Effects of different improvement measures on physicochemical properties of saline-alkaline soil and ryegrass growth and yield in Dingbian

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Abstract. In order to explore the effect of different improvement measures on saline-alkali soil, related experiments were carried out in the field with four treatments sand covering(SC), straw mulching(SM), saline-alkali land amendments(SG) and control group(CK). The results, compared with the control, showed as follows: Soil physical and chemical properties were improved, soil salt content reduced by 1.16-2.22 g kg⁻¹, soil pH reduced by 0.05-0.94, soil density declined by 0.03-0.10 g cm⁻³ after improvement measures. Furthermore, the growth of ryegrass had been greatly improved, the ryegrass emergence rate increased by 18.4% to 31.7%, and the total yield of fresh grass increased by 35.24%-113.52%. The soil Hg, Pb, As, Cr contents and the plant Pb, As, Cr contents were significantly influenced by desulphurization gypsum. Whereas the heavy metal content in soil did not exceed Grade-II Soil National Standard for Agricultural Environment Quality, and the ryegrass Hg, Cd, Pb and Cr contents were within National Standard for Feed Hygienic Quality. This research suggested that the application of desulphurization gypsum, among the three improvement measures, produced the best effects. It was therefore recommended for wide application in similar saline-alkali soil conditions.

1. Introduction

With the rapid development of social and economic and the accelerating progress of urbanization in recent years, the number and quality of cultivated land was declining. Saline-alkali soil is the largest reserve land resource in China at present. According to the second national soil survey data, there were 16 million hectares of saline land, 866 thousand and 600 hectares of alkaline land and 16 million hectares of all kinds of salinized alkali land in China. So far, about 80% of the saline soil had not been effectively exploited and utilized [1]. At present, there were still about 140 thousand hectares of...
saline alkali land in Shaanxi Province, 79.7% of which was cultivated. At present, there were still about 140 thousand hectares of saline-alkali land in Shaanxi Province, 79.7% of which was cultivated land. Salinization degree of saline-alkali land in Shaanxi tended to be serious. Moderate-severe saline-alkali land accounted for about 75%. There were more than 300 saline-alkali land with an area of more than 1,000 mu [2]. Stepping up efforts to control saline-alkali land could have great significance to increase the income of farmers, guarantee the effective supply of important agricultural products and protect the ecological security.

In recent years, many studies had been made on saline-alkali land in Northern Shaanxi, and certain achievements had been obtained. Shaanxi Academy of Agricultural Sciences found that sand-covering measure had been widely used in the saline-alkali soil improvement in Yulin. Especially in areas with low temperature, high groundwater level and heavy soil salinization, the improvement effect was particularly significant. The thickness of sand covering was determined by the degree of soil salinization. It was better to take 5 to 10cm in moderate-severe saline-alkali land. [3] Li Furong showed that the straw surface coverage could effectively reduce the phreatic evaporation, increase soil water storage space and infiltration capacity, improve water utilizing efficiency, have obvious, soil moisture conservation and salt restraint effects, conducive to crop growth and accelerates growth and development of crop through field test [4]. Xiao Guoju showed that the application of desulphurization gypsum could significantly improve the salt content, alkalinity, total alkalinity and pH of moderate and severe saline alkali soil, and the best application amount of desulphurization gypsum was 20000 kg hm⁻²[5]. The formation of salinized soil was a long and complicated process. Due to great differences among soil matrix, natural environment and other factors of saline alkali soil in different regions, the effect of different improvement measures was quite different [6,7]. In this study, improvement tests of severe saline-alkaline soil were carried out in Dingbian. The dynamic change of soil physical and chemical properties and the growth status of crops under different improvement measures were comparatively analyzed. The research played the certain roles of providing theoretical reference and technical basis for the improvement and utilization of salinized soil in Northern Shaanxi.

2. Materials and methods

2.1. General situations of study region
The research is located at 36°58′ N and 107°42′ E in Dingbian county, Shaanxi province, and belongs to the semi-arid temperate continental monsoon climate, with average elevation of 1605m, annual average temperature of 7.9°C, average annual rainfall of 316.9mm, annual average frost free period of about 141d, average annual sunshine 2600h. It can fully meet the need for the light and heat of the crops, and is also one of the best ryegrass growing areas. Dingbian country had 192 thousand hectares of farmland, 73 thousand and 300 hectares of saline, in which there were 42 thousand and 700 hectares of severe saline alkali land, 19 thousand and 300 hectares of moderate saline alkali land and 11 thousand and 300 hectares of mild saline alkali land [2]. The background of soil was measured before the test in 2016, and the results were shown in Table 1.

Table 1. The background of the soil.

| Depth (cm) | pH     | Salinity content (g kg⁻¹) | organic matter (%) | Total N content % | Available P (mg kg⁻¹) | Available K content (mg kg⁻¹) |
|-----------|--------|--------------------------|--------------------|-------------------|-----------------------|-----------------------------|
| 0-20      | 9.21±0.14 | 6.84±0.12               | 2.47±0.05         | 0.25±0.04         | 0.25±0.04             | 32.77±3.02                  |
| 20-30     | 9.19±0.09 | 7.06±0.10               | 2.28±0.03         | 0.46±0.04         | 0.34±0.02             | 33.02±2.14                  |
| 30-50     | 9.01±0.21 | 7.11±0.11               | 4.47±0.03         | 0.32±0.03         | 0.39±0.03             | 38.75±2.03                  |
| 50-70     | 9.14±0.12 | 6.98±0.07               | 2.53±0.05         | 0.31±0.05         | 0.43±0.07             | 19.56±1.14                  |

2.2. Test materials and design
Four treatments, including blank control (CK), sand covering (SC), straw mulching (SM) and saline-alkali land amendments desulphurization gypsum (SG) were established in 2016 in Dingbian. The thickness of sand covering, the amount of straw mulching and the amount of desulphurization gypsum referred to the best application rates of medium-severe saline-alkali land, 10cm, 7500kg hm$^{-2}$ and 20000kg hm$^{-2}$ [8-9], respectively. The experiment was conducted as completely random block design. Each processing was set with 3 repetitions; the area of experimental plot was 3 m$^2$×5 m. The cultivar of ryegrass was Yilite developed by the Prairie Research Institute of Chinese Academy of Agricultural Sciences.

Planted ryegrass in September 10th, and the panting density was 6,000-12,000 plants per hectare. Phosphorus diamine fertilizer 200 kg hm$^{-2}$ was applied when snowing. Urea 50 kg hm$^{-2}$and potassium chloride 35kg hm$^{-2}$ were applied at the tillering stage. On the second day after mowing of ryegrass, using the mixture of urea 150 kg hm$^{-2}$, potassium chloride 10kg hm$^{-2}$ and water to irrigate the test field, and controlled for insects and weeding.

2.3. Sample collection and processing

2.3.1. Soil samples. From September 10, 2016 to October 23, 2017, soil sample were collected from each experimental plot, and the soil total salt, pH and bulk density were measured in the different periods of Ryegrass. After the harvest in October 2017, soil samples were collected in CK and SG to determine its contents of heavy metals such as Cd, Hg, Pb, Se, As and Cr.

2.3.2. Plant samples. 16 parts of the ryegrass leaves were collected in CK and SG, and the leaves were used to determine the content changes of heavy metals such as Cd, Hg, Pb, As, Cr and so on. The collected samples were cleaned with tap water and deionized water in the room, killed out at 90°C for 30 minutes, and then dried to constant weight at 75 °C.

2.3.3. Sample detection. Soil salt content was tested by mass method, soil pH by potentiometric method(Soil and water ratio was 5 to 1), soil bulk density by cutting ring method, and heavy metals in soil and ryegrass leaves by inductively coupled plasma mass spectrometry (ICPMS).

3. Interpretation of result

3.1. Effects of different improvement measures on the physical and chemical properties of saline-alkali soil

3.1.1. Soil salt content. Salt in saline-alkali soil has the movement rule of "salt along with water", and the salt content of soil is greatly influenced by precipitation and irrigation [10]. Figure 1 illustrated the change of soil salt content of soil plough layer under different improvement measures in 2016 and 2017. The salt content of SC, SM and SG showed a slow decreasing trend. The average salt content of CK, SC, SM and SG 2016 was 4.82, 4.08, 3.55 g and 2.89 g kg$^{-1}$, respectively. Compared with the natural control, the salt content of 0-20 cm soil layer of SC, SM and SG decreased by 1.16 g kg$^{-1}$, 1.47 g kg$^{-1}$, 2.22 g kg$^{-1}$.

It could be seen from the Figure 1 that the decrease of salt content in the soil of the plough layer was fairly small in 2016, and the soil salinity in the late growth period (after reaping of ryegrass) was even slightly increased. On the one hand, the soil water permeability was poor, the background value of salt was high, the leaching effect was inconspicuous in the first year of reclaiming wasteland, and there was a lot of water on the surface. On the other hand, due to the high water level, the high degree of salinity and the large amount of evaporation, the deep soil salinity had been strongly evaporated by the surface and moved to the ploughing layer.

The soil salt content in 0-20 cm soil layer in 2017 was obviously lower than that in 2016. On the one hand, tillage measures and improvement measures increased the 0-20cm soil nutrient content,
improved soil structure and physicochemical properties, and the irrigation could effectively extract soil salt to deeper soil layer. On the other hand, the groundwater level in the study area from May 2017 to September is low, and the high salinity groundwater had little influence on the salt content in 0-20 cm soil layer.

From 2 years of monitoring results of soil salinity, three measures of sand covering, straw mulching and desulphurization gypsum could conducive to reduce soil salinity. The order of decreasing soil salinity is: desulphurization gypsum, sand covering and straw mulching.

![Figure 1](https://example.com/f1.png)

**Figure 1.** Change of soil salt content in 2016 and 2017 with different improvement measures.

3.1.2. **Soil pH.** Table 2 was the monitoring result of the soil pH in the plough layer. The soil pH under different improvement measures showed a decreasing trend in the ryegrass growth period in 2016 and 2017. The soil pH of SC, SM and SG was 0.27, 0.43 and 1.13 lower than that of CK. The results of variance analysis showed that the soil pH had no significant difference among SC, SM and CK in the same monitoring period. The soil pH of the plough soil treated with desulphurization gypsum was significantly lower than that of the CK. In 2016, the average decreased by 0.63, and the average decreased by 0.96 in 2017 compared with the control, which indicated that the application of desulphurization gypsum to the salt-alkali land still had an effect on the soil for second years.

| treatment | 2016  | 2017  |
|-----------|-------|-------|
|           | 9-10  | 10-15 | 11-05 | 5-27 | 6-21 | 7-12 | 7-25 | 8-13 | 8-24 |
| CK        | 9.13b | 9.12b | 9.11b | 9.22c | 9.18b | 9.11b | 9.09b | 9.14c | 9.01b |
| SC        | 9.11b | 9.07b | 9.15b | 9.09b | 9.11b | 9.03b | 8.98b | 8.87b | 8.83b |
| SM        | 9.13b | 9.05b | 9.07b | 9.12b | 9.11b | 9.03b | 9.01b | 8.98b | 8.96b |
| SG        | 8.62a | 8.51a | 8.35a | 8.32a | 8.21a | 8.11a | 8.20a | 8.05a | 8.07a |

3.1.3. **Soil bulk density.** The saline-alkali soil had the character of high bulk density, compact structure, more aggregate, poor air and water permeability. Therefore, it was difficult to improve and utilize [11]. The results of soil bulk density in each layer after ryegrass harvest in 2016 and 2017 in Table 3 showed that: Soil bulk density and physical properties could be effectively ameliorated by improved measures. According to the data in 2016, straw mulching had no significant effect on soil bulk density of 0-60 cm soil layer. Sand cover and application of desulphurization gypsum
significantly reduced soil bulk density of 0-20cm soil layer, but these had no significant effect on bulk density of deeper soil. In addition, from the data in 2017, it could be seen that 3 improvement measures had certain effect on soil bulk density, and as time goes on, soil structure and soil depth would be improved.

Table 3 The soil bulk density (g cm⁻³).

| Years | Treatment | Depth (cm) | 0-10 cm | 0-20 cm | 20-40 cm | 40-60 cm |
|-------|-----------|------------|---------|---------|----------|----------|
| 2016  | CK        | 1.46       | 1.54    | 1.43    | 1.45     |
|       | SC        | 1.39       | 1.46    | 1.46    | 1.43     |
|       | SM        | 1.45       | 1.52    | 1.43    | 1.46     |
|       | SG        | 1.37       | 1.47    | 1.44    | 1.44     |
| 2017  | CK        | 1.45       | 1.52    | 1.45    | 1.45     |
|       | SC        | 1.39       | 1.42    | 1.41    | 1.42     |
|       | SM        | 1.42       | 1.43    | 1.41    | 1.43     |
|       | SG        | 1.35       | 1.38    | 1.39    | 1.41     |

3.2. Effects of different improving measures on growth and yield of ryegrass
It could be seen, from Table 4, that three different improvement measures could significantly improve the emergence rate of ryegrass. The emergence rate of sand covering, straw mulching and application of desulfurization gypsum increased by 54.18%, 43.35% and 69.95%, and the fresh yield increased by 60.84%, 39.24%, 112.48% in 2016, compared with the blank control, respectively. The results showed that the three different improvement measures could improve the emergence rate and yield of ryegrass. The treatment of desulfurization gypsum had the highest fresh grass yield in 2016, and the treatment of desulfurization gypsum also had the highest fresh grass yield after the harvest of 1 stubble ryegrass. The results showed that the improvement measures of first years still had significant effect on production increase of fresh grass for second years. The yield of 3 stubble ryegrass with desulfurization gypsum increased by 5759, 4463 and 4530 kg hm⁻², respectively, and increased by 89.66%, 112.48% and 86.19%, compared with CK.

Table 4. The emergence rate and yield of ryegrass with different improvement measures.

| Treatments | 1st mowing in 2016 | 2nd mowing in 2017 | 3rd mowing in 2017 |
|------------|--------------------|--------------------|--------------------|
|            | Average (%)        | Increase percentage (%) | Average (%)        | Increase percentage (%) | Average (%)        | Increase percentage (%) |
| CK         | 50.75c             | -                  | 5120c              | -                  | 5652c              | -                  |
| SC         | 72.75b             | 43.35              | 7129bc             | 39.24              | 7253b              | 28.33              |
| SM         | 78.25b             | 54.18              | 8235b              | 60.84              | 9023ab             | 59.64              |
| SG         | 86.25a             | 69.95              | 10879a             | 112.48             | 10115a             | 78.96              |

3.3. Effect of application of desulfurization gypsum on heavy metal content in plough soil and Ryegrass
As a waste from coal-fired power plants, the desulfurization gypsum contains some heavy metal elements that would enter the soil with the application of desulfurization gypsum to improve saline alkali land [12]. In order to know the effects of desulfurization gypsum on soil environment, ryegrass and forage safety, the contents of Cd, Hg, Pb, As and Cr in the 0-20cm soil layer and the ryegrass leaves harvested in 2017 were detected. The results showed (Table 5) that the content of Hg, Pb, As and Cr in soil and the contents of Pb, As and Cr in the leaves of ryegrass were significantly increased by the application of desulfurization gypsum. The Hg, As, Pb and Cr in the soil increased by 0.02 mg kg⁻¹, 0.92 mg kg⁻¹, 0.48 mg kg⁻¹ and 0.77 mg kg⁻¹, respectively. In the leaves of ryegrass, Cd was not detected, the content of Hg was not increased, and the content of Pb, As and Cr increased significantly
as the application of desulfuration gypsum, compared to the blank control. The content of Pb in 0-20 cm soil and ryegrass leaves was the highest, followed by As, Hg and Cr.

Table 5. Content of heavy metals in the leaves of 0-20 cm soil and ryegrass with the application of desulfuration gypsum.

| Sample    | Treatment | Cd   | Hg   | Pb   | As   | Cr   |
|-----------|-----------|------|------|------|------|------|
| Soil      | CK        | 0.03 | 0.11 | 1.19 | 1.4  | 1.58 |
|           | SG        | 0.03 | 0.13 | 2.11 | 1.9  | 2.35 |
| Ryegrass  | CK        | ND   | 0.03 | 0.89 | 0.01 | 1.21 |
|           | SG        | ND   | 0.03 | 1.21 | 0.21 | 1.51 |

Note: ND indicated that the content was lower than the detection limit, and the detection limit of Cd was 0.02 mg kg⁻¹.

4. Discussion

The fundamental problem of soil salinization was the movement of high salinity water in the soil. Therefore, controlling the rising of groundwater level or lowering the groundwater level and reducing the evaporation of soil water were the key to solve the soil salinization [13]. The surface coverage measures could separate the soil from the atmosphere to reduce the loss of soil moisture, reduce surface evaporation, prevent the rising of soil salt content, regulating soil water heat process, promote nutrient cycling and crop growth, and further make the saline soil ecological process to the benign transformation [14]. Northern Shaanxi was one of the suitable regions of corn and wheat in Shaanxi and even the whole country. The planting area of corn and wheat was large, and the amount of plant straw was abundant [15]. The literature showed that straw mulching could effectively reduce the evaporation of soil surface, improve soil structure, reduce soil bulk density and improve soil permeability. Straw mulching also had important influence on soil moisture conservation, inhibition of salt surface accumulation, promotion of rain drenching salt, and increase of crop yield. In addition, the crop straw contains a large number of nutrients such as carbon, nitrogen, phosphorus, potassium and trace elements which are important sources of recharge of soil nutrients [16].

Sand covering is one of the important measures to improve the secondary salinization of soil, and is also one of the best methods for the development and utilization of saline alkali land in Northern Shaanxi. It could change the physical and chemical properties of soil, improve the ground temperature and prevent the rise of salt, so there was a proverb ‘Salinized land covered with sand like the gold brick’ [17]. Covering sand on medium and severe saline soil can help restrain salt and alkali content. The pore of sandy soil is large, and the suction cannot be formed, thus limiting the salinity of the saline alkali soil to move upward and distributing it to a certain depth of the soil, which help to achieve the purpose of developing plough horizon. Or due to a certain degree of mixing between the covered sand soil and the saline alkaline soil, the soil viscosity can be adjusted to reduce the bulk density, improve the soil structure, and reduce the salt effect.

As a traditional chemical modifier, gypsum can reduce soil pH value, alkalinity and bulk density, and improve the infiltration rate, soil porosity and desalination rate, thereby increasing the difficulty of the soil surface crust [18]. The successful experience of improving alkaline soil with gypsum had been recognized by many scholars at home and abroad. In general, the soil with high pH is improved by gypsum. Calcium ions in gypsum replace sodium ions adsorbed on Soil Colloids, and sodium ions are moved to the root layer of the crop under the action of leaching, thereby reducing the degree of dispersion of sodium ions on the soil particles, and decreasing soil pH. A good soil water and salt environment are created for the growth of crops in the end [19]. The desulfuration gypsum is mainly composed of CaSO₄ and CaSO₃₄, similar to the natural gypsum, contains rich mineral nutrients such as Ca, S, Si and other mineral nutrition, and can replace natural gypsum to improve saline-alkali soil [20]. The research showed that when desulphurization gypsum was used to improve saline alkali soil and grow oil sunflower. The improved depth of desulfuration gypsum was generally 20-30 cm. So, it is
suggested that plough after rotary tillage will be beneficial to improve the improvement effect and promote the growth and development of crops [21].

5. Conclusion
The results showed as follows compared with the control: soil salt content reduced by 0.11-1.46, soil pH reduced by 0.11-1.46, soil density declined by after improvement measures. Furthermore, the physical and chemical properties of soil have been improved effectively, and the growth of ryegrass had been greatly improved. The ryegrass emergence rate increased by 18.4% to 31.7%, and the total yield of fresh grass increased by 35.24% to 113.52%. Overall, 3 improvement measures are conducive to Dingbian Shaanxi saline soil, and the application of desulfurization gypsum had the best effect.

When using to improve saline soil, the harmful elements contained in desulfurization gypsum had no direct pollution, but the content of harmful elements in different parts of the ryegrass have been relatively increased, forming a potential harm to the food chain. The results showed that the application of desulfurization gypsum to improve saline alkali soil significantly increased the content of heavy metals in cultivated soil and ryegrass, but the contents of heavy metals such as Cd, Hg, Pb, As and Cr in Ryegrass and soil did not exceed Grade-II Soil National Standard for Agricultural Environment Quality and National Standard for Feed Qygienic Quality. Therefore, it is safe to apply the desulfurization gypsum to improve the agricultural soil and the ryegrass produced in the saline alkali land.

Ryegrass is a high quality forage and green manure crop widely cultivated in Northern Shaanxi Province. Enlarging the scale of medium and severe saline alkali soil improvement and ryegrass planting was of great reference value for establishing a circular agricultural economic mode of "improving saline alkali soil forage grass, developing animal husbandry, returning organic fertilizer to saline soil" [22].

The formation of salinized soil is a long and complex process, and the improvement of saline soil is also a complex systematic project. Any single measure has its own applicable conditions, technical advantages and limitations [23]. According to the present situation of Dingbian saline alkaline land, the suggestion is as follows: adopting comprehensive measures to improve and heavily using physiological acid fertilizer which also neutralizes soil alkalinity while supplementing soil nutrients. In addition, straw can be covered or covered with sand to further improve the soil physical and chemical structure and inhibit the soil back to salt [24].

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