13 Chemical Properties of Selected Soils from the North China Plain

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Abstract

Saline and sodic soils occur in large areas on the North China Plain (NCP). This presents a serious problem for sustainable agricultural development in the area. This study identified and characterised saline, sodic and sodic-saline soils on the NCP and recommended some strategies to deal with salinity in the region. Three distinct regions were identified: the coastal, middle and western zones. The parent material of the soils is river alluvium. Illite (Hydromica) is the dominant layer silicate mineral; smectite, kaolinite and chlorite are subdominant.

华北平原大面积的盐碱土是区内农业持续发展所面临的一个严重问题。本研究提供了几个代表性盐化地点盐碱土的化学和矿物学性质的定量信息，提出了一些治理措施。该区可划分为滨海、中部和西部三个区。土壤母质属于河流冲积物。水云母为主导层状硅酸盐粘土矿物，蒙脱石、高岭石、绿泥石为次要矿物。

SOIL salinisation is a growing problem in agriculture worldwide. As we try to meet global needs for agricultural production, more and more countries are concerned about the increasing problem of salinity. China is one of the nations that have a serious problem with saline soils; the North China Plain (NCP), a major food production area, has especially suffered from this problem.

For instance, in the early 1950s the NCP had more than 2 million ha of saline soils; at the end of the 1950s, 4 million ha were affected, and in the mid-1980s only 2 million ha were affected. This overall decrease in extent of saline affected soils has been largely due to changes in irrigation practices and an associated fall in the depth of the groundwater table in the region. Areas where the extent of salinisation

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is still considered serious include the lower elevated plains of the Bo Gulf, the four lakes in the south of Shandong Province and the Huang (Yellow) River irrigation area in Henan Province.

The Cangzhou prefecture (115°42'–117°50'E and 37°28'–38°57'N) or subregion is a small part of the NCP adjacent to the Bo Sea in the lower-lying plain of the Hai River's southern reach downstream. With a total area of 14,056 km^2, the subregion is characterised by low and smooth relief, a deficient freshwater supply, waterlogged land, salty groundwater and a serious saline soil problem. It experiences frequent dry periods and its soils are saline-alkaline with low levels of nutrients. All these factors contribute to low crop yields (Mao and Liu 2000). The Overview provides some background information on the NCP.

The main objectives of our study were:

- to determine the chemical, distribution (dynamic changes) and mineralogical properties of salt-affected soils in the Cangzhou prefecture;
- to develop an understanding of the processes occurring in the soils; and
- to use an increased understanding of the conditions at Cangzhou to recommend strategies to ameliorate existing degradation and prevent further damage to soils elsewhere (the strategies would aim to improve the use and management of soil resources to increase crop yields and arrest the decline in soil quality).

Saline Soils on the North China Plain

Soil salinisation is the accumulation of soluble salts in the soil that results in some degree of decrease in soil productivity (see Chapter 8). Saline-alkali soils include solonchak and solonetz (alkaline soils), and various other soils affected by salt or sodium ions. Soil salinity, the concentration of soluble salts in soil, is commonly graded by considering the integrated biophysical effect on crops or the extent of damage to crops (Xiong and Li 1987). Poor plant growth can result from:

- toxicity due to high concentrations of ions, such as Cl^-, SO_4^{2-}, Na^+ and Mg^{2+};
- diminished absorption of nutrients because of poor ion balance;
- decreased water absorption by roots because high ion concentrations lead to water stress; and
- a decline in soil structure, particularly where Na^+ is the dominant cation to generate soils with high exchangeable sodium percentages (ESPs).

In the NCP, soil salinity and sodicity are strongly influenced by:

- the monsoon climate with annual wet and dry seasons;
- the chemistry and depth of groundwater and surface waters, which have changed substantially over the past two decades;
- topography; and
- soil type (in the NCP, the principal soil type is ‘Chao soil’, a Chinese term; other soil types found in the region include meadow and coastal solonchak, saline swamp, saline meadow, sandy and cinnamon).

Distribution of soil types

Saline soil types can be characterised by the ratio of the principal anions present (e.g. Cl^- and SO_4^{2-}) measured in centimoles (cmol). On the NCP, the soil types are broadly distributed between the following three geographical zones:

- the coastal zone, with ‘Cl-type’ soils, in which Cl^- is dominant ($Cl^-:SO_4^{2-} > 8$), and in which there is a wide range in the ratios both between different profiles and along the same profile;

- the western zone, with 'SO_4^{2-}Cl-type' soil, in which SO_4^{2-} is dominant ($Cl^-:SO_4^{2-} < 2$); and
- the middle zone, with 'mixed anions', in which there are roughly equal amounts of Cl^- and SO_4^{2-} (this zone is located between the coastal and western zones).

Figure 1 shows the ratio of $Cl^-: SO_4^{2-}$ in soil profiles from the coastal and middle soil zones of the NCP. Table 1 shows anion data for two soil profiles with layers extending below 40 cm. Macun village is located in the coastal zone and the soil has a ratio of $Cl^-: SO_4^{2-} > 8$. The Cl^- in the upper layers is currently active and moves downwards and accumulates together with SO_4^{2-}. However, the soil from Wangsi village basically has a constant ratio ($Cl^-:SO_4^{2-} = 1–2$) in all layers, indicating that it is of mixed type.

Salt accumulation at the soil surface

Figure 2 illustrates the trend in total salt content with depth for representative soil types from the coastal and middle zones of the NCP. A total salt content of 2–6% was measured at 0–1 cm in both soil types from the middle zone, which decreased sharply to 1–2% at 1–5 cm and 0.8% at 5–10 cm. The salt concentration remained essentially constant, at around 0.5%, at depths below 40 cm. The saline soil in Dalangdian, Nanpi County, is considered to be a typical example of this kind of salt distribution. The soil solution contains a mixture of Cl^-, SO_4^{2-}, Na^+, Mg^+, HCO_3^- and K^+ ions, with the Na^+ cation being the dominant ion (concentrations of about 44 cmol/m^3 in the surface layer). The salt distribution in this soil progressively stabilises below depths of 50 cm, with total salt concentrations being 20–40 g/kg at 0–5 cm and 1–2 g/kg at 40–50 cm, though there was more Cl^- and Na^+ at 100–120 cm than in the upper layers.

Saline soils on the NCP are characterised by accumulated salts near the surface. This has occurred for a variety of reasons. Because of the critical depth to saline groundwater and intense evaporation, salts have progressively moved or wicked up from the saline groundwaters and lower-lying soils. Salinity has also expanded from lower topographic sites to higher sites because of uneven microtopography. The level of salinity in soils is closely correlated with crop development and yield because cultivation management, seed emergence and crop growth all occur in the plough layer (major rooting depth). Thus, salt content at the soil surface (0–20 cm) can be used to categorise the extent and nature of soil salinisation and provide a sound basis for rehabilitating saline-sodic soils. Good farming practices and appropriate biological approaches should enable salt to be redistributed and leached out of the soil.

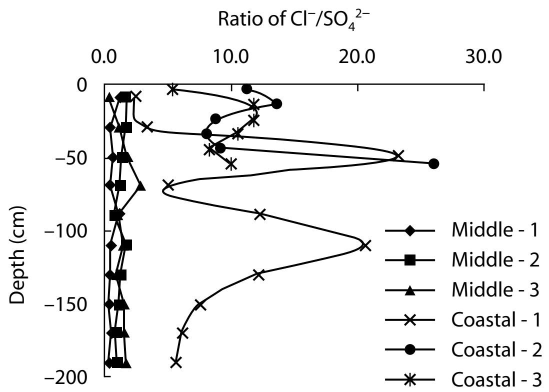

Figure 1. Ratio of Cl^-/SO_4^{2-} in coastal and middle zones of the North China Plain.

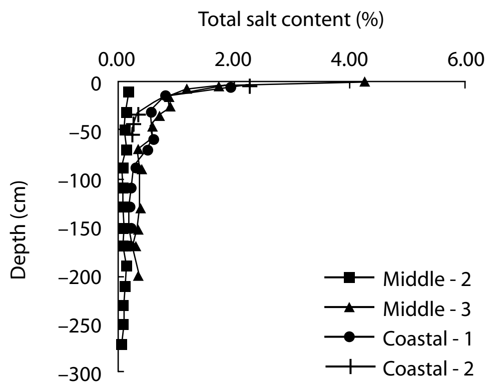

Figure 2. Trend in total salt content with depth in coastal and middle zones of the North China Plain.

Salt accumulation in subsoils and lower soil layers

In the 1980s, the leaching process was exacerbated by the lowering of the saline groundwater table in the western zone of the saline region of the NCP, causing salt to accumulate in subsoil horizons and lower layers of the soil. Consequently, there were changes in soil salinity in the 0–20 cm layer. In addition, there was a decrease in the area affected by salinity and in the level of salinity in the surface layers. For example, Figure 3 shows that salt accumulated significantly in the subsoil horizons

Table 1. Salt composition of soils from two locations in Cangzhou subregion, 1998–99.

Location	Depth (cm)	Ion concentration (cmol/kg)						Total salt content (%)	Cl^-/SO_4^{2-}
		HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^++K^+		
Wangsi village Nanpi County (98N-2)	0–1	0.55	60	23.05	2.93	21.65	57.5	6.34	2.6
	1–5	0.35	18	5.58	0.90	6.18	15.35	1.73	3.2
	5–10	0.4	11.8	3.78	0.98	3.95	9.9	1.17	3.1
	10–20	0.45	8.3	2.83	0.45	2.68	8.15	0.86	2.9
	20–30	0.45	9.1	2.80	0.53	3.20	7.7	0.90	3.3
	30–40	0.45	6.1	2.43	0.38	2.33	6	0.69	2.5
	40–50	0.45	4.95	2.00	0.35	2.05	4.6	0.57	2.5
	50–60	0.45	4.15	2.58	0.35	2.48	4.1	0.59	1.6
	60–80	0.45	3.4	1.10	0.30	1.55	2.35	0.36	3.1
	80–100	0.5	3.05	1.35	0.33	1.63	2.35	0.38	2.3
	100–140	0.5	2.9	1.33	0.35	1.48	2.4	0.37	2.2
	140–160	0.55	2.2	1.40	0.30	1.45	2.05	0.34	1.6
	160–180	0.35	2	1.15	0.33	0.98	2.05	0.29	1.7
	180–210	0.4	2.1	1.55	0.38	1.03	2.8	0.35	1.4
Macun village Yanshan County (99Y-1)	0–10	0.3	22.5	4.70	1.03	3.93	22.3	1.92	4.8
	10–20	0.3	10.2	1.55	0.40	1.55	9.7	0.81	6.6
	20–40	0.45	9.2	0.20	0.28	1.08	7.35	0.58	46.0
	40–60	0.4	8.1	0.83	0.35	1.38	6.7	0.59	9.8
	60–80	0.35	7.95	0.33	0.35	1.33	5.6	0.51	24.1
	80–100	0.35	5.1	0.13	0.23	0.85	3.55	0.33	39.2
	100–120	0.35	3.6	0.15	0.18	0.78	2.35	0.24	24.0
	120–140	0.3	3	0.20	0.18	0.63	2.1	0.22	15.0
	140–160	0.3	3	0.25	0.18	0.53	2.4	0.22	12.0
	160–180	0.3	3	0.28	0.20	0.63	2.2	0.23	10.7

(40–100 cm) of Heijian County. In 1990, the same process occurred in the middle zone of the region. Table 2 shows the mean total salt content for 43 profiles along the 20 km Daima Canal transect in Nanpi County and for 14 of these sites that were selected to represent the status of salt accumulation in subsurface and lower layers. The results are representative of the variation in soil salinisation for the middle zone of the NCP.

Seasonal salt movement

The NCP has a monsoon climate, with annual wet and dry seasons. Under natural conditions, salt leaches out in the wet season (July to September) but accumulates at the surface during the dry season, particularly from March to May. Water and salt movements vary with seasonal changes. In winter, salt and water are frozen and immobile; in spring salt accumulates in soils; in summer it leaches out; and in autumn it moves slowly to the soil surface. Hence, seasonal changes cause salts to be redistributed in soils, both vertically and laterally. Evaporation of the shallow groundwater has led to high salt concentrations in certain surface soils, but final concentrations depend on soil texture and heat.

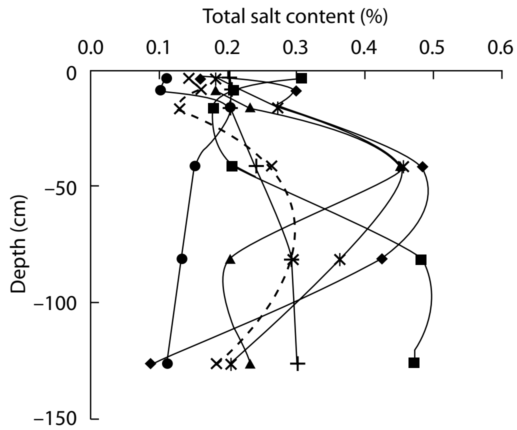

Figure 3. Distribution of salt content in seven different soil profiles in Heijian County.

Table 2. Soil salinity on a transect along Daima Canal, Nampi County, 1997.

	14 sites		43 sites	
Depth (cm)	Mean TSC (%)	SD	Mean TSC (%)	SD
0–10	0.12	0.04	0.13	0.05
10–20	0.11	0.03	0.12	0.06
20–30	0.11	0.04	0.12	0.08
30–40	0.14	0.06	0.13	0.11
40–60	0.25	0.36	0.15	0.22
60–80	0.23	0.24	0.15	0.15
80–100	0.20	0.15	0.13	0.10
100–120	0.25	0.22	0.15	0.14

SD = standard deviation; TSC = total salt content

Figure 4 shows salt content in the soil profile at Nanpi County (in the middle zone of the NCP saline region) at different times of the year. Salt in the 0–10 cm layer in this profile migrated upwards with capillary water, and accumulated in the upper soil layers in winter and spring. In July and August (summer), heavy rains leached salts to subsoil horizons or deep layers in the regolith and decreased the total salt content. This process tends to increase the levels of exchangeable Na^+ and Mg^{2+} in these soils, thus increasing soil sodicity.

In contrast, following the wet season, the total salt content increased rapidly in the profile as water evaporation increased. There was a sharp change in soil salt levels in the layer above 40 cm and a gradual

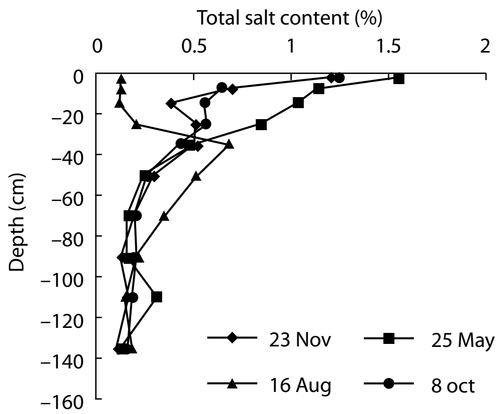

Figure 4. Salt distribution in the soil profile at Nanpi County at different times of the year.

change from 40–60 cm; below 100 cm, the level was relatively stable. For example, in 1998, 252 mm of rain fell in 24 hours, giving rise to large amounts of water in ponds and depressions (Mao and Liu 2000). Regional climatic data suggest that when there is about 300 mm of rainfall in 24 hours and a runoff volume of 24–85 mm, such conditions will occur. It is estimated that the root zone (about 2 m deep) could contain as much as 145 mm of precipitation. When there is more than 50 mm of rain at any one time, salt could accumulate in the 40–80 cm layer in the profile if it was carried with water seeping down under gravity. Salt loss occurs naturally only in the soil layers above 60 cm. In the coastal region, the groundwater is shallow and has a relatively high total salt content. The dynamics of salinisation in the coastal zone are considered to be basically the same as for Nanpi County.

Localised spatial distribution of salinisation

Figure 5 shows the nonuniform distribution of the salt ions among three saline soils in the Dalangdian depression, located 10 m apart from each other. We measured large differences in salt concentrations or accumulations at the surface of these profiles. For example, at the eastern point, the saline soil profile had an uneven distribution of salt concentration because of differences in the water–salt movement caused by variations in surface microtopography, soil compaction, soil texture, ditch arrangement and water allocation. Salt concentrations were variable or 'transient' depending on the groundwater level, ion activity or stage of salinisation and desalinisation.

Alkalisation

Primary alkalisation was uncommon in the three study regions on the NCP, but secondary alkalisation appeared to be an increasing problem because of 'artificial' or farming activities, even though there was less salinisation and a smaller area was affected. Alkalisation has occurred via two pathways. First, as the natural environment has altered, saline soils have begun to lose salt and have gradually transformed to more alkaline saline soils. Second, alkalisation has resulted from poor land management, such as applying high levels of fertilisers or irrigating with highly saline water. The commonly believed theory is that, as the groundwater level was lowered, salts moved from the upper to the lower layers in these soils and the Na^+ ion was adsorbed by complex colloids to form more alkaline soils when Na^+:(Ca^{2+}+Mg^{2+}) > 4 (in cmol/L).

Alkalisation and salinisation sometimes occur in the same zone. Alkalisation occurs mainly as a result of alkaline freshwater from deep groundwater areas around old rivers with high levels of Na^+, HCO_3^- and CO_3^{2-}. Soil colloids in contact with alternating Na^+-rich and fresh waters can develop sodic properties (colloid with high amounts of exchangeable Na^+ adsorbed on its surface) and can disperse as rain or surface water percolates through soils. This causes soil particles to move with the water and collect in holes or at low-lying sites, making it difficult for water to move through soils. Consequently, at lower-lying sites, after evaporation, soil tended to form a layer of 'tile-like' pieces about 1–5 cm thick, covered by a layer of blue-green algae. However, at higher sites, a gray, thin silt–sand layer about 0.5–1.0 cm (sometimes up to 3 cm) was formed on the soil surface, under which was a crust about 1 cm thick. There was a honeycomb-like layer 2–3 cm below the soil crust of 'tile-like pieces'; under

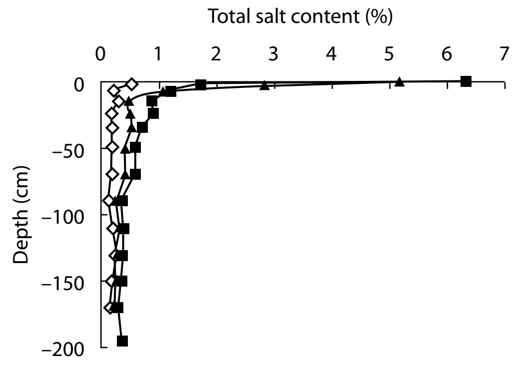

Figure 5. Salt distribution in the soil profile in three saline soils 10 m apart, near the Dalangdian depression.

that was a layer of 20–30 cm consisting of aggregated soil particles and sandy soil. Tables 3 and 4 show properties of sodic soil profiles in Hejian. An alkaline soil near Hejian has recently been found to have a pH of 8.5–9.1, and an ESP of 15–35%, with an HCO_3^- content of more than 0.7 cmol/km.

Alkaline soils were categorised into 'slightly sodic soils', 'moderately sodic soils', 'severely sodic soils' or 'solonetz soils', depending on the degree of alkalisation, the proportion of alkaline area and their toxicity to crops or plants. For example, if the sodic area was more than 60–70% and the degree of sodicity more than 40–50%, the soil was identified as solonetz. Alkaline soils were classified as coastal meadow sodic soils, meadow sodic soils or sodic Chao soils depending on whether they occurred in coastal or western inland zones.

Table 3. Properties of sodic soil in Heijian County.

Depth (cm)	pH	CEC (cmol/kg)	Exchangable Na^+ (cmol/kg)	ESP (%)
0–5	8.84	4.63	0.75	16.11
5–10	9.10	4.82	1.60	33.28
10–20	8.96	6.56	1.70	29.85
20–40	8.92	8.05	1.80	22.41

CEC = cation exchange capacity; ESP = exchangeable sodium percentage

Table 4. Salt composition of sodic soil in Heijian County.

Depth (cm)	Ion concentration (cmol/kg)							TSC (%)
	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^++K^+	
0–5	0.05	1.00	0.30	0.33	0.05	0.09	1.35	0.14
5–10	0.00	0.99	0.40	0.06	0.10	0.04	3.14	0.16
10–20	0.00	0.60	0.52	0.16	0.13	0.17	2.00	0.13
20–40	0.00	0.36	0.63	0.30	0.18	0.14	2.57	0.14
40–60	0.11	2.04	1.14	0.10	0.21	0.11	3.04	0.26
60–100	0.05	0.76	2.60	0.42	0.07	0.07	4.78	0.29
100–150	0.05	0.76	2.03	0.15	0.10	0.14	1.74	0.18

TSC = total salt content

Causes of Salinisation

Climate

The study region is semiarid with a continental monsoon climate. The average annual rainfall is 500–600 mm. Rainfall distribution is uneven in most years (coefficient of variation 30–40%), with 3% of the total rain falling from December to February, 16% from March to May, 79% from June to August, and 2% from September to November. Thus, the wet season lasts for three months, with the other months essentially remaining dry. Yearly potential evaporation is three to four times more than precipitation, so drought and waterlogging occur alternately. Waterlogging may be accompanied by salinisation. Water and salts accumulate in spring and decrease in summer. Climate strongly influences evaporation and concentration of salts in groundwaters, with mineralisation being 2–5 g/L. Consequently, salinisation occurs easily, with total soil salinity levels reaching 0.3–0.4%.

Topography and landform

Landform in the study region is strongly controlled by old river systems and includes flat highlands, sloping land, flat lowlands and wetland depressions. Surface runoff could drain away in flat highlands, recharging groundwater, raising the watertable and tending to cause soil salinisation.

Parent materials

The parent material in the region is alluvium from the Huang and Hai rivers, which overflow and change course many times. Sandy loam soils develop because of their close proximity to rivers, whilst clayey soils may develop further away from rivers. Loamy soils occupy zones between the sandy loam and clayey soils. The stratification and variation of parent materials with certain salt minerals is the primary cause of saline soil formation in the study region. Table 5 shows the distribution of soil texture characteristics in the area. In 2-m profiles, silty clayey loams were relatively wide-ranging; this is a condition for salinisation. Silty clayey loams and clayey loams were dominant in topsoil; clayey soil occupied nearly one-third of the total area in the bottom soil. Clayey layers at depth could be an obstacle to salt movement.

Table 5. Distribution of soil texture characteristics in Cangzhou prefecture.

	Proportion of land (%)				
Depth (cm)	LS	SL	ZCL	CL	LC
0–20	0.08	1.77	45.49	41.66	11.01
20–60	0.33	2.89	41.35	31.92	23.51
60–100	1.29	4.83	36.46	24.67	32.75
100–200	5.64	11.93	46.00	5.74	30.68

CL = clayey loam; LC = loamy clay; LS = loamy sand; SL = sandy loam; ZCL = silty clay loam

Surface water and groundwater

Salinisation requires water to transport salts in and out of the regolith. Fresh surface water can transport salt from one catchment to another in floods. Saline groundwater can transport salts at or to certain critical depths, although the water moves slowly in a lateral direction. Runoff water is the main way in which groundwater in the study region is recharged. In some seasons, water can result in sustainable or secondary salinisation.

Sources of salt

The study region contains zones that are rich in various types of soluble salts. The dominant source is the shallow layer of salty groundwater. Water from the upland river systems played a major role in the past but its importance has decreased in the last 30 years and such water is no longer a source of salt.

Saline waters (2–3 g/L) and salty waters (> 3 g/L) occur in the groundwater systems that underlie most of the region (7230 km^2 or 51%). There are high levels of Cl^-, SO_4^{2-}, and Na^+; the total salt content depends directly on the concentrations of these ions. Groundwater was the most active cause of saline soils. However, saline soils have gradually decreased in extent because the groundwater levels have declined during the past 20 years.

Wind and air are other sources of salt accumulation in coastal zones. Salt from the sea can be carried long distances inland by wind as spindrift or can fall to the ground with rain after being carried by warm northwesterly winds.

'Desalted Chao soil' results from large-scale improvements in saline soils. Surface soils have gradually lost salt as water, fertiliser and salt regimes have changed. However, salt remains below the subsoil and is therefore a potential source of surface salt, which could accumulate if groundwater levels rise.

Clay Minerals in Soils of the North China Plain

Typical profile

Clay minerals (< 2 μm) in the study region consist of aluminosilicates and a range of oxides, hydroxides and oxyhydroxides. These minerals occur in most soils and exhibit colloidal properties, which make soils stable (prevent erosion), play a key role in nutrient mineralisation and control the physical and chemical processes of soil formation. No matter what they inherit from parent material or develop in the process of soil formation, clay minerals all have a unique set of characteristics: they are stable, they are resistant to weathering, and they are very fine-grained. Research involving aluminosilicates (or clay minerals) is important in understanding the origin, classification and utilisation of soils.

There has been little research on the nature and properties of clay minerals of saline soil in the Haihe low plain; there are a variety of opinions about the composition of clay minerals. According to Xiong and Liu (1987), the major component of the Chao soil is Hydromica (illite), and the yellow Chao soil (a subclassification of Chao soil) is mainly composed of Hydromica, with chlorite and smectite as minor components. Xiong and Liu (1987) suggested that Chao soil is mainly composed of Hydromica (90%), with smectite, kaolinite and vermiculite as minor components. X-ray diffraction (XRD) and X-ray fluorescence (XRF) were used to obtain further information about the composition of these alluvial saline soils in typical soil profiles.

Determining the profile

Tables 6 and 7 and Figure 6 show properties of soil collected in Xiaowang village, Nanpi County. The soil is characterised as moderately saline Chao soil; there is a shallow watertable at about 4 m. Changes in soil texture in the profile are obvious because of the influence of the alluvium of old and modern rivers. The profile studied is typical of the region.

Composition of clay minerals

XRD and XRF were used to determine the clay mineral composition. Figure 7 shows the pattern of XRD of clay fractions from soil samples treated with magnesium-saturated glycerol and air-dried. Samples were taken from five soil layers. Hydromica or illite (1 nm), smectite (1.83 nm), chlorite or vermiculite (1.42 nm and 0.353 nm), kaolinite and microcrystal quartz (0.426 nm) were found in every layer. Hydromica is the major mineral in the soil in this region; minor minerals include kaolinite, chlorite and montmorillonite; and trace minerals are microcrystal quartz and vermiculite. Amorphous material was not considered in this study. The mineral composition of the clay mineral was not closely correlated with soil texture. Chlorite and vermiculite had four feature peaks at the same position, but the two kinds of minerals can be roughly diagnosed by peak intensity.

Table 6. Some properties of soils in Nanpi County.

Depth (cm)	Texture	Consistency	EC (dS/m)	pH
0–15	L	Firm	0.89	8.11
15–35	L	Firm	0.94	8.22
35–75	SL	Soft	1.64	8.20
75–160	ZC	Rigid	1.16	8.23
160–250	S	-	0.72	8.37

EC = electrical conductivity; L = loamy; S = sand; SL = sandy loam; ZC = silty clay

Table 7. Properties of Chao soil at Xiaowang village, Nanpi County.

Depth (cm)	Proportion of soil components (%)									
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	CaO	MgO	K_2O	P_2O_5	Other
0–15	47	23	9	0.56	0.16	0.56	4.8	3.7	0.3	11
15–35	48	22	9	0.6	0.15	0.86	4.4	3.6	0.3	11
35–75	48	22	9	0.56	0.13	1.08	4	3.5	0.3	11.5
75–160	47	22	8	0.53	0.11	1.27	3.4	3.3	0.2	14
160–250	49	21	10	0.56	0.1	0.42	4.6	3.9	0.5	10

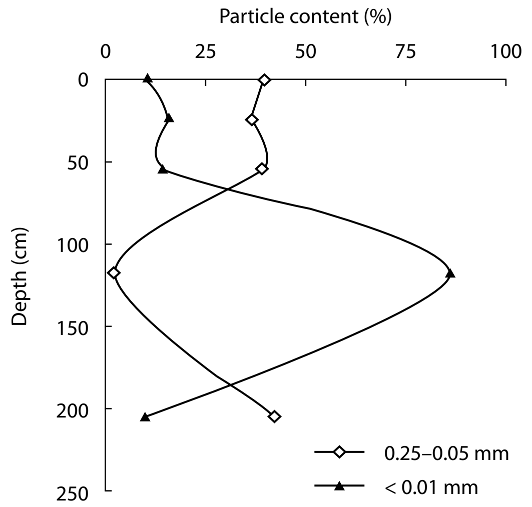

Figure 6. Distribution of different sized particles in Chao soil at Xiaowang village, Nanpi County.

A barium-saturated solution can also be used to see if the peak at 1.42 nm disappears or appears at 1.2 nm. Figure 8 shows the results for three soil layers. The peak beyond 1.42 nm disappeared, but peaks were otherwise similar to those in the magnesium–glycerin treatment: peak position did not change but peak intensity did. These data suggest that vermiculite is not very likely to occur in saline Chao soil.

Difference between soil layers

The theory of XRD requires the different peaks at 1.2, 1.4, 1.8, 2.4, and 3.2 nm to be adjusted by a weighting factor relative to the 1.0 nm peak so that peak intensities are strictly comparable. The PW 1800 XRD instrument (Philips) fitted with a variable automatic divergence slit can be used to approximately cancel out the influence of relatively broad peaks. The intensities of the diffractions of different layers suggested that the peaks of bottom-layer soil (160–250 cm) were the most intense and those of the clayey layer (75–160 cm) were the weakest in all layers. The data also indicated the decrease of crystallinity in finer grains. The peaks of higher-angle spacings were very weak or not obvious, which showed that crystallinity was poor and there were smaller amounts of interlayer minerals.

We examined the difference between the peaks of Ch_{d004} and Kl_{d002} in this diffraction. For clays in the bottom layer with a coarser texture, the intensity of the chlorite peak was higher than that of kaolinite; in other layers the reverse was true (see Figure 7). The clay minerals in each layer reflect the integrated effect of the parent material and the environment. The mineral composition and crystallinity in the bottom layer were similar to the loess parent material (Mao 1998), indicating that the material in this area came from the Loess Plateau. The clay minerals in the upper layers, however, were not very different from those in the bottom layer. The results also show that bioclimatic conditions have had little effect on the composition and changes of clay minerals during the short time for which there are records.

Effects of clay minerals on properties of saline soil

Aluminosilicate minerals with high amounts of exchangeable Na^+ (e.g. > 15%) can lead to dispersing in water. Illite (Hydromica) and smectites tend to disperse easily in soils with wide ranging electrolytic concentrations (Rengasamy and Sumner 1998). The content and properties (e.g. fine particle mixtures with < 0.2 μm) of the clay minerals in soils may influence the physical and chemical properties of colloids in soils. For example, in saline soils that are rich in available K^+, exchangeable Mg^{2+} may enhance the dispersion of illite by comparison with Ca. Soils of the NCP are known to tend to become alkaline in the process of losing salt; further research on the mechanism for this is needed.

Interpretation of Thematic Mapper Data

Thematic mapper (TM) data or images can provide information on the distribution of saline soils. Chapter 16 provides an introduction to Landsat Thematic mapper data. From previous work by Tian et al. (1995) using TM data from 1985, variation in the distribution and extent of saline

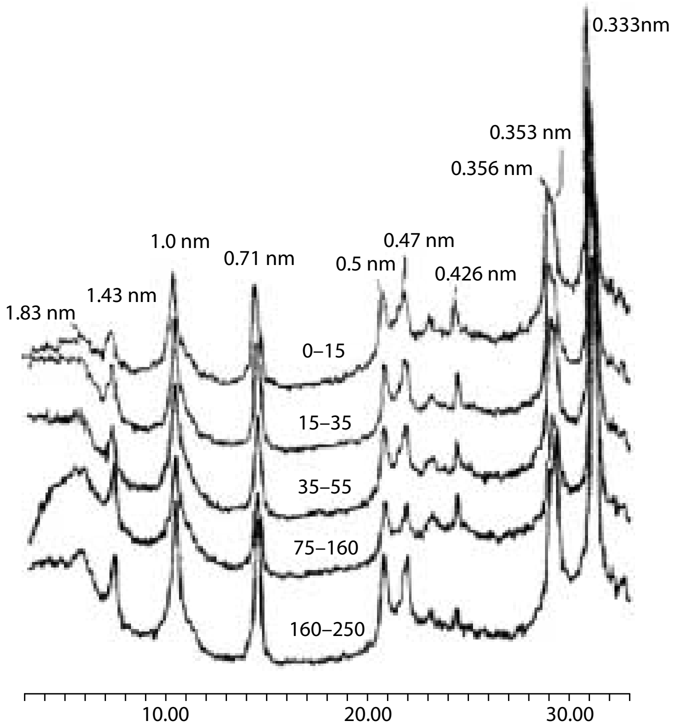

Figure 7. X-ray diffraction pattern of clay treated by magnesium–glycerol.

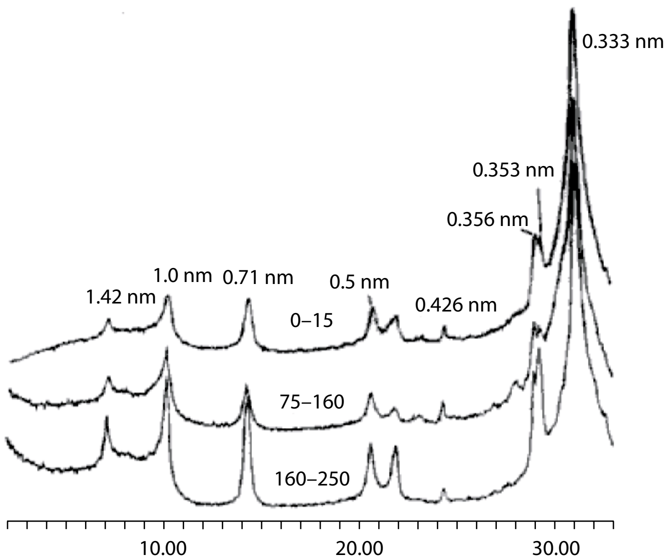

Figure 8. X-ray diffraction pattern of clay treated by barium.

soils patches was assessed for the Cangzhou prefecture from 1985 to 1997. After 1985, the area of the NCP covered by saline soils greatly decreased and salinity was reduced as water resources were fully used for irrigation. Table 8 shows the results of TM interpretation for an image acquired in 1997. In the southwest (Suning, Renqiu, Xian, Botou, Dongguang and Wuqiao), the dominant soils are slightly saline, accounting for 30% of the total area. In coastal areas (e.g. Huanghua, Haixing, Zhongjie and Dagang) there are large areas of moderately or severely saline soils.

Developing Strategies for Dealing with Saline Soils

The improvement and use of saline soils should take into account season, local conditions and type of crop, and combine specialised use with comprehensive control. Technical measures should be based on knowledge about the causes of saline soil and the principles of movement of water and water–salt. It is important to find solutions for the permanent control of salinisation as well as quick temporary solutions. Four main types of measures can be considered.

- *Controlling salt movement into soils*. The normal growth of crops prevents salt from going into the upper layers of the soil. Improved irrigation and drainage are required to control the rise of the groundwater table and environmental salt accumulation. For example, landwater could be irrigated with saltwater and freshwater alternately, surface mulch could be used or surface soils could be furrowed after rain.
- *Removing excessive salts*. In saline cultivated fields and/or grassland the normal growth of crops or grasses will be encouraged by measures that remove excessive salt from the soil — for example, using freshwater storage to leach salt out, removing the salt in the surface layer or replacing soil.

Table 8. Extent of soil salinity in Cangzhou Prefecture determined by Thematic mapper.

Location		Area affected (ha × 10^4)				
		Slightly saline	Moderately saline	Severely saline	Solonchak	Total
County	Huanghua	2.64	2.39	0.58	0.28	5.89
	Haixing	0.70	1.29	0.57	0.44	3.00
	Zhongjie	0.58	0.25	0.09	0.01	0.93
	Nandagang	0.43	0.43	0.14		1.00
	Yanshan	0.84	0.20			1.04
	Mengcun	0.62	0.22			0.84
	Qing	0.32	0.31	0.06	0.02	0.70
	Cang	1.03	0.23	0.04	0.03	1.33
	Nanpi	0.23	0.21	0.11	0.03	0.58
	Dongguang	0.29	0.13	0.03		0.45
	Wuqiao	0.11	0.03			0.14
	Botou	0.18	0.12			0.30
	Xian	0.52	0.37	0.08		0.97
	Hejian	0.42	0.24	0.01		0.67
	Renqiu	0.49	0.17			0.66
	Suning	0.14				0.14
Type of area	Coastal	7.12	5.31	1.48	0.78	14.68
	Middle and inland	2.42	1.28	0.23	0.03	3.96
Total		9.54	6.59	1.71	0.81	18.65

- *Establishing a fertile soil layer*. An agronomic proverb says, 'The more fertiliser, the less saline-alkali soils.' Improving soil fertility and reducing salt in the surface layer will result in improvements in physical and chemical properties of the soil and in biological activity, with better soil structure, higher nutrient content and better self-regulating capacity. The movement of capillary water will also be restrained. Therefore it is necessary to reduce evaporation and salt accumulation in the surface soil to promote crop growth.

- *Adaptive cultivation of plants and crops*. Crops and grasses have different tolerance for salt in different water and salt environments, so selected crops or grasses must be cultivated on the basis of different types and salinities of soils. In addition, some agronomic measures are required — for example, delaying the time of seeding.

Using the appropriate technique for the degree of salinisation

Slightly salinised soils

Slightly salinised soils lie in the upper soil layers where there are good irrigation and drainage systems and surface or groundwater flows. In the study area, the groundwater was usually at 3–4 m, but sometimes at 5–8 m. Some shallow wells contain salty or slightly salty water that can be used to a limited extent. Cultivated lands that lack irrigation equipment could yield only 750–1500 kg/ha, in contrast to areas with irrigation systems that could yield about 6000 kg/ha. Poor physical properties are some of the main factors preventing crops from utilising saline soils. The key limiting factors are drought and reduced fertility. Techniques to improve the soil should therefore emphasise drought resistance, moisture preservation and soil fertility. Examples are:

- greatly exploiting water sources and water-saving irrigation, for instance by using moderately salty water, collecting local rainfall, introducing offsite water use or improving the capacity of the soil to retain moisture;

- fertilising soils to adjust the relationship between fertiliser and salt, for example by applying organic matter, feeding straw back to the soil, combining chemical fertiliser and manure or rotating cultivation to increase biomass and soil fertility;

- paying more attention to arid agricultural techniques to maximise crop yield under conditions of drought and salinisation, particularly by ploughing, harrowing and getting rid of weeds;

- regulating crop distribution, for example by selecting drought-resistant varieties or growing crops like corn, soybean, cotton and pasture; and

- covering the soil surface with plastic film to keep it warm and wet and to impede salt from moving up.

Moderately salinised soils

Moderately saline soils can be irrigated and drained to some extent, but cannot escape waterlogging in some wet seasons. The groundwater table in the study region was at about 2.5–3.5 m, with a large amount of salty water. Drought, low fertility and, especially, salinity were the main limiting factors. The following improvement techniques therefore concentrated mainly on cultivation and management in the better drainage systems:

- flattening land in order to reduce the effect of microrelief on salt accumulation;

- changing seeding practices to take better account of water and salt movements;

- applying fertiliser to soils to improve soil productivity and allow more suitable plants to be grown (e.g. the common green manure plants *Astragalus adsurgens* Pall, *Medicago sativa* L. and *Melilotus albus* Desr);

- regulating crop and grass distribution;
- covering the soil with plastic film and straw; and
- treating seeds with special biochemicals to protect seedlings from diseases and insect pests.

Severely salinised soils

Most severely salinised soils occur as large areas in coastal regions, but smaller patches are scattered away from the sea. These soils lie in low areas with poor drainage, where it is easy to accumulate water in wet seasons. The depth to groundwater was 0.5–1.5 m, but salty water that could not be used for irrigation was extensively distributed in the area. Improving the soil therefore focused on developing better drainage systems, pasture and husbandry rather than on crop cultivation. In particular, it focused on developing and using the existing natural pasture and introducing salt-tolerant plants for husbandry (e.g. *Puccinellia chinampoensis* Ohwi, reeds, *Bromus inermis* Leyss, *Elymus dahuricus* Turcz and *Festuca arundinacea* Schreb).

Developing Strategies for Dealing with Sodic Soils

In the past, the problem of sodic soil on the NCP seemed of low significance in comparison to the damage caused by salinity. Sodic soils have very poor physical and chemical properties and are more difficult to improve than saline soils. Therefore, integrated measures are needed to reclaim sodic soils, including the following measures:

- improving irrigation and drainage systems, and controlling the groundwater table;
- constructing field terraces (similar to bed farming) to conserve rainfall;
- applying fertilisers, in particular, combining chemical fertiliser with manure, to improve soil productivity;
- planting salt-tolerant grasses; and
- adding soil ameliorants (e.g. gypsum for neutralisation of sodicity).

Conclusions

Saline and sodic soils on the NCP present a serious problem for sustainable agricultural development. The area covered by saline soils has greatly decreased since 1980 but further improvements in soil and water management practices through both temporary and permanent measures are needed.

We need to develop a regional perspective that will allow the management of saline and sodic soils to be integrated into a comprehensive management package. This would aim to improve use of soil resources to increase crop yields and arrest the decline in soil quality. We can then develop models of soil processes and recommend strategies to ameliorate existing problems and prevent further damage to soils.

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