu, Y. (2016): Soil salt distribution and tomato response to saline water irrigation under straw mulching. – PLoS One 11: 1-17.
[40] Zhang, W., Zhang, W., Wang, S., Liu, J., Li, Y., Zhuo, Y., Zhao, Y. (2021): Band application of flue gas desulfurization gypsum improves sodic soil amelioration. – Journal of Environmental Management 298: 113535.
[41] Zhang, W., Zhao, Y., Wang, S., Li, Y., Liu, J., Zhuo, Y., Zhang, W. (2021): Combined application of flue gas desulfurization gypsum and straw pellets to ameliorate sodicity, nutrient content, and aggregate stability of sodic soil. – Journal of Soil Science and Plant Nutrition 21: 1806-1816.
[42] Zhao, Y., Wang, S., Li, Y., Liu, J., Zhuo, Y., Zhang, W., Xu, L. (2018): Long-term performance of flue gas desulfurization gypsum in a large-scale application in a saline-alkali wasteland in northwest China. – Agriculture, Ecosystems & Environment 261: 115-124.
[43] Zhao, W., Zhou, Q., Tian, Z., Cui, Y., Liang, Y., Wang, H. (2020): Apply biochar to ameliorate soda saline-alkali land, improve soil function and increase corn nutrient availability in the Songnen Plain. – Science of The Total Environment 722: 137428.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_18211835

[44] Zhou, Z., Li, Z., Zhang, Z., You, L., Xu, L., Huang, H., Cui, X. (2021): Treatment of the saline-alkali soil with acidic corn stalk biochar and its effect on the sorghum yield in western Songnen Plain. – Science of The Total Environment 797: 149190.
[45] Zhu, H., Yang, J., Yao, R., Wang, X., Xie, W., Zhu, W., Tao, J. (2020): Interactive effects of soil amendments (biochar and gypsum) and salinity on ammonia volatilization in coastal saline soil. – Catena 190: 104527.
[46] Zong, R., Wang, Z., Zhang, J., Li, W. (2021): The response of photosynthetic capacity and yield of cotton to various mulching practices under drip irrigation in Northwest China. – Agricultural Water Management 249: 106814.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_18211835