Improvement of Salt-affected Soils by Deep Ploughing

—Part 2: Plot Field Tests in a Sodic Soil (Solonetz) Region*—

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Abstract

A method was investigated for improvement of salt-affected soils in regions where a sufficient amount of rainfall to percolate into subsoil occurs in summer. A coarse layer is provided in the subsoil by deep tillage, making soil clods to cut off the capillary rise from groundwater. This paper deals with plot test fields constructed by hand in a local spot of a sodic soil (solonetz) region. The results showed that deep tillage up to the subsoil (C horizon) was beneficial for improvement of the solonetz soil. Application of the gypsum also reclaimed the solonetz soil, and should be mixed into the A horizon. The pH values decreased from about 10 to 9. The EC values decreased from about 8 dSm⁻¹ to 2 dSm⁻¹.

[Keywords] sodic soil (solonetz), salt-affected soil, soil improvement, deep ploughing

I Introduction

Salt-affected soils are formed in dry areas of the world. In this paper, the sodic soil (solonetz) in the salt-affected soils distributed in the People's Republic of China was examined.

The sodic soil in China is called meadow alkali soil (Fig. 1), which is common in the Heilongjiang, Jilin and Liaoning provinces (about 35 Gm²). As this soil contains sodium carbonate (Na₂CO₃), it belongs to the sodic soil group (solonetz) according to pedological classification (Dudal, 1969; Scheffer & Schachtschabel, 1976; Abrol et al., 1988; Cardon & Mortvedt, 2001). If this soil is left undisturbed for a long time, white crystals of efflorescence (alkali spots) accumulate on the soil surface, and no plant can survive (Fig. 2).

In the previous paper (Guo et al., 2006), a method of soil improvement was discussed for the salt-affected soils with sufficient rainfall to percolate into subsoil in summer season; basically, a coarse layer was provided below the B horizon (subsoil). It was demonstrated with soil column experiments that the capillary water from groundwater could be cut off, thus preventing the rise of dissolved salts to the soil surface. It was shown that the salts accumulating in the A horizon were leached out by rainfall, which then decreased the pH values to acceptable levels.

In order to cut off the capillarity, deep ploughing had been achieved (Antipov, 1954; Botov, 1959; Cairns, 1962; 1976a).

Fig. 1 Typical sodic soil (solonetz) in Dajing City, Heilongjiang Province, P. R. of China. A horizon, soil where sodium carbonate accumulates; A horizon, humic soil with organic matter; B horizon, soil where A horizon leaches; C horizon, parent material.
Table 1 shows the chemical properties of the solonetz soil in this study. Every horizon is extremely alkaline with pH of about 10, and the pH value of the soil surface (Ana) where Na$_2$CO$_3$ was accumulated was more than 10.

A pH value more than 8.5 is characteristic for the sodic soil group (solonetz) which is mainly due to Na$_2$CO$_3$, and that less than 8.5 is for the saline soil group (solonchak) which is mainly due to CaCO$_3$ (Abrol et al., 1988; Cardon & Motvedt, 2001). The soil in this study, therefore, belongs to the solonetz group according to this parameter. The EC of the solonetz group is less than 4 dSm$^{-1}$, and that of the solonchak group is more than 4 dSm$^{-1}$ (Abrol et al., 1988; Cardon & Motvedt, 2001). The EC values of the Ana and A horizons of the soil in this study were greater than 4 dSm$^{-1}$. The ESP value less than 15% is for the solonchak group, and that more than 15% is for the solonetz group (Abrol et al., 1988; Cardon & Motvedt, 2001) and the ESP values of this soil were much greater 15%. Taking into account all values of pH, EC, ESP and Na$_2$CO$_3$, we determined that the soil in this study belongs to the solonetz group on the whole.

The CEC value of the soil surface (Ana horizon) of this soil was a little smaller than those in other horizons because the soil particles of the Ana soil are coarse (Guo et al., 2004). The CEC values of the other horizons (A, B and C horizons) were a little higher because of the presence of heavy clays (Fujivara et al., 2003).

The humus content in the topsoil (A horizon) of this soil was about 2%, and that in the subsoil (B and C horizons) was about 5%. In the planosol which is distributed in the Heilongjiang Province, the humus content in the topsoil was about 5%, and that in the subsoil was about 1% (Araya, 2001). In the meadow soil which is also distributed in Heilongjiang Province, humus content in the topsoil was about 20%, and about 3% in the subsoil (Zhang, et al., 2000). The humus

<table>
<thead>
<tr>
<th>Values for solonetz layers</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (H$_2$O)</td>
<td>10.34</td>
<td>9.93</td>
<td>9.81</td>
</tr>
<tr>
<td>Electrical conductivity EC, dSm$^{-1}$</td>
<td>12.38</td>
<td>5.11</td>
<td>2.27</td>
</tr>
<tr>
<td>Exchangeable sodium percentage ESP, %</td>
<td>79.9</td>
<td>100</td>
<td>98.0</td>
</tr>
<tr>
<td>Cation exchange capacity CEC, meq kg$^{-1}$</td>
<td>124</td>
<td>234</td>
<td>250</td>
</tr>
<tr>
<td>Humus, %</td>
<td>1.6</td>
<td>3.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Exchangeable sodium Na, mg kg$^{-1}$</td>
<td>5257</td>
<td>7818</td>
<td>10245</td>
</tr>
<tr>
<td>Available phosphate P$_2$O$_5$, mg kg$^{-1}$</td>
<td>40</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>Exchangeable calcium Ca, mg kg$^{-1}$</td>
<td>6930</td>
<td>6360</td>
<td>5790</td>
</tr>
<tr>
<td>Exchangeable magnesium Mg, mg kg$^{-1}$</td>
<td>630</td>
<td>616</td>
<td>570</td>
</tr>
<tr>
<td>Exchangeable potassium K, mg kg$^{-1}$</td>
<td>330</td>
<td>288</td>
<td>558</td>
</tr>
<tr>
<td>Available nitrogen N, mg kg$^{-1}$</td>
<td>111</td>
<td>172</td>
<td>64</td>
</tr>
</tbody>
</table>
content of the solonetz soil in this study, especially in Ana and A horizons, was low because the vegetation on the soil surface is poor (Fig. 2) and the amount of organic matter produced in one year is small.

The amount of exchangeable sodium (Na₂O) in all horizons of this soil was more than 5000 mg kg⁻¹, and the deeper two horizons had double that amount. The available phosphate (P₂O₅) was low in all horizons of the solonetz soil in this study, and all horizons had a deficiency of phosphate. Consequently, P₂O₅ should be supplied with a chemical fertilizer or other source. The solonetz soil in this study had appropriate exchangeable calcium (CaO), exchangeable magnesium (MgO) and exchangeable potassium (K₂O).

The soil in this study had sufficient available nitrogen (N) and was a little fertile. The available nitrogen in the topsoil of the planosol was 25 mg kg⁻¹, and that in its subsoil was 8 mg kg⁻¹ (Araya, 2001). The topsoil of the meadow soil had an available nitrogen of 103 mg kg⁻¹, and the subsoil contained 13 mg kg⁻¹ (Zhang et al., 2000). Compared to these soils, the solonetz soil in this study is relatively fertile.

2. Plot test fields

Figure 3 shows four kinds of plot test fields (No. 1-No. 4) constructed in 2004, and two more plot test fields (No. 5 and No. 6) constructed in 2005 in Daqing City, Heilongjiang Province. The size of each field was 5 m by 5 m. Field No. 5 was divided into adjoining plots 5a and 5b (described below); each measured 2.5 m by 5 m. The seven kinds of test fields were established close to each other as a randomized complete block design in three replicates.

Table 2 shows the soil treatment in each test field. The No. 0 field is a bare land (control, CK) seen in Fig. 2 where horizons were never tilled (A×, B×). This served as an overall control field.

In the No. 1 field, the Ana and A horizons (about 25 cm deep) were dug out by a shovel, and then the B horizon (including a part of C horizon) was tilled (about 35 cm deep) by the shovel to produce soil clods with the size of 100-140 mm which size was suitable for interception of the capillarity rise (Araya et al., 2010). The soil clods on the soil surface of the tilled B horizon were pulverized a little, in order to prevent collapse and loss of volume of the A horizon (Araya et al., 2010). Then, the Ana and A horizons were returned back onto the coarse B horizon without soil mixing of the A and B horizons (A○, B○).

In No. 2 field, when the B horizon was tilled, organic (cow) manure was mixed into the B horizon (2 kg m⁻²) [A○, B○(m)]. The size of soil clods produced in the B horizon was 100-140 mm.

In the No. 3 field, manure was mixed into the A horizon. The B horizon was not tilled [A○(m), B×]. The manure has two effects: neutralization with its organic acids and the replacement of the exchangeable sodium Na for Ca or Mg (Abrol et al., 1988; Guputa et al., 1983; Kochaba et al., 2004; Swarup, 1980; Swift & Posner, 1972; Yamada, 2002; Yamada et al., 2003).

In the No. 4 field, the A horizon was tilled, and the B horizon was not tilled (A○, B×). The A horizon was easily pulverized with the organic matter and the produced average size of the soil clods was 30 mm.

In 2005, two more plot test fields were prepared. The No. 5 is a gypsum field, and it was divided into halves (Fig. 3).

In the No. 5a field, the A horizon was dug out, and then the B horizon was tilled, producing soil clods. The A horizon was returned back on the coarse B horizon without soil mixing. At this time, 12.5 kg of gypsum (CaSO₄·2H₂O) (in the percentage of 1 kg m⁻²) was mixed into the A horizon by shovels [A○(g), B○].

In the No. 5b field, the same amount of gypsum was firstly spread on the soil surface, and then the A horizon was tilled.

![Figure 3](image)

**Table 2: Soil treatment and yields in each plot test field**

<table>
<thead>
<tr>
<th>Test field</th>
<th>Mark</th>
<th>A</th>
<th>B</th>
<th>Grass height yield mm</th>
<th>Dry yield kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 0</td>
<td>A×</td>
<td>B×</td>
<td>non-tilled</td>
<td>non-tilled</td>
<td>102*</td>
</tr>
<tr>
<td>No. 1</td>
<td>A○</td>
<td>B○</td>
<td>tilled</td>
<td>tilled</td>
<td>456*</td>
</tr>
<tr>
<td>No. 2</td>
<td>A○</td>
<td>B○(m)</td>
<td>tilled</td>
<td>tilled with manure</td>
<td>406*</td>
</tr>
<tr>
<td>No. 3</td>
<td>A○(g)</td>
<td>B×</td>
<td>tilled</td>
<td>non-tilled</td>
<td>476*</td>
</tr>
<tr>
<td>No. 4</td>
<td>A×</td>
<td>B×</td>
<td>tilled</td>
<td>non-tilled</td>
<td>350*</td>
</tr>
<tr>
<td>No. 5a</td>
<td>A○</td>
<td>B○(g)</td>
<td>tilled</td>
<td>gypsum tilled</td>
<td>506*</td>
</tr>
<tr>
<td>No. 5b</td>
<td>A○</td>
<td>B×(g)</td>
<td>tilled</td>
<td>gypsum tilled</td>
<td>506*</td>
</tr>
<tr>
<td>No. 6</td>
<td>A×</td>
<td>B○(upside down)</td>
<td>tilled</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Significant at 5% level for No. 0 field (CK).
The B horizon was not tilled [A○(g), B×].

It has been reported that the application of the gypsum is useful as an ameliorate material to replace the exchangeable sodium in the soil, which is toxic for plants, for calcium (Amezketa et al., 2005; Aydemir & Najjar, 2005; Endo et al., 2002; Khosla et al., 1979; Lebron et al., 2002; Overstreet et al., 1980; Sahin et al., 2003; Li et al., 1998; Ohkura et al., 2001). The calcium sulphate (CaSO₄) is a byproduct produced from coal power stations where sulphur dioxide (SO₂) in the exhaust gas is absorbed by lime (CaCO₃). CaSO₄ is less costly than gypsum (Matsumoto, 1995 & 1997; Sakai et al., 2004).

No. 6 field is an inverted field where the A horizon and B horizon were reversed [A○, B○ (upside down)]. Alfalfa was seeded on all test fields in 2004 and 2005.

3. Investigated items

In order to know the degree of soil improvement quickly, following six parameters were investigated in every year: grass height, yield, soil penetration resistance, pH value, EC value and soil water content.

(1) Grass height

The grass height of ten millets (described below) selected

![Vegetation on the soil surface in 2006 in each plot test field. No. 0, A×, B×; No. 1, A○, B○; No. 2, A○, B○ (m); No. 3, A○(m), B×; No. 4, A○, B×; No. 5a, A○ (g), B○; No. 5b, A○ (g), B×; No. 6, A○, B○ (upside down).](image-url)
at random in each plot test field was measured. The total thirty data obtained in each treated sites were evaluated for the values in the No. 0 field (CK), using a t-test ($P\leq0.05$) of the statistical function of Microsoft Excel.

(2) Yield
The dry mass of whole grasses (salt-tolerant grass and millet) in 1 m$^2$ was determined. Three points were selected at random in each plot test field. The total nine data obtained in each treated sites were evaluated using for the values in the No. 0 field (CK), using a t-test ($P\leq0.05$) of the statistical function of Microsoft Excel.

(3) Soil penetration resistance
The soil hardness (soil penetration resistance) was measured by a cone penetrometer ($30^\circ$ cone angle, 16 mm base diameter). Three to five tests were made each time.

(4) pH (H$_2$O)
The pH (H$_2$O) values were determined by a commercial pH meter. The soil sample (10 g) was put into a beaker, and distilled water (50 g) was added (1:5) and mixed well (Society of Soil and Fertilizer, 2003). The soil samples were taken at four depths: 0 mm (Ana horizon), 100 mm (Ap horizon), 300 mm (Bca horizon) and 500 mm (C horizon). Three samples were taken at each depth and the mean value was determined.

(5) Electric conductivity (EC)
The EC values were determined by a commercial EC meter using the same aqueous solution of the pH.

(6) Soil water content
The soil water content was measured by an infrared lay moisture meter (Society of Soil Physics, 1987) with a 5 g soil sample.

III Results and Discussion

1. Vegetation on soil surface
Figure 4 shows the vegetation on the soil surface in eight plot test fields. The vegetation in 2006 is shown as a
representative. There was no alfalfa seeded in 2004 and 2005 but the wild grasses [salt-tolerant grass (Aneurolepidium Chinese Kitag) and millet] survived. The alfalfa seeded did not germinate due to draught. Table 2 shows the mean grass height and mean dry yield.

The No. 0 field is the bare land where the alkali spots were found and the vegetation was very poor. At a single glance, the vegetation in the No. 1, No. 3 and No. 5a fields was excellent. There were bald spots of grass on the soil surface in the No. 2, No. 4 and No. 5b fields. No grass was found on the No. 6 field. From the results of Fig. 4 and Table 2, following things could be known.

① Compared to the No. 1 and No. 4 fields, and compared to the No. 5a and No. 5b fields, the tillage should be deep up to the C horizon and the capillary rise should be intercepted at the subsoil.

② Compared to the No. 2 and No. 3 fields, the application of manure is effective for the improvement of the solonetz soil. It should not be mixed into the B horizon but rather mixed into the A horizon.

③ Compared to the No. 5a and No. 5b fields, the application of the gypsum has a good effect for the improvement of the solonetz soil. The gypsum should be mixed into the A horizon.

④ With No. 6 field, making upside down the A and B horizons has no meaning. That is making upside down the soil layer by the single mouldboard plough (Bower & Cairns, 1967) is not appropriate for the improvement of the salt-affected soils.

2. Soil penetration resistance

Figure 5 shows the soil penetration resistance (2007). That in the No. 0 field (bare land) was more than 5 MPa below the soil surface. In No. 3, 4 and 5b fields where the B horizon was not tilled, the soil penetration resistance was more than 5 MPa below 300-400 mm deep. In the No. 1, 2, 5a and 6 fields, the soil penetration resistance was 1-2.5 MPa up to 600 mm deep. Therefore, the soil penetration
resistance did not return back to the previous level within three years after operation.

3. pH value

Figure 6 shows the pH values measured in each plot test field. The pH values in any fields decreased from about 10 to about 9 until August 2006. Especially, at 0, 100 and 300 mm deep in the No. 3 \( (\text{A}<\text{m}, \text{B}>\text{m}) \) field, reduction of about 1.5 in pH was obtained because of the manure application.

However, in August 2007, the pH values increased except the A horizon in the No. 3 field. The precipitation in 2007 was about 200 mm which was one third of usual year.

4. EC value

Figure 7 shows the EC values measured in each plot test field. The EC value of the alkali spots on the soil surface in the No. 0 field (0 mm deep of the Ana horizon) was 12.38 dSm\(^{-1}\).

The EC values decreased from about 8 dSm\(^{-1}\) to about 2 dSm\(^{-1}\) in any plot test field, if any tillage was given. The pH value increased in 2007 (Fig. 6) but the EC value did not increase and so, the interception of the capillarity with the soil clods will be still working.

In the No. 5a field, the mean EC value was about 1.5 dSm\(^{-1}\) in August 2006 and on other hand, in the No. 5b field, it was about 3.0 dSm\(^{-1}\). Therefore, the application of gypsum and the deep tillage gave a good effect for the improvement of the solonetz.

Compared to Fig. 4, in the plot test fields where the EC value (especially in the topsoil) was more than 3 dSm\(^{-1}\), their vegetation was poor.

5. Soil water content

Figure 8 shows the soil water content measured in the each plot test field. Compared to the vegetation on the soil surface in Fig. 4, the soil water content in the plot test fields with good vegetation was great because the growing grasses intercept from the sunshine and the evaporation of water from the soil surface was prevented. In 2007, a severe drought took place and the soil water content at the soil surface was about 8 %d.b. in the fields with a good vegetation and it was about 3 %d.b. in the fields with a poor vegetation.

IV Summary and Conclusions

A method was investigated for improvement of sodic soil (solonetz) in salt-affected soils in regions where a sufficient amount of rainfall to percolate into subsoil occurs in summer. A coarse layer with soil clods is provided in the subsoil by deep tillage and the capillary rise from groundwater is cut off. This paper deals with plot test fields constructed by hands at a local spot of a sodic soil (solonetz) region.

1) The deep tillage up to the subsoil gave a good effect for the improvement of the solonetz soil.

2) From the results of vegetation on the soil surface and yields, following things could be known.

① Tillage should be deep up to the C horizon and the capillary rise should be intercepted at the subsoil.
② Application of manure was effective for improvement of the solonetz soil. It should not be mixed into the B horizon but rather mixed into the A horizon.
③ Application of the gypsum had also a good effect for the improvement of the solonetz. The gypsum should be mixed into the A horizon.

3) The soil penetration resistance did not return back to the previous level within three years.

4) The pH values in any fields decreased from about 10 to about 9.

5) The EC values decreased from about 8 dSm\(^{-1}\) to about 2 dSm\(^{-1}\) with the elapsed time. In the plot test fields where the EC value (especially at the topsoil) was more than 3 dSm\(^{-1}\), their vegetation was poor.

6) The soil water content in the plot test fields with good vegetation was great.

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