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REVIEW

The causes of soil alkalinization in the Songnen Plain of Northeast China

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Abstract The causes of soil alkalinization in the Songnen Plain of Northeast China were mainly analyzed from two aspects, natural and anthropogenic. Natural factors of alkalinization are parent materials, topographic positions, freeze-thaw action, wind conveyance, water properties and semi-arid/sub-humid climate. Some of them were always being neglected, such as freeze-thaw action and wind conveyance. Anthropogenic causes are mainly population pressure, overgrazing and improper agricultural and economic policies. In recent decades, overgrazing played a main role in secondary soil alkalinization, which led to the decline of *Leymus chinensis* grasslands. Now, the alkalinization is very severe, and more than 3.2×10^6 ha area has been affected by salt, which becomes one of the three largest sodic–saline areas in the world.

Keywords Songnen Plain · Soil alkalinization · Groundwater · Human activities · Overgrazing

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Introduction

Songnen Plain covers an area of about 17.0×10^6 ha in the central part of northeastern China (43 30′–48 40′N; 121 30′–127 00′E), and is a big basin that is surrounded by Changbai Mountain (east), Xiaoxing'an Mountain Ranges (north) and Daxing'an Mountain Ranges (west). Its south border is Liao River Plain. Songhua River and Nen River are streaming through the central part of the region (Fig. 1). Also, there are many branch rivers originated from surrounding mountains. Inside the region, many closed-flow areas and ephemeral rivers are distributed, which caused a lot of wetlands. The climate is classified as the transition of sub-humid and semi-arid, therefore, it is the transitional zone of agriculture and grazing. Grasslands dominated by *Leymus chinensis*, which is ideal for grazing and forage, are widely distributed in the region (Xiao et al. 1995; Wang et al. 1997). The usual growing conditions on the plain produce herbage superior both in quality and in quantity, so that this type of grassland is one of the best suited in northern China for the rangeland industry (Li et al. 1983).

However, Songnen Plain eco-system is very fragile, and many environmental harms as soil alkalinization, desertification, soil erosion, flood and drought disasters occur. Among them, soil alkalinization, especially in grasslands, is the severest one. Increasing demand for agricultural land has resulted in both the reduction in the area of the grassland and the need for it to support more livestock. This increase in grazing pressure has led to a substantial reduction in canopy cover throughout much of the grassland. Combined with soil compaction, these impacts have resulted in increased evaporation and runoff, and diminished the infiltration of water into the soil (Guo et al. 1994; Zhang and Gao 1994). This has allowed the saline

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Fig. 1 The map of Songnen Plain

groundwater to rise and, together with increased erosion of surface soil, has resulted in increased salinity of surface soils (Wang et al. 1997). Now, there is more than 3.2×10^6 ha salt-affected land that becomes one of the three largest soda saline–alkali areas in the world. Every year, about 20.0×10^3 ha land is newly salinized/alkalized (Li 2000; Yin et al. 2003). Development of salinity, sodicity and alkalinity in soils not only reduces grass productivity and quality but also limits the diversity of grasses. As the grassland environment has worsened, the quality and quantity of high-grade grasses (such as *L. chinensis*) and legumes has declined (Wang and Li 1995a), and the economic viability of the grassland has decreased, seriously restricting the economic development of the area. So, soil alkalinization has become the main negative factor for regional sustainable development of grazing and agriculture. Solving this issue is highly relevant to the proper management of agriculture and grazing activities.

Salinization and alkalinization are time- and space-dynamic soil degradation processes that reduce the extent and productivity of grazing and agricultural lands. Alkalinization results from the concentration and precipitation of water-soluble salts such as chlorides, sulfates and carbonates of sodium, magnesium or calcium on the soil surface, in the subsoil and groundwater. Alkalinization involves enrichment in sodium ions (Metternicht 2001). The main processes by which soluble salts enter the soil and groundwater include weathering of primary and secondary minerals and application of waters containing salts. The importance of each source depends on the type of soil, climate conditions and agricultural activities. Therefore, the geologic, climatic, topographic and hydrologic factors without human interference, as opposed to secondary alkalinization resulting from human activities, such as population pressure and overgrazing, may be responsible for salinization and alkalinization (Szabolcs 1992).

In this review paper, the main causes of soil alkalinization are analyzed from the factors of natural processes, human activities and interactions between them. The intention of this paper is to present an overview of how soil is affected by salt in the Songnen Plain, to increase the awareness of environmental conditions of grassland and to encourage the implementation of policies that will promote sustainable development of the Songnen Plain.

Distribution of soil alkalinity

Salt-affected land, accounting for 18.8% of total area of Songnen Plain, is mainly distributed in the western part of the Plain. It is divided into south and north parts by Songhua and Nen Rivers. The south part is mainly inside of Jilin Province, including Zhenglai, Da'an, Qianguo, Changling and Tongyu Prefectures. The north part is located at Heilongjing Province, including Dumeng, Daqing, Anda, Zhaoyuan and Zhaozhou Prefectures (Table 1). This distribution characteristic is affected by geomorphic structure such as rivers and closed-flow areas. For example, alkalinization often occurs in the lower landscape positions, such as margins of playas and middle flat landforms where groundwater is relatively low and rich in chlorides and carbonates of sodium and magnesium, with small amounts of calcium. Among those Prefectures, the largest area of alkali land is Tongyu Prefecture of Jilin Province, which is up to 343×10^3 ha; The most affected one is Da'an Prefecture (also in Jilin Province) in which alkalinization area accounts for 59% of its total area, and severely alkalized area is more than 74% of saline/alkali area (Li et al. 2003).

In fact, there is even no agreement on the salt-affected area in the Songnen Plain. In the literature, one can find data such as 5.0×10^6 ha (Wang et al. 1995), 3.4×10^6 ha (Li et al. 1998; Song et al. 2000), 2.0×10^6 ha (Wang 1999), 3.2×10^6 ha (Li 2000; Sheng et al. 2002), 3.7×10^6 ha (Li et al. 2002), 3.0×10^6 ha (Li et al. 2003; Wang et al. 2004a, b, c), and 2.5×10^6 ha (Lin et al. 2005) and others. The difference between the largest and the smallest area is approximately 3.0×10^6 ha. Unfortunately, those authors estimated the salt-affected area without descriptions of the methods used. As mentioned above, most of the data are between 3.0×10^6 and 4.0×10^6 ha, and the average value is 3.2×10^6 ha, which is chosen as the best expression for salt-affected area of the Songnen Plain in this paper.

The process of salinization, sodification and alkalinization is defined as follows. Salinization is the process of accumulation of free salts such as Na^+, K^+, Ca^+, Mg^+ and Cl^- to such an extent that it leads to degradation of soils and hinders the growth of plants by limiting their ability to take up water. When the Na^+ is the main salt of salinization, it is also called sodification. Alkalinization, the increase of pH of soil, is associated with sodification. As shown in Table 2, saline and alkali soil are classified according to their electrical conductivity (EC) of saturation extract at 25 C as the index of the extent of salinization, the exchangeable sodium percentage (ESP), defined as the exchangeable sodium content divided by the cation exchange capacity, as the index of the extent of sodification, and pH as the index of the extent of alkalinization (Richards 1954). Saline soils, for which EC is more than 4 mS cm^{-1}, ESP is less than 15 and pH is less than 8.5, are often recognized by the presence of white crusts of salts on the surface. Saline–alkali soils have EC greater than 4 mS cm^{-1} and ESP greater than 15. When the pH is below 8.5, the appearance and properties of saline–alkali soils are generally similar to those of saline soils. If the pH is greater than 8.5, the properties of saline–alkali soils may change markedly and become similar to those of alkali soils. Alkali soil is applied to soils for which the ESP is greater than 15, EC is less than 4 mS cm^{-1} at 25 C, and the pH is greater than 8.5. These soils form as result of alkalinization that is a process of removal of excess salts but increase of Na^+, thus causing darkening and giving rise to the " black alkali" (Hilgard 1906). Li and Zheng (1997) reported that more than 80% of salt-affected area was alkali

Table 1 The distribution of saline–alkali land in some prefectures of Songnen Plain (Li et al. 2003)

Prefectures	Area of saline–alkali land ($\times 10^3$ ha)	Percentage of total area (%)	Degree of salinization/alkalinization		
			Light (%)	Middle (%)	Severe (%)
Zhenglai	171.5	31.9	27.2	21.3	51.5
Taonan	59.6	9.5	23.2	27.2	49.6
Tongyu	342.5	40.4	50.8	27.4	21.8
Da'an	287.8	59.0	20.0	6.0	74.0
Qianguo	191.3	29.9	49.7	19.7	30.6
Fuyu	77.0	13.3	58.8	9.2	32.0
Changling	164.3	28.9	36.6	37.4	26.0
Qian'an	180.3	39.7	22.9	34.6	42.5
Longjiang	63.5	10.3	5.2	91.2	3.6
Dumeng	117.4	19.4	–	92.8	7.2
Daqing	136.9	28.3	32.1	33.2	34.7
Anda	147.6	41.2	27.8	13.7	58.5
Zhaoyuan	109.2	26.8	39.5	3.1	57.4
Zhaozhou	66.5	27.1	20.3	–	79.7

Table 2 Salt-affected soils (data are from the references cited)

	EC[a] (mS cm^{-1})	ESP (%)	pH
Alkali soil	<4	>15	>8.5
Saline-alkali soil	>4	>15	> or <8.5
Saline soil	>4	<15	<8.5

[a] EC (mS cm^{-1}; soil solution)

Table 3 The values of EC, ESP and pH of salt-affected soils in the some prefectures of the Songnen Plain

Prefectures	EC (mS cm^{-1})	ESP (%)	pH	Types of soil
Anda	1.32	57.6–87.8	10.4	Alkali
Da'an	1.5–2.3	20.0–30.0	10.3	Alkali
Harbin	0.578	20.37	9.81	Alkali
Qianguo	0.559	–	10.2	Alkali/ saline–alkali
Changling	1.0–6.0	>15	9.8–10.7	Alkali/ saline–alkali

Number of replicates is 3

in the Songnen Plain, especially for grassland. Table 3 showed the values of EC, ESP and pH of salt-affected soils in some prefectures (Li et al. 2006; Wang et al. 2004a, b, c; Guo et al. 1998; Zhang 1994; Wang et al. 1997), which indicated that soil alkalinization is very active in the Songnen Plain.

Causes analysis

Geological conditions

Salt origin

Songnen Plain's saline–alkali soil is mainly caused by soda, so the origin of soda has a close relation with soil alkalinization. In the Changbai Mountain, Xiaoxing'an Mountain Ranges and Daxing'an Mountain Ranges, there are wide distributions of Granites, Andesites, trachytes, phonolites, rhyolites that contain the abundant sodium aluminosilicates such as orthoclase, plagioclase, albite, sodalite, nepheline (Lin et al. 2005). Those alkali rocks, which are parent materials of soil, have direct impacts on the soil salinization and alkalinization. During the process of minerals weathering, salt formation such as bicarbonates, comprised potassium, sodium, calcium and magnesium takes place, which dissolve into surface and ground runoffs of rain water, then accumulate in the flat lands. Some of them become insoluble carbonates and deposit, and the others such as sodium and potassium carbonates become the main origins of soda. The accumulation of these soluble salts in groundwater affects water quality, which depends on the natural salinity of the soil and geologic materials with which the water has been in contact.

Geomorphic patterns

Neotectonic movement shaped the Songnen Plain's geomorphic pattern that favors salinizing and alkalizing (Lin et al. 2005). The Songnen Plain is surrounded by mountains from three sides and thus has very poor drainage. On the whole, it is a big valley originated from a tectonic depression basin filled by Quaternary sediments. Its landscape consists of alluvial glacis that is mountain pediments, and lacustrine-alluvial fans that are main part of Songnen Plain. In the central part, there are many playas and lacustrine-flats. Playas occupy the lowest parts of the basin, have flat to concave topography and are composed of thick beds of clay and sandy clay materials. The playa soil surface shows saline crusts during the dry season. Lacustrine-flats are almost leveled terrain surfaces of alluvio-lagunary origin, forming transitional zones between the playas and the alluvial fans or glacis of the piedmonts. Lenses of gravel and coarse sand are intercalated with the clayey materials of the lacustrine deposits. Most of the salt-affected areas correspond to the lacustrine depressions, especially where temporary waterlogging occurs because of insufficient natural drainage. Soils on the distal parts of the glacis also have significant salt contents.

The weathering rocks with lots of dissoluble saline/alkali compounds (such as $NaHCO_3$ and Na_2CO_3) move downward with the runoffs that carry about of 150 tons of a net solute input down to the plain every year (Gao et al. 1996). The accumulation of the solute causes a primary soil alkalinization process with Na_2CO_3 and $NaHCO_3$ as major sources of soil alkali. Inside the region, the land form is very flat and the slope is only 1/8,000–1/50,000, therefore, the streams are slow running, the drainage is blocked and salts are difficult to be leached outside of the region. In addition, the soil texture is very clayey and its saturated hydraulic conductivity is low (Wu and Li 2003; Wang et al. 2007), so the dissoluble saline matters could not infiltrate down the soil profile but stay in the soil surface or subsurface. By analysis of geomorphic patterns and saline–alkali land distribution based on Geographic Information System and Remote sensing (Li et al. 2003), soil alkalinization is obviously related to geomorphic patterns, and mainly occurred in lower landscape positions, such as margins of playas and middle flat landforms. For example, the low-river terrace has largest area of land affected by alkalinization accounting for 36.6% of its total alkalized area; whereas in the high and low fluvial flood-plains, they are 16.5 and 15.6%, respectively. In those three geomorphic patterns above, the alkalinization reaches up to 68.7% of their total area, which might be attributed to the nature of the deposits originating from the carbonate-rich mountains in the Songnen Plain.

Climate conditions

Monsoon climate's effect on soil alkalinization

The southeast ocean monsoon cannot enter the region due to the barrier of Changbai Mountain. Also, influenced by the Mongolian inner climate, the climate has characteristics of continental monsoon. Majority of the region is dominated by the Mongolian anticyclone (high pressure) system, which produces a westerly flow of cold, dry air and little precipitation during winter. As the anticyclone breaks down in spring, warm and moist oceanic air is drawn into the region under the influence of Pacific air masses, reaching a climax in the summer monsoon, which lasts 2–3 months in northeast China. Its mean annual air temperature is about 5 C, varying from −18 C in January to 23 C in July. Annual precipitation ranges from 300 to 600 mm (Wang et al. 2003). More than 80% of the rains occur mainly during the summer monsoon (between June and September), causing a moisture deficit during 7 months per year. In winter and spring, the precipitation is very few and only accounts for about 13% of total level. The average annual evaporation is 1,200–1,800 mm and that is 2–3.5 times more than the annual precipitation. Potential evaporation is smaller than pan evaporation in this region (annual potential evaporation in Harbin is 788 mm), but it is still larger than annual precipitation in this region (Wang and Tian 2002; Zhang et al. 2006). The main characteristics of the climate of the region are a cold, dry, frequently windy spring; a warm, wet summer, with uneven precipitation and frequent droughts; early autumn frosts and a long and severe cold winter with relatively little snowfall (Gao et al. 1994; Yao et al. 2006).

Thus, the salinization and alkalinization are fundamentally related to this monsoon climate that favors salt accumulation in dry season whereas salt elimination in rainy season is not sufficient. Rainfall periods, during which the salts are leached to the deeper soil horizons, and drought periods, in which salts ascend to superficial horizons, result in significant seasonal variations in salinity, both in salt quantity and type (Álvarez et al. 2001). Affected by the climate monsoon, the movement of soil water and salt can be classified into four stages: salt accumulation in spring, salt elimination in summer, salt recovery in autumn and salt accumulation in winter. The period for salt elimination is consistent with the rainy season that is about 3 months, but the period for salt recovery and accumulation is more than 5–6 months. So, the overall trend is the accumulation of salt in the soil surface. As mentioned above, the annual evaporation is larger than precipitation and the humidity is low (Wang et al. 2004a, b, c), so the upward capillary movement of soil water is stronger than infiltration and gravity movement. The soluble saline compounds are accumulated in the soil surface with the water evaporation and condensation especially in spring and autumn, which causes soil salinization and alkalinization.

Effect of freeze-thaw action on soil alkalinization

The process of freeze-thaw action is closely related to soil alkalinization in the region (Zhang and Wang 2001), which is always neglected. From the end of October or the beginning of November, soil begins to freeze, and it will completely thaw in the end of next June or the beginning of July (as showed in Fig. 2). In the process of freezing, the water of bottom soil moves up to freezing layers because of temperature gradient and the salt is also accumulated among the freezing layers. In the lower layer soil of the freezing layers, water and salt content decreases, but it can be supplied by groundwater instantly through capillary action. Therefore, with the thickening of freezing layers, salt is largely accumulated. Next spring, with the beginning of thawing, salt among the freezing layers is transported to soil surface by strong evaporation until the freezing layers are completely thawed. Before completely thawed, the freezing layers cut off the soil water exchange between soil surface and groundwater (Qiu et al. 2005). So, it is obvious that salt accumulation in winter by freezing, which is called as latent accumulation, induces further soil alkalinization

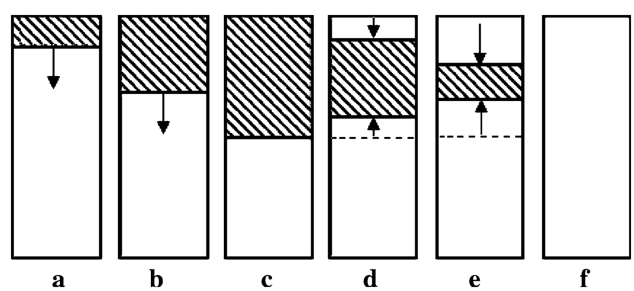

Fig. 2 The schematic illustration for process of freeze-thaw action. The shaded part refers to the freezing layer. In a and b, the *arrows* show the direction that the freezing layer becomes thicker from up to down. In d and e, the *arrows* indicate the directions that the freezing layer begins to be thawed due to solar radiation from soil surface and due to geothermal from the bottom of the freezing layer. (a The freezing layer begins to be formed from the end of October or the beginning of November; b the freezing layer becomes thicker; c the freezing layer reaches the thickest in January; d the freezing layer begins to be thawed from the end of next March; e the freezing layer becomes thinner; f the freezing layer disappears until the end of next June.)

in next spring. But to date, there is still no quantitative description of changes of soil moisture, salt content, ESP, pH, etc., in the process of freeze-thaw action, and in-depth research should be made to clarify this theory.

Salt conveyed by wind

Wind is another factor for soil alkalinization. In the Songneg Plain, there are yearly 15–31 windy days, and about 6–20 heavy wind days, in average. The average wind speed is 3.4–4.4 m s^{-1}, up to 20–40 m s^{-1}. In spring, wind storm is common. Wind storm can carry salt dust from salt-affected area to no alkali areas and enhance the salt level of soil (Zhang and Wang 2002). However, because wind is not the primary reason of soil alkalinization, it is not attached importance by scientists and there is lack of quantitative description of wind effect on the soil alkalinization. Taking into account recent increase in the frequency of wind storms more attention should be paid to this phenomenon (Zhang and Wang 2002).

Water environment's effect on soil alkalinization

Water environment also plays a major role to soil alkalinization. Hydrographic conditions such as surface rivers and runoffs, groundwater elevation and chemical property of water, have much more close relation with the occurrence, distribution and evolution of soil alkalinization.

Rivers and runoffs

The chemical runoffs of river play a key role to salt accumulation of inflow areas. The formation of soil, soil water and groundwater is related to the activities of all big rivers of inflow areas whose water balance is mainly regulated by evaporation that is an important factor for soil alkalinization. Table 4 shows the ion's contents of all types of water in the Songnen Plain. Large rivers include main and branch streams of Songhua River, Nen River and Lalin River; large branches include Zhao'er River, Huolin River, Jiaoliu River, and so on. The degree of mineralization of those Rivers is not so high, about 0.15–1.30 g l^{-1} on average. But there are many ephemeral rivers (that are located in the dish-like depression, usually have water only in wet season, so whose water flow are always intermittent) in the region, such as Huolin River, Wuyu'er River, Shuangyang River, etc. Those ephemeral rivers provide much quantity of surface water that can not flow out of the region through surface flow of water, but influx in the low floodplains or branch of rivers that are stagnant and low-lying pools of water attached to a waterway. In addition, there are more than 7,000 tectonic lakes (Lin et al. 2005) that are located in the middle of Plain, but the actual lake area is small, and the lakes are distributed in a network structure (Bian et al. 2008). Each lake is shaped like a water drop, regardless of the area of the lake, and its tip points northwest, which shows that the shape of the lake has been influenced by wind erosion. The lake is a kind of HCO_3–Na closed inland lakes. The alkali soil around the lake is distributed concentrically from the lake center and the salt was mainly concentrated in the dried lake after strong evaporation. This hydrological effect of those tectonic lakes (generally distributed in the dish-like lowland) is also a major cause to soil alkalization.

Groundwater

In the Songnen Plain, groundwater is embedded in the unconsolidated Quaternary deposits. It flows very slowly and is depleted by evaporation (Lin et al. 2005). Soil alkalinization occurs mostly in the areas where groundwater level is below 2.0–2.5 m. In those areas, the groundwater levels vary with the seasonal changes and the up and down movement of soil water is frequent, so the processes of soil alkalinization are very active (Wang and Tian 2002).

Also, as Table 4 shows, the ion's content of groundwater is very high, which is usually more than 3.0 g l^{-1}. As groundwater belongs to $NaHCO_3$ type, the Na^+ concentration of groundwater is accordingly high. In low lands

Table 4 Chemical properties of surface water and groundwater in the Songnen Plain (Wang et al. 1995)

Water types	Locations	Total ionic concentration (g l^{-1})	Main ions		Main salinity
			Cations	Anions	
Surface water	Rivers	0.07–0.09	$Ca^{2+} + Na^+$	CO_3^{2-}	$CaCO_3$
	Lakes in meadows-grasslands	1.0	$Na^+ + Ca^{2+}$	$Cl^- + SO_4^{2-}$	NaCl, Na_2SO_4
	Lakes in forest-grasslands	0.4–0.5	$Ca^{2+} + Na^+$	CO_3^{2-}	$CaHCO_3$
Groundwater	River-lake diluvial Plains	0.1–0.5	Ca^{2+}	CO_3^{2-}	$CaHCO_3$
	Low lands	>3.0	Na^+	$CO_3^{2-} + Cl^- + SO_4^{2-}$	$NaHCO_3$
	Deep-seated layers	3.0–8.0	$Na^+ + Ca^{2+} + Mg^{2+}$	$Cl^- + CO_3^{2-} + HCO_3^-$	$NaHCO_3$, Na_2CO_3

Number of replicates was not given in the reference and deep-seated layers, the Na^+ concentration would be more than 3.0 g l^{-1}, and soil alkalinization always happens. Therefore, salinity easily enters soil surface with water evaporation and vegetation transpiration.

Human-related factors

In addition to the soil alkalinization resulting from the topographical condition, the grassland is also degraded by human-related factors, such as overgrazing and hay cutting due to the population pressure and improper management. The degradation of grasses in turn induces a secondary soil alkalinization process, resulting in further deterioration of the soil conditions for plant growth. Natural factors provided a potential environment for soil salinization/alkalinization, and human-related factors such as population, overgrazing, policy, and unreasonable utilization of land and water resources produced secondary salinization and accelerated the process of alkalinization.

Population

At the end of nineteenth century, there were only about 5.9 million persons in the northeast of China because of "population immigration forbidden policy" that prevented people living in other provinces from immigrating into the Northeast. From the beginning of twentieth century, the policy was changed to encourage people to migrate into the undeveloped area of China, and more than 15 million people moved into the Northeast from the year of 1900 to 1930. There were about 30.1 million persons in 1930. From 1940 to 1945, about 6.5 million people migrated into the Northeast and there were 40.1 million persons in 1945 (Wang 2000, 2006). As shown in Fig. 3, population increased by 580% during the half of the century. After the founding of the People's Republic of China in 1949, the population of Northeast increased more quickly. Total population increased by 177%, from 42.7 million persons in 1950 to 118.4 million in 2004. We can see that, the rate of population growth from 1951 to 1975 was the highest in the past 50 years. After 1978, due to the implementation of "one couple one child" policy, the rate of population growth slowed down though the increasing quantity was still large.

With the growth of population, the salt-affected land increased, and grassland and wetland decreased sharply. According to Lin et al. (2005), about 100 years ago the Songnen Plain was covered mainly by grasses and swamps. The areas of grassland and wetland were about 6.4×10^6 ha and 7.6×10^6 ha, accounted for 37.6 and 44.7% of total Songnen Plain, respectively. In that time, less than 5% of grassland was salinized and the area of alkali spots was few. In 1980, there was about 2.4×10^6 ha

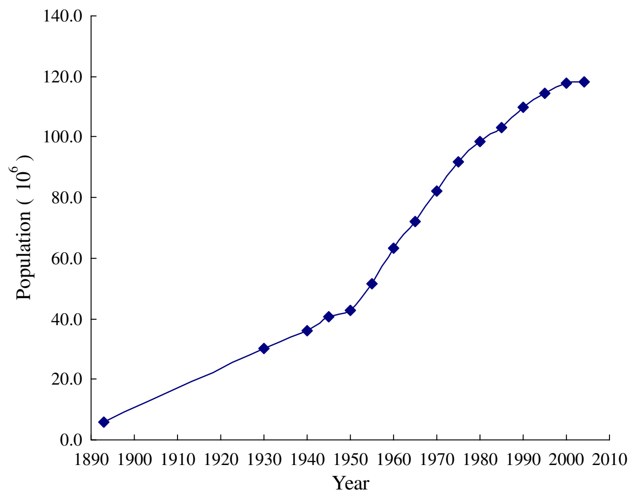

Fig. 3 Changes of total population of Northeast China in recent 100 years

grassland and 1.7×10^6 ha wetland, decreased by 62.5 and 77.6%, respectively; while the salinized area was up to 2.7×10^6 ha. In 2000, there was only about 1.8×10^6 ha grassland and 1.0×10^6 ha wetland, decreased by 71.9 and 86.8%, respectively; while the salinized area was up to 3.2×10^6 ha (Wang et al. 2004a, b, c; Zhao et al. 2004; Wang et al. 2005; Li et al. 2006), increased about 18.5%. Li et al. (2007) studied that increased salinized area mainly originated from grassland and wetland.

It is believed that the rapid population growth with the concomitant requirement of grain brought a heavy burden and great pressure for agriculture, environment and society because each person created a certain demand on Earth's resources, thus caused the overgrazing and unreasonable reclamation of grassland and wetland, which make the soil become secondary salinization and alkalinization (Liu et al. 2007).

Overgrazing

Grasses are the most important resources both economically and ecologically in the Songnen Plain. Not only are they a source of food for animals and livestock, but they also provide important aesthetic benefits. Furthermore, they have a key role in water conservation and the prevention of alkalinization. Grasses together with the macropore of the surface soil can help to increase the rate and extent of soil desalinization/dealkalinization or to decrease the rate and extent of soil salinization, or even alter the direction of salination/desalination. Despite their importance, grasses in the Plain, as in other parts of the world, are vulnerable to the effects of human activities, especially of overgrazing.

Overgrazing is an important human-related factor that claims responsibility for the soil salinization and alkalinization in the Songnen Plain. Overgrazing is very common because people need much more meat to consume, especially after the implementation of reform and open policy that resulted in the rapid development of China's economy due to population pressure. Zhao et al. (2004) reported that in 1949, there were about 1.42 millions of livestock (cattle and horse) and 0.07 millions sheep in the Songnen Plain, while in 1997 there were about 6.7 millions and 7.26 millions, increased by 4.72 and 103.7 times, respectively. The unreasonable development of stockbreeding substantially damaged the grassland quality and reduced the ground cover, thus increasing the evaporation, soil temperature and soil organic decomposition, which all catalyzed the process of soil salinization and alkalinization (Zhang and Lin 1999; Guo and He 2005; Lin and Tang 2005). Table 5 showed that due to overgrazing, the dominant species, average vegetation fraction, grass height, density and productivity all decreased to a large extent from 1950s to 1990s in Da'an County of Songnen Plain (Li et al. 2007). The number of species and total canopy cover of more palatable perennial grasses decreased and even vanished, whereas those of less palatable plants increased significantly. Tables 6 and 7 shows the degradation process of *L. chinensis* community under heavy grazing. In saline soil (Table 6), *L. chinensis* community changed into *S. glauca* or *S. corniculata* community, and in alkali soil (Table 7), it changed into *S. glauca* + *Artemisia anthifolia* community or finally into bare soil with alkali spots. Changes in plant composition were reflected primarily in decreasing number of perennial mesophytes (such as *L. chinensis*, *Calamagrostis epigeios* and legumes), and increase of annual grasses (especially *Chloris virgata*) and halophytes (such as *Suaeda corniculata* and *Puccinellia tenuiflora*), with halophytes becoming dominant. The height, biomass, biodiversity (Table 8) and aerodynamic roughness of the plant canopy decreased, its albedo increased, and less amount of macropores in the surface soil occurred (Qu and Guo 2003). As the plant canopy reduces, the direct solar radiation to the soil surface increases, enhancing evaporation of water from the soil surface and increasing salinization of upper soil layers. With the increase of salt-affected spots in grassland, the product of grass decreased continuously, thereby reduced the capacity of grassland for stockbreeding.

The degradation of grasses always accompanies soil degeneration. Tables 9 and 10 shows the relationship between soil properties and depression of *L. chinensis* community (Guo et al. 1994; Qu and Guo 2003). First, soil is compacted by trampling by large animals that markedly increases soil bulk density, and reduces soil porosity and water infiltration, especially after rain (Zhang and Gao 1994). For instance, as compared to *L. chinensis* community, on bare soil the bulk density increased by 24.1% (from 1.42 to 1.87 g cm^{-3}), while soil hydraulic conductivity decreased by 93.3% (from 0.15 to 0.01 mm min^{-1}) (Table 9). Simultaneous decrease of humus, nutrients (N and P), and organic matter indicated lost in soil fertility. As shown in Table 9, with the degradation of *L. chinensis* community to bare soil due to overgrazing, humus, total N, total P and hydrolytic N of soil decreased by 67.0, 65.6, 29.7 and 78.6%, respectively. Also, there are secondary impacts, such as changes in microclimate and community composition, and effects on soil processes, including nutrient dynamics (Li and Xiao 1965; Archer and Smeins 1991; Zhang 1993; Wang and Li 1995b). The exposure of soil to sun and wind most often leads to more extreme surface temperatures, lower infiltration rates and higher soil evaporation (Whitman 1971; Willms et al. 1986) that

Table 5 Characteristics of degradation of grassland in 1950s and in 1990s, in Da'an County, China (Li et al. 2007)

Period	Main vegetation types	Average vegetation fraction (%)	Height in July (cm)	Density individual plant (m^{-2})	Productivity (kg ha^{-1})
1950s	More than 80% palatable species, such as *Stipa baicalensis* and *L. chinense*	>85	>80	800–1,500	1,500–3,000
1990s	Less than 50% palatable species, with exuberant salt-tolerant species, such as *Suaeda glauca Bunge* and *Puccinellia tenuiflora*	30–40	30–40	450–750	600–900

Table 6 The effects of over grazing on vegetation in saline soil (Re-tabled by data from Guo et al. 1998)

Grazing	Normal	Overgrazing		Greatly overgrazing
Saline soil	Light	Moderate	Severe	Greatly severe
Vegetation community	*Leymus chinensis*	*L. chinensis* + *Puccinellia tenuiflora*	*Puccinellia sp.* + *Stipa klemenzii Roshev* + *Suaeda glauca*	*Suaeda corniculata* (C.A.Mey.) Bunge

The study was conducted in the western Jilin Province

Table 7 The effects of over grazing on vegetation in alkali soil (Re-tabled by data from Guo et al. 1998)

Grazing	Normal	Overgrazing		Greatly overgrazing
Alkali soil	No or light	Moderate	Severe	Greatly severe
Vegetation community	*L. chinensis*	*L. chinensis* + *Chloris virgata* Swaetz.	*Suaeda* glauca + *Artemisia anthifolia*	Bare soil with alkali spots

The study was conducted in the western Jilin Province

Table 8 The quantitative characteristics of main plant communities (Qu and Guo 2003)

No.	Community types	Coverage (%)	Height (cm)	Species saturation (ind m^{-2})	Diversity index	Biomass (g m^{-2})
1	Ruderal forb	100	55	23	2.525	320
2	*Calamgrostis epigeios*	90	60	14	1.628	310
3	*L. chinensis*	80	50	8	0.930	281
4	*C. virgata* Swaetz.	70	40	5	0.664	257
5	*P. tenuiflora*	60	55	6	0.784	201
6	*S. glauca*	50	35	2	0.170	127

The study was conducted in Changling Prefecture of Jilin Province. Number of replicates is 5

Table 9 The relationship between soil alkalinization and vegetation community (Guo et al. 1994)

No.	Community types	pH	ESP (%)	Total content of soluble salt (%)	Na^+ (cmol kg^{-1})	Total porosity (%)	Bulk density (g cm^{-3})	Saturated hydraulic conductivity (mm min^{-1})	Organic matter (%)
1	*L. chinensis*	8.50	28.9	0.220	5.09	46.4	1.42	0.15	1.85
2	*L. chinensis* + *P. tenuiflora*	9.20	45.6	0.403	8.75	40.4	1.59	–	1.24
3	*L. chinensis* + *Aeluropus pungens*	9.13	38.2	0.347	8.24	45.1	1.64	–	1.52
4	*L. chinensis* + *C. virgata* Swaetz.	9.00	40.3	0.389	8.30	42.3	1.56	–	1.29
5	*P. tenuiflora*	9.72	60.4	0.437	10.06	28.1	1.58	0.05	1.06
6	*A. pungens*	9.64	57.8	0.433	11.30	42.0	1.62	0.09	1.21
7	*C. virgata* Swaetz.	9.68	53.2	0.425	9.84	44.5	1.48	0.12	1.16
8	*S. glauca*	9.97	64.5	0.498	12.10	37.6	1.67	0.02	0.87
9	Bare soil with alkali spots	10.05	77.8	0.546	13.75	34.4	1.87	0.01	0.53

The study was conducted in the western Jilin Province. Number of replicates is 5. Soil depth is 30 cm

Table 10 Main soil nutrients of different plant communities (Qu and Guo 2003)

No.	Community types	Humus (%)	Total N (%)	Total P (%)	Total K (%)	Hydrolytic N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
1	*L. chinensis*	1.3973	0.1088	0.0292	2.488	62.78	7.06	85.63
2	*C. virgata* Swaetz.	1.3250	0.1047	0.0252	2.367	62.56	10.23	72.63
3	*P. tenuiflora*	0.5445	0.0507	0.0192	2.465	24.13	6.86	88.60
4	*S. glauca*	0.5282	0.0460	0.0180	2.279	23.47	2.30	82.70
5	Bare soil with alkali spots	0.4618	0.0374	0.0205	2.288	13.43	14.83	114.23

The study was conducted in Changling Prefecture of Jilin Province. Number of replicates is 5

consequentially causes the reduction in moisture content of the surface. The soil moisture reduction has a major impact on grassland productivity (Chang and Zhu 1989), tends to retard decomposition of accumulated litter and reduces soil humus formation that is very important for forming aggregate structure of soil. These changes of soil characteristics increase the evaporation and decrease the amount of macropores in surface soil, and hence accelerate the upward flux of the alkali elements such as Na^+, which are highly soluble in soil liquid at higher soil temperatures (Guo et al. 1994; Wang and Zhou 2001).

The excessive and unreasonable use of grassland destroyed the structure of original landscape. In general, overgrazing causes a transition in grassland composition from palatable to unpalatable species (Wang and Li 1993), even to bare soil with alkali spots, worsens the grass ecosystems, and leads to soil alkalinization which affects intrinsic soil properties and plant productivity, and makes sustainable development of agriculture and pasture in the Songnen Plain impossible.

Agricultural and economic policies

Agricultural and economic policies also intensified the soil salinization/alkalinization through affecting land use change. To suffice grain need for the increasing population under the 'food first' agricultural policy, more than 1.2×10^6 ha grassland and wetland was reclaimed to cropland during the 'Great Leap Forward' movement from 1955 to 1960. For example, one third of grassland was altered into farmland due mainly to the reclamation of natural pastures, which finally became the saline/alkali areas in the west part of Jilin Province (Yin et al. 2003). Owing to the extensive cultivation, some of cropland converted from grassland and wetland were salinized and alkalized finally. Due to this reason, the area of cropland was not increased though grassland and wetland were reclaimed incessantly in 1970s. At the beginning of 1980s, in order to encourage farmers, the Chinese government reformed the land tenure policy and introduced a system of household contract responsibility, in which remuneration was linked to output. Influenced by this policy, farmers began to reclaim more grassland and wetland. So the newly cultivated cropland increased from 1980, and there was about 22.8×10^6 ha until 2004 in the Northeast China (Here it is necessary to explain that more than 60% of cultivated cropland in the Northeast China is located in the Songnen Plain). Due to salinization and alkalinization, part of cropland was abandoned after reclaimed for a period, but the area of newly reclaimed cropland was more than that of abandoned farmland. Additionally, more than 10 large dams were constructed to irrigate the cropland from early 1970s to 2000 (Luo et al. 2002). Those dams played important role in increasing the food yield in the early stages, but led to serious land salinization and alkalinization because the water conservancy projects blocked the hydraulic link between the floodplain and the river, leading to higher level of groundwater, destroyed the water-salt balance and induced salinization/alkalinization. The building of Xingfu Dam in early 1970s, is a typical example, which is the main reason that made the salinized land increase at very fast speed during 1954–1975 in the northern part of Da'an county of Jilin Province (Li et al. 2007).

Conclusion

In the Songnen Plain, both natural and anthropogenic factors are responsible for salinization and alkalinization. Natural factors include parent materials, topography, water properties (hydrology as a driving factor) and semi-arid/sub-humid climate. Human factors are mainly population growth, overgrazing and improper management. Population growth brings great pressure for environment and resources, which accelerates the process of soil salinization and alkalinization. Overgrazing destroys vegetation and increases soil bulk density and decreases hydraulic conductivity. Therefore, as precipitation is not enough to maintain regular percolation of rainwater through the soil, salts from parent materials could not be transported outside the region because of its topographic position, and these are accumulated in the soil, thus decreasing soil productivity. It is necessary to point out that salinity/soidicity is a natural phenomenon related to the nature of the parent material, hydrology and subsequent pedogenic processes. But in recent decades, the increased grazing induced severe secondary soil alkalinization that caused the deterioration of the *L. chinensis* grasslands in the Songnen Plain. It is expected that secondary alkalinization of soils will considerably increase in the future, because of growing use of poorer quality waters and soils for grass production to meet the demand of increasing livestock. So, it is urgent to protect the productive grasslands based on scientific managements. Besides reducing stocking rates and periodical fallowing of heavily grazed areas, the primary approach should involve controlling of the intensity and time of grazing. In addition, it is better to use the seeded pastures to reduce pressure on the natural grassland, to modify the areas of grassland by shallow plowing or harrowing to improve soil properties and application of sand cover to rehabilitate saline/alkali areas (Li et al. 1983; Wang and Earle 1997). Here, it is also important to indicate that since 1998 the Chinese Central Government has enacted the policy for the restoration of vegetation, overgrazing has been controlled to a certain extent as livestock is now more and more home-raised by farmers. Therefore, Songnen Plain is now more agriculture than rangeland and overgrazing is not that big issue anymore, while irrigation and water resources management become gradually more crucial factors on soil salinization and alkalinization in recent years. How to rationally manage water resources and efficiently irrigate is another critical topic for preventing soil salinization and alkalinization in the future.

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References

Álvarez RJ, Ortiz SR, Alcaraz AF (2001) Edaphic characterization and soil ionic composition influencing plant zonation in a semiarid Mediterranean salt marsh. Geoderma 99:81–98

Archer S, Smeins FE (1991) Ecosystem-level processes. In: Heitschmidt RK, Stuth JW (eds) Grazing management: an ecological perspective. Timber Press, Portland, pp 109–139, 259

Bian J, Tang J, Lin N (2008) Relationship between saline-alkali soil formation and neotectonic movement in Songnen Plain, China. Environ Geol 55:1421–1429

Chang J, Zhu TC (1989) Study on the water condition of Aneurolepidium chinense community (in Chinese). Acta Phytoecologica et Geobotanica Sinica 13:219–229

Gao Q, Zheng HY, Li JD (1994) A simulation model for the plant-environmental system of alkalized grassland on the Songnen Plain in the Northeast China (in Chinese with English abstract). Acta Phytoecologica Sinica 18(1):56–67

Gao Q, Yang XS, Yun R, Li CP (1996) MACE, a dynamic model of alkali grassland ecosystems with variable soil characteristics. Ecol Model 93:19–32

Guo YD, He YF (2005) The dynamics of wetland landscape and its driving forces in Songnen Plain (in Chinese with English abstract). Wetland Sci 3(1):54–59

Guo JS, Zhang WZ, Xiao HX (1994) Vegetation degeneration and soil alkalinization in the *Leymus chinensis* lands (in Chinese). Agric Technol 2:39–43

Guo JS, Jiang SC, Suo G (1998) Comparative study on remedy ways of saline-alkali grassland in Songnen Plain (in Chinese with English abstract). Chin J Appl Ecol 9(4):425–428

Hilgard EW (1906) Soils, their formation, properties, composition, and relations to climate and plant growth. Macmillan, New York, p 593

Li XJ (2000) The Alkili-saline land and agricultural sustainable development of the Western Songnen Plain in China (in Chinese with English abstract). Sci Geogr Sin 20(1):51–55

Li B, Wang ZC (2006) The alkalization parameters and their influential factors of saline-sodic soil in the Songnen Plain (in Chinese with English abstract). J Arid Land Resour Environ 20(6):183–191

Li SY, Xiao YF (1965) Primary dividing of grazing stages in *Leymus chinensis* grassland in Muodamuji, Nei Mongolia (in Chinese). Acta Phytoecol Geobot Sin 3:200–207

Li JD, Zheng HY (1997) Amelioration of alkalized grassland and its ecological mechanism in the Songnen Plain (in Chinese). Science Press, Beijing

Li CH, Zheng XF, Zhao KY, Ye JX (1983) Basic types of pasture vegetation in the Songnen plain. In: Proceedings of XIV International Grassland Congress, 15–24 June 1981, Lexington. Westview Press, Boulder, pp 432–434, 876

Li QS, Qiu SW, Deng W (1998) Study on the secondary saline-alkalinization of land in the Songnen Plain (in Chinese with English abstract). Sci Geogr Sin 18(3):268–272

Li XJ, Li QS, Wang ZC, Liu XT (2002) A research on characteristics and rational exploitation of soda saline land in the Western Songnen Plain (in Chinese with English abstract). Res Agric Mod 23(5):361–364

Li QS, Li XJ, Wang Z, Song CC, Zhang GX (2003) Sodium bicarbonate soil management and utilization in Songnen Plain (in Chinese with English abstract). Resour Sci 25(1):15–20

Li JP, Zhao JH, Zhang B (2006) Research on spatial-temporal dynamics and landscape pattern change of grassland in Songnen Plain (in Chinese with English abstract). Chin J Grassl 28(2):6–12

Li X, Wang Z, Song K, Zhang B, Liu D, Guo Z (2007) Assessment for salinized wasteland expansion and land use change using GIS and remote sensing in the west part of Northeast China. Environ Monit Assess 131:421–437

Lin NF, Tang J (2005) Study on the environment evolution and the analysis of causes to land salinization and desertification in Songnen plain (in Chinese with English abstract). Quater Sci 25(4):474–483

Lin NF, Bounlom V, Tang J, Bian JM (2005) Study on the relation between the formation of saline-alkali soil and the neotectonic movement (in Chinese with English abstract). Global Geol 24(3):282–288, 311

Liu CM, Xia J, Yu JJ (2007) Strategic study on the issues of resources distribution, protection of eco-environment and sustainable development in the Northeast China. Science Press, Beijing, pp 96–101, 168–187

Luo XZ, Zhu T, Sun GY (2002) Influence of human activities on ecological environment of the Songnen Plain (in Chinese with English abstract). Chin Popul Resour Environ 12(4):94–99

Metternicht G (2001) Assessing temporal and spatial changes of salinity using fuzzy logic, remote sensing and GIS Foundations of an expert system. Ecol Model 144:163–179

Qiu SW, Zhang B, Wang ZC (2005) Analyses on current situation, causes of formation, and way of management of desertification in western Northeast Plain of China (in Chinese with English abstract). Quat Sci 25(1):63–73

Qu GH, Guo JS (2003) The relationship between different plant communities and soil characteristics in Songnen grassland (in Chinese with English abstract). Acta Pratac Sin 12(1):18–22

Richards LA (1954) Diagnosis and improvement of saline and alkali soils. United States Salinity Laboratory Staff, US Department of Agriculture, Washington, USA. Agriculture Handbook No. 60, pp 1–6

Sheng LX, Ma XF, Wang ZP (2002) Study on the recovery and control of the alkili-saline lands in the Songnen Plain (in Chinese with English abstract). J Northeast Normal Univ 34(1):30–35

Song XS, He Y, Deng W, Yan BX, Zhang GX (2000) Study on saline-alkali soil moisture diffusivity in the Songnen Plain (in Chinese with English abstract). Soil Environ Sci 9(3):210–213

Szabolcs I (1992) Salinization of soil and water and its relation to desertification. Desertif Bull 21:27–32

Wang ZC (1999) Sustainable development of rice in the Songnen Plain (in Chinese). Territ Nat Resour Stud 2:51–52

Wang XF (2000) Analysis on population growth of the Northeast China before 1949 (in Chinese with English abstract). Northeast Asia Forum (4): 86–88

Wang HJ (2006) The change of cropland and ecological effect on the Northeast China since 1949. Master thesis, Northeast Normal University, Changchun, pp 25–26

Wang RZ, Earle AR (1997) Effects of grazing on a *Leymus chinensis* grassland on the Songnen plain of north-eastern China. J Arid Environ 36:307–318

Wang RZ, Li JD (1993) Effect of grazing on distribution of plant populations of Aneurolepidium chinense grassland on Songnen plain (in Chinese). Pratacult Sci 10(3):27–34

Wang RZ, Li JD (1995a) Dynamic population models of the ecological dominance during the deterioration of *Leymus chinensis* grassland (in Chinese with English abstract). Acta Phytoecol Sin 19:170–174

Wang RZ, Li JD (1995b) Grazing succession pattern of alkalized Aneurolepidium chinense grassland in Songnen plain (in Chinese with English abstract). Chin J Appl Ecol 6:277–281

Wang ZY, Liu ZX (2004) Effect of soil conditioner MDM on meadow alkali soils and growth of rice (in Chinese with English abstract). Agric Res Arid Areas 22(2):31–34

Wang FS, Tian ZC (2002) The groundwater effect in the process of soil salinization of the Songnen plain, Jilin province (in Chinese with English abstract). Jilin Geol 21(1–2):79–87

Wang CY, Wu ZJ (2004) Salt-affected soil in Northeast China (in Chinese). Science Press, Beijing

Wang YH, Zhou GS (2001) Analysis on ecophysiological characteristics of leaf photosynthesis of *Aneurolepidium chinense* in Songnen grassland (in Chinese with English abstract). Chin J Appl Ecol 12(1):75–79

Wang J, Xiao YH, Zhu P, Suo Y, Shi YL (1995) Development and effect factors of salt-affected lands in the Songnen Plain (in Chinese). Agric Sci Jilin 2:66–71

Wang P, Li JD, Ou YL (1997) Studies on the adaptability and tolerance of *Puccinellia tenuiflora* to salinity in the salinized grassland in the Songnen Plain (in Chinese with English abstract). Acta Agrestia Sin 5(2):80–84

Wang RZ, Gao Q, Chen Q (2003) Effects of climatic change on biomass and biomass allocation in *Leymus chinensis* (Poaceae) along the North-east China Transect (NECT). J Arid Environ 54:653–665

Wang CY, Wu ZJ, Shi YL, Wang RY (2004a) The resource of saline soil in the Northeast China (in Chinese with English abstract). Chin J Soil Sci 25(5):643–647

Wang HX, Wan ZJ, Yu SP, Luo XZ, Sun GY (2004b) The restoration of wetlands in the Songnen Plain about 150 years ago (in Chinese with English abstract). J Northeast Normal Univ 36(2):75–81

Wang ZC, Li QS, Li XJ, Song CC, Zhang GX (2004c) Saline-alkali land management and countermeasures of sustainable agricultural development in Songnen Plain (in Chinese with English abstract). Chin J Eco-Agric 12(2):161–163

Wang ZM, Zhang B, Huang SJ, Li JP, Song KS, Duan HT (2005) Evolution analysis of land use structure of Songnen plain based on GIS and information entropy-In terms with disorder degree, complexity and diversity (in Chinese with English abstract). Syst Sci Compr Stud Agric 21(3):196–200

Wang L, Miyazaki T, Ishihama Y, Seki K (2007) The variation of soil physical properties on alkali grasslands in Anda City of Heilongjiang Province (in Chinese with English abstract). Pratacult Sci 24(10):19–25

Whitman WC (1971) Influence of grazing on the microclimate of mixed-grass prairie. In: Kreitlow KM, Hart RH (eds) Plant morphogenesis as the basis for scientific management of range resources. Agricultural Research Service, Miscellaneous Publication No. 1271. USDA, Washington, pp 207–218

Willms WD, Smoliak S, Bailey AW (1986) Herbage production following litter removal on Alberta native grasslands. J Range Manag 39:536–540

Wu L, Li QS (2003) Research of mechanism of saline desertification in Western Songnen Plain (in Chinese with English abstract). J Soil Water Conserv 17(4):79–81, 93

Xiao XM, Wang YF, Jiang S, Ojima DS, Bonham CD (1995) Interannual variation in the climate and above-ground biomass of *Leymus chinensis* steppe and Stipa grandis steppe in the Xilin river basin, Inner Mongolia, China. J Arid Environ 31:283–299

Xu J, Haginoya S, Saito K, Motoya K (2005) Surface heat balance and pan evaporation trends in Eastern Asia in the period 1971–2000. Hydrol Process 19:2161–2186

Yao RJ, Yang JS, Liu GM (2006) Characteristics and agro-biological management of saline-alkalized land in the Northeast China (in Chinese with English abstract). Soils 38(3):256–262

Yin HN, Tang Z, Lu F (2003) Analysis of eco-environment degradation mechanism in the west of Northeast Plain in China during the last 100 years (in Chinese with English abstract). Res Soil Water Conserv 10(4):190–192

Zhang WZ (1993) Secondary salinization of grassland soil: the formation of secondary saline-alkali soil patches in grassland of Songnen plain (in Chinese with English abstract). Acta Pedol Sin 30:182–190

Zhang WZ (1994) The relationship between vegetation degeneration and soil salinization in an *Aneurolepidium Chinense* grassland of the Sonenen Plain (in Chinese with English abstract). Acta Phytoecol Sin 18(1):50–55

Zhang WZ, Gao Q (1994) Exploration of the movements of water and dissolved salts in soils under different plant community in *Aneurolepidium chinense* grassland of Songnen plain (in Chinese with English abstract). Acta Phytoecol Sin 18(2):132–139

Zhang DF, Lin NF (1999) Cause and countermeasure of land degradation in Jilin west plain (in Chinese with English abstract). J Changchun Univ Sci Technol 29(4):355–358

Zhang DF, Wang SJ (2001) Mechanism of freeze-thaw action in the process of soil salinization in northeast China. Environ Geol 41(1–2):96–100

Zhang DF, Wang SJ (2002) Study on the eco-geo-environment of land salinization in West Jilin Province (in Chinese). Chin J Soil Sci 33(2):90–93

Zhang GX, Deng W, He Y, Salama R (2006) Hydrochemical characteristics and evolution laws of groundwater (in Chinese with English abstract). Adv Water Sci 17(1):20–28

Zhao YL, Ye ZS, Cui GW (2004) Sustainable use and development of grassland in the Songnen Plain (in Chinese). Heilongjiang Ani Sci Vet Med 8:56–57