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Desalinization Characteristics after Reclamation of Tidal Flat on the Western Coast of Korea

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西海岸 干拓地 土壤의 脫鹽 特性

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ABSTRACT

Vertical and temporal characteristics of desalinized reclaimed soil were analyzed from reclaimed coastal land on the western coast of Korea. Of the vertical changes during desalting, pH values were the lowest at the topsoil without regard to reclaimation time. The content of Cl were designated as the early period (the first 2~4 years) which decreased exponentially; and the later period (the last 5~7 years) which was almost constant, from top to down. In temporal changes of the soil attributes, pH values increased for 5 years and decreased at 6 year after reclamation. Chlorine leaches more rapidly than Na does, K and Ca are constant but Mg increases as time elapsed after reclamation. Sometimes the content of Ca and K in the reclaimed soil are of higher concentration than that of the seawater after reclamation. During desalinization as exemplified by decreasing EC of the soil, Cl and Na are rapidly leached, but K, Ca and Mg are somewhat enhanced. The ratio of Na/Cl in the soil equals 1 when the EC registers 5 mmho and then increases dramatically as the EC decreases. Rapid leaching of Cl^- elicits an increasing pH value. The electrostatic balance of the soil is achived by replacement of Cl^- with OH^- until stationary or until a decreasing pH value is reached again.

Key words: Desalinization, Reclaimed land, Changes of ion content

INTRODUCTION

The electrical conductivity as a measure of desalination of the soil after reclamation of tidal marsh secondary to rain intensity and leaching velocity as time elapses differed with each ion as shown in the previous paper (Min and Kim 1997). Such characteristics of desalinization concurs with the salt mobility theory proposed by Polynov (1937), wherein elements of stone were compared with sea water, and with leaching order of ions from soils by Cho *et al.* (1980). The differences of ion leaching velocity of the tidal soil changes the various attributes including pH value.

Plant species invading into the reclaimed land differ from each other as the degree of soil desalinization differance because of the species salt tolerance. Plant distribution in a saline environment is seriously restricted by both the salt concentration and humidity of the soil (Penfound 1952, Mall 1969, Ungar 1974). The most important salt in the coastal tidal soil is NaCl out of the various chemical elements of seawater (Ungar 1974). Because gradual leaching of NaCl from the tidal soil changes its attributes, early development of vegetation in the reclaimed land is profoundly influenced by the subtle leaching processes of salt from the soil.

Coastal tidal marsh, one of the most important ecosystems in the Korean peninsula, is being reclaimed as farmland. Although basic soil surveys and their methodology have been studied from the point of view in agriculture (Agricultural Development Corporation, ADC, 1986), ecological studies of the leaching characteristics of the soil under natural conditions are scant.

The reclaimed land at the tidal flat, that is gradually built up by dikes and then invaded by glycophytes for some period of time, is termed the sediment or the parent material (ADC 1986). In the terminology of this study, however, the reclaimed land will be termed as the soil to avoid confusion because the degree of desalinization is diverse and the border between the sediment and soil is obscure.

The purpose of this study is to make clear the succession of vegetation invading into the reclaimed soils and to verify the change of ion content in the soils during the period of desalinization.

MATERIALS AND METHODS

Soil materials were divided into two: one was the surface soils of 2-, 8-, 12- and 30-years reclaimed lands, sampled 2~10 cm deep, from Hyundai B, Jangdeog, Mado and Baegseog Areas on July 15~20, 1984, respectively; the other was the vertical soils from 0 to 100 cm deep from Hyundai B at every year for 6 years (Min and Kim 1997).

For chemical analyses the soil samples were air-dried under shade. pH and electrical conductivity of the soil were measured by both a glass electrode pH meter (Fisher 230A) and a conductivity meter (Takemura DM 35). The cations were measured with an extractant of 2 N ammonium acetate by flame photometer (Coleman 51) for K and Na, and atomic absorption spectrophotometer (IL Model 901) for Ca and Mg, respectively. To determine Cl of soil, the extract with H_2O was titrated with 0.1 N $AgNO_3$ solution. Methods of soil chemical analyses followed APHA-AWWA-WPCF (1981), Jackson (1969) and Allen (1974).

RESULTS AND DISCUSSION

Vertical and temporal changes of soil properties

Fig. 2 shows vertical changes of soil chemical properties from the topsoil to 100 cm deep for 6 years in the reclaimed land of Hyundai B. The changes of pH value with a range between pH 7.0 and 8.5 show the lowest at the topsoil and the highest in the 20~40 cm deep. The reason that the pH value of the

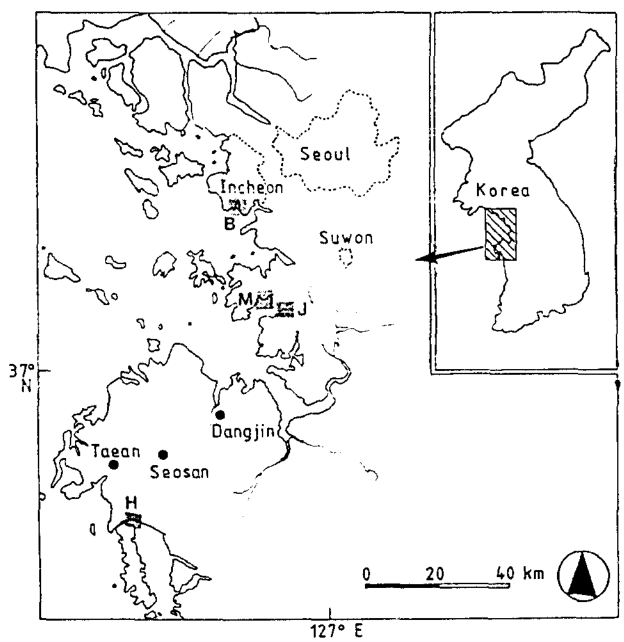

Fig. 1. Map showing the study area. B: Baegseog, M: Mado, J: Jangdeog, H: Hyundai B.

top is lower than that of bottom is due to the accumulation of NaCl on the topsoil owing to evaporation (Campbell and Richard 1950, Bolen 1964).

The Cl contents in the soil are differed largely in quantity with a range of 0.1~10.0 mg Cl/g of soil. The vertical changes of Cl content were remarkably divided into the early period of 1984~1986 and the later period of 1987~1989: the former had a large average amount as well as a high content at the topsoil and decreased exponentially with the depth of the soil profile, the latter had a small average amount and increased little in a straight line from top to bottom.

The Na content range was 2~5 mg Na/g of soil with the exception of the topsoil of the early period (1984~1986, 4.3~7.5 mg Na/g of soil). Na content at 40 cm depth was stable regardless to the reclamation time and that in deeper soil increased a little.

The K content range was 0.5~1.5 mg K/g of soil, its content fluctuating regardless to reclamation time or to soil depth. Mg content had broad ranges of 0.7~3.7 mg Mg/g of soil and distinguished the two groups: the later period, with exception of 1987, had larger Mg content from top to bottom than the early period (Fig. 2).

The Ca content of the soil ranged from 0.2~1.0 mg Ca/g of soil and did not show a regular tendency in the reclaimed time and vertical distribution.

Temporal and vertical changes of the soil properties for several years after the reclamation show that the pH values, content of Cl and Na are distinguishable from the early and later periods but the contents of K, Mg and Ca are irregular. From these results it is concluded that leaching of various ions are not carried out with a given ratio because of different leaching velocities, but due to interactions with each other (Donahue *et al.* 1983).

Fig. 3 shows the temporal changes of the soil properties at 50~100 cm depth, a zone which is relatively stable. The pH values of the soil lower in 1984 with a pH 7.1, thereafter increasing to the maximum in 1988 with a pH 8.4 but decrease in 1989 with pH 8.0. The content of Cl continuously decrease after the reclamation: the former is more conspicuous than the latter. The content of Mg is stable with a small quantity for the first 4 years but increases as much as 490% for the last 2 years. The content of K and Ca are constant regardless to the reclamation ages.

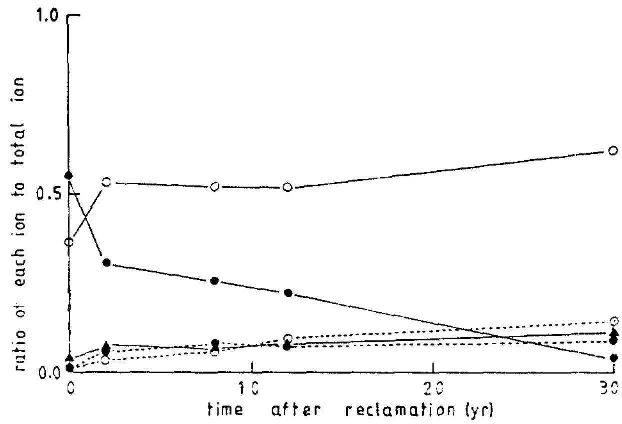

Fig. 2. Vertical changes of soil properties for six years in Hyundai B Area.
●—● ; 1984 ○……○ ; 1985 ■—■ ; 1986
□……□ ; 1987 ▲—▲ ; 1988 ×—× ; 1989

These results explain that the Cl ion leaches supremely fast and that the Na ion is followed by it. On the contrary, the Mg ion increases during leaching of above 2 ions, for reasons which are not confirmed. Possible the Mg ion accumulates unevenly during sedimentation or it concentrates from a lower layer by a capillary phenomenon. It is most likely to be attributed to a capillary phenomenon according to the results of a previous paper (Min and Kim 1997).

The content of K and Ca in the soil may remain through the alterating concentartion increases and dilution decreases during the early period, unlike the large fluctuations of the Mg. The increase of pH value in the soil during the early period of reclamation might be due to Cl as an anion decreasing rapidly in quantity compared to Na as a cation yet remains in a relatively large quantity in spite of its leaching, compared with Cl content and to the huge Mg increase. The pH value in the soil of the later period decreases again owing to Na as decreasing

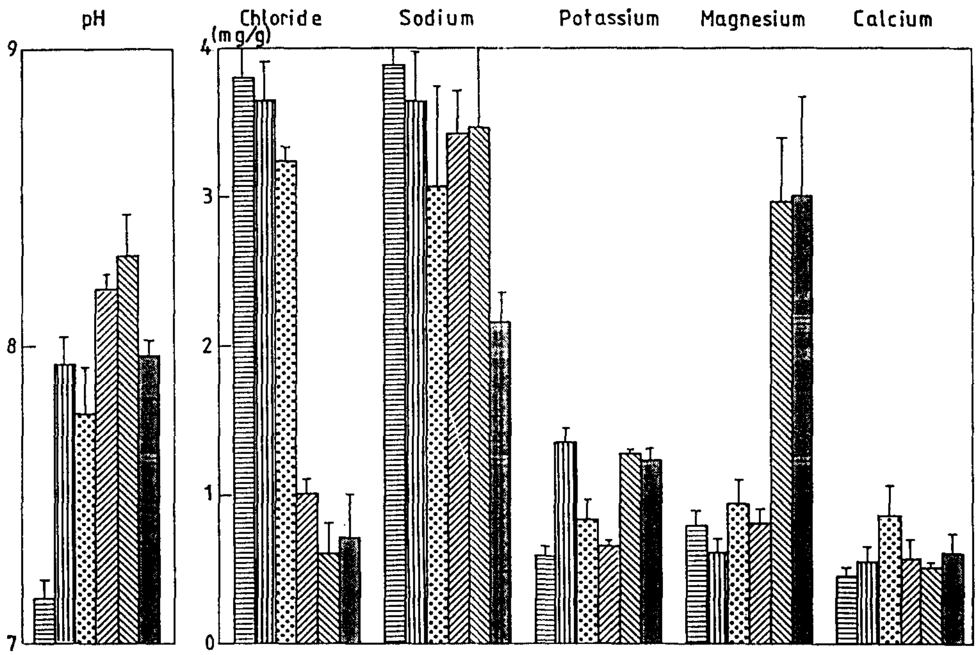

Fig. 3. Changes of soil properties at 50~100 cm depths for six years.
▤ ; 1984, ▥ ; 1985, ░ ; 1986, ▨ ; 1987, ▧ ; 1988, ▒ ; 1989

cation rapidly.

Temporal changes of soil attributes

Table 1 shows correlation coefficients among soil attributes in the reclaimed lands of Baegseog (30-years), Mado (12-years), Jangdeog (8-years) and Hyundai B (2-years). Electrical conductivity (EC) of the soil, measure of total ion charge, have positive correlations to the content of Cl, Na, K and Mg. An especially high correlation is shown by the EC between Cl or Na with r=0.93 and over 1% of a significant level. The order of the absolute content of ions in the soils are $Na^+ > Cl^- > K^+ = Mg^{2+} > Ca^{2+}$. The EC has completely negative correlation to the pH values with 5 to 1% of a significant level with the exception of the reclaimed land of Baegseog. These results of correlation coefficients coincide with the vertical distribution of the soil attributes shown in Fig. 2.

A positive correlation shows between Cl and Na, K or Mg, between Na and K or Mg, and between K and Mg, with 1% significant levels. Negative correlation, however, shows the pH value among all ion contents in the 4 reclaimed lands with the exception of 4-year Jangdeog and 2-year Hyundai B. These results explain that the changes of pH are due to ion content in the soil of old reclaimed lands.

The changes of ion content of the soil as the EC decreases in the 4 reclaimed lands are shown in Fig. 4. The content of Cl, Na, K and Mg decrease proportionally with the decreasing of EC. The decreasing rates are the highest in Cl, high in Na and the lowest in K and Mg. On the contrary, the content of Ca increases more or less as the EC decreases (Fig. 4). These results agree with the vertical changes of the soil attributes as time elapsed after the reclamation shown in Fig. 2.

The EC of the coastal reclaimed soil is affected greatly by the content of NaCl (Bolen 1964). If NaCl dissociate into two ions, the decreasing EC in the soils is at first affected by Cl leaching and secondarily by Na. Under such conditions it gives rise to an unbalance of cations and anions and a change of

Table 1. Correlation coefficients among soil properties
B; Baegseog (df=49), M; Mado (df=43), J; Jangdeog (df=41), D; Hyundai B (df=39)

		E. C.	pH	Cl	Na	K	Mg
pH	B	−0.155					
	M	−0.859**					
	J	−0.624**					
	H	−0.310*					
Cl	B	0.973**	−0.109				
	M	0.966**	−0.824**				
	J	0.993**	−0.600**				
	H	0.984**	−0.235				
Na	B	0.952**	−0.087	0.963**			
	M	0.958**	−0.730**	0.962**			
	J	0.955**	−0.469**	0.960**			
	H	0.936**	−0.151	0.931**			
K	B	0.708**	−0.109	0.737**	0.802**		
	M	0.252*	−0.108	0.235	0.400**		
	J	0.463**	−0.065	0.464**	0.650**		
	H	0.711**	0.131	0.738**	0.862**		
Mg	B	0.806**	−0.182	0.855**	0.876**	0.816**	
	M	0.413**	−0.230	0.419**	0.521**	0.802**	
	J	0.318*	0.069	0.330*	0.434**	0.651**	
	H	0.773**	−0.049	0.764**	0.824**	0.849**	
CA	B	0.226	−0.268*	0.267*	0.284*	0.404**	0.481**
	M	−0.201	−0.001	−0.262*	−0.158	0.659**	0.632**
	J	−0.301*	0.408**	−0.278*	−0.299*	−0.100	0.198
	H	0.128	0.133	−0.046	0.086	0.308*	0.470**

* : significant at a 5% level
** : significant at a 1% level

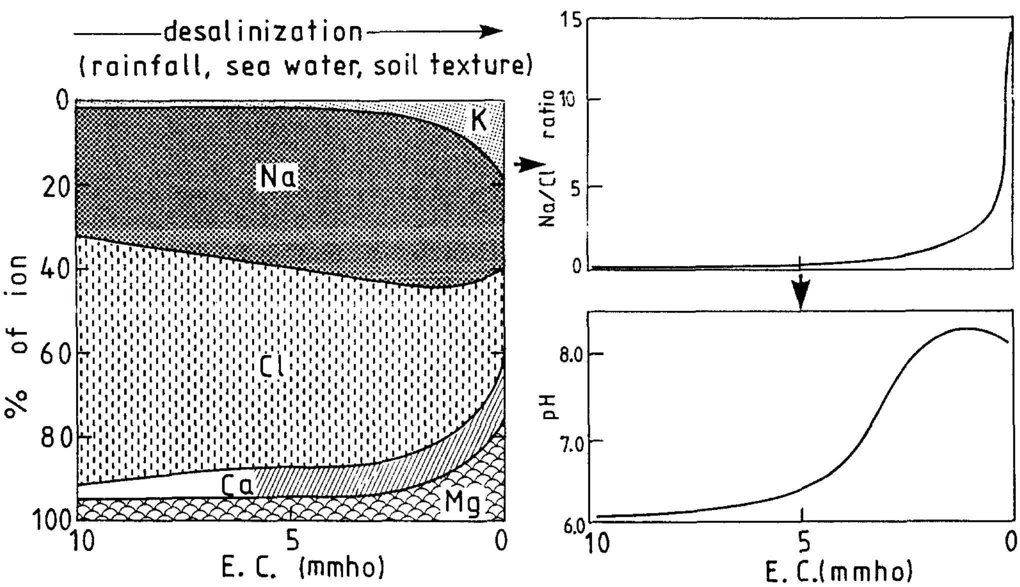

Fig. 4. The changes of Cl, Na, K, Mg and Ca content in the soil as a function of decreasing electrical conductivity (EC) at the reclaimed lands of Hyundai B, Baegseog, Jangdeog and Mado.

pH value (Donahue *et al.* 1983). K, Mg and Ca that are contained in relatively large amounts in seawater may not affect the decreasing EC because these are much lesser amounts than Cl and/or Na.

The ratios of average ion content in the reclaimed soil to those in the seawater are shown in Fig. 5. Ratios of Cl, Na and Mg decrease suddenly until 2 years after reclamation and thereafter decrease gradually. While the ratios of K and Ca in the soil increase much more until 8 and 12 years after reclamation than those in seawater, respectively. These results might explain that the ion composition of the reclaimed soil appear to be serve changes within the first 2 years, particularly by Cl leaching rapidly for the first 2 years.

Fig. 6 shows the changes of ratio of content of each ion to total ions in the soil after reclamation. The ratio of Cl, highest in seawater, decreases suddenly in the reclaimed soil for the early period, and thereafter decreases gradually. The ratio of Na in the soil increases correlatively to the time elapse. The ratios of K, Mg and Ca, of little content in seawater, was infinitesing increase for the early period.

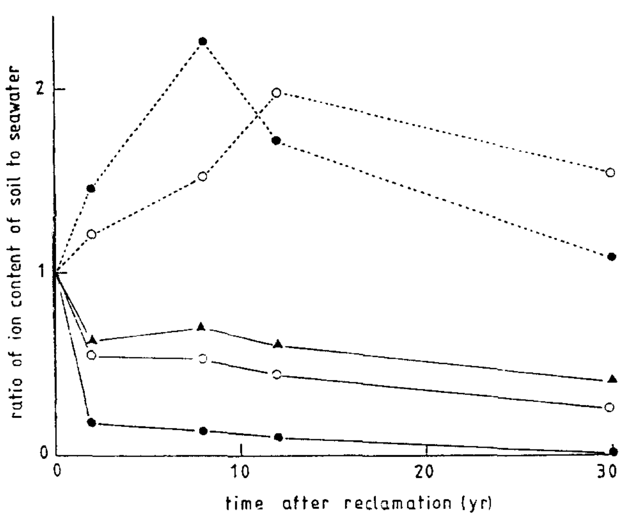

Fig. 5. Ratios of average ion content in the 4 reclaimed soils to those in the seawater.
●–●: Cl, ○–○: Na, ●···●: K, ○···○: Ca, ▲–▲: Mg.

As for growth of plants in saline soil, Chapman (1942) and Iversen (1936) proposed the classification of halophytes as plants growing in more than 0.5% (5 mg NaCl/g soil) salt and glycophytes as growing in less than 0.5% salt. The reason why salt is the basis of classification is not because the major ions are Na^+ and Cl^- in the coastal reclaimed soils but because these ions profoundly affect plant growth (Waisel 1972). Especially, halophytes store NaCl in their vacuoles and become a succulent form of plant because Cl affects growth adversely. From these experimental results it is known that Cl is rapidly leached but Ca is enhanced more than other ions. If no seawater inundates the reclaimed lands it is possible for glycophytes to proceed into the reclaimed land within 2 years after reclamation because the soil contains less than 0.5% salt. Black alkali or sodic soils, with an exchangeable Na percentage exceeding a value of 15, which occur in arid and semi-arid deserts, have been reclaimed with the application of $CaCl_2$ (Alperovitch and Shainberg 1973, Magdoff and Bresler 1973). The soils studied here are white alkali soils from the coast that enrichment by $CaCl_2$ would be useless. Certain plants grown in a haline soil maintain a salt equilibrium mechanism where the plants absorb and release the Cl ion but only absorb Na through their roots (Ganmore-Neumann 1970). For example, *Phragmites communis* accumulates 1.5 mg Na/g DM in leaves and 8.0 mg Na/g DM in roots (Min 1990). Na decreases the water permeability of soil by decreasing soil pore size but Ca weakens the deleterious effect of Na, and the uptake of water is promoted by the plants (Berstein 1970, Poljakoff-Mayber 1975).

Hypothetical figures on changes of ion content, Na/Cl ratio and pH value during desalinization or EC decrease is shown in Fig. 7. The contents of Cl and Na decrease but K, Ca and Mg, the Na/Cl ratio and pH value increase as desalinization proceeds. At 5 mmho of EC the Na/Cl ratio approaches 1: the ratio decreases below 1 as the EC increases and the ratio increases exponentially as the EC decreases, for

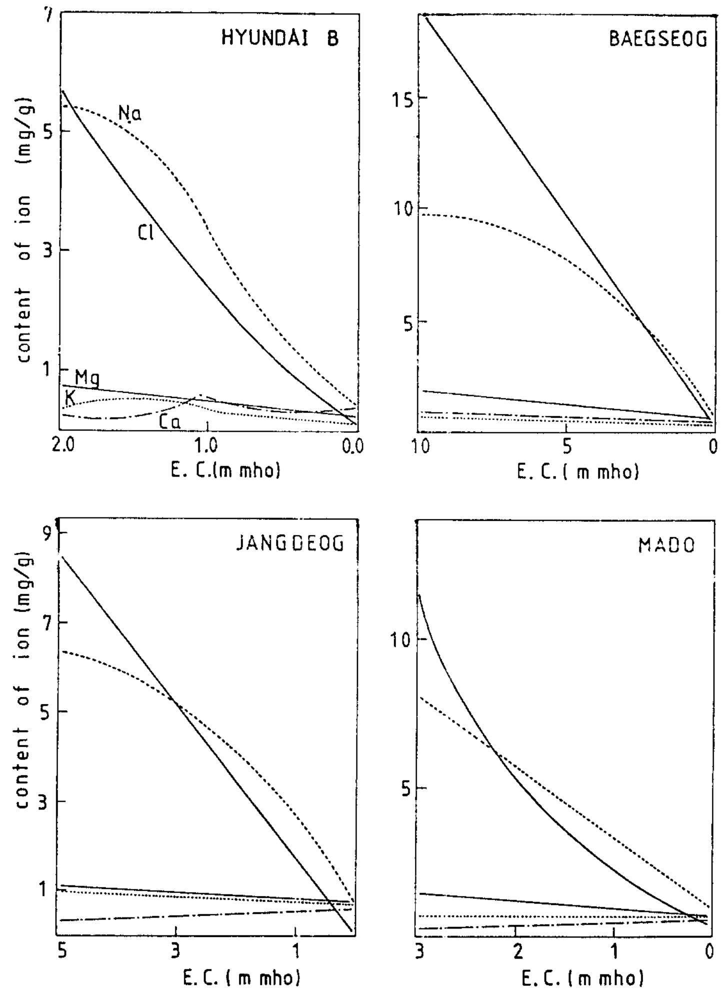

Fig. 6. The changes of ratio of content of ions to total ions in the soil after reclamation.
●−●; Cl, ○−○; Na, ●···●; K, ○···○; Ca, ▲−▲; Mg.

example, 0.2 mmho of EC equals 12 of the Na/Cl ratio (Fig. 7 right above). Such a relationship could be utilized to evaluate the desalinization of reclaimed land. The pH value of saline soil increases with a sigmoid as EC decreases (Fig. 7 right below). Rapid leaching of Cl^- from the reclaimed soil might be brought about by a lack of anions, replacing Cl^- by OH^- and rasing the pH value. When a considerable amount of Na^+ is leached, the pH value is stationary or decreases because the relative ion content of the soil is enhanced compared with ions other than Cl^- and Na^+.

摘 要

한국 서해안의 간척토양의 탈염 특성을 토양의 수직 단면과 간척시간의 경과에 따라 분석하였다. 토양의 pH는 표층이 가장 낮고 20 cm 깊이까지 증가하였으며, 그 이하에서는 하층으로 갈수록 낮아졌다. 토양의 Na, Cl 및 Mg 함량은 개간후 4년까지는 상층이 가장 많고 30 cm 깊이까지 급격히 감소하며 그보다 밑에서 다소 증가하였으며, K와 Ca은 깊이에 따른 경향성이 없었다.

50∼100 cm 깊이 토양의 pH는 간척초기에 7.1이었고 5년 후에 8.4로 상승하고 그 이후에 다시 하강하였으며, 간척후 시간경과에 따라 Cl는 크게 감소하였고, Na는 5년 경과후 감소하였으며, Mg는 후기에 오히려 크게 증

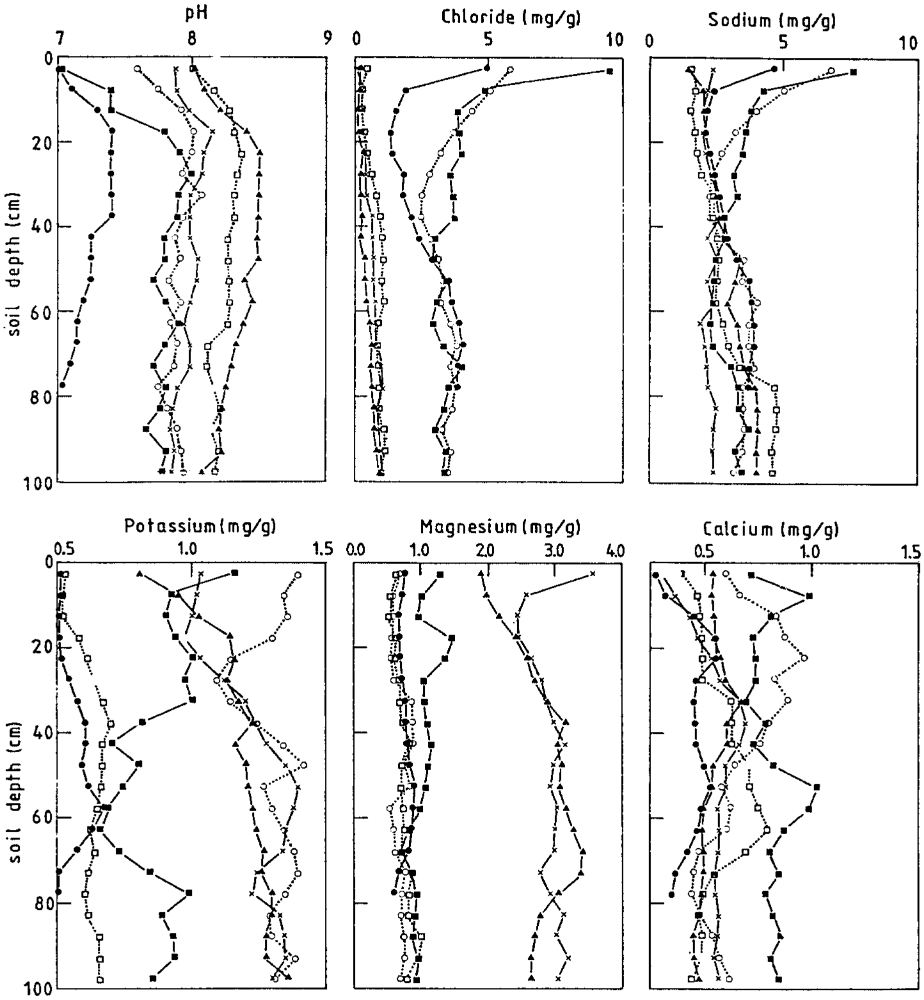

Fig. 7. Schematic diagrams showing the distribution ratio of easily leached ions (left), consequent change of Na/Cl ratio (right above) and pH value (right below) as electrical conductivity (E.C.) decreases.

가하였지만 K와 Ca는 변동하지 않았다.

간척후 2 내지 30년 경과한 4 지역의 표층토의 토양 속성 사이의 상관관계는 EC와 pH사이에 음의 상관을, EC와 Cl, Na, K 또는 Mg사이에 양의 높은 상관을 보였고, pH와 모든 이온사이에 음의 낮은 상관을 보였다. 조사된 이온 중 Ca을 제외하면 각 이온사이에 양의 높은 상관을 보였다.

토양의 Na/Cl 비는 EC값이 5 mmho일 때 1이고, EC가 감소함에 따라 크게 증가하였다. 간척 초기의 Cl^-의 빠른 세탈은 pH값을 상승시키고, Cl^-가 OH^-로 대치하는 정전기적 평형은 pH값의 하강 또는 정체를 가져온다고 해석된다.

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