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MONITORING OF SHALLOW GROUNDWATER SALINITY IN LIVESTOCK MANURE APPLICATIONS TO RECLAIMED TIDAL LAND†

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ABSTRACT

Reclaimed tidal lands have been developed to provide quality cropland in Korea, mainly for rice cultivation. However, due to rice overproduction, diverse developments of reclaimed land are required for economic and industrial utility. One of the recent plans for developing these areas is to establish a poplar forest in the reclaimed tidal land for green space creation. To establish such a forest, typical problems such as soil salinity, unfavourable soil chemical composition, and a high groundwater table with poor drainage must be addressed. To investigate the effectiveness of low concentration liquid manure (LCLM) application in desalinization, we monitored shallow groundwater salinity in a reclaimed tidal poplar forest including electrical conductivity (EC), pH, cations, anions, T-N and T-P. The EC, Na^+ and K^+ are of lowest average concentration in the LCLM plots, but highest in the control (undrained) plot during and after LCLM application. And those in the control (drained, undrained) plots showed greater salt leaching and accumulation than the LCLM plots. LCLM application plots had lower salinity than control plots, indicating that LCLM application may be an effective desalinization measure. However, because of the high groundwater levels in reclaimed land, applying LCLM may cause shallow or soil water quality problems. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: shallow groundwater; salinity; tidal reclaimed land; low concentration liquid manure; poplar forest

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RÉSUMÉ

L'aménagement des zones d'estran a été développé pour fournir des terres arables de qualité en Corée, principalement pour la culture du riz. Toutefois, en raison de la surproduction de riz, d'autres valorisations des terres récupérées sont nécessaires pour l'utilité économique et industrielle. L'un des derniers plans de développement de ces zones est d'établir une forêt de peupliers dans les terres récupérées pour la création d'espaces verts. Pour établir une telle forêt, les problèmes typiques tels que la salinité du sol, la composition chimique du sol défavorable, la nappe phréatique élevée et un drainage pauvre doivent être pris en compte. Pour étudier l'efficacité du lisier à faible concentration (LCLM) sur le dessalement, nous avons suivi la salinité de la nappe peu profonde dans la forêt de peupliers (conductivité électrique (CE), pH, cations, anions, TN et TP). La CE, et les concentrations moyennes en Na^+ et K^+ sont les plus basses dans la parcelle LCLM, tandis qu'elles sont les plus élevées dans la parcelle de contrôle (non drainée) pendant et après l'application LCLM. Les contrôles drainés et non drainés ont montré plus de lessivage du sel et d'accumulation que les parcelles LCLM. Les parcelles avec épandage de LCLM ont une salinité plus faible que les parcelles témoins, indiquant que l'application LCLM peut être une mesure efficace de dessalement. Cependant, en raison du niveau élevé de la nappe dans les zones aménagées, appliquer LCLM peut causer des problèmes de qualité des sols ou de l'eau. Copyright © 2013 John Wiley & Sons, Ltd.

MOTS CLÉS: eaux souterraines peu profondes; salinité; terres d'estran asséchées; lisier à faible concentration; forêt de peupliers

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†Suivi de salinité des nappes peu profondes dans le cas d'épandage de déjections de bétail sur une zone d'estran aménagée.

INTRODUCTION

To address low food self-sufficiency and rapid economic development with population growth, the demand for arable land in Korea has increased during the last several decades because the percentage of available land is limited and mountain forest covers 64% of the national land of Korea. Thus, tidal land reclamation projects have progressed over the past few decades along the southern and western shorelines of Korea. Korea has about 155 600 ha of total reclaimed land as a result of mega reclamation projects. Reclaimed tidal lands developed in Korea provided quality cropland, mainly for rice cultivation, until 2000 (Choung *et al*., 2002; Jo *et al*., 2010).

However, tidal land reclaimed through enormous cost and effort has often not been used and land use plans have not been implemented, leaving the reclaimed land as wasteland. The primary constraints for crop cultivation in reclaimed land are soil salinity, a high water table, poor drainage, low fertility, and unfavorable soil chemical composition (Selim, 2004; Jung and Yoo, 2007; Yang *et al*., 2008). In addition, due to rice overproduction, diverse development strategies for reclaimed land are required for economic and industrial reasons (Lee *et al*., 2003; Sohn *et al*., 2010).

Reclaimed tidal land could be changed from paddy usage to upland, fruit trees and biomass trees (Sohn *et al*., 2010). Poplar is a bioenergy crop that can endure and thrive in extreme situations such as those on reclaimed tidal land. The creation of poplar forests for green space has been suggested to develop these areas. Although poplar has a positive effect on reclaimed land desalinization, the development of poplar forest on reclaimed tidal land is hampered by typical problems not only of desalinization but also of nutrient supply. The use of organic fertilizer affects soil property remediation due to changes of soil composition (Son and Cho, 2009; Choi *et al*., 2010). Applying organic manure to reclaimed tidal land would improve physicochemical and biological properties that can ameliorate soil organic matter, soil microorganism activities, cation exchange capacity (CEC), soil moisture-holding capacity and soil salinity (Ashman *et al*., 2003; Ghoname and Shafeek, 2005; Son and Cho, 2009; Jo *et al*., 2010). Low concentration liquid manures (LCLM) may be considered as organic fertilizers for reclaimed tidal land to provide nutrients. LCLM has a low nutrient concentration and is odorless and homogeneous in quality. Furthermore, because it is used only after decomposing for a period of time, crop damage due to high salt or nutrient concentrations can be minimized. Liquid manure may also improve pH, carbon, nitrogen and CEC in reclaimed tidal land (Chiudhary *et al*., 1996; Park *et al*., 2008).

There have been several studies of plant growth and salinity in reclaimed tidal lands in Korea. Lee and Kim (1997) investigated the effects of salinity on the growth and production of rice. Lee *et al*. (2003) investigated the relationship between upland crop growth and soil salinity. Yang *et al*. (2008) analyzed the physicochemical properties of saline soils in 10 different reclaimed tidal land areas in 2000 and 2004. There are also studies of the application of fertilizer or livestock manure to reclaimed tidal lands in Korea. Son *et al*. (2004) analyzed changes of electrical conductivity (EC) by fertilizer treatment. Park *et al*. (2008) studied the effects of slurry composting biofiltration (SCB) liquid fertilizer on the growth of poplars planted on reclaimed land and found that SCB treatment of poplars planted on reclaimed land helped tree growth. Son and Cho (2009) studied the effects of organic material treatment on aggregate formation. Jo *et al*. (2010) studied the productivity of summer forage crops by applying SCB liquid manure. From these studies, it is found that applying proper manure in reclaimed tidal lands can improve plant growth and also plant growth can reduce soil salinity in reclaimed tidal lands.

Studies of the application of livestock manure to reclaimed tidal land have mainly focused on paddy rice and upland crops to determine the effects on crop growth rather than on desalinization and water quality. In this study, to investigate the effectiveness of LCLM application and the effects of drainage systems on reclaimed tidal land regarding desalinization, four different plots (LCLM plot with drainage system, control plot with drainage system, control plot without drainage system and reference plot) were constructed. Shallow groundwater and soil water from poplar fields cropped in the Gimpo reclaimed tidal land of the four different plots were sampled and analyzed.

MATERIALS AND METHODS

Study area

The Gimpo reclaimed land area is located at 37° 35´ 57" N and 126° 34´ 58" E (Figure 1) and is representative of reclaimed lands in Korea. This land, located on the outskirts of the Seoul metropolitan area, was reclaimed during the 1980s and the area of the Gimpo reclaimed tidal land is about 1650 ha. Due to social and economic changes, land use plans for the Gimpo reclaimed tidal land changed from paddy fields to green open spaces while leaving a large amount of bare ground. One of the recent plans for developing these areas is to create a poplar forest for use as green space. Poplar, a strong, rapidly growing tree, is adaptable to a variety of environments and is able to thrive in extreme situations. Moreover, poplar reduces surface evaporation and induces infiltration and absorption of salt in the soil through transpiration. Poplar forest also promotes drainage and desalinization by improving soil physical properties (Park *et al*., 2008).

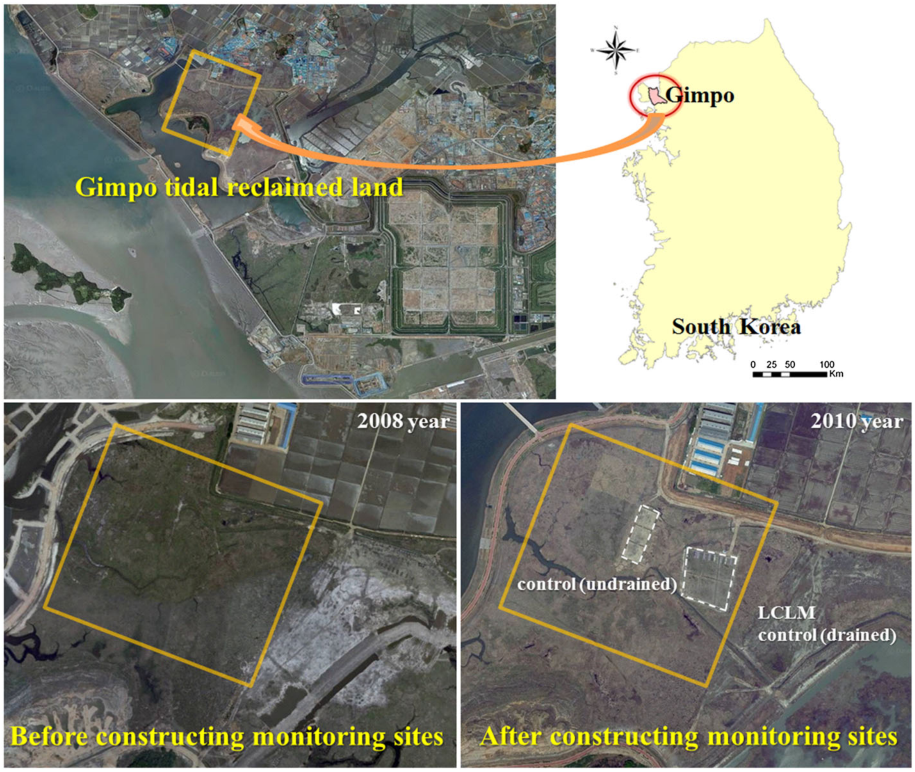


Figure 1. Location map of experimental sites

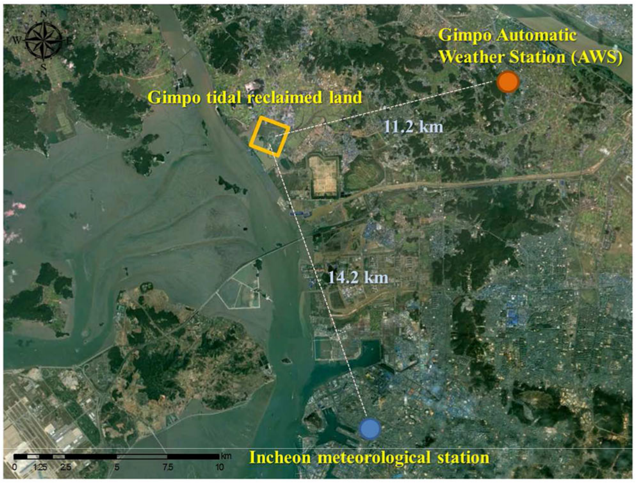
Figure 2(a) is the location map of Gimpo automatic weather station (AWS) and Incheon meteorological station. Gimpo AWS is about 11.2 km and Incheon meteorological station about 14.2 km from study area. Figure 2(b) outlines the 30-year monthly average precipitation and the monthly total precipitation at Gimpo AWS in 2010, the monthly average temperature of Incheon meteorological station near this study area in 2010, and the monthly total precipitation at the Seoul meteorological station for reference in 2010. The total annual precipitation in 2010 was 1954 mm and about 80% occurred during the summer, from June to September. The average annual temperature in 2010 was 12.3 °C, with the highest occurring in August and the lowest in January.

Soil properties and low concentration liquid manure application

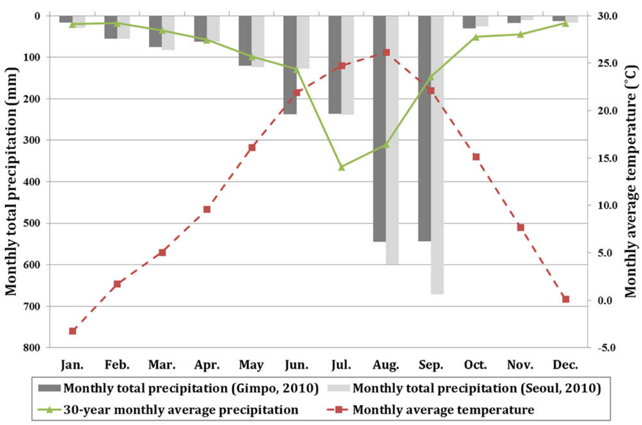
This study area is approximately at 8 m + MSL (mean sea level) and the soil texture according to the United States Department of Agriculture (USDA) soil taxonomy is silt loam or silty clay loam with high silt content. The experimental fields were flat and soils were deep and had hardened formation without rocks. Soil samples were collected before experiments at 0–20, 20–40, 40–60, and 60–80 cm from the surface to analyze soil characteristics (Table I). Before applying LCLM on experimental fields, EC were recorded at 1.48 (20–40 cm)–3.26 (60–80 cm) dS m^{-1} in the LCLM plot, 0.96 (20–40 cm)–2.23 (60–80 cm) dS m^{-1} in the control (drained) fields and 1.71 (0–20 cm)–2.60 (60–80 cm) dS m^{-1} in the control (undrained) fields. Na^+ concentrations were 1.83 (20–40 cm)–3.74 (60–80 cm) $cmol^+$ kg^{-1} in the LCLM plot, 2.25 (20–40 cm)–3.82 (60–80 cm) $cmol^+$ kg^{-1} in the control (drained) fields and 2.39 (0–20 cm)–4.20 (60–80 cm) $cmol^+$ kg^{-1} in the control (undrained) fields.

To compare soil characteristics including chemical properties, reclaimed tidal land soil chemical properties of early studies were consulted as shown in Table II. Though there may be differences in soil chemical properties depending on planting, periods after reclamation, soil texture and other factors, pHs were between 7.3 and 8.6, ECs between 0.8 and 86.5, and Na^+ concentrations between 1.9 and 75.8 in general.

The chemical properties of LCLM used in this study are shown in Table III. The LCLM that was applied had comparably lower fertilizer concentrations than chemical fertilizer. In this study, LCLM was applied as 51 per application from May 11 to August 13 in 2010. Table IV includes dates of LCLM application and total amounts of nutrients (T-N, T-P, NH_4-N, and NO_3-N) per plant stand per month in the study area. Total amounts of LCLM were 1001 per plant stand and 35 t per 0.04 ha LCLM was applied in total



(a) The locations of Gimpo AWS and Incheon meteorological



(b) Monthly total precipitation and average temperature in the study area

Figure 2. Location map of weather station and weather data in the study area

during the experiment. The total amount of T-N was 4650 mg per year per plant stand, 4069 mg yr^{-1} m^{-2} and that of T-P was 7971 mg per year per plant stand and 6974 mg yr^{-1} m^{-2}.

Shallow groundwater monitoring and analysis

To investigate the effectiveness of LCLM application for desalinization, shallow groundwater monitoring wells were installed (Figure 3) and sampled every 2 weeks in the Gimpo reclaimed tidal poplar field, in the LCLM plot with a drainage system, in the control (control (drained)) plot with a drainage system, in the control plot without a drainage system (control (undrained)) and in an upstream groundwater plot (reference). Table V is the depth to shallow groundwater below the surface in four shallow groundwater monitoring plots during the monitoring periods. In the control (drained) plot, the shallow groundwater level was lowest and in the control (undrained) it was highest. In the LCLM plot, average groundwater level was between the levels in control (drained) and control (undrained) and the fluctuation of groundwater was more stable than other plots. Generally, groundwater level in plots without a drainage system were higher than those with a drainage system.

In addition, soil water samplers 1900 L (ENVCO, Auckland, New Zealand) were installed at 40 and 80 cm soil depths and monitored to compare shallow groundwater monitoring results. From these shallow groundwater and soil water samples, salinity including EC, pH, cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), anions (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, NO_3-N) and nutrients including T-N and T-P were analyzed.

Samples were analyzed at the Seoul National University National Instrumentation Center for Environmental Management (NICEM). Analysis items and methods are shown in Table VI.

RESULTS AND DISCUSSIONS

Shallow groundwater salinity

Precipitation, LCLM application date and changes in the ECs of four different fields are presented in Figure 4(a) in time series. Figures 4(b) and (c) are the box plots (maximum,

Table I. Soil characteristics of experimental sites: LCLM plot and control

Soil depth (cm)		Sand (%)	Silt (%)	Clay (%)	Soil texture	EC (dS m^{-1})	Na^+ ($cmol^+$ kg^{-1})
LCLM	0 ~ 20	8.6	69.0	22.4	Silt loam	1.70	1.83
	20 ~ 40	3.0	68.0	29.0	Silty clay loam	1.48	2.92
	40 ~ 60	1.8	72.2	26.0	Silt loam	2.27	3.70
	60 ~ 80	4.0	70.9	25.2	Silt loam	3.26	3.74
Control (drained)	0 ~ 20	1.1	80.8	18.0	Silt loam	1.21	1.62
	20 ~ 40	1.8	81.2	17.0	Silt loam	0.96	2.25
	40 ~ 60	3.8	82.7	13.5	Silt loam	1.41	2.87
	60 ~ 80	1.3	85.9	12.8	Silt loam	2.23	3.82
Control (undrained)	0 ~ 20	2.7	73.3	24.0	silt loam	1.71	2.39
	20 ~ 40	14.6	62.5	22.9	silt loam	1.74	3.70
	40 ~ 60	0.2	78.1	21.7	silt loam	2.09	4.35
	60 ~ 80	3.4	81.0	15.6	silt loam	2.60	4.20

Table II. Soil chemical properties of reclaimed tidal land from several studies in Korea

Site		pH	EC	K+	Na+	Ca2+	Mg2+	References
				Exchangeable cation				
		–	(dS m-1)	(cmol+ kg-1)				
Daeho	Topsoil	7.7	10.2	1.6	15	23.4	29.1	Lee *et al*. (2003)
	Subsoil	7.9	12.9	4.0	1.9	23.0	37.8	
Daeho		7.4	–	0.4	8.9	3.9	10.4	Kim *et al*. (2009)
Gimpo		7.6	–	10.7	–	16	40	Jung *et al*. (2003)
Hwaseong	Willow plantation	–	5.3	0.7	4.5	1.8	3	Yeo *et al*. (2010)
	No vegetation	–	86.5	2.7	50.5	1.4	16.4	
Hwaong		–	–	2.1	3.6	2.4	5.8	Jo *et al*. (2010)
Goheung[a] (Kohenung)[b]		8.3	8.6	62.4	75.8	285.3	22.9	Kim *et al*. (2002)
Namyang		7.9	–	1.1	9.6	1.2	22.4	Kim *et al*. (2008)
Saemangeum		8.6	7.8	8.0	35.8	113.2	13.9	Kim *et al*. (2002)
Saemangeum	Before experiment	8.4	1.9	0.68	3.22	0.7	1.8	Sohn *et al*. (2010)
	After experiment	8.0	0.8	0.62	2.02	0.9	1.8	
Seokmun[a] (Seukmun)[b]		7.3	–	0.4	11.6	3.2	4.9	Kim *et al*. (2008)
Sihwa		7.7	–	0.5	8.1	6.2	1.4	Kim *et al*. (2008)
Seokmun[a] (Sukmoon)[b]	0 ~ 10 cm	8.7	3.8	0.7	2.1	6	2.3	Choi *et al*. (2010)
	11 ~ 20 cm	8.7	3.4	0.6	2.0	5.1	2.3	
	21 ~ 30 cm	8.7	2.8	0.5	2.0	5.2	2.2	
	31 ~ 40 cm	8.7	2.3	0.4	1.8	5.3	2.1	
	41 ~ 50 cm	8.7	2.4	0.4	2.1	6.3	2.5	
	51 ~ 60 cm	8.5	2.5	0.3	2.7	6.5	2.5	

[a]An official name.
[b]( ): Author notation.

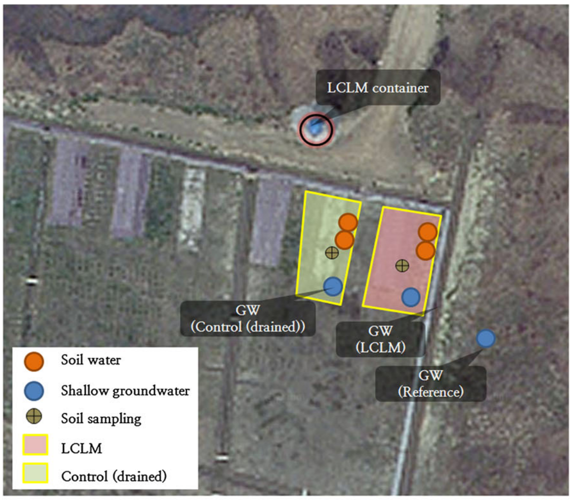
Table III. Chemical properties of LCLM

pH	T-N (mg l-1)	T-P (mg l-1)	NH_4-N (mg l-1)	NO_3-N (mg l-1)	EC (dS m-1)
8.43	46.5	79.7	3.87	21.3	0.015

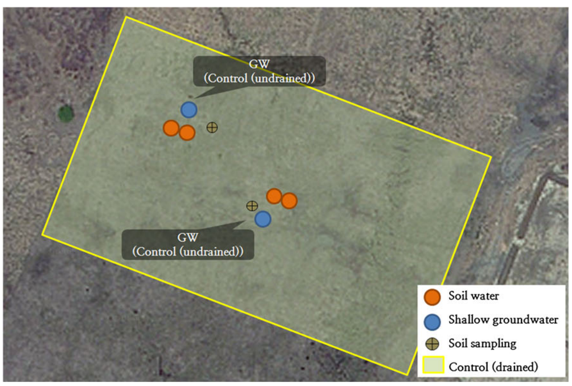
minimum, average, first quartile, and third quartile) of ECs and pH at each monitoring sampling point for four different experimental plots. EC is used as a parameter of salinity and is highly correlated with salinity. ECs of the LCLM, control (drained) and control (undrained) plots were 1.28, 3.77, and 6.27 dS m^{-1}, respectively. During and after application periods, EC was at its lowest average concentration in the LCLM plot, while the highest average concentration was in the control without drainage systems. The EC of the LCLM plot was an average of 3.82 dS m^{-1} and ranged from 2.34 to 5.29 dS m^{-1}. The average ECs of the control (drained) and control (undrained) plots were 10.3 dS m^{-1} (range: 1.8–19.5 dS m^{-1}) and 11.1 dS m^{-1} (range: 6.48–8.32 dS m^{-1}), respectively, indicating greater salt leaching and accumulation than the LCLM plot. Average groundwater pHs of the experimental fields were 7.54 in the LCLM, 7.53 in the

Table IV. LCLM application date and total amount of nutrient per stand and per unit area (m^2)

	Application date	T-N (mg)	T-P (mg)	NH_4-N (mg)	NO_3-N (mg)
		Total amount of nutrient per plant stand			
May	11, 17 (2 days)	465	797	38.7	213
June	10, 21, 22 (3 days)	698	1200	58.1	320
July	15, 19 ~ 22, 26 ~ 29 (9 days)	2090	3590	174	959
August	5, 9 ~ 13 (6 days)	1400	2390	116	640
Total amount of nutrient per plant stand per year		650	7970	387	2130
Total amount of nutrient per m^2 per one application		203	349	16.9	93.3
Total amount of nutrient per m^2 per year		4070	6970	339	1870



(a) Monitoring points with drainage system



(b) Monitoring points without drainage system

Figure 3. Monitoring points of soil water and shallow groundwater

Table V. Depth to shallow groundwater below surface

	LCLM	Control (drained)	Control (undrained)	Reference
Avg.[a]	0.76	0.97	0.54	0.74
Std[b]	0.19	0.44	0.26	0.18
Max.[c]	1.26	2.04	0.46	0.38
Min.[d]	0.30	0.25	0.46	0.38

[a]Avg.: average.
[b]Std: standard deviation.
[c]Max.: maximum.
[d]Min.: minimum.

control (drained), 7.34 in the control (undrained), and 7.60 in the reference plots. Groundwater was moderately alkaline and satisfied the national agricultural water standard of groundwater (pH 6.0–8.5).

To investigate the shallow groundwater quality in the study area, a Piper diagram and a Stiff diagram were created using the major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions

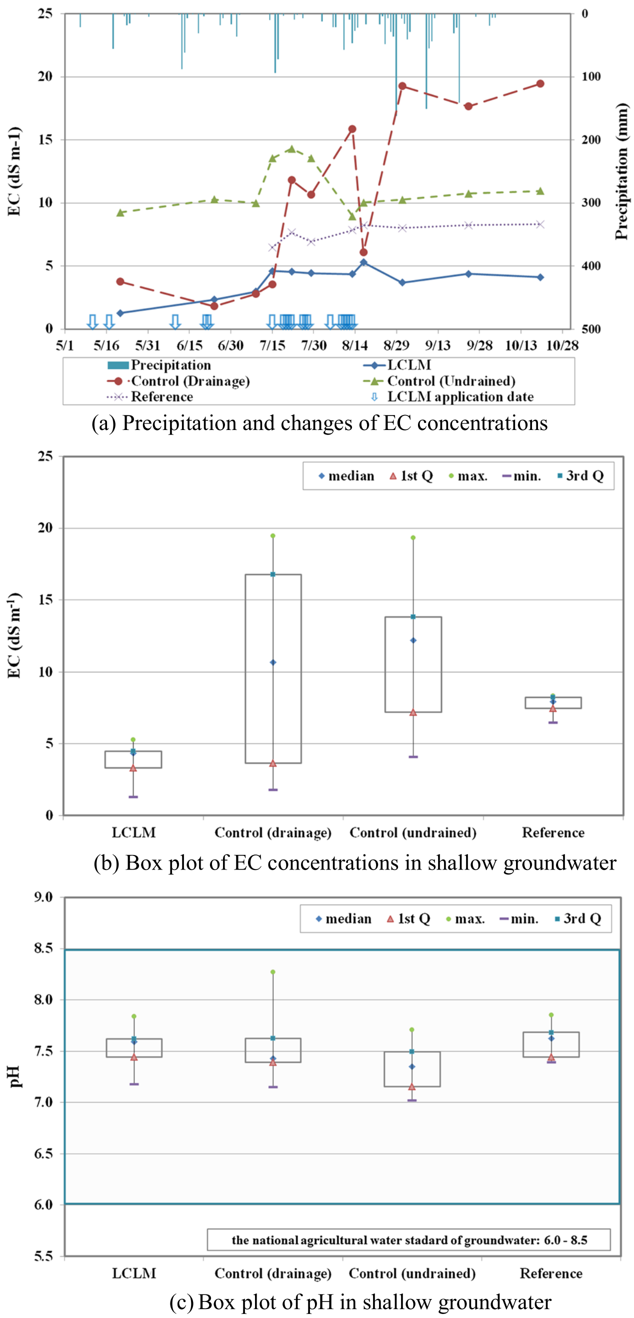
Table VI. Sampled water quality analysis items and methods

Analysis items		Analysis methods
pH		pH meter (Orion 550A)
EC (electrical conductivity)		EC meter
Cation	Na^+, K^+, Ca^{2+}, Mg^{2+}	Ion electrode method
Anion	Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, NO_3^- (NO_3-N)	Ion chromatography method
T-N (total nitrogen)		Reduction–distillation Kjeldahl method
T-P (total phosphorus)		Absorption photometry method

(Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) of the annual average concentration (Figures 5(a) and (b)). The Piper diagram was introduced to represent water type in terms of salinity and the Stiff diagram was drawn to provide an in-depth profile of sampled water type in terms of quantity. In the Piper diagram, the shallow groundwater type represents (Na, K)–(Cl); especially, it is included in the Na-Cl type. According to Ryu *et al.* (2009), despite the low levels of salty land that were removed during soil decontamination, reclaimed tidal land can be salty due to high concentrations of Na^+ and Cl^- ions. Although the Gimpo tidal land was reclaimed about 30 years ago, the shallow groundwater in the study area is saline, as shown in the Piper diagram (Hounslow, 1995). From the Stiff diagram, Na^+ and Cl^- were the dominant ions in this area, but there were differences in concentration among the four study fields. Compared with the reference point, the major cation and anion concentrations of the LCLM plot were lower, whereas those of the control points in the drained and undrained plots had more than twice the concentration. In particular, Na^+ and K^+ concentrations in the control (drained) plot were three times higher, and those in the control (undrained) plot four times higher, than those in the LCLM plot. The low salinity of the LCLM plot compared with the two control plots and the reference plot indicated that desalinization may be effective on reclaimed tidal land treated with LCLM.

Figures 6 and 7 are the time series variation and box plots (average, maximum, minimum, first quartile, and third quartile) of Na^+ and K^+ concentrations in shallow groundwater. In addition, Na^+ and K^+ average concentrations at a soil depth of 40 and 80 cm were compared with shallow groundwater ion concentrations. Figure 6(a) shows variations of Na^+ concentration over time. Since Na^+ is a major toxic and saline cation, extreme Na^+ concentrations in soil and water can interfere with plant growth by blocking K^+ absorption causing accumulation of K^+ in soils (Selim, 2004; Ryu *et al.*, 2009).

Na^+ concentrations in the LCLM plot were the lowest with little change. Although initial Na^+ concentrations in



(a) Precipitation and changes of EC concentrations

(b) Box plot of EC concentrations in shallow groundwater

(c) Box plot of pH in shallow groundwater

Figure 4. EC and pH results of shallow groundwater in each experimental site

the control (drained) plot were similar to the LCLM plot, the Na^+ concentration in the control (drained) plot shallow groundwater increased because both the LCLM plot and the control (drained) plot had drainage systems. After precipitation, the salt in the soil leached into the shallow groundwater containing high Na^+ concentrations due to rainfall infiltration. However, the reason why the average and standard deviation of the Na^+ concentration in the LCLM plot were lower than in the control (drained) plot was that LCLM can improve soil structure composition and ion exchange capacity. In addition, LCLM application in poplar fields promotes the growth of poplar trees by providing nutrients. Poplars are well known for high salt absorption, so accordingly, the salt concentrations in the soil and leaching into shallow groundwater decreased. Compared with the control (drained) plot and the LCLM plot, the control (undrained) plot had a high average Na^+ concentration. In addition, Na^+ concentration changes due to precipitation were minimal. However, compared to the Na^+ concentration of soil water at a depth of 40 cm, the average concentration in the control (undrained) plot was 1.5–2 times higher than the other two monitoring points. Despite the high amounts of sodium in the soil, poor drainage caused slow leaching into groundwater in the control (undrained) plot.

Average K^+ concentration in shallow groundwater was highest in the control (undrained) plot and lowest in the LCLM plot. Even though the average K^+ concentration in the control (drained) plot was lower than in the control (undrained) plot, variation was greater. After increasing the Na^+ concentration in shallow groundwater, the K^+ concentration tended to increase and within 40 cm depth soil water was similar to Na + concentration. The highest K^+ concentration at 40 cm depth soil water was in the control (undrained) plot followed by the control (drained) plot and the LCLM plot.

Figure 8 is the time series variation and box plots (average, maximum, minimum, first quartile, and third quartile) of Cl^- concentrations in shallow groundwater. The average Cl^- concentration in the shallow groundwater was highest in the control (undrained) plot and lowest in the LCLM plot. The maximum Cl^- concentration in the LCLM plot was lower than both the minimum concentration in the control (undrained) plot and the average concentration in the control (drained) plot. In addition, the variation was lower than in the control plots. Whereas the Cl^- concentration at time when had the highest concentration of Na^+ and K^+ in the control (undrained) was also the highest and increased three times more than initial Cl^- concentration.

According to experimental results at the Gimpo reclaimed tidal area, the control (undrained) plot contained higher salinity at 40 cm soil depth than other experimental plots and showed less fluctuation of shallow groundwater salinity with a high average salinity concentration and low desalinization tendency. However, salinity in the control (drained) plot showed lower concentrations than the control (undrained) plot, indicating that salt in the soil leached into the shallow groundwater according to precipitation and drainage. Therefore, the salt concentration in the upper soil water depth was lower than in the

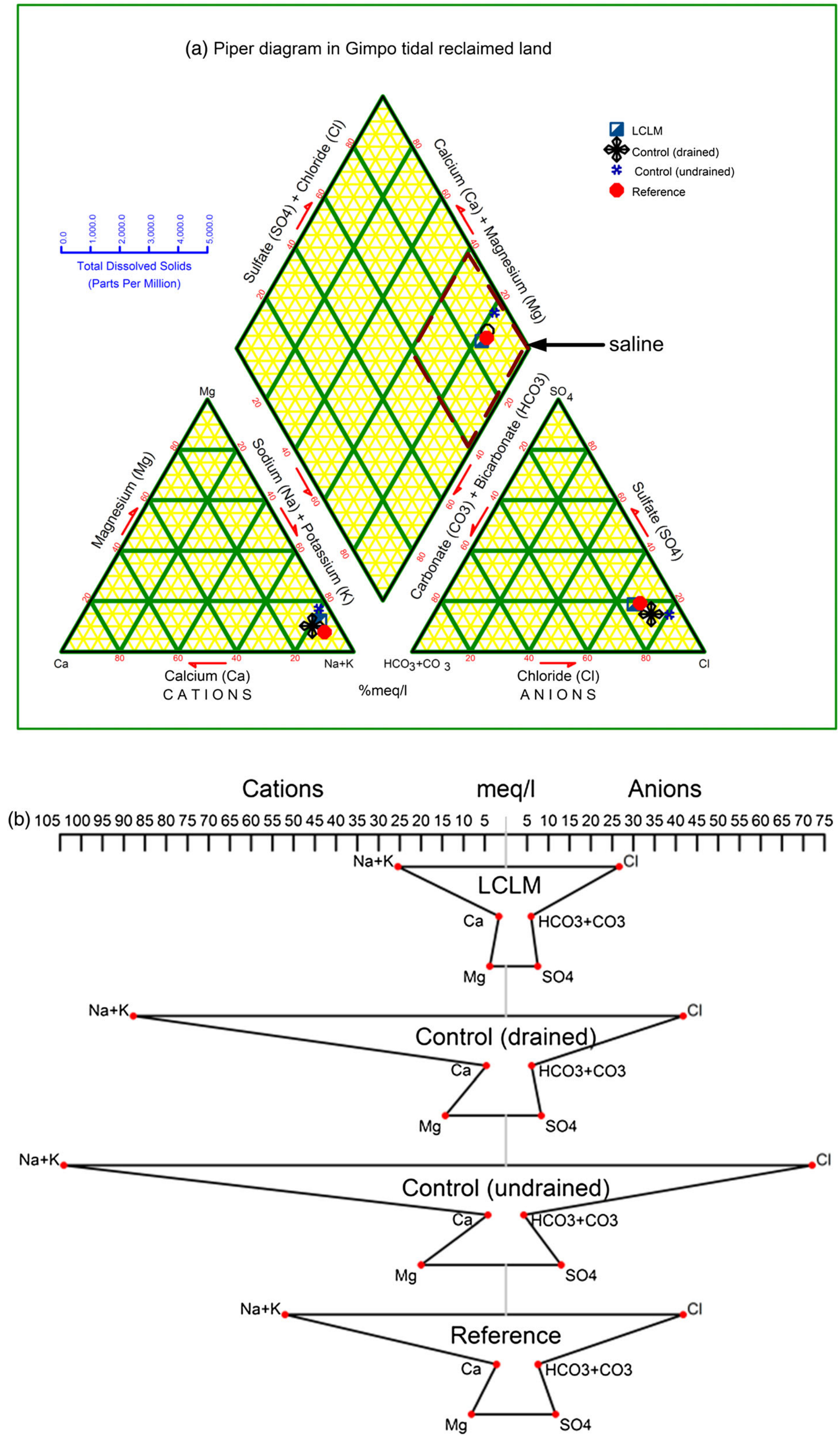
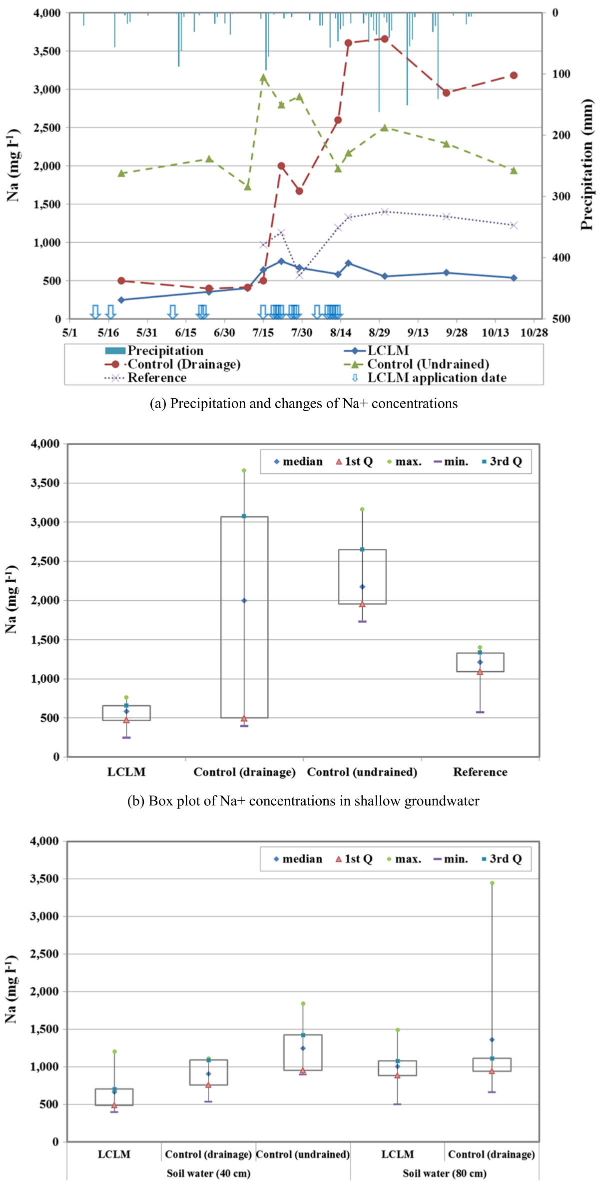


Figure 5. Piper (a) and Stiff (b) diagrams of shallow groundwater at each experimental site

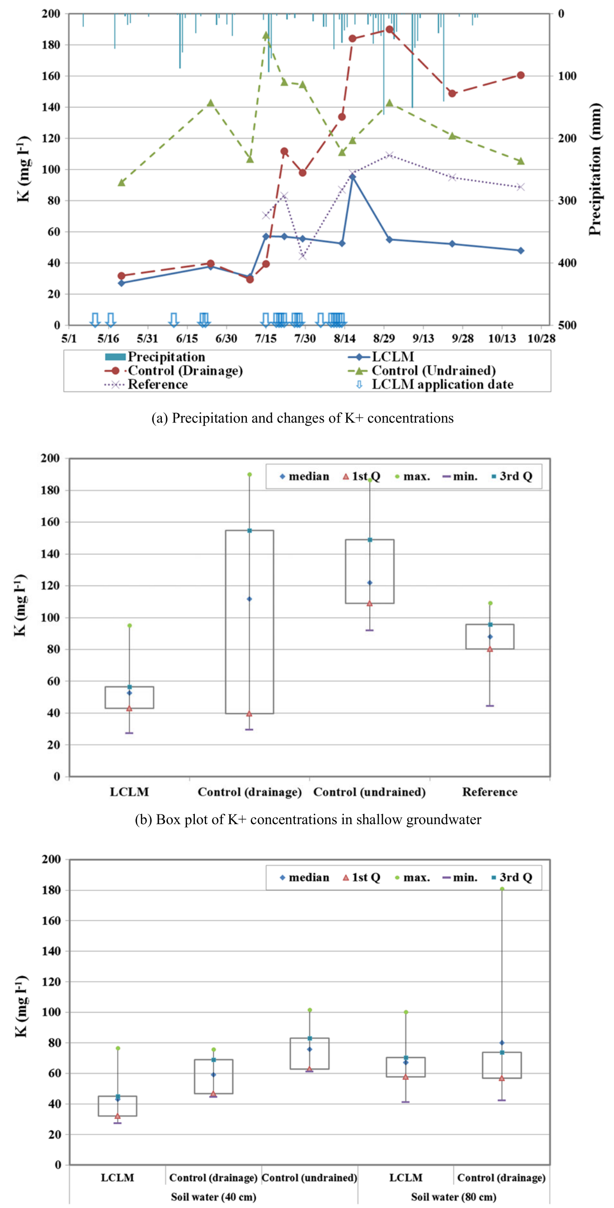


(a) Precipitation and changes of Na+ concentrations

(b) Box plot of Na+ concentrations in shallow groundwater

(c) Box plot of Na^+ concentrations in soil water

Figure 6. Na^+ concentrations in shallow groundwater and soil water at each experimental site



(a) Precipitation and changes of K+ concentrations

(b) Box plot of K+ concentrations in shallow groundwater

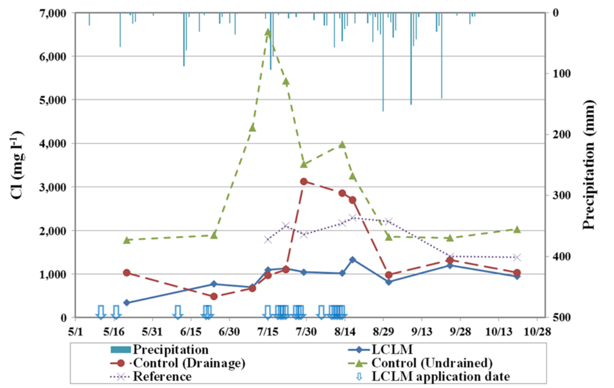
(c) Box plot of K^+ concentrations in soil water

Figure 7. K^+ concentrations in shallow groundwater and soil water at each experimental site

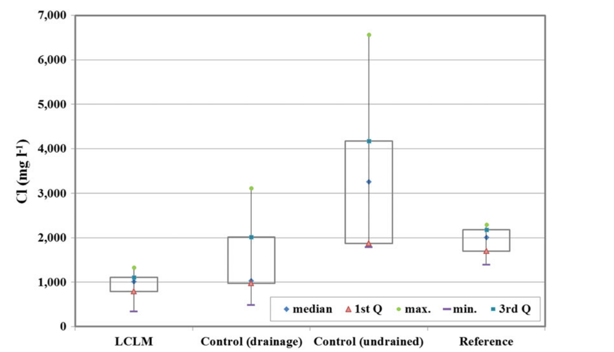
control (undrained) plot and variation of shallow groundwater in the control (drained) plot was significantly high due to precipitation. LCLM plot salinity was lower than in other plots, showing correlations in between LCLM application and soil water/groundwater salinity. LCLM could assist soil granulation for better drainage and increased CEC. In addition, the fertilizer content of LCLM provides nutrients that aid the growth of poplar trees. Active poplar growth plays a role in the absorption of salinity. Inclusion of a drainage system is important for lowering salinity concentrations in LCLM plots compared to other plots.

Shallow groundwater nutrients

The impacts of applying LCLM, NO_3-N, T-N, and T-P in shallow groundwater were monitored. Figure 9 shows the average, maximum and minimum NO_3-N, T-N, and T-P concentrations in shallow groundwater.



(a) Precipitation and changes of Cl⁻ concentrations



(b) Box plot of Cl⁻ concentrations in shallow groundwater

Figure 8. Cl⁻ concentrations in shallow groundwater at each experimental site

The concentration of NO_3-N in shallow groundwater in the LCLM plot was the highest, followed by the control (undrained) plot, the control (drained) plot, and the reference plot. However, the average NO_3-N concentration was less than 1.0 mg l^{-1} and was significantly lower than the national agricultural and drinking water standard for groundwater (less than 10 mg l^{-1}). T-N and T-P showed similar tendencies to NO_3-N.

Table VII shows the average, standard deviation, maximum and minimum concentrations NO_3-N, T-N, and T-P. The average NO_3-N concentration at 40 cm soil water depth in the LCLM plot was 19.73 mg l^{-1}, which was higher than the concentration of shallow groundwater and had a greater standard deviation. In particular, the NO_3-N concentration monitored immediately after application of LCLM was higher than the concentrations at other monitoring times at 40 cm soil water depth. However, a few days after LCLM application, the NO_3-N concentration at 40 cm depth was not greater than other plots compared to the result assessed immediately after application. Average concentration of NO_3-N in the LCLM plot at 80 cm soil water depth was 1.48 mg l^{-1} and was similar to the shallow groundwater NO_3-N concentration. The NO_3-N concentrations of other monitoring plots were less than 1.00 mg l^{-1} and were similar to the results for shallow groundwater NO_3-N. T-N in the LCLM plot was also similar to the NO_3-N in soil water and T-N in shallow groundwater. T-N in the control plot was higher than the NO_3-N result in soil water, but had similar tendencies to T-N in shallow groundwater. TP concentrations in soil water were lower than in shallow groundwater and there were few differences between the T-P concentrations of the LCLM plot and the control plot.

Even though reclaimed tidal land is usually infertile and barren, supplying nutrients through LCLM application can positively affect plant growth and desalinization. However, due to typically high groundwater levels in reclaimed land, applying LCLM can cause shallow or soil water quality problems before desalinization. Therefore, continuous monitoring is necessary when applying LCLM.

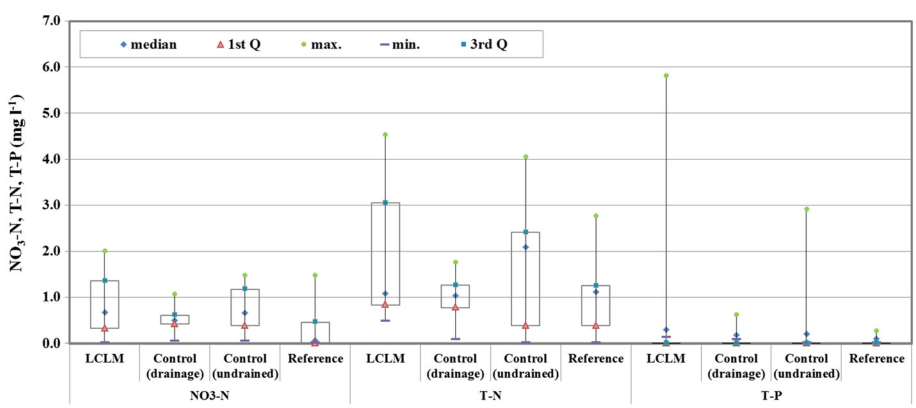


Figure 9. NO_3-N, T-N, and T-P concentration in shallow groundwater

Table VII. Average, standard deviation, minimum and maximum NO_3-N, T-N, and T-P concentrations in soil water

Soil depth		40 cm			80 cm		
Treatments		LCLM plot	Control (drained)	Control (undrained)	LCLM plot	Control (drained)	Control (undrained)
NO_3-N	Average	19.7	0.12	0.02	1.48	0.07	0.01
	Std[a]	26.2	0.28	0.04	3.77	0.18	0.02
	Max.[b]	66.3	0.82	0.12	11.5	0.55	0.06
	Min.[c]	ND[d]	0.01	ND	ND	ND	ND
T-N	Average	23.3	2.80	1.83	5.30	2.32	1.23
	Std.	27.4	1.13	1.15	6.46	1.14	0.79
	Max.	68.1	4.91	3.52	22.4	3.66	3.03
	Min.	0.44	1.54	0.49	1.70	0.97	0.49
T-P	Average	0.08	0.10	0.06	0.06	0.07	0.02
	Std.	0.06	0.03	0.05	0.05	0.03	0.04
	Max.	0.13	0.16	0.10	0.16	0.12	0.08
	Min.	ND	0.08	ND	ND	0.04	ND

[a]Std: standard deviation.
[b]Max.: maximum.
[c]Min.: minimum.
[d]ND: not detected.

CONCLUSIONS

In this study, the effects of LCLM application on desalinization in reclaimed tidal land areas were evaluated in the Gimpo area, a representative reclaimed tidal area in Korea. Popular trees were planted in different drainage conditions to investigate the efficacy of LCLM application in terms of desalinization and water quality. A number of variables were analyzed in shallow groundwater and soil water at 40 and 80 cm depths, including EC, pH, cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), anions (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, and NO_3-N) and nutrients (T-N and T-P).

EC exhibited the lowest average concentration in the LCLM plot, while the highest average concentration was in the control (undrained) plot during and after application of LCLM. The EC of the control (drained) and the control (undrained) plots show higher salt accumulation than the LCLM plot. Groundwater pHs of the experimental fields were similar to each other, and the moderately alkaline conditions satisfied the national agricultural water standard of groundwater.

The shallow groundwater type shown in the Piper diagram for the Gimpo reclaimed tidal land represents the (Na, K) – (Cl) type with excess sodium. The major cation and anion concentrations of the LCLM plot were lower than those of the reference plot, whereas those of the control plots had more than twice the concentrations compared with the reference plot. Average Na^+ and K^+ concentrations in shallow groundwater were highest in the control (undrained) plot and the lowest in the LCLM plot. Even though the Na^+ and K^+ average concentrations in the control (drained) plot were lower than in the control (undrained) plot, their variation was greater. The highest Na^+ and K^+ concentrations at 40 cm depth soil water were in the control (undrained) plot, followed by the control (drained) plot and the LCLM plot.

Concentrations of NO_3-N, T-N, and T-P in shallow groundwater were highest in the LCLM plot followed by the control (undrained), control (drained), and reference plots. The NO_3-N concentration was less than 1.0 mg l^{-1} and was significantly lower than the national agricultural and drinking water standard for groundwater (less than 10 mg l^{-1}). Average NO_3-N and T-N concentrations at 40 cm soil water depth in the LCLM plot were higher than in shallow groundwater and had greater standard deviations. TP concentrations in soil water were similar between the LCLM plot and control plots, and lower than in shallow groundwater concentrations.

LCLM may result in better drainage and increased cation exchange capability. In addition, the nutrition content of LCLM provides poplar trees with aid to growth. Active poplar growth facilitates salinity absorption. The inclusion of a drainage system is important for lowering salinity concentrations in LCLM plots. Applying LCLM to reclaimed tidal land supplies nutrients and mitigates salinization. Because of the high groundwater levels in reclaimed land, applying LCLM may cause shallow or soil water quality problems. Therefore continuous monitoring is necessary when applying LCLM.

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