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# ALKALI SOIL RECLAMATION IN CHINA USING GYPSUM PRODUCED IN FLUE GAS DESULFURIZATION PROCESS; A CASE STUDY

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## Abstract

In China, increasing desertification due to alkalization of the soil is one of the most serious environmental problems. Moreover, air pollution from coal combustion is another serious problem. The effect of alkali soil reclamation using gypsum produced in flue gas desulfurization processes has been investigated in northeastern China. As a result, a good harvest of corn has been obtained from the test field. It was shown that adding 0.5wt% gypsum from both wet and semidry desulfurization processes improved the soil of the field test. These results showed the possibility of alkali soil reclamation using a by-product of the desulfurization process.

**KEYWORDS:** *alkali soil, China, desulfurization, gypsum, soil reclamation*

## 1. Introduction

In China, coal is presently the main source of energy. It is estimated that coal will provide about 67% of the primary energy in 2020, dropping from the present 76%. However, the total coal consumption will be increased to 2.3 billion tons from the current 1.2 billion tons per year (Xu et al., 2000). Moreover, with the rapid economic growth and continuously increasing energy consumption, China is facing serious air pollution problems. In particular, sulfur dioxide originating from coal combustion facilities causes acid rain. Most of the coal combustion facilities in China do not include a desulfurization process due to economical limitations, even when high-sulfur-content coal is used. In order to solve such serious air pollution problems, it is necessary, for example, to immediately introduce the desulfurization process at coal-fired power plants. The most popular desulfurization process is the flue gas desulfurization (FGD) process. Flue gas desulfurization (FGD) can be achieved by various methods, generally wet processes (e.g., wet lime/limestone), semidry processes (e.g., spray dry scrubbers, duct sorbent injection) and dry processes (e.g., furnace sorbent injection, electron beam method). In order to spread the desulfurization process in China, effective use of the desulfurization by-products is required. In general, these desulfurization processes generate by-products such as gypsum, sulfuric acid and sulfuric ammonium.

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China has been acclaimed for its ability to feed over 20 percent of the world's population with only 7% of the world's arable land. Considering the continued growth of the population in China in the near future, it is necessary to enlarge the cultivated acreage. However, the desertified area in China is about 350,000km$^2$, which corresponds to 3.7% of China's total area. The total area of semi-arid and arid land in China occupies 52.5% of the total area. Moreover, the desertified area is increasing 2100km$^2$ per year. In the northeastern part of China, salt-affected soil is spreading due to the increase of the evaporation rate and excessive cultivation. The United States Salinity Laboratory (US Salinity Laboratory Staff, 1954) classifies salt-affected soils into three groups of soil types based on pH, EC (electric conductivity) and ESP (exchangeable sodium percentage). These soils are classified as follows: saline soil: pH<8.5, EC>4dS/m and ESP<15; alkali soil: pH>8.5, EC<4dS/m and ESP>15; saline-alkali soil: pH>8.5, EC>4dS/cm and ESP>15. Soils in arid and semi-arid regions often contain significant amounts of carbonate mineral that may contribute calcium and magnesium ions to the soil solution (Nadler et al., 1996). This addition of divalent cations to the soil solution can reduce clay dispersion and increase hydraulic conductivity in the soil profile (Keren et al., 1990). The effect of sodium (Na) and electrolyte concentrations in relation to hydraulic conductivity, infiltration, crusting, runoff and erosion have been discussed, because swelling and dispersion are the primary processes responsible for the degradation of the physical properties of soil in the presence of sodium. In pure sodium systems, montmorillonite separates into single platelets and develops high swelling pressures that are predictable by the diffuse double layer theory (Van Olphen, 1963).

The total area of alkali soils in the arid and semi-arid regions of China has reached 320,000km$^2$. The reason behind this has been investigated through recent soil surveys carried out by Japanese and Chinese soil scientists. More than 50,000km$^2$ of Mollisol distributed in semi-arid regions of China is suffers from alkalization (Matsumoto et al., 1998). Mollisol is one of the main world soil types and is expected to yield the highest productivity in semi-arid lands. According to our investigation of the soil of the arable land near Shenyang City in China, many clear zones were found in patches at cornfields. All soil profiles suffering from alkalization were composed of newly deposited topsoil with extremely high pH and subsoil consisting of buried Mollisol exhibiting a slightly alkaline reaction. The boundary between the topsoil and the subsoil is very clear.

Reclamation of sodic soil involves the replacement of exchangeable $Na^+$ with $Ca^{2+}$ that can be supplied by the presence or addition of gypsum, soil lime, or both (Oster et al., 1980). Reclamation can be achieved by leaching with or without chemical amendments added to the soil or irrigation water (Keren et al., 1990). Chemical amendments are as follows: 1) soluble calcium salts (e.g., $CaCl_2$), 2) sparingly soluble salts (e.g., $CaSO_4 \cdot 2H_2O$, $CaCO_3$, dolomite), 3) acids or acid forms of chemicals (Miyamoto et al., 1975). Among them, gypsum is the most common alkali soil amendment, because it has the advantages of being nontoxic to plants, easy to handle, and moderately soluble. Hence, gypsum amendment can be an efficient and cost effective method of reclaiming saline-alkali soils (US Salinity Laboratory Staff, 1954; Gupta et al., 1990; Keren et al, 1990).

Hence, it would be considered a true case of killing two birds with one stone if the gypsum generated in the desulfurization process of coal fired power plant and factories could be used as soil amendments for sodic soil. In this research such gypsum has been used as soil amendment since 1996. The experiment of the cultivation of corn in the alkali soil was carried out at a field in the northeastern part of China. The objective of this study is to examine the possibility of using the by-product from the desulfurization process for the amelioration of alkali soils, aiming to create an incentive for the acceptance of the desulfurization process in China. In this report, the change of the soil chemical properties and corn production from 1996 to 2000 is mainly presented.

## 2. Material and Methods

Field experiments were performed in the semi-arid area at Kangping (42°70'N, 123°50'E) which is about 100km north of Shenyang in northeastern China. Chemical properties of Kangping soil are shown in Table 1. This soil is characterized by a high pH and high exchangeable sodium percentage (ESP). Moreover it has characteristics typical of calcareous sodic soil containing $CaCO_3$ (Chun S. et al., 2001). From the soil pH, EC and ESP (Table 1), the experimental field soil is classified as alkali soil following the classification of saline and alkali soils by USSL (US Salinity Laboratory Staff, 1954).

Table 1 Chemical properties of Kangping soil

| Parameter | Value |
|---|---|
| pH | 10.2 |
| EC (electrical conductivity) ($dSm^{-1}$) | 0.84 |
| CEC (cation exchangeable capacity) ($(+)cmolkg^{-1}$) | 8.4 |
| $CaCO_3$ ($gkg^{-1}$) | 22.5 |
| ESP (exchangeable sodium percentage) (%) | 34 |

Flue gas desulfurization gypsum (FGDG) has been used as alkali soil amendment since 1996. In 1996, Field 1 (3.6m×3.6m×12plots) was set up and 48 seeds of corn were sown in each plot on June 16. In Field 1, gypsum from the wet desulfurization process was used as alkali soil amendment at application rates of 0, 0.25 ($5.8tha^{-1}$), 0.5 ($11.6tha^{-1}$), and 1.0wt% ($23.1tha^{-1}$) only in 1996. Four out of twelve plots were supplied with only desulfurization gypsum without chemical fertilizers. One plot was not supplied with gypsum (control plot).

In 1997, Field 2 (3.6m×1.8m×12) was set up and 24 seeds of corn were sown in each plot on May 31. In Field 2, gypsum from wet and semidry desulfurization processes was added to soil at application rates of 0, 0.25 ($5.8tha^{-1}$), 0.5 ($11.6tha^{-1}$), and 1.0wt% ($23.1tha^{-1}$) only in the first year. Desulfurization gypsum and application rate in each plot are shown in Table 2. There are two each of control, 0.5wt% and 1.0wt% application plots in the test field. In data processing for Field 2, average values were used; chemical fertilizer was added to all plots in Field 2.

Fig.1 shows the corn production in Field 2 in 2000. Plot No.1 was supplied with 0.5wt% wet desulfurization gypsum and plot No.2 was reclaimed with 0.5wt% semidry desulfurization gypsum. No.3 is a control plot (no gypsum application). For two plots except the control plot, it was confirmed that corn grew very well.

The compositions of the desulfurization gypsum from wet and semidry processes are shown in Table 3. Wet desulfurization gypsum mostly consists of $CaSO_4$ and semidry desulfurization gypsum consists of $Ca(OH)_2$, $CaCO_3$, $CaSO_3$ and $CaSO_4$ (Table 3). The pH of semidry desulfurization gypsum is higher than that of wet gypsum.

Naturally, the precipitation and the temperature during the growing season are very important factors that govern the growth of plants. Precipitation and temperature data from April to September in each year are shown in Table 4. The precipitation in 1996 and 1999 was lower than in other years. Moreover, the precipitation in July and August is greater than in other months in each year. The difference in the temperature among years is small, except for April in 1998.

Table 2 Variety of desulfurization gypsum and application rate in each plot in Field 2

| plot | soil amendment | application rate |
|---|---|---|
| 1 | wet[a] | 0.5% (11.6t/ha) |
| 2 | semidry[b] | 0.5% (11.6t/ha) |
| 3 | control[c] | 0% (0t/ha) |
| 4 | control | 0% (0t/ha) |
| 5 | wet | 0.5% (11.6t/ha) |
| 6 | semidry | 0.5% (11.6t/ha) |
| 7 | wet | 1.0% (23.1t/ha) |
| 8 | semidry | 1.0% (23.1t/ha) |
| 9 | wet | 0.25% (5.8t/ha) |
| 10 | semidry | 0.25% (5.8t/ha) |
| 11 | wet | 1.0% (23.1t/ha) |
| 12 | semidry | 1.0% (23.1t/ha) |

[a] flue gas desulfurization gypsum from wet process, [b] flue gas desulfurization gypsum from semidry process, [c] no gypsum application

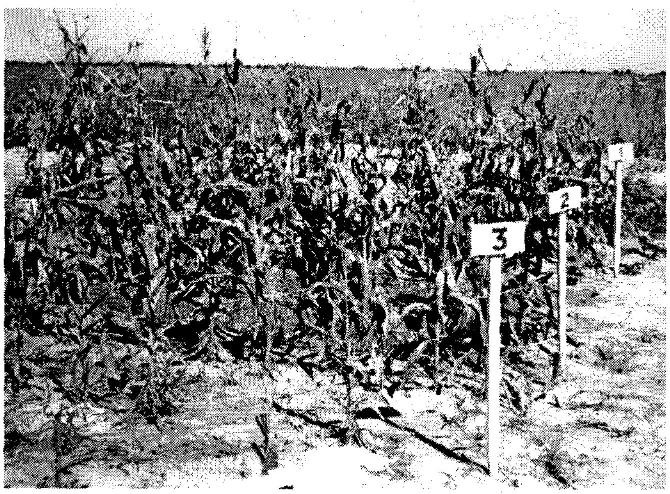


Fig.1 Photograph of Field 2 in 2000

In figure, plot No.1 and No.2 indicate 0.5wt% wet and 0.5wt% semidry desulfurization gypsum, respectively. Plot No.3 is control plot (no gypsum application).

Table 3 Composition of wet and semidry desulfurization gypsum

| | Wet desulfurization gypsum | Semidry desulfurization gypsum |
|---|---|---|
| pH | 7.6 | 12.6 |
| $CaSO_4$ | 88wt% | 20wt% |
| $CaSO_3$ | 0wt% | 35wt% |
| $CaCO_3$ | 9wt% | 20wt% |
| $Ca(OH)_2$ | 0wt% | 20wt% |
| Others | 3wt% | 5wt% |

Table 4 Precipitation and temperature for test field (1996-2000)

| | Year | April | May | June | July | Aug. | Sept. | Total |
|---|---|---|---|---|---|---|---|---|
| Precipitation (mm) | 1996 | 15.8 | 43.6 | 38.0 | 97.6 | 54.3 | 9.4 | 258.7 |
| | 1997 | 12.2 | 43.3 | 34.7 | 79.3 | 282.7 | 66.6 | 518.8 |
| | 1998 | 20.2 | 23.2 | 118.8 | 292.7 | 222.9 | 28.4 | 706.2 |
| | 1999 | 19.7 | 16.3 | 56.7 | 96.5 | 141.0 | 5.4 | 335.6 |
| | 2000 | 18.9 | 26.2 | 28.7 | 51.0 | 288.4 | 50.6 | 463.8 |
| Temperature (℃) | 1996 | 9.1 | 17.3 | 22.4 | 23.2 | 21.9 | 17.2 | |
| | 1997 | 10.9 | 16.5 | 23.4 | 26.2 | 24.2 | 16.3 | |
| | 1998 | 13.6 | 17.8 | 21.2 | 23.5 | 22.2 | 18.5 | |
| | 1999 | 9.3 | 16.7 | 21.6 | 25.6 | 22.8 | 17.8 | |
| | 2000 | 9.2 | 17.9 | 24.6 | 26.3 | 24.4 | 19.0 | |

### Experimental procedure

Soil samples from the surface (0cm) to 20cm depth were air-dried and crushed to pass through a 2mm sieve. The pH of 50ml solution mixed with 10g of the soil was measured with a pH meter (TOA Electronics Ltd., Japan). EC was measured with an electric conductivity meter (HORIBA Ltd., Japan). CEC is the cation exchangeable capacity determined using 1N NaOAc at pH 8.2. Cations and anions in soil solution (1:5 water extraction) were measured by atomic absorption spectrometry (680A, Shimadzu Co. Ltd., Japan) and ion chromatography (LC-6A, Shimadzu Co. Ltd., Japan), respectively. The desulfurization gypsum compositions were measured by thermogravimetry -differential thermal analysis (TG-DTA) (Shinkuriko Co. Ltd., Japan). The conditions of measurement are as follows: increase rate of the temperature is 20℃/min to 1050℃ and flow rate of ambient $N_2$ gas is 50ml/min.

## 3. Results and Discussion

In order to evaluate the continuity of desulfurization gypsum as soil amendment, corn production and soil pH of a small test field from 1996 (Field 1) have been investigated. In this test field, desulfurization gypsum from the wet process was used as soil amendment. Gypsum treatment had a significant effect on all soil properties compared with the control plot. The size of each plot in the test field was 3.6m×3.6m. One plot was sown with 48 seeds of corn.

Sodic soils contain an excess of exchangeable sodium ions on soil colloids and have soluble carbonates in the form of $Na_2CO_3$ and $NaHCO_3$. This results in a high pH (>8.4) of the soil, clay dispersion, soil swelling, and overall poor soil physical properties (Suarez et al., 1984; Gupta et al., 1990). In order to reclaim sodic soils, it is necessary to replace the exchangeable $Na^+$ with $Ca^{2+}$ by gypsum treatment. $Ca^{2+}$ from $CaCO_3$ is not effective for inducing the Na-Ca exchange reaction because the solubility of $CaCO_3$ at high pH is extremely low.

Fig.2 shows the change of soil pH from 1996 to 2000 for Field 1. Soil pH declined with increasing amount of applied desulfurization gypsum. It is assumed that this tendency probably shows the effect of gypsum as soil amendment. Soil pH was 9.75 (control), 9.27 (0.25wt%), 8.66 (0.5wt%) and 8.49 (1.0wt%) in each application fields in 1996. Soil pH (9.57 (control), 9.4 (0.25wt%), 8.89 (0.5wt%) and 8.41 (1.0wt%)) in 2000 was almost the same as in 1996. Thus, it was concluded that the effect of soil pH reclamation continued for at least five years with one application of gypsum in the first year. In the 1.0wt%-gypsum plot, the soil pH ultimately decreased to 8.41. It has been reported that the dispersion of clay in sodic soils could be reduced threefold by reducing soil pH from 9 to 7 (Chorom et al., 1994). Thus soil pH is a very important factor in the management of dispersive soils under field conditions.

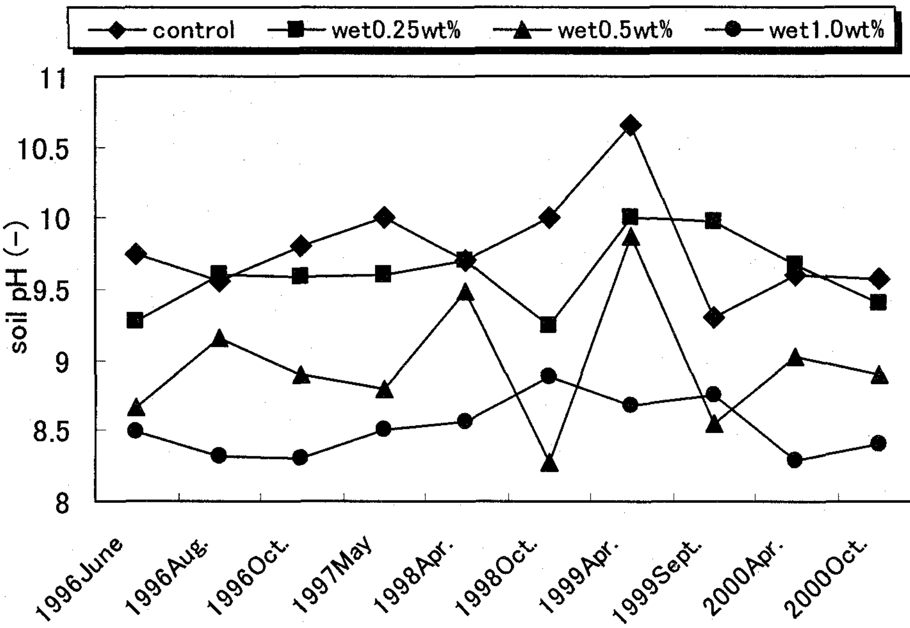


Fig.2 Change of soil pH in Field 1 from 1996

In figure, wet indicates gypsum as by-products from wet desulfurization process

Table 5 Germination rate and corn production in soil supplied with wet desulfurization gypsum in 1996

| Gypsum addition | Germination rate (%) | | | | | Corn production (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1996 | 1997 | 1998 | 1999 | 2000 | 1996 | 1997 | 1998 | 1999 | 2000 | total |
| 0wt% (0tha$^{-1}$) | 0 | 0 | 43 | 63 | 94 | 0 | 0 | 0 | 432 | 486 | 918 |
| 0.25wt% (5.8tha$^{-1}$) | 27 | 75 | 98 | 100 | 100 | 216 | 1929 | 1258 | 3434 | 2585 | 9422 |
| 0.5wt% (11.6tha$^{-1}$) | 73 | 77 | 96 | 100 | 100 | 501 | 1967 | 583 | 1774 | 1852 | 6677 |
| 1.0wt% (23.1tha$^{-1}$) | 100 | 92 | 96 | 100 | 100 | 2547 | 2816 | 731 | 2377 | 1389 | 9860 |

Figures in parenthesis under "Gypsum Addition" indicate the quantity (ton) of desulfurization gypsum per hectare.

Table 5 shows the germination rate and corn production in soil supplied with wet desulfurization gypsum in 1996. Germination rate increased with the increase of the gypsum application rate in 1996 (Table 5). This tendency depends on the decrease of soil pH upon the increase of the gypsum application rate. However, the germination rate in all plots with added gypsums is near 100% after 1998. Germination and production in 0.25wt % and 0.5wt%

plots responded to gypsum treatments performed in 1997 (Table 5). Even in the control plot, this value was 43% in 1998 and about 100% in 2000. However, corn production in the control was low after 1999. Moreover, in contrast to the high germination rate in 2000, the production was lower than in other plots because of high soil pH. Total corn production in the 1.0wt% plot was highest, but locally, corn production in the 0.25wt% plot achieved the maximum value in 1998 and 1999. From these results, we can conclude that the effect of using desulfurization gypsum as soil amendment persisted for at least five years with only one initial treatment.

In addition to pH, germination rate and production, $Na^+$, $Ca^{2+}$, $K^+$, $Mg^{2+}$, $SO_4^{2-}$, $Cl^-$, $CO_3^{2-}$, and $HCO_3^-$ concentrations in soil have been measured since 1996. In order to evaluate the correlation among these ion concentrations, pH and production, the correlation coefficient was evaluated. The correlations between $Mg^{2+}$ and $K^+$, $Mg^{2+}$ and $Ca^{2+}$, and $Ca^{2+}$ and $SO_4^{2-}$ were high, 0.82, 0.71, and 0.89 ($P<0.001$), respectively, and those between $Na^+$, $K^+$, and $Mg^{2+}$ and $SO_4^{2-}$ was also high, 0.90 ($P<0.01$), 0.82 ($P<0.05$), and 0.77 ($P<0.01$), respectively. Therefore, there were high correlations between all cation concentrations and $SO_4^{2-}$ concentration. This result indicates that supplying desulfurization gypsum (mainly $CaSO_4$) and the resulting decrease of soil pH increase the $Ca^{2+}$ and $SO_4^{2-}$ concentrations and bring about dissolution of $Na_2SO_4$, $K_2SO_4$ and $MgSO_4$, respectively.

Next, the results for a small field (Field 2) from 1997 are described in detail. The size of each plot in the test field is 3.6m×1.8m. One plot was sown with 24 seeds of corn. In this test field, gypsum from wet and semidry desulfurization processes was used as soil amendment. The difference between the two types of gypsum is mainly the content of gypsum (Table 3).

Gypsum addition to alkali soil at rates from 5.8 to 23.1 t/ha significantly improved the physical and chemical properties of the soil. For alkali soil the chemical effect of gypsum is given by the following equation:

$$2NaX + CaSO_4 = CaX_2 + Na_2SO_4$$

where X designates the soil exchange phase (US Salinity Laboratory Staff, 1954). Excessive Na in the exchange phase causes the collapse of soil particles, giving rise to soil with a dense structure and poor permeability. The exchange of Ca for Na on the soil complex results in the flocculation of soil particles and the restoration of porous structures causing high water permeability.

Fig.3 and Table 6 indicate the change of soil pH and the production of corn in Field 2 from 1997 to 2000, respectively. The soil pH of all plots decreases from 1997 to 1998 due to the gypsum treatment. In 2000, the pH of the control plot is the highest and that of the wet 1.0wt% plot is the lowest (Fig.3). Moreover, soil pH of the control plot is the highest every year. Hence, it was confirmed that desulfurization gypsum treatment causes the reduction of soil pH.

Germination rate in Field 2, unlike that in Field 1, was unrelation to the amount of gypsum added in 1997 (Table 6). The germination rates for almost all plots except the control plot have been high since 1998. The high value in the control plot may be due to the interfusion of desulfurization gypsum added to plots in the first year.

In the case of corn production in 1997, it was confirmed that production increased with increasing gypsum application rate in the wet desulfurization gypsum treated plot. However, the same result was not confirmed in the semidry desulfurization gypsum treated plot. It may be that the germination rate is unrelated to production. For example, corn production in control and wet 1.0wt% plots, where the germination rates were the same, is completely different. In terms of total production, 0.5 and 1.0wt% of wet desulfurization gypsum and 0.5wt% of semidry desulfurization gypsum were optimal application rates. The production between the wet 0.5wt% plot and the wet 1.0wt% plot showed no difference and soil pH decreased to about 8.5 in 2000 in both plots. The semidry

0.5wt% plot yielded the best harvest of all plots. Soil pH of this plot was minimum in 1997 and subsequently, no increase of the soil pH was observed. It is considered that this led to the high production rate. The correlation coefficient between pH and production is –0.31 ($P<0.05$), indicating that the increase of soil pH decreases the corn production rate to some degree.

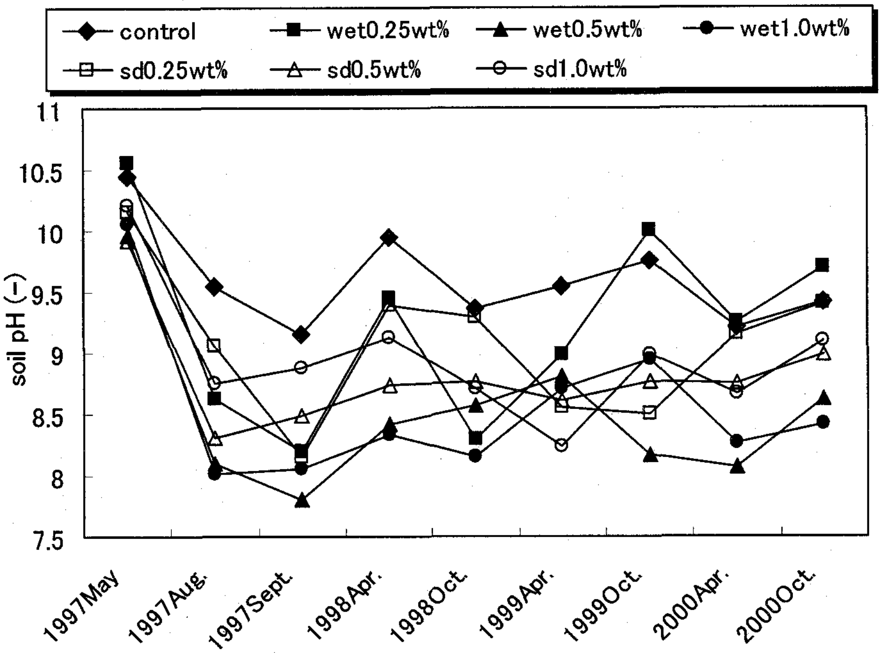


Fig.3 Change of soil pH in Field 2 from 1997

control: no gypsum treatment; wet: desulfurization gypsum from wet process; sd: desulfurization gypsum from semidry process

Table 6 Germination rate and corn production in soil with added wet and semidry desulfurization gypsum from 1997

| Treatment | Germination rate (%) | | | | Corn production (kg/ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 1998 | 1999 | 2000 | 1997 | 1998 | 1999 | 2000 | total |
| Control | 85 | 71 | 63 | 79 | 366 | 787 | 1543 | 463 | 3159 |
| Wet0.25wt% | 75 | 92 | 92 | 71 | 154 | 941 | 849 | 0 | 1944 |
| Wet0.5wt% | 96 | 100 | 100 | 100 | 1674 | 2754 | 4244 | 1890 | 10562 |
| Wet1.0wt% | 79 | 100 | 92 | 98 | 2078 | 2492 | 3797 | 2006 | 10373 |
| SD0.25wt% | 92 | 100 | 100 | 92 | 401 | 1574 | 2701 | 1235 | 5911 |
| SD0.5wt% | 94 | 100 | 100 | 100 | 2183 | 3464 | 4630 | 2932 | 13209 |
| SD1.0wt% | 58 | 92 | 96 | 79 | 1097 | 1435 | 2470 | 1620 | 6622 |

Wet and SD indicate wet desulfurization gypsum and semidry desulfurization gypsum, respectively.

The accumulation of Na in the surface soil is one of the most important causes of soil alkalization. The change of exchangeable Na and Ca concentrations in Field 2 has been investigated since 1997 (Fig.4, Fig.5). Fig.4 shows that the Na concentration in 2000 is lower than that in 1996. The Na level decreases drastically in 1997 and then increases gradually in all plots. It is considered that this tendency indicates that Na in the surface soil was leached underground immediately after gypsum treatment in 1997. The increase of Na from 1998 might be due to the rise of underground water and evaporation caused due to the low precipitation in 1999. In particular, the Na level in the wet 0.25% plot remains high, which causes the low production. The correlation coefficient between Na concentration and production, –0.45 ($P<0.01$), confirms that the increase of Na concentration does decrease the corn production.

As is the case of Field 1, the evaluation of the correlation coefficients among pH, production, $Na^+$, $Ca^{2+}$, $K^+$, $Mg^{2+}$, $SO_4^{2-}$, $Cl^-$, $CO_3^{2-}$, and $HCO_3^-$ concentrations in soil was performed. As a result, good correlations between $Na^+$ and pH, $Na^+$ and $SO_4^{2-}$, $Na^+$ and $Cl^-$, and $Na^+$ and $HCO_3^-$ were confirmed: 0.39 ($P<0.01$), 0.43 ($P<0.01$), 0.50 ($P<0.01$) and 0.54 ($P<0.001$), respectively.

Fig.5 shows the change of Ca level of soil in each plot. After gypsum treatment in 1997, Ca levels in soil increase due to the addition of desulfurization gypsum. In 1998, the Ca level at each plot decreased drastically because of the acceleration of Ca leaching due to physical soil reclamation. Moreover, it is considered that the increase of precipitation in 1997 is one of the reasons why Ca in soil decreased drastically. However, the production in each plot has remained high since 1998.

From the results of correlation analysis, good correlations between $Ca^{2+}$ and pH, $Ca^{2+}$ and $K^+$, $Ca^{2+}$ and $Mg^{2+}$, $Ca^{2+}$ and $SO_4^{2-}$, and $Ca^{2+}$ and $HCO_3^-$ were confirmed: -0.55 ($P<0.001$), 0.84 ($P<0.001$), 0.72 ($P<0.001$), 0.85 ($P<0.001$), and –0.39 ($P<0.05$), respectively. Therefore the increase of Ca concentration upon desulfurization gypsum treatment causes pH reduction, the increase of $SO_4^{2-}$ and the decrease of $HCO_3^-$. Moreover, increases of $K^+$ and $Mg^{2+}$ indicate the exchange reaction by $Ca^{2+}$ on the soil colloid surface.

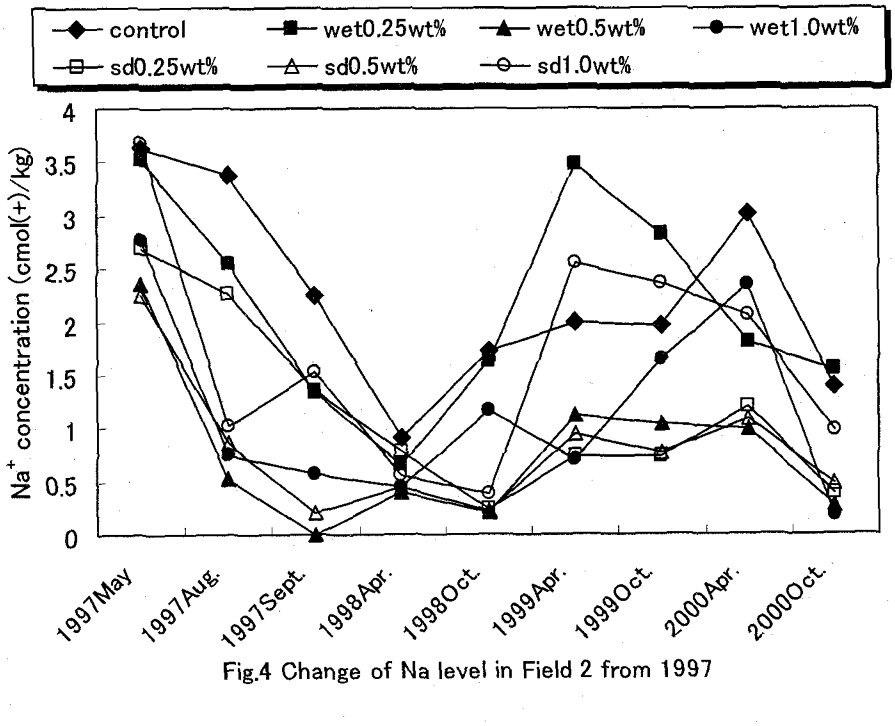


Fig.4 Change of Na level in Field 2 from 1997

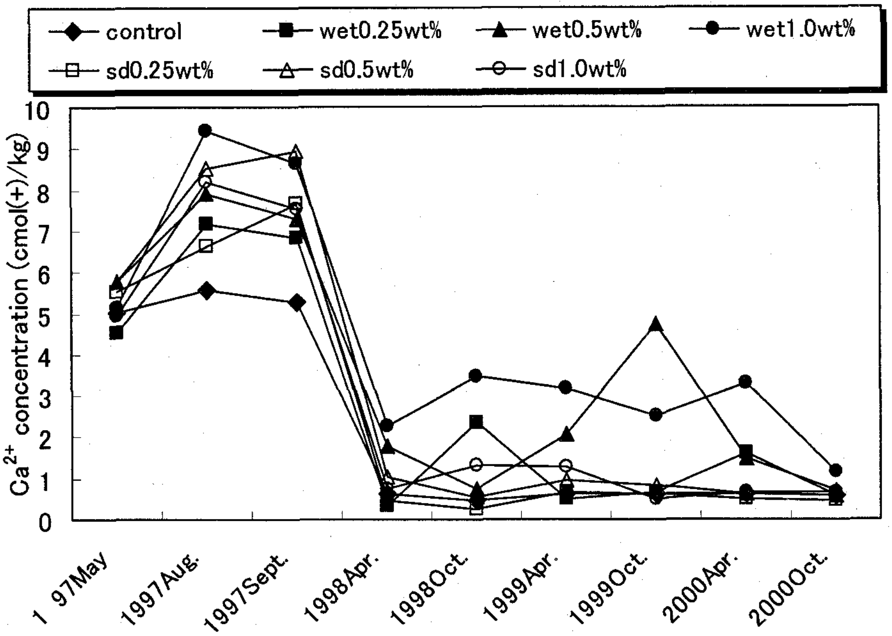

Fig.5 Change of Ca level in Field 2 from 1997

Table 7 Change of ESP in Field 1 and Field 2 in 1996, 1997 and 2000

| Plot | Soil amendment | ESP(%) | |
|---|---|---|---|
| Field 1 | | 1996 | 2000 |
| | control | 26.0 | 6.10 |
| | Wet 0.25wt% | 21.6 | 17.2 |
| | Wet 0.5wt% | 8.54 | 10.2 |
| | Wet 1.0wt% | 3.64 | 1.91 |
| Field 2 | | 1997 | 2000 |
| | control | 43.3 | 16.5 |
| | Wet 0.25wt% | 41.9 | 18.3 |
| | Wet 0.5wt% | 28.1 | 3.24 |
| | Wet 1.0wt% | 33.0 | 2.03 |
| | SD0.25wt% | 32.1 | 4.55 |
| | SD0.5wt% | 26.8 | 5.76 |
| | SD1.0wt% | 43.8 | 11.6 |

In addition, ESP is one of the most important factors for evaluating the effectiveness of alkali soil reclamation. The ESP value of 15 is the critical point for deterioration of the soil structure (US Salinity Laboratory Staff, 1954). Table 7 shows the change of ESP in Field 1 and Field 2 in 1996, 1997 and 2000. ESP was calculated using ESP (%) = exchangeable Na concentration / CEC (cation exchangeable capacity) ×100. In this calculation, 8.4((+)cmol/kg) was used as the CEC value (Table 1). These results revealed that ESP in almost all plots decreased to below 15% in 2000, particularly in Field 2. Thus, the change of ESP also confirms that the effect of using desulfurization gypsum as soil amendments has lasted for four or five years. Gypsum treatment was effective for decreasing ESP as well as the soil pH.

# 4. Conclusion

The use of gypsum from wet and semidry desulfurization processes for the reclamation of alkali soils in China was investigated in terms of soil pH, germination, corn production, ESP, and Na and Ca levels. Both kinds of desulfurization gypsum induced decreases of the soil pH, Na level, and ESP and increases of the germination rate, corn production, and Ca level after their application. The possibility of using the by-product from the desulfurization process for the amelioration of alkali soil was examined to give an incentive for the acceptance of desulfurization processes in China.

In Field 1, soil pH declined with increasing desulfurization gypsum application rate. It was confirmed that the optimum quantity of gypsum from the wet desulfurization process is 1.0wt% (23.1t/ha) in terms of corn production and soil pH. Moreover, the effect of soil amendment of this gypsum is continued for at least five years. In Field 2, it was shown that treatment with 0.5wt% of the gypsum from the semidry desulfurization process, which is favored owing to its low construction and running costs, enables extremely effective alkali soil reclamation. It is concluded that gypsum from the semidry desulfurization process has the same amelioration effect on alkali soil as the by-product from the wet lime slurry used in developed countries.

Moreover, the correlation coefficient between $Mg^{2+}$ and $K^+$($P<0.001$), $Ca^{2+}$ and $Mg^{2+}$($P<0.001$), $Ca^{2+}$ and $SO_4^{2-}$($P<0.001$), $Na^+$ and $SO_4^{2-}$($P<0.01$), $Mg^{2+}$ and $SO_4^{2-}$($P<0.01$, $P<0.05$), and $K^+$ and $SO_4^{2-}$ ($P<0.05$, $P<0.001$) indicated an increase tendency in both Field 1 and Field 2. In Field 2, corn production, and $K^+$, $Ca^{2+}$, $Mg^{2+}$, and $SO_4^{2-}$ concentrations decreased and $Na^+$, $Cl^-$, $CO_3^{2-}$, and $HCO_3^-$ concentrations increased with increasing soil pH.

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